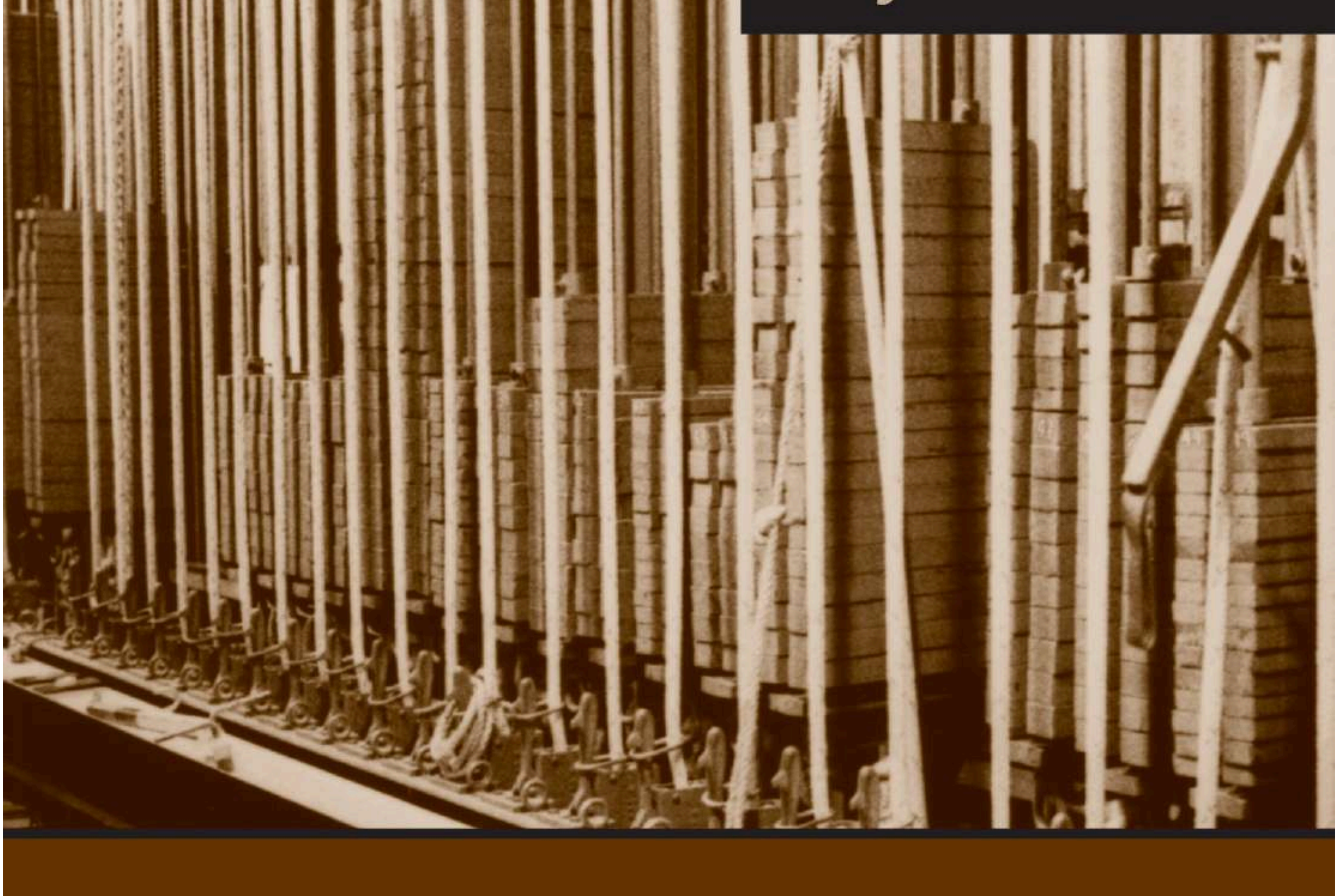
Third Edition

STAGE RIGGING HANDBOOK

Jay O. Glerum



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To my granddaughters, Katie, Maddie, and Mae,
the next generation

Contents

Preface to the Third Edition

The third edition contains a number of additions and changes requested by readers and participants in the rigging master classes and workshops that I have taught over the last ten years. The additions also reflect some of the changes in the way that the entertainment industry is approaching rigging. Stagehands, technical directors, and venue managers are increasingly aware of the dangers of unsafe rigging practices, and there is a concerted effort in the industry to do things correctly and safely. In a number of venues, from legitimate theatres to theme parks and Las Vegas spectaculars, a new attitude is emerging: The show does *not* have to go on—unless it can go on safely. On Broadway, stagehands no longer use Genie lifts without outriggers, they keep maintenance logs on the rigging equipment, and regular rigging-equipment inspections are part of the standard practice. The Entertainment Technician Certification Program is up and running, and there are now nationally certified flymen and riggers.

In an effort to help stage technicians more easily locate information they need on installing, maintaining, or operating equipment, this third edition is indexed. It also contains new sections with detailed checklists for rigging inspections, installing rigging, and creating venue-specific training programs. The section on fire curtains was added to help stagehands understand how existing fire curtains work and to keep the curtains operating according to code.

As with the first and second editions, thanks are due to a number of people who willingly and generously shared their knowledge with me to help make this edition more useful. Thank you to Dan Culhane of SECOA for his drawings and counsel on fire curtains and to Barry Grothause of Loos & Co. and John Quinn, senior development engineer of National Telephone Supply Co., for answering my many questions and providing detailed information on terminating wire rope. A special thanks to Craig Ryan of Ver Sales for helping me understand the various standards for wire rope as well as providing information and hardware samples used in the termination section. Thanks also to Jerry Gorrell, who provided much needed information on fire-curtain fabric, and to Reid Neslage of H & H Specialty and Tom Young of J. R. Clancy, who provided drawings and counsel during the research process. To everyone above, I extend my grateful appreciation. Also, I would like to thank the United States Institute for Theatre Technology (USITT) for sharing information during the research process.

To my wife, Sallie, I owe a debt that can never be repaid for her editing skills, commentary, and support during the process of creating and bringing this edition to print.

I wish to express my deepest gratitude to the staff at Southern Illinois University Press who worked on this edition: Kristine Priddy, assistant acquisitions editor; Mary Lou Kowaleski, copy editor; Wayne Larsen, project editor; Erin Longwell, designer and typesetter; Paula Durbin-Westby; and Barbara Martin, editorial, design, and production manager. Without their professionalism and consistently enthusiastic, diligent, and good-humored support, the show could not have gone on.

Preface to the Second Edition

In the last twenty years, stage scenery has changed noticeably with steel being used as a common building material and hard covering replacing muslin on flats. Movement of scenery can be exceedingly complex as directors and designers at all levels of the entertainment industry strive to create new techniques and production modes. With the dynamics of moving heavier scenery, added strain is placed on building structures and rigging systems. The technology used in such shows as *Starlight Express*, *Phantom of the Opera*, and *Siegfried and Roy* requires an understanding of physics and engineering to the extent that some production companies hire structural engineers to assist in modifying the venue and to design the structure of the scenery.

With increased magnitudes of loads and complexity of movement comes greater risk, as well as greater possibility, for injury. The courts have found facility owners, managers, supervisors, and riggers to be responsible for the maintenance and proper use of their rigging equipment and for providing adequate training of those who use it. Gathering a group of stagehands around the hemp lines to all pull together is no longer sufficient. Technology has progressed beyond that point.

This book is not a course in engineering. It is intended to help you understand theatrical rigging equipment, how to inspect and maintain it, and how to use it. It is your responsibility to use the equipment safely, and when the complexity of a rigging problem is beyond your expertise, it is your responsibility to find a reliable source to help solve the problem. Just as no single stage technician could possibly be expected to have the breadth and depth of knowledge required to understand all of the intricacies of people flying and stage, arena, outdoor, convention center, and ballroom rigging, neither does this handbook. It is a resource that touches on the scope of our profession but does not exhaust it.

The second edition of *Stage Rigging Handbook* includes two new parts. The first is an expanded discussion of the forces and loads on stage rigging components and the structure supporting them. The second is devoted to block and tackle rigging. Both of these parts are intended to increase your understanding of the equipment you use. The remaining four parts contain many minor revisions that have come about from written comments from readers and feedback from the rigging master classes that have been held since the first edition was printed. This edition does not include the "Recommended Guidelines for Stage Machinery and Stage Rigging" that constituted the appendix of the first edition. At the time of this printing, the United States Institute For Theatre Technology and the Entertainment Services and Technology Association are in the process of writing standards to replace the recommended guidelines. And as in the first edition, the information on applying wire-rope clips, now in section 6.02.C-1, is adapted from the *Wire Rope Users Manual*, 2d ed., Copyright © 1981 by American Iron and Steel Institute, and is used courtesy of the American Iron and Steel Institute.

Beyond the acknowledgments contained in the original preface, some additional thanks are due. I owe a debt of gratitude to Randy Davidson for organizing the first master classes and to David Lofton and Jerry Gorrell for making them happen. From the teachers in the classes I learned much: Bob Beebe, Wally Blount, Randy Davidson, Harry Donovan, Peter Foy, Steve Langley, Randy Longerich, Rocky Paulson, and Mike Wheeler. Thanks also go to all of the participants who shared with me their knowledge of rigging. Special thanks are due to Rocky Paulson and John Burgess for critiquing early drafts of part 1. Credit is due to Harry Donovan for algebraically deriving the formulas for hanging points of unequal heights in section 1.05.E.

Thanks to Teresa White of Southern Illinois University Press for shepherding the manuscript to its finished form and Kathryn Koldehoff for her meticulous copyediting. As with the first edition, my wife, Sallie, spent hours editing and commenting on the work in progress. This book could never have happened without her.

Preface to the First Edition

The single greatest cause of rigging accidents in the American theatre is operator error. While some of this error is due to carelessness, much of it is due to lack of knowledge about rigging systems and their safe operation.

Stage Rigging Handbook is intended as a source of written information on the care and safe use of stage rigging equipment. It is hoped that its availability will help to reduce operator error–related accidents, thereby making the theatre a safer place to work.

This book could not have been written without the knowledge so generously shared by the people with whom I have worked.

I wish to thank Charlie Ford and Jim Waring of Catholic University; Warren "Tyke" Lounsbury, John Ashby Conway, and the late Lance Davis of the University of Washington; Floyd Hart and the stagehands of Local 15, IATSE in Seattle; the stagehands of Local 18, IATSE in Milwaukee; and all the road crews with whom I worked over the years.

I would also like to thank my colleagues in the stage rigging industry, especially those at the Peter Albrecht Corporation: Paul Birkle, President; the engineers and staff members.

The words could never had been put into print without the understanding, encouragement and help of my family, particularly my wife, Sallie.

For permission to quote from the *Wire Rope Users Manual*, 2d ed., I thank the American Iron and Steel Institute. I also thank the United States Institute for Theatre Technology for allowing me to reprint their *Recommended Guidelines for Stage Rigging and Stage Machinery Specifications and Practices*. For permission to reproduce a number of the illustrations, I gratefully acknowledge the Peter Albrecht Corporation, the Macwhyte Company, and the American Iron and Steel Institute. And for illustration reproduction, I thank Wes Jenkins.

Symbols and Abbreviations

∠ = angle
↘↑ etc. = a force
° = degree
' = foot
" = inch
× = multiplication
∑ = summation
a, b, c . . . = values
A = area
AF = applied force
AL = allowable load
ALL = allowable load limit
d = rope diameter
D = sheave diameter
D = distance
DF = design factor
D_F = free-fall distance
D_S = stopping distance
e = strain
FA = fleet angle
ft.-lb. = foot-pound
H = horizontal force
HF = horizontal tension force
in.-lb. = inch-pound
kip = kilopound
kip-ft. = kilopound-foot
kN = kilonewton
l = change in length
l = left
L = load
L = length
lb. = pound
lb.-ft. = pound-foot
lb./ft. = pound per foot
LIF = load increase factor
LL = lead line
LLP = lead line pull

M = multiplier
M = moment
MA = mechanical advantage
N = newton
N = number
N-m = newton-meter
P = point load force
r = radius
r = right
R = ratio
R = reactive force
RP = radial pressure
S = stress
S1, S2, etc. = support line
SRF = strength reduction factor
SWL = safe working load
T = tension
UBS = ultimate breaking strength
V = vertical force
VF = vertical tension force
W = weight
WLL = working load limit
Y = yield point

Stage Rigging Handbook

Part 1 Loads and Reactions

1.01 The 4 Ks

Rigging is a tool used in the theatre. It supports and provides movement of overhead objects that are part of a production. If it works as it should, it rarely calls attention to itself. If something goes wrong, it may not only be noticeable but life threatening as well. The functions of the rigging equipment and the rigger are to do the job as the designer designed it, and the director directed it, and do it safely. In order to do that, there are four principles that a rigger needs to follow, called the *4 Ks* of rigging.

1. Know the rigging system you are working with.
2. Keep the equipment in safe working order.
3. Know how to use it.
4. Keep your concentration.

Everything that follows in this book is an elaboration of these four principles.

1.02 Knowing the Rigging System

A typical rigging system is made up of individual line sets. The line sets may be hemp, counterweight, or motorized (or a combination). Each line set is made up of individual components, such as rope, a head block, loft blocks, and so on. Each line set is a separate subsystem, that is, a group of components interrelated and working together. Knowing the rigging system means knowing three things.

1. *The capacity of the equipment.* You must know how much weight each line set is designed to hold, the maximum speed that motorized line sets are designed to travel, the maximum weight that all of the line sets together can hold, and the maximum additional weight that the grid steel can support.

2. *The capacity of the components.* You should know the maximum load that each component is designed to carry. A six-line counterweight set may be designed with a total capacity of 1,500 lb. The individual loft blocks may be designed to support only a load of 250 lb. each. The head-block support steel may or may not be designed to support all of the line sets at full load.

3. *The operating characteristics of the system.* Each line set is unique. It has its own sound and feel; it even has its own smell. In order to know the system, the rigger should know the individual peculiarities of each line set in the system. By knowing how a line set operates normally, the rigger can detect abnormal operation and possible problems.

A. Load and Force

A part of knowing the rigging system is understanding the forces that an object places on each component of a rigging system and the structural members supporting the components. When an object—whether it is a piece of scenery, a lighting instrument, or an actor—is flown, it exerts a force on all of the elements that support it. Within the confines of this book, the object will be referred to as the *load*. The elements include all of the components of the rigging system and the structural members of the building supporting those rigging components. The term *force* can be thought of as a *strength or energy trying to cause motion or change*.

B. Static Equilibrium

Newton's third law of physics states that for every action there is an equal and opposite reaction. Applied to rigging, this means that the rigging components and supporting members resist the applied force of the load with a reactive force exactly equal and opposite to the applied force. For example, imagine yourself holding a cup of coffee. The muscles in your arm and hand apply only enough force to support the weight of the arm and the cup of coffee. If less force is applied, your arm bends down, and the coffee spills. If more force is applied, the coffee is thrown up in the air. A lighting instrument is hung on a batten. If the light is steady and does not move, all of the supporting components—the C-clamp, batten, lift lines, loft blocks, loft block support steel, head block, head-block beams, arbor, rope lock, and lock rail—are exerting exactly enough force to hold it in place.

Two distinct branches of mechanics, *statics* and *dynamics*, apply to stage rigging. *Statics* is the study of forces and the effect of forces acting on rigid bodies *at rest*. Dynamics deals with motion and the effect of forces acting on rigid bodies *in motion*. A *body* is any object or component that can be isolated and analyzed separately, and a *rigid body* is an object that essentially retains its shape. An examination of some of the principles of statics will help in understanding how the load affects the rigging components and the support members. When there is no movement of an object, it is in *static equilibrium*. There is a balance of all of the forces acting on the system. *The force law of equilibrium* states that the algebraic sum of all forces acting on an object in static equilibrium is zero. This means that all of the forces acting on the body are equal and opposite.

1.03 Supporting a Load

A. The Engineer and the Rigger

The following discussion is for the purpose of helping riggers to become aware of the forces acting on rigging systems and components, to help you know the rigging system that is being used. It is not intended to be a course in structural or mechanical engineering. Of necessity, the information on forces and strength of materials is condensed. The structural design of a building and the mechanical design of a rigging component are both complex procedures and require the expertise of a professional engineer. When in doubt, consult one.

Until antigravity devices are perfected, the load and rigging components must be supported by something. Frequently that "something" is a beam made from steel, concrete, aluminum, or other material. Each of these materials has its own strength characteristics that enable it to resist applied forces. Strength of materials will be discussed in section 1.06. First, we'll look at exactly how applied and resultant forces act on supporting members.

B. Seat-of-the-Pants Experience

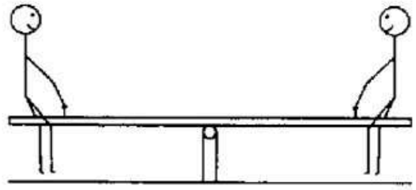


Fig. 1.1. Two 200-lb. stagehands on a seesaw

One common experience with resultant forces is riding on a seesaw (see fig. 1.1). This is a simple beam with a center pivot point, or fulcrum. If you have been a rider on a seesaw, you have personal experience with beam loading and the strength of the beam material. The seesaw works best if both people are about the same weight. It is easier to balance and easier to operate. For purposes of this discussion, assume that the seesaw is not moving, that it is a perfectly balanced plank 16′ long supporting two stagehands, each weighing two hundred pounds, sitting on the ends. The components of the system are a 16′ beam (the seesaw), a section of pipe (the fulcrum), and two pipe legs supporting the fulcrum.

C. Free-Body Diagram (FBD)

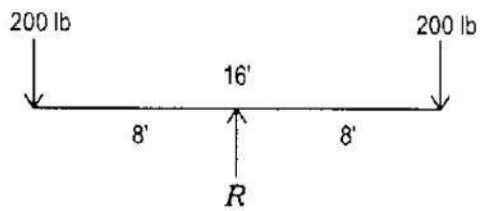


Fig. 1.2. Free-body diagram (FBD) of forces on a seesaw beam, with *R* indicating reactive forces

Analyzing the forces acting on a body can be quite complicated at times. A good technique to follow is to make a drawing of the object isolated, or free, from all of its support members, showing all of the applied and reactive forces acting on it. This type of diagram is called a *free-body diagram* (FBD). Figure 1.2 is an example of using an FBD to show the forces acting on the seesaw beam. Forces are indicated by arrows. Reactive forces are indicated by *R*. The diagram used for analysis should contain

• the *lengths* of all supporting members and the distances among forces
• the *magnitudes* of all of the known forces
• the *points of application* of all forces
• the *directions* of all of the forces
• the *senses* of all forces

The *length* of a supporting member is self-explanatory. The *magnitude* is the amount of force acting on the object. It can be expressed in units of

pound (lb.)
1,000 lb. or a kilopound (kip)
2,000 lb. (ton)

Metric units are expressed in units of

newton (N)
1,000 N or a kilonewton (kN)

The *point of application* is the place on the object where the force is being applied. The *direction* indicates the line of force at the point of application, such as an up-and-down direction. The *sense* indicates if the force is positive or negative, that is, up or down. Sometimes the sense is not always obvious; this will become clearer in a later example.

D. Summation of Forces

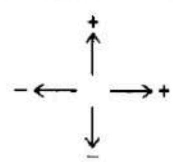


Fig. 1.3. Positive and negative forces

Earlier, it was indicated that a body is in equilibrium when the algebraic sum of all the forces acting on it is zero. All forces have sense, and the following conventions will be used in this book. Forces up and to the right are positive. Forces down and to the left are negative (fig. 1.3). The positive or negative direction of a force is its *sense*.

The symbol used to indicate sum or summation is the Greek capital letter sigma, $\sum$. When the forces acting on an object are in equilibrium, the equation can be written as $\sum F = 0$. That is, the sum of all of the forces acting on the object equals zero. For purposes of analysis, it is usually necessary to determine all of the horizontal and vertical forces acting on an object. The equations for those forces are $\sum H = 0$ for the horizontal forces and $\sum V = 0$ for the vertical forces.

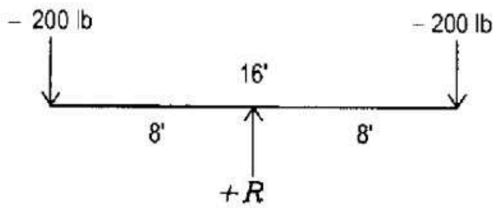


Fig. 1.4. FBD with negative and positive forces

Ignoring the weight of the seesaw for the time being and labeling the forces in figure 1.4, there is on the left (*l*) a downward (thus negative) force of –200 lb., on the right (*r*) a negative force of –200 lb., and an unknown upward (thus positive) reaction, *R*. These are the vertical applied forces. There are no horizontal forces in this example. We will use the letter *P* to indicate all applied point load forces and the letter *R* to indicate all reactive forces. The equations are:

$$\sum V = 0$$
$$\sum V = P_l + P_r + R$$
$$R + P_l + P_r = 0$$
$$R + -200 \text{ lb.} + -200 \text{ lb.} = 0$$
$$R = 400 \text{ lb.}$$

The fulcrum is supporting a load of 400 lb. and therefore must be reacting with a force of 400 lb.

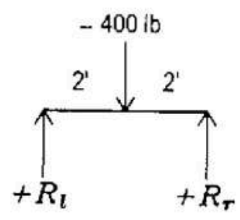


Fig. 1.5. FBD of pipe legs

This is only part of the equation. The pipe legs supporting the fulcrum still must be analyzed. Isolating the fulcrum in figure 1.5, the FBD shows the applied force on the fulcrum and the reactions of the pipe legs. The total applied load on the fulcrum is 400 lb. (or 200 lb. from each stagehand). Using the same formula but reflecting this figure, the equations are:

$$\sum V = 0$$
$$\sum V = R_l + R_r + P$$
$$P = -400 \text{ lb.}$$
$$R_l + R_r - 400 \text{ lb.} = 0$$
$$R_l + R_r = 400 \text{ lb.}$$
$$\text{Each } R = 200 \text{ lb.}$$

When the beam is supported at each end, and the load is in the center of the beam, the formula can be simplified to $V = P/2$, meaning the vertical reaction at each end is one-half the load.

E. Moment of Force

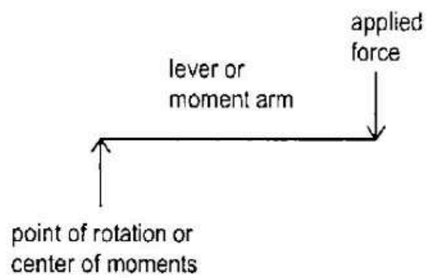


Fig. 1.6. Moment of force

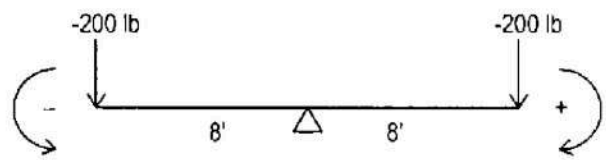
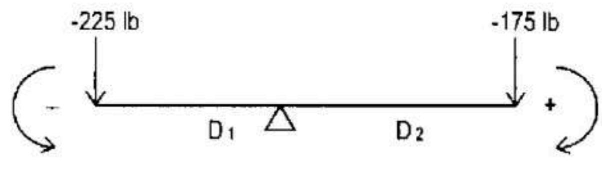


Fig. 1.7. Moment diagram of seesaw

The *moment of force* is the force's tendency to produce rotation of the object on which it acts. This rotation is about some axis or *point of rotation*. The point of rotation is called *the center of moments*, and the distance between the applied force and the axis is called the *lever arm*, or *moment arm*. The length of the lever arm is measured from a line drawn through the axis perpendicular to the line of action of the force (fig. 1.6). Units of measurement of a moment are expressed in force and distance, that is, pound-inch (lb.-in.), pound-foot (lb.-ft.), kilopound-foot (kip-ft.), and newton-meter (N-m.). (Sometimes, the order of the units is reversed, such as foot-pound (ft.-lb.), but the meaning is the same.) In the seesaw example (fig. 1.7), the seesaw is 16´ long. The fulcrum, or axis, is in the center, 8´ away from the applied force of the 200 lb. stagehand. To calculate the moment of force applied by a stagehand, multiply the length of the lever arm (8′) by the weight of the stagehand (200 lb.). The result is 1,600 lb.-ft.

The law of equilibrium applies to moments as well as to vertical and horizontal forces. It is written $\sum M = 0$. Since the moment on the right end of the beam is 1,600 lb.-ft. in a clockwise direction, the moment on the left is also 1,600 lb.-ft. in the counterclockwise direction. That is, the moments must be equal and opposite in direction. Think of it as clockwise being positive and counterclockwise being negative.

Fig. 1.8. FBD of seesaw with unequal loads



Some seesaws have movable pivot points. This is to accommodate people of unequal weights. By moving the beam off center, the length of the moment arm is changed, and the balance can be maintained. For example, if one stagehand weighs 225 lb., and the other weighs 175 lb., the distances from the fulcrum would have to be adjusted to keep the seesaw balanced. Figure 1.8 is an FBD showing the applied forces and the length of the beam. By simple addition, $\sum V = 0$, the reaction at the fulcrum is 400 lb. D_1 and D_2, the distances from the fulcrum to the applied loads, can be found by calculating, or *taking moments*, from a point of rotation along the beam. Using the left end of the beam as the point of rotation, starting at the right end and moving toward the point of rotation, and taking moments of all of the forces acting on the beam, the moments are:

175 lb. × 16′ = 2,800 lb.-ft. clockwise (+)
400 lb. × D_1 = 2,800 lb.-ft. counterclockwise (–)
225 lb. × 0′ = 0

Because the moment is being taken at the left end, there is no length to the moment arm at the support point of the 225 lb.

To find the length of the moment arm for the left side (the distance from the left end to the fulcrum), take the total moment of the right end and divide it by the force at the fulcrum.

$$\sum M = 0$$

$$\sum M = (D_1 \times 400 \text{ lb.}) + (175 \text{ lb.} \times 16')$$

$$(D_1 \times 400 \text{ lb.}) + (175 \text{ lb.} \times 16') = 0$$

$$D_1 = \frac{2{,}800 \text{ lb.-ft.}}{400 \text{ lb.}}$$

$$D_1 = 7'$$

$$D_1 + D_2 = 16'$$

$$D_2 = 16' - D_1$$

$$D_2 = 16' - 7'$$

$$D_2 = 9'$$

This can be checked by taking moments at the right end of the beam.

F. Examples

Three examples of using moments to calculate reactions on beam supports follow.

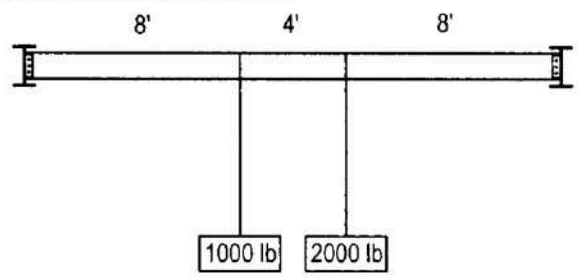


Fig. 1.9a. Example 1

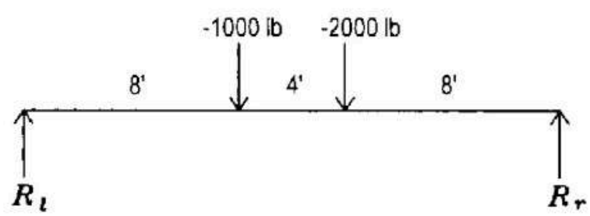


Fig. 1.9b. FBD of figure 1.9a

Example 1. Two rigging points are hung from a 20′ beam as indicated in figure 1.9a. What are the reactions on the left and right support points? Constructing the FBD in figure 1.9b and taking moments at the right end:

$\sum M = 0$
$(R_l \times 20') + (-1{,}000 \text{ lb.} \times 12') + (-2{,}000 \text{ lb.} \times 8') = 0$
$(R_l \times 20') - 12{,}000 \text{ lb.-ft.} - 16{,}000 \text{ lb.-ft.} = 0$

$$R_l = \frac{28{,}000 \text{ lb.-ft.}}{20'}$$

$R_l = 1{,}400$ lb.

Using $\sum V = 0$
$\sum V = 0$
$R_l + R_r - 1{,}000 \text{ lb.} - 2{,}000 \text{ lb.} = 0$
$R_r = -1{,}400 \text{ lb.} + 1{,}000 \text{ lb.} + 2{,}000 \text{ lb.}$
$R_r = 1{,}600$ lb.

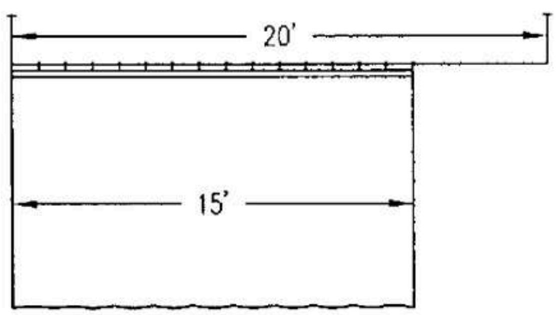


Fig. 1.10a. Example 2

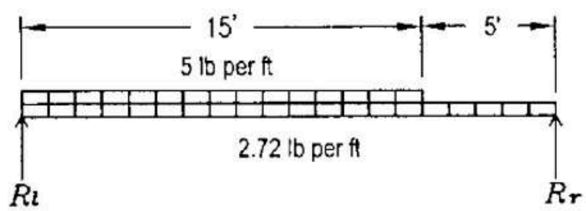


Fig. 1.10b. Weight distribution of figure 1.10a

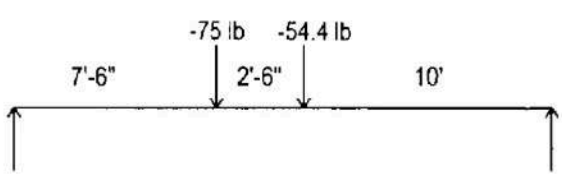


Fig. 1.10c. FBD of figure 1.10a

Example 2. This example illustrates how to find the reactions for an evenly distributed load and includes the weight of the beam in the calculations. Until now we have ignored the self-weight of the supporting beam. In practice, it must always be included in the calculations.

Figure 1.10a shows a 15′-wide curtain weighing 5 lb. per linear foot (lb. per ft.), hung at one end of a 20′ length of 1 ½″ schedule-40 pipe. The pipe is dead hung by rope at each end. How much weight does each rope support?

Weight of curtain = 5 lb. per ft. (75 lb. total)
Weight of 1 ½″ schedule-40 pipe = 2.72 lb. per ft. (54.4 lb. total)

Figure 1.10b illustrates the FBD of the pipe and the evenly distributed loads.

Evenly distributed loads are calculated by adding up the total distributed load and assuming it to be a point load in the center of the distributed span as shown in figure 1.10c. Taking moments from the left end,

$$\sum M = 0$$
$$(-75 \text{ lb.} \times 7.5') + (-54.4 \text{ lb.} \times 10') + (R_r \times 20') = 0$$
$$(R_r \times 20') = 562.5 \text{ lb.-ft.} + 544 \text{ lb.-ft.}$$
$$R_r = \frac{1{,}106.5 \text{ lb.-ft.}}{20'}$$
$$R_r = 55.3 \text{ lb.}$$
$$\sum V = 0$$
$$R_l - 75 \text{ lb.} - 54.4 \text{ lb.} + 55.3 \text{ lb.} = 0$$
$$R_l = 74.1 \text{ lb.}$$

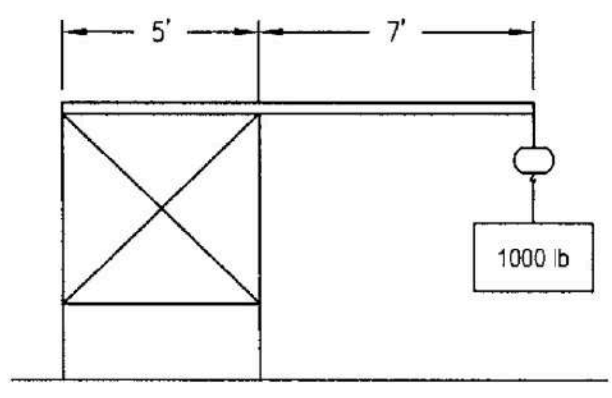


Fig. 1.11a. Example 3

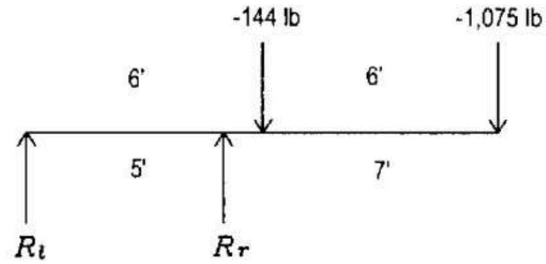


Fig. 1.11b. FBD of figure 1.11a

Example 3. This example (fig. 1.11a) illustrates the reactions of a wide-flange beam 10″ deep, weighing 12 lb.-ft. (W10 × 12) overhanging a 5′-wide scaffold tower. A half-ton chain hoist loaded to capacity is at the overhanging end of the beam. The equations to determine the reactions at each of the support points of the beam (fig. 1.11b) are:

$P = 1{,}000$ lb.
Weight of beam = 12′ × 12 lb./ft. = 144 lb.
Weight of chain hoist = 75 lb.

Taking moments at R_l

$$\sum M = 0$$
$$(R_r \times 5') + (-144 \text{ lb.} \times 6') + (-1{,}075 \text{ lb.} \times 12') = 0$$
$$R_r = \frac{(864 \text{ lb.-ft.} + 12{,}900 \text{ lb.-ft.})}{5'}$$
$$R_r = 2{,}753 \text{ lb.}$$

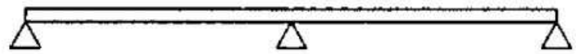
$$\sum V = 0$$
$$\sum V = R_l + R_r - 144 \text{ lb.} - 1{,}075 \text{ lb.}$$
$$R_l = -2{,}753 \text{ lb.} + 144 \text{ lb.} + 1{,}075 \text{ lb.}$$
$$R_l = -1{,}534 \text{ lb.}$$

In this case, the left reaction is negative, or a force in the down direction. There is a tendency for the beam to rotate with the fulcrum at R_r. A force of −1,534 lb. on the left side, in the down direction, is necessary to keep the beam in equilibrium.

G. Continuous Beams

In the last section were several examples of beams supporting loads. In each case, statics was used to calculate the reactions

Fig. 1.12. Continuous beam with three supports



at the support points of the beam. Figure 1.12 illustrates a continuous beam with three or more supports. *Statics* CANNOT *be used to calculate the reactions if the beam has three or more supports*. A more complex method called the *three-moment theorem* is used for continuous beams. The three-moment theorem is beyond the scope of this book but is touched upon in section 3.04.B.2 on battens.

1.04 Summation of Forces

Fig. 1.13a. Load supported by pipe

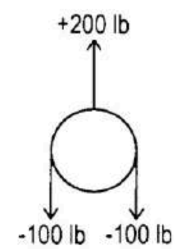


Fig. 1.13b. FBD of figure 1.13a

A. Resultant Force

Figure 1.13a illustrates a 100-lb. load suspended by a rope that is bent 360° around a pipe. Figure 1.13b is an FBD illustrating the forces at work in figure 1.13a. The load is 100 lb. on the right side, and a 100-lb. force on the left side holds the load in equilibrium. The sum of these two vertical forces is 200 lb. in the down direction. The forces are acting on a common point, in this case the pipe, and the sum of the forces is called the *resultant force*. The reaction is 200 lb. in the up direction and is equal and opposite to the resultant. Two or more forces acting on a common point produce a single resultant force.

Figure 1.14a depicts a line bent 90° around a pipe holding the same load. The FBD in figure 1.14b shows horizontal and vertical forces with 90° between the parts of the line. The pipe will tend to bend at a 45° angle between the parts of line. The

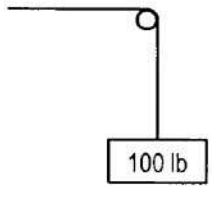


Fig. 1.14a. Line bent 90° around pipe

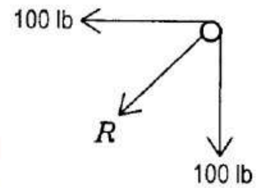


Fig. 1.14b. FBD of figure 1.14a

magnitude of the force is unknown. When two equal forces in different directions act on a common point, the direction of the *resultant force*, or *R*, is halfway between the applied forces. This is true for the example of the line bending around the pipe, a line going over a block, or a line bending around any point.

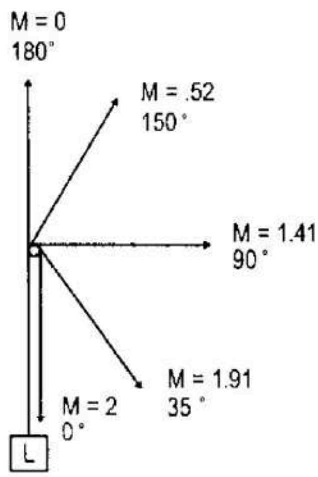


Fig. 1.15. Line bent around pipe at various angles, showing the multipliers, *M*

Figure 1.15 shows a line bent around a pipe at various angles. At 180° it is obvious that there is no load *M* on the pipe. At 0° the resultant is 200% of the applied load. As the angle between parts of line decreases from 180° to 0°, the resultant increases from 0% to 200% of the load.

B. The Law of Sines

Using a variation of the trigonometric law of sines, the resultant force can easily be calculated if the magnitude of the applied force and the angle between the parts of line are known. The formula to use is

$$F_r = \frac{P \times \sin \angle}{\sin \angle / 2}$$

F_r = resultant force
P = applied force
$\angle$ = angle between parts of the line
$\angle \div 2$ = half of the angle between the parts of line

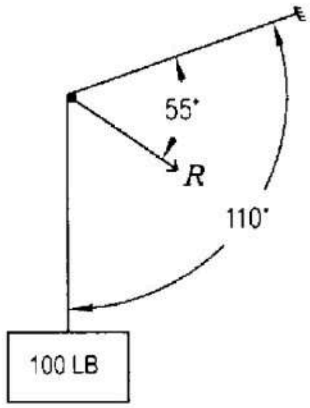


Fig. 1.16. Line bent 110° around pipe

Figure 1.16 indicates a line supporting 100 lb. bent 110° around a pipe. Using a calculator with trigonometric (trig) functions, do the following:

Enter 110, sin (the sin of the included angle).
The calculator should read .93969, (the sin of 110°).
Enter ×, 100 (the load).
Enter ÷, 55, sin (the sin of 1/2 the included angle).
The calculator should read: 114.71.
F_r is 114.71 lb. or rounded off, 115 lb.

C. Table of Multipliers for Resultant Forces

Changing the load to 2,500 lb. and using the same formula, F_r = 2,868 lb., divide the resultant load by the applied load and round off: 2,868 ÷ 2,500 = 1.15. From the above example of 100 lb., dividing 115 lb. by 100 lb. equals 1.15. It becomes apparent that 1.15 is a multiplier for 110°. To find the resultant for any two forces separated by 110°, multiply the applied force by 1.15. The multipliers used to find the resultant forces for equal loads in increments of 5° are listed in table 1.1.

Table 1.1. Resultant-Force (R) Multipliers

Angle (°)	Multiplier	Angle (°)	Multiplier	Angle (°)	Multiplier
180	0.00	120	1.00	60	1.73
175	0.09	115	1.07	55	1.77
170	0.17	110	1.15	50	1.81
165	0.26	105	1.21	45	1.85
160	0.35	100	1.30	40	1.88
155	0.43	95	1.36	35	1.91
150	0.52	90	1.41	30	1.93
145	0.60	85	1.47	25	1.95
140	0.68	80	1.53	20	1.97
135	0.77	75	1.59	15	1.98
130	0.85	70	1.64	10	1.99
125	0.92	65	1.69	0	2.00

The reaction is equal and opposite to the resultant; this table gives the reactive forces for the listed angles.

D. Vectors

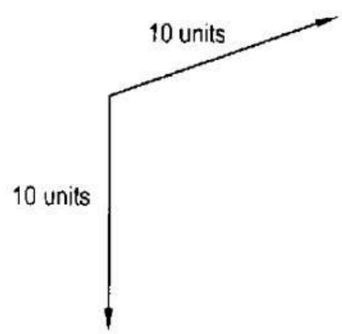


Fig. 1.17a. Vector drawing of figure 1.16

Forces that have *magnitude*, *direction*, and *sense* can be drawn as vectors. Figure 1.17a is a *vector* drawing of the forces shown in figure 1.16. A scale is chosen to represent the magnitudes of the force. In this case, each unit of length represents 10 lb. of force. A line representing the magnitude and direction of each force is drawn to scale with an arrowhead indicating the sense of the force. The resultant force can be calculated by *geometrically* adding the vector forces. There are two ways to do this.

1. Parallelogram Method

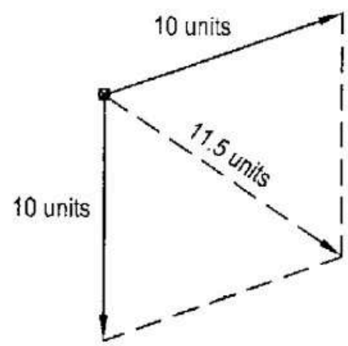


Fig. 1.17b. Completed vector drawing of figure 1.17a

Figure 1.17b illustrates the method whereby a parallelogram is constructed, and the diagonal from the origin to the opposite corner is drawn. The diagonal represents the resultant force. If the vectors are carefully drawn, the length of the diagonal can be measured, and the resultant force can be closely approximated.

2. Tip-to-Tail Method

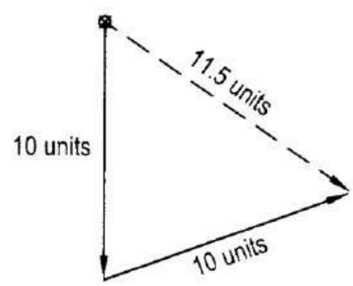


Fig. 1.17c. Tip-to-tail vector drawing of figure 1.17a

In the method shown in figure 1.17c, the vector for the vertical force is drawn starting at the origin. The diagonal-force vector at 110° is drawn from the tip of the vertical vector. A resultant vector is drawn from the origin to the tip of the diagonal-force vector and measured. If a large enough scale is selected, and the drawing carefully done, the results can be very accurate.

1.05 Bridle Analysis

In section 1.04, it was shown that component forces can be combined to produce a resultant force. Often it is necessary to do the opposite and determine the horizontal and vertical components of a diagonal force.

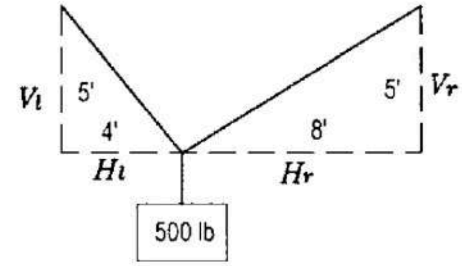


Fig. 1.18a. Bridle suspending load from two support points

Using bridles typically requires an analysis of the bridle components and the loads placed on all of the supporting members. The items that need to be calculated are the length of the bridle members; the force, or tension, on each bridle member; and the horizontal and vertical forces on each suspension point. Figure 1.18a shows a bridle being used to suspend a load from two support points. The given information includes the load and the horizontal and vertical distances of the load point from the hanging points.

A. Bridle-Length Calculation

If the horizontal and vertical distances from the hanging points are known, then calculating the required length of the bridle members can be done in two ways.

1. Scale Drawing

Carefully making a scale drawing of the bridle system, then, measuring the length of the bridle members will give a close approximation of the required bridle length. If done on a computer-aided drafting system (CAD), the results can be extremely accurate.

2. Pythagorean Theorem

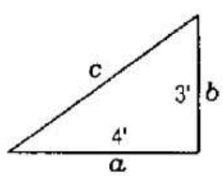


Fig. 1.18b. Right triangle

The Pythagorean theorem can be used to find the length of the bridle legs mathematically. Figure 1.18b shows a right triangle with legs *a* and *b*. The theorem states that the square root of the sum of the square of the sides is equal to the hypotenuse, *c*. Mathematically stated,

$$c = \sqrt{a^2 + b^2}$$
$$c = \sqrt{3^2 + 4^2}$$
$$c = \sqrt{9 \text{ sq.-ft.} + 16 \text{ sq.-ft.}}$$
$$c = \sqrt{25 \text{ sq.-ft.}}$$
$$c = 5 \text{ ft.}$$

Applying the formula to the bridle example shown in figure 1.18a, the length of the bridle members (L) can be calculated.

$L_l = \sqrt{V_l^2 + H_l^2}$	$L_r = \sqrt{V_r^2 + H_r^2}$
$L_l = \sqrt{5 \text{ sq.-ft.} + 4 \text{ sq.-ft.}}$	$L_r = \sqrt{5 \text{ sq.-ft.} + 8 \text{ sq.-ft.}}$
$L_l = \sqrt{25 \text{ sq.-ft.} + 16 \text{ sq.-ft.}}$	$L_r = \sqrt{25 \text{ sq.-ft.} + 64 \text{ sq.-ft.}}$
$L_l = \sqrt{41 \text{ sq.-ft.}}$	$L_r = \sqrt{89 \text{ sq.-ft.}}$
$L_l = 6.4 \text{ ft.}$	$L_r = 9.4 \text{ ft.}$

B. Vertical and Horizontal Forces

All of the forces supporting the load must be in equilibrium. At this point in the bridle analysis, the length of the components and the weight of the load are known. The next step is to find the magnitude of the vertical and horizontal forces on each suspension point. Looking again at figure 1.18a, it is obvious that the total vertical force in the up direction must equal 500 lb. and $\sum V = 0$. It is also obvious that there will be more load on the left suspension point than on the right because the load is closer to the left side.

1. Vertical Forces

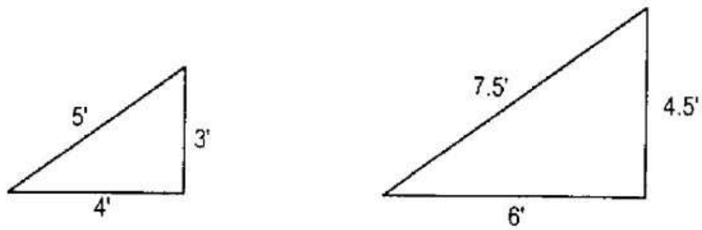
As long as both hanging points are the same height, $V_l = V_r$, the moment formula, $\Sigma M = 0$, can be used. It makes no difference that the applied load is a vertical distance away from the support points. (See section 1.05 E. for hanging points of different heights.) Taking moments at the left support point to solve for the vertical force (VF) at the right support point, VF_r, we have:

$$\Sigma M = 0$$
$$\Sigma M = (H_l \times \text{P}) + [(H_l + H_r) \times VF_r]$$
$$\Sigma M = (4 \text{ ft.} \times 500 \text{ lb.}) + (12 \text{ ft.} \times VF_r)$$
$$(4 \text{ ft.} \times 500 \text{ lb.}) + (12 \text{ ft.} \times VF_r) = 0$$

$$VF_r = \frac{2{,}000 \text{ lb.-ft.}}{12 \text{ ft.}} = 166.6 \text{ lb.} = 167 \text{ lb.}$$

$$\sum V = 0$$
$$\sum V = 500 \text{ lb.} - 167 \text{ lb.} - VF_l$$
$$VF_l = 500 \text{ lb.} - 167 \text{ lb.}$$
$$VF_l = 333 \text{ lb.}$$

2. Horizontal Forces



5/4 = 7.5/6 = 1.25
5/3 = 7.5/4.5 = 1.66
3/4 = 4.5/6 = .75

Fig. 1.19. Similar triangles

The horizontal forces must be equal to each other ($\Sigma H = 0$), or the load will be moving from side to side. When the force in any one direction on a bridle leg is known, and the horizontal and vertical distances of the bridle point from the suspension points are known, the other forces can be determined by using ratios of similar triangles. When two triangles have the same angles but sides of different lengths, they are similar. This means that the ratios of any two sides of one triangle will be equal to the ratio of the same two sides of a similar triangle as shown in figure 1.19.

Figure 1.20a is the bridle diagram with the corresponding vertical-force magnitudes shown. The diagram indicates the

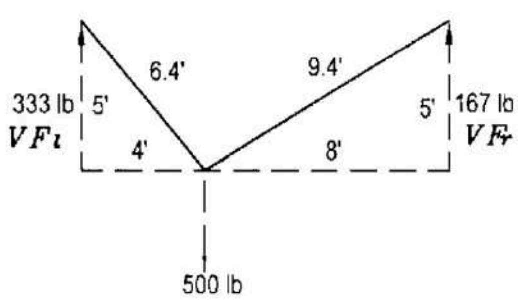


Fig. 1.20a. Bridle diagram showing vertical-force magnitudes

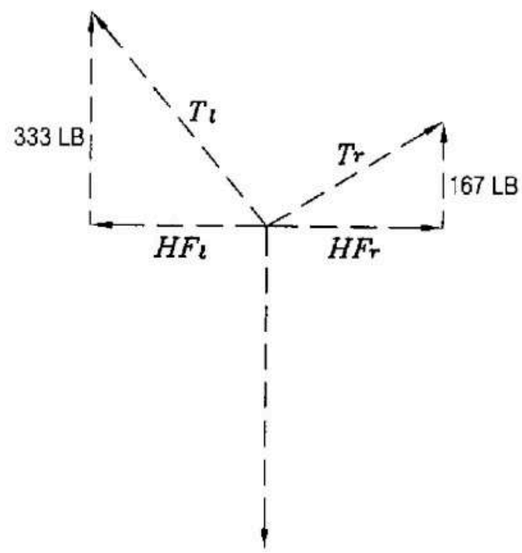


Fig. 1.20b. Vector drawing of figure 1.20a

length of the bridle members and the distances the load is from the supporting points. It also indicates the direction and sense of the vertical forces. Figure 1.20b shows a vector drawing of the forces (in which *T* is the tension). Note that the legs of the triangles in Figures 1.20a and 1.20b are of different lengths; the angles are the same. Setting up the ratios to find the horizontal forces, we have

$$\frac{5'}{4'} = \frac{333 \text{ lb.}}{HF_l} \qquad \frac{5'}{8'} = \frac{167 \text{ lb.}}{HF_r}$$

$$HF_l = \frac{4' \times 333 \text{ lb.}}{5'} \qquad HF_r = \frac{8' \times 167 \text{ lb.}}{5'}$$

$$HF_l = 266 \text{ lb.} \qquad HF_r = 267 \text{ lb.}$$

The 1-pound difference is due to rounding off the vertical forces and is of no consequence; 267 lb. is used for further calculations.

C. Bridle Tension

The tension in the bridle leg can be calculated in several ways. Two of the methods are illustrated here.

1. Pythagorean Theorem

Using the Pythagorean theorem and the values for the horizontal and vertical forces, we have (after rounding off)

$T_l = \sqrt{267 \text{ lb.}^2 + 333 \text{ lb.}^2}$ $\quad$ $T_r = \sqrt{267 \text{ lb.}^2 + 167 \text{ lb.}^2}$

$T_l = 427$ lb. $\quad$ $T_r = 315$ lb.

2. Comparative Ratio Method

$$\frac{6.4'}{4'} = \frac{T_l}{267 \text{ lb.}} \qquad \frac{9.4'}{8'} = \frac{T_r}{267 \text{ lb.}}$$

$$T_l = \frac{267 \text{ lb.} \times 6.4'}{4'} \qquad T_r = \frac{267 \text{ lb.} \times 9.4'}{8'}$$

$T_l = 427$ lb. $\quad$ $T_r = 314$ lb.

D. Vector Analysis

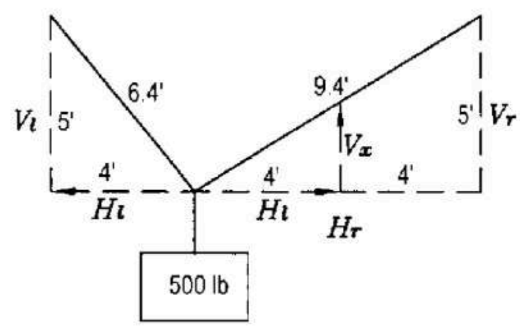


Fig. 1.21. Partial vector drawing superimposed on figure 1.18a

Making a vector drawing for bridles is another way of solving for the vertical, horizontal, and bridle-leg tensions. Use the original bridle drawing of figure 1.18a as a starting point. The horizontal forces acting on the bridle point are equal, therefore, the horizontal components of the vector drawing are equal. Take the shortest horizontal component of the scale drawing, in this case H_l, and mark it off on the longest horizontal leg. Construct a new vertical, V_x, to intersect the bridle leg. Figure 1.21 shows the modified original drawing of figure 1.18a with the vector drawing superimposed.

The vector drawing is a scale drawing of the *forces* acting on the various elements of the bridle. Although the drawing is accurate, the scale, or value of the units, is unknown. Determine the length of V_X by using the ratio of similar triangles.

$$\frac{V_x}{H_l} = \frac{V_r}{H_r}$$

$$V_x = \frac{(V_r \times H_l)}{H_r}$$

$$V_x = \frac{(5 \times 4)}{8}$$

$$V_x = 2.5$$

$\sum V = 0$; therefore, the two vertical components in the vector drawing must equal 500 lb. Adding the number of units and dividing them into the weight gives the weight-per-unit value of the vector drawing, that is, 500 lb. ÷ (5 + 2.5) = 66.6 lb. per unit. Now the force value of any component in the vector diagram can be found by multiplying the vector length by the unit value.

$V_l = 5 \times 66.6$ lb. = 333 lb.
$V_x = 2.5 \times 66.6$ lb. = 167 lb.

E. Hanging Points of Different Heights

1. Vector Method

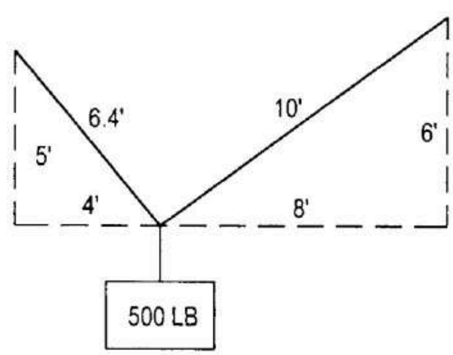


Fig. 1.22a. Bridle with hanging points of different heights

When the hanging points are of different heights, as in figure 1.22a, the bridle component lengths can still be calculated by the Pythagorean theorem, and the tension and forces can be calculated by the vector method in 1.05.D. Figure 1.22b is constructed from

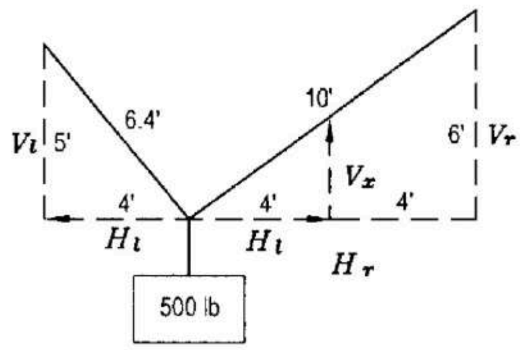


Fig. 1.22b. Partial vector drawing superimposed on figure 1.22a

figure 1.22a and a superimposed partial vector drawing. The weight-per-unit value in the vector diagram is

weight-per-unit = $P \div (V_l + V_x)$

P is the point load force. This equation is the sum of the vertical forces, or $\Sigma V = 0$. Using similar triangles,

$$\frac{V_x}{H_l} = \frac{V_r}{H_r}$$

$$V_x = \frac{(V_r \times H_l)}{H_r}$$

$$V_x = \frac{(6' \times 4')}{8'}$$

$$V_x = 3'$$

The weight-per-unit value is 500 lb. ÷ 8′ = 62.5 lb. per ft.

All of the forces can be calculated by multiplying the appropriate vector lengths by 62.5 lb. The left vertical force (VF_l) is

VF_l = 62.5 lb. × 5 = 312.5 lb.
VF_r = 62.5 lb. × 3 = 187.5 lb.
T_l = 62.5 lb. × 6.4 = 400 lb.
T_r = 62.5 lb. × 5 = 312.5 lb.
HF_l = 62.5 lb. × 4 = 250 lb.
$HF_l = HF_r$ = 250 lb.

2. Moment Method

If a vector diagram is not constructed, and the value for the weight-per-unit is not found, the moment theorem, $\sum M = 0$, requires some modification for finding the vertical forces. The following section will derive and illustrate the formulas.

$$VF_l = \frac{(V_l \times P)}{(V_l + V_x)}$$

Without a vector diagram, the value for V_x is not known. Using the similar-triangle formula and substituting $(V_r \times H_l) \div H_r$ for V_x in the VF_l formula,

$$VF_l = \frac{(V_l \times P)}{\left[V_l + \frac{(V_r \times H_l)}{H_r}\right]}$$

To simplify the equation, both sides are multiplied by $H_r \div H_r$. (Note that $H_r \div H_r = 1$, so it does not change the VF_l side of the equation.)

$$VF_l = \frac{(V_l \times H_r \times P)}{[(V_l \times H_r) + (V_r \times H_l)]}$$

$$VF_l = \frac{(5 \times 8 \times 500)}{[(5 \times 8) + (6 \times 4)]}$$

$$VF_l = 312.5 \text{ lb.}$$

Follow the same procedure for the other side:

$$VF_r = \frac{(V_r \times H_l \times P)}{[(V_l \times H_r) + (V_r \times H_l)]}$$

$$VF_r = \frac{(6 \times 4 \times 500)}{[(5 \times 8) + (6 \times 4)]}$$

$$VF_r = 187.5 \text{ lb.}$$

The tension in the bridle legs can be found by similar triangles:

$$\frac{T_l}{VF_l} = \frac{L_l}{V_l}$$

$$T_l = \frac{(VF_l \times L_l)}{V_l}$$

Substituting the VF_l formula above for VF_l:

$$VF_l = \frac{(V_l \times H_r \times P)}{[(V_l \times H_r) + (V_r \times H_l)]}$$

$$T_l = \frac{(L_l \times H_r \times P)}{[(V_l \times H_r) + (V_r \times H_l)]}$$

$$T_l = \frac{(6.4 \times 8 \times 500)}{[(5 \times 8) + (4 \times 6)]}$$

$$T_l = 400 \text{ lb.}$$

Substituting the VF_r formula to find the tension in the right bridle leg,

$$T_r = \frac{(L_r \times H_l \times P)}{[(V_l \times H_r) + (V_r \times H_l)]}$$

$$T_r = \frac{(10 \times 4 \times 500)}{[(5 \times 8) + (4 \times 6)]}$$

$$T_r = 312.5 \text{ lb.}$$

Summarizing the formulas,

$$VF_l = \frac{(V_l \times H_r \times P)}{[(V_l \times H_r) + (V_r \times H_l)]}$$

$$VF_r = \frac{(V_r \times H_l \times P)}{[(V_l \times H_r) + (V_r \times H_l)]}$$

$$T_l = \frac{(L_l \times H_r \times P)}{[(V_l \times H_r) + (V_r \times H_l)]}$$

$$T_r = \frac{(L_r \times H_l \times P)}{[(V_l \times H_r) + (V_r \times H_l)]}$$

F. Ratio of Horizontal to Vertical Distance

Changing the ratio of horizontal to vertical distance for the hanging points has an effect on the bridle tension and the horizontal forces on the hanging points. Figure 1.23 shows a series of bridles in which the vertical distance gets shorter in relationship to

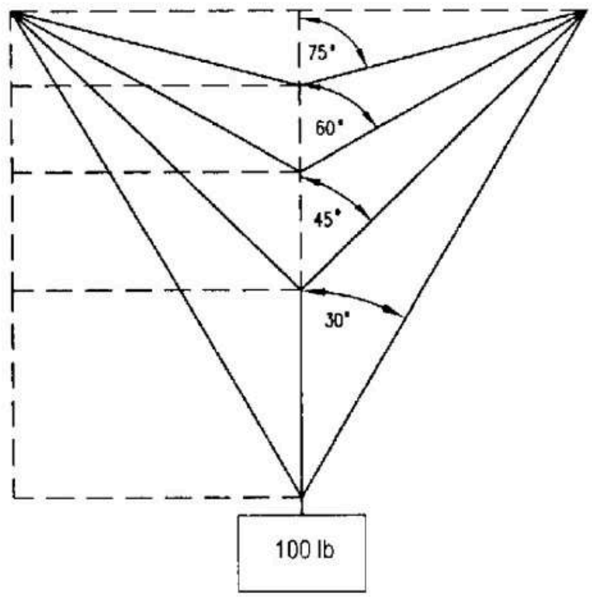


Fig. 1.23. Increasing vertical angles

the horizontal distance. As the vertical angle approaches 90°, the tension in the bridle increases, and the horizontal force on the hanging points increases. Assuming a 100-lb. load, the vertical load on each hanging point is 50 lb. A comparison of the bridle tension and horizontal forces at various angles illustrates the increase in forces.

Angle	Bridle Tension	Horizontal Force
30°	58 lb	29 lb
45°	70 lb	50 lb
60°	100 lb	87 lb
75°	193 lb	186 lb
89°	2,865 lb	2,865 lb
89.9°	28,648 lb	28,648 lb

Note: When the angle between the bridle leg and the vertical is known, the following trigonometry formulas can be used: $T = VF \div \cos$ of the vertical angle; $HF = T \sin$ of the vertical angle.

The above comparisons show that even though the supported load may be small, as the vertical distance decreases between the bridle point and the hanging points, the tension increases in the bridle. If too shallow a bridle angle is chosen, the tension in the bridle and the applied horizontal forces to the hanging points can be many times the load.

G. Allowable Loads

Sling manufacturers (a sling is just a bridle upside-down) derate the strength of their bridles as the angle changes between the sling leg and the vertical. Because the tension is increasing in the sling member as the vertical angle approaches 90°, the sling will support less weight. The sling member is given a working-load rating based on a straight vertical load. To find the allowable load of a bridle member at any angle, multiply the allowable load of the bridle member by the cos of the vertical angle. The cos of 0° is 1 and therefore can support the full load rating. The cos of 89° is .017. Due to the increased tension in the member, at 89° the sling can support only a small percentage of the load that it can support at 0°. If the rating of a bridle member is 1,000 lb., then

$$1{,}000 \text{ lb.} \times \cos 89° = \text{allowable load}$$
$$1{,}000 \text{ lb.} \times .017 = 17 \text{ lb.}$$

Generally, the manufacturers want a vertical angle of 45° or less maintained.

H. The Effect of Bridles on Hanging Points

When using a bridle, be sure that the hanging points can support both the horizontal and vertical forces of the bridle.

1. Separate Hanging Points

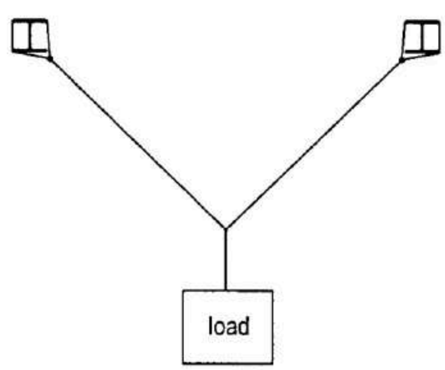


Fig. 1.24. Hanging points on separate members

When the hanging points are separate, such as with individual beams shown in figure 1.24, the beams must be braced in the horizontal direction to withstand the horizontal forces of the bridle. While this may seem obvious, quite often no one told the engineer who designed the beams that the supporting members would have to withstand these forces. Consequently, there may not be sufficient horizontal bracing. Imagine hanging a bridle from two separate battens with no stiffener between them. The horizontal force would pull the battens together. The same thing can happen to the beams in a building. Always calculate the horizontal, vertical, and tension loads on a bridle system before installing the bridle. Inspect the hanging points for horizontal bracing and any signs of deflection. (See 1.06.C for allowable deflection.) If there is no horizontal bracing or if there is any question about the bracing being able to withstand the applied forces, have an engineer verify that the structure can support the load.

2. Hanging In-line on a Beam

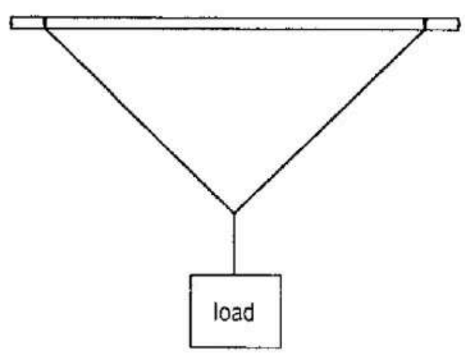


Fig. 1.25. Hanging points on same member

Hanging the bridles in-line on a beam (fig. 1.25) ensures that there is horizontal support. A batten is a simple beam, and bridling from it is a clear example of this type of hanging. There is a finite amount of weight that the batten, or any beam, can support in this manner. If the horizontal forces are too great, the beam will bend just like a bow when the string is drawn.

1.06 Strength of Materials

The following discussion on strength of materials is brief and included to provide a foundation for understanding the terminology that component manufacturers use in rating their products. Listed in the bibliography are some excellent books on the subject that do not require a degree in higher mathematics to understand. Not only are they very well written, some of them are even fun to read.

Every material used for stage-rigging components and support members has a finite strength, a limited ability to resist the load placed on it. Generally speaking, the manufacturers of components tell the users how much load a component made from a given material can support before failure. This information is conveyed in several ways, and understanding the terminology is part of the rigger's job.

A. Types of Applied Forces

There are four types of applied forces that affect materials. These are *tensile*, or stretching, forces; *compressive* forces; *shear* forces; and *torsional* forces. (Torsional forces are discussed in section 1.06.F.)

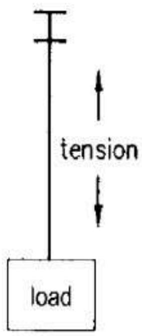


Fig. 1.26a. Tensile force on a line

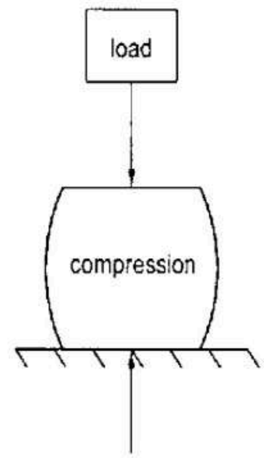


Fig. 1.26b. Compressive force

A *tensile force* attempts to pull the material apart (fig. 1.26a). This is generally the type of force placed on rope, cable, bolts clamping two objects together, and the bottom chord of beams. Not all materials withstand tensile forces well.

Compressive forces tend to push the material together and cause it to bulge (fig. 1.26b). Footings, the top chord beams, bolts used as leveling legs on appliances, and walls are examples of objects that have to resist compressive forces.

A *shear force* is a sliding force (fig. 1.26c). It tends to make two parts of an object try to slide past one another. A load on the pin of a shackle is an example of a shear force.

In each of these cases, the external force is attempting to deform the material, and the material is resisting the force through the molecular bond of atoms within the material. Some materials resist one type of force better than others. Steel resists both

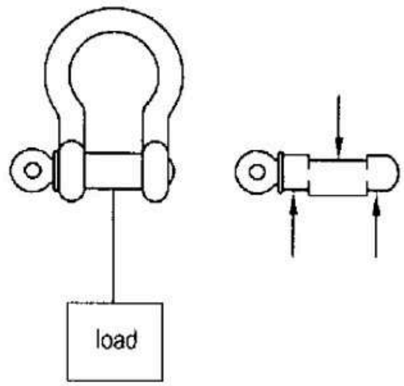


Fig. 1.26c. Shear force on a shackle

tensile and compressive forces fairly well. Concrete and Styrofoam resist compressive forces well but by themselves are almost useless in resisting tensile forces. Rope and cable withstand tensile forces but are ineffective in resisting compressive forces. Trying to move a load by pushing a rope is a futile task.

B. Stress, Strain, and Hooke's Law

Stress (S) is defined as the load per unit of cross-sectional area. It is found by dividing the point load forces (P) by the cross-sectional area (A) of the object being tested. $S = P \div A$. If a steel rod 1″ square is supporting a load of 1 ton in tension, the amount of stress on the rod is 2,000 lb. per square inch,

$S = 2{,}000 \text{ lb.} \div 1''$

This same principle is true for compressive forces. If a woman weighing 120 lb. walks on a pair of high heels, and each side of the bottom of the heel is .5 in., the area of one heel is .25 in.^{2} (.5 in. × .5 in. = .25 in.^{2}). When all of her weight is on that one heel, the compressive stress on the area of the floor where she puts her heel at the moment is 120 lb. ÷ .25 in. = 480 lb./in.^{2} As the construction of a tall building is completed, more and more material is added to the structure, increasing the weight that the building supports. The building compresses and actually gets shorter. Engineers must take this compression into consideration when designing the structure.

Stress can be caused by either tensile or compressive forces. In everyday life, the terms *stress* and *strain* are used interchangeably: The stage manager is "stressed out." The technical director (TD) is under a lot of "strain." In the science of material, stress and strain are very different. Strain is defined as the change in length of an object as force is applied to it. Strain (*e*) equals the change in length (l) divided by the original length (*L*) of the object, $e = l \div L$.

Robert Hooke was the first person to realize the relationship between stress and strain and write about it. His theory, Hooke's law, states that stress is directly related to strain. This is true for many materials, especially steel. When a piece of steel is subjected to a given load, either in compression or tension, its length changes in proportion to the applied force. The steel rod with a cross-sectional area of 1 square inch will stretch a certain length under a load of 1 ton. It will stretch exactly twice as much under a load of 2 tons. If the woman wearing high heels weighed 240 lb., the floor would compress twice as much. Or, if the heel of her shoe had an area of only .125 in.^{2}, the floor would compress twice as much.

C. Yield Point and Elasticity

For many materials, when forces within a certain range are applied and then removed from an object, the object will go back to its original shape. These applied forces are within the *elastic range* of the material from which the object is made. If the amount of force is increased, it will reach a point where the object will not return to its original shape. This point is called the *yield point*. At this point, the molecular structure of the material has been permanently altered. An example of this is a rubber band that has been stretched to the point where it will no longer go back to its original shape. Common examples are a thimble that has been permanently deformed by stress (see fig. 4.15) or a beam that is bent.

The yield point for a material is usually determined by laboratory testing. A sample of the material with a known cross-sectional area is subjected to carefully increasing forces, and the change in length is measured. This information is plotted on a standard stress-strain graph. Figure 1.27 is a typical stress-strain diagram for mild steel, the material from which structural and bar-stock steel components are usually made. As the stress induced by the load increases, the strain increases at a constant rate until it reaches the yield point.

If the force is released at any point of the test before the yield point is reached, the material will go back to its original shape. The force up to this point is within the *elastic range* of the material, and there is no change in the strength of the material.

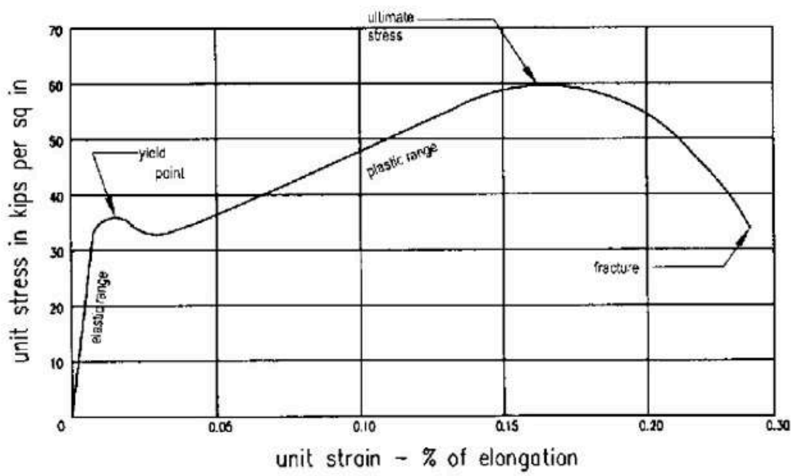


Fig. 1.27. Stress-strain diagram of mild steel

At point *Y*, the yield point, the material stretches a greater distance than before in relation to the applied force. If the force is released at this point or any point beyond, the material will not return to its original shape. The molecular bonds have been changed, and the elastic limit has been exceeded. Permanent deformation has occurred, and the material is now in a *plastic* state. At this point, the material is no longer as strong as it was originally.

D. Breaking Point

As increased force is applied to the material, the material continues to stretch in a plastic state until it reaches the point of ultimate stress. This point is called the *breaking point* or *failure point*. The material continues to stretch with no additional force being applied until it fractures. With any piece of hardware, there will be variances in the strength from piece to piece. For example, if an entire batch of shackles with a rated breaking strength of one ton was tested to failure, the shackles would not all break at exactly one ton. Some would break above, some would break right at, and some would break below the design strength. If reasonable quality control was used in manufacture of the shackles, they all will break within an acceptable range. If the breaking point for each shackle is recorded and plotted against quantity on a graph, a standard bell curve results. Figure 1.28 is an example of a bell curve with each dot representing one shackle test. The average absolute-value for the deviation from the design strength is calculated and is called the *standard deviation*.

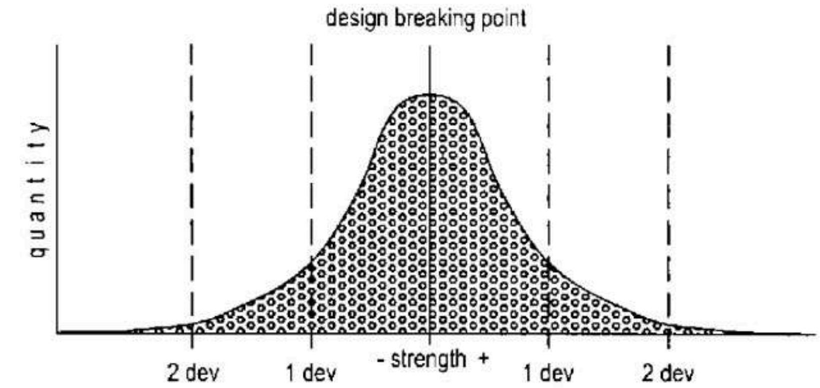


Fig. 1.28. Standard-deviation bell curve

Typically, about 68% of the samples fall within the first deviation, and about 95% fall within the first and second combined. A problem arises if a particular shackle is below the median design strength, because, obviously, the user does not know where any shackle falls on the deviation curve. Manufacturers publish the strength of materials in different ways. The terms *breaking strength*, *tensile strength*, *nominal breaking strength*, and *average breaking strength* are various ways manufacturers express the average breaking strength, the mid-point on the bell curve. About half the samples tested will fail above the average, and half will fail below.

Minimum breaking strength is the measurement of strength at about two standard deviations below the average. Almost all of the samples will test above this point.

Ultimate or *maximum breaking strength* is a point on the curve below which more than 90% of the samples broke. How this affects hardware selection and design factors is discussed in section H. Although these terms have slightly different meanings for the user, they are basically synonymous.

When a component fails and breaks apart, the official phrasing used in accident reports is "The component suffered a catastrophic failure." Because the failure is usually accompanied by a loud noise, the riggers on the job will say, "The son-of-a-bitch blew up." These two phrases are also synonymous. "Catastrophic failure" equals "son-of-a-bitch blew up." Whatever the term used, this result is to be avoided.

E. Allowable Deflection

When a load is placed on a beam, such as a head-block beam, roof beam, or grid channel, the beam deflects, or bends. There

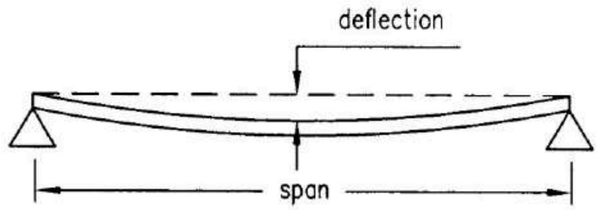


Fig. 1.29. Allowable deflection for a steel beam

is a limit to how far the beam can deflect before it reaches the yield point. A reasonable amount of deflection, based loosely on building-code recommendations, is 1/240 of the span (fig. 1.29).

To determine the deflection of a beam, measure the length of the beam in inches between supporting points. Divide the length by 240 to get the allowable deflection. For example, a beam 120˝ long has an allowable deflection of 0.5˝ (120 ÷ 240 = 0.5). Stretch a string along the top of the beam between the supporting points, and measure the distance from the string to the top of the beam. If the distance is less than the allowable deflection, there is no problem. If it is more than the allowable deflection, the beam should be inspected by a qualified person.

F. Torsion

A *torsional force* is a twisting force. Using a wrench to tighten a nut and bolt subjects the bolt and the nut to torsional force. The longer the wrench, the greater the force that can be applied. The strength of the bolt and nut must be able to withstand the force applied by the wrench, or the bolt will fail. Most of us have, at one time or another, "over-torqued" a bolt and had that sinking feeling when it suddenly got easier to turn because the threads were stripped, or the bolt broke apart. In both cases, the torsional force caused the material to fail in shear. *Shear*, as defined earlier, is when two parts of the material slide against one another. This torsional force that causes shearing is highly destructive and relatively easy to apply to a component. It is impossible for anyone to pull apart a ¼˝-diameter steel rod (tensile force) but relatively easy to strip a bolt of the same diameter if given a long-enough wrench.

G. Unpredictable Forces

Tension, compression, shear, and torsion forces are fairly easy to predict and calculate under static conditions. Once the load starts moving, the forces are increased and might be applied in unpredictable modes. Two of these modes are fatigue and shock loading.

1. Fatigue

Fatigue stress is caused by the repeated applying and removing of force on an object. The force can be tensile, compressive, torsional, or any combination of these. The components used for rigging are all subject to dynamic loads and fluctuating stresses. The actual stress can be well below the tensile strength or even the yield point of the material.

Fatigue is progressive, hard to see, and very difficult to predict. If a rigging system is designed for a single use with a constant load and a constant number of cycles per time period, predicting fatigue failure is possible. Most of the time, though, the loads and cycles are changing and therefore unpredictable. Bending a paper clip back and forth will eventually fatigue the piece of wire until it breaks. That it *will* break is certain. *When* it will break is very difficult to predict. Only regular inspection of the components can tell when the fatigued parts are in danger of failing.

2. Shock Loads

The rapid application of force to an object is *shock loading*. It usually involves rapid acceleration or deceleration. Hitting the arbor on the crash bar, a batten fouling on an adjacent batten and then falling free, or starting and stopping a motorized system are all examples of shock loading. The magnitude of shock load due to a free fall can be approximated if the free fall distance (D_F), the stopping distance (D_S), and the weight (W) of the falling object are known. The formula is

$$\text{shock load} = \frac{(W \times D_F)}{D_S} + W$$

On theatrical rigging systems, calculating the effect of a shock load on specific components is extremely difficult. The stopping distance is dependent on the cross-sectional area, the length of the supporting wire or rope, the coefficient of elasticity, and the percentage of load applied to each component of the system.

The following formula and sample problem are courtesy of Reid Neslage of H & H Specialties. This formula appears in the Macwhyte G-18 catalog. Neslage has reworked it for ¼″ galvanized aircraft cable. In order to use the formula, you need to know the modulus of elasticity and the cross-sectional area of the wire for the type of wire rope you are calculating the shock load for. The modulus of elasticity and area formulas are not in the catalog and were obtained from Macwhyte by Neslage. They are included here for your use.

Type of Wire Rope	Modulus of Elasticity	Area
1 × 7 carbon	25,000,000	.605 d^2
1 × 19 carbon	22,500,000	.597 d^2
1 × 37 carbon	22,000,000	.573 d^2
7 × 7 carbon	19,000,000	.491 d^2
7 × 19 carbon	15,000,000	.476 d^2
6 × 19 carbon IWRC	15,000,000	.490 d^2
18 × 7 carbon	13,000,000	.433 d^2
7 × 19 stainless	13,000,000.	476 d^2

The d^2 is the nominal diameter squared. Quarter-inch wire rope is .25″ squared.

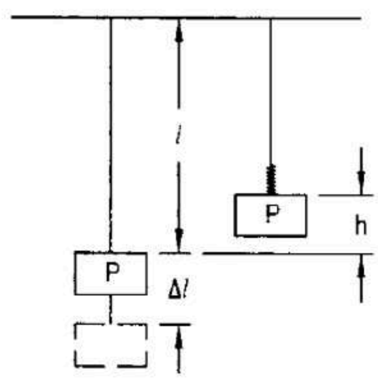


Fig. 1.30. Shock load on 1/4″ cable

The following formula can be used to calculate shock loads on a single piece of wire rope as shown in figure 1.30. The following symbols are used in the formula.

l = length of wire rope in inches
P = static load in pounds
h = slack in inches
Δl = elastic stretch of wire rope
A = metallic area of wire rope (in^2)
d = wire rope nominal diameter
E = modulus of elasticity
Pf = stress at impact in pounds

$$Pf = P \times f \qquad K = 1 + \sqrt{1 + \left(\frac{2h}{\Delta l}\right)} \qquad \Delta l = \frac{Pl}{AE}$$

$$Pf = P \times 1 + \left[\sqrt{1 + \left(\frac{2h \times A \times E}{P \times l}\right)}\right]$$

A sample problem for ¼″ galvanized aircraft cable follows.

l = 75 ft.
P = 500 lb.
h = 6 in.
A = .476 d^2
E = 1.5 × 10^7

$$Pf = 500\text{lb.} \times \left[1 + \sqrt{1 + \left(\frac{2 \times 6 \text{ in} \times .02975 \text{ in.}^2 \times 1.5 \times 10^7 \text{ psi}}{500 \text{ lb.} \times 75 \text{ ft.} \times 12\text{in./ft.}}\right)}\right]$$

Pf = 2296 lb.

H. Design Factor of Components

It is unsafe to load rigging components beyond the yield point. Usually a component is given a *working load limit* (WLL) that is a percentage of the ultimate breaking strength of the material from which the component is made. Other synonymous terms for WLL are *allowable load limit* (ALL), *allowable working load* (AWL), *recommended working load* (RWL), *and safe working load* (SWL). The terms *safety factor* and *safe working load* are not the preferred terms because they imply safety, which may or may not exist.

The ratio of the allowable load to the ultimate breaking strength is called the *design factor* (DF) and is determined by dividing the *ultimate breaking strength* (UBS) by the *allowable load* (AL). Like any equation, this formula can be manipulated algebraically to solve for any of the three terms.

DF = UBS ÷ AL
AL = UBS ÷ DF
UBS = AL × DF

I. Determining the Design Factor

The design factor provides a margin of safety for selecting and sizing rigging components. The question is, how large should the margin of safety be? The design factor, when not specified by a law, such as an Occupational Safety and Health Administration (OSHA) regulation, depends on the degree of risk involved in the situation. Dead-hanging a 10-lb. sack of feathers 8′ off the floor poses little risk to anyone. If it falls, there is not much chance of someone getting hurt or killed. The design factor for the suspension materials can be very low. Hanging a 200-lb. chandelier on a single line that moves during an a vista (in view of the audience) scene change over a stage full of actors has a much higher degree of risk. The design factor for all components should be increased to reflect the risk and provide an adequate margin of safety.

When calculating the design factor, every known force should be added to the load. Typical load-increase factors are the added weight that curtains will gain by absorbing moisture from the air and by the added force required to overcome the inertia of starting to move an object at rest.

Other factors will decrease the strength of the materials that are being used and are called *strength reduction factors* (SRF). Examples of strength reduction factors are a knot in a rope and the type of termination on a wire rope. Because these factors are known, the strength of the hardware device should be derated before starting the equation. For example, the efficiency of properly applied wire rope clips is 80% for sizes of ⅛″ through ⅞″. Therefore, multiply the catalog breaking strength of the wire rope by 0.8 to find what the breaking strength of the wire is after the clips are applied. The margin of safety provided by the design factor should allow for the unknown factors, such as shock loading and fatigue.

Common *minimum design factors* used in the entertainment industry are

Static-wire rope and hardware	5:1
Running-wire rope	8:1
Fiber rope	10:1

Running-wire rope is subject to fatigue bending and therefore requires a higher minimum design factor than a sling requires when wrapped around a beam for concert rigging. The 10:1 minimum design factor for fiber rope takes into account fatigue bending and abrasion.

When using wire or fiber rope, it is always a good idea to multiply the catalog breaking strength by the termination efficiency before calculating the allowable load. Seven-by-nineteen galvanized aircraft cable ⅛″ diameter has a catalog breaking strength of 2,000 lb.

Terminating the wire rope with copper Nicopress sleeves provides a 100% efficient termination. No derating is necessary. For a static application, 2,000 lb. divided by a design factor of 5 gives a 400-lb. allowable load. For a running application in which the line will be bent over a pulley, dividing 2,000 lb. by a design factor of 8 gives an allowable load of 250 lb.

Terminating with wire rope clips provides an 80% efficient termination. Multiplying 2,000 lb. by 0.8 gives a derated breaking strength of 1,600 lb. The allowable static load at 5:1 is 320 lb. The allowable running load at 8:1 is 200 lb.

To determine the size of rope required to hang the 200-lb. chandelier in the above example, start with the known information and reasonable assumptions. The weight of the object and the efficiency of a bowline (60%) are known. A design factor of 10 is common practice for this kind of situation.

Weight of chandelier (AL)	200lb.
Required design factor (DF)	10
Efficiency of knot (SRF)	60%

Modifying the formula to solve for the ultimate breaking strength of the rope with design factor of 10 gives the equations

$$DF = \frac{(UBS \times SRF)}{AL}$$

$$UBS = \frac{(DF \times AL)}{SRF}$$

$$UBS = \frac{(10 \times 200 \text{ lb.})}{.60}$$

$$UBS = \frac{2{,}000 \text{ lb.}}{.60}$$

$$UBS = 3{,}333 \text{ lb.}$$

Selecting a rope with an ultimate breaking strength of 3,333 lb. provides a design factor of ten times all of the known forces and allows for the strength reduction of the knot. This allows for shock loading, fatigue, and any other unforeseen forces hidden in the factor of ignorance.

The problem can also be solved by breaking the formula down into two steps.

$$DF = \frac{UBS}{AL}$$

$$UBS = DF \times AL$$

$$UBS = 10 \times 200 \text{ lb.} = 2{,}000 \text{ lb.}$$

Then divide the breaking strength by the efficiency of the termination.

$$UBS = \frac{2{,}000 \text{ lb.}}{.60}$$

$$UBS = 3{,}333 \text{ lb.}$$

Because the chandelier has to be lowered and raised by hand (obviously on a bagged line), the diameter of the rope has to be large enough to pull comfortably. Five-millimeter Spectra would be strong enough but hard to handle.

Part 2 Block-and-Tackle Rigging

2.01 Introduction

Section 1.01 introduced the four main principles of rigging called the 4 Ks. In the following sections, these principles will be applied to different kinds of rigging systems. Section 2.01 looks at their application to block and tackle rigging. Begin by getting to know the system. Under this heading, the things that the rigger needs to know to use a block and tackle safely are

1. the weight of the load to be lifted
2. the weight of the block and tackle
3. the capacity of the block and tackle
4. the working-load limit (WLL) of the rope
5. the lead line pull (LLP)
6. the load capacity of the supporting member
7. the total load on the supporting member

2.02 Anatomy of a Block-and-Tackle System

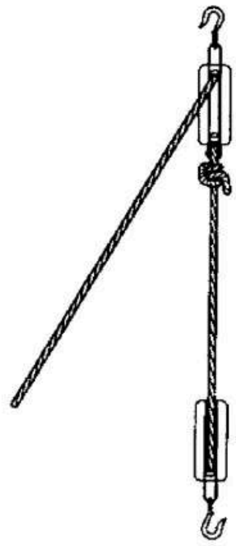


Fig. 2.1. Block and tackle

A block and tackle consists of a *standing* (or *fled*) *block* attached to the supporting member, a *running* (or *fall*) *block* attached to the load, and a line of fiber rope (see fig. 2.1). The line for a block-and-tackle system can be natural or synthetic fiber. (More detailed information on types and strength of line is given later.)

The principal part of a block is the *pulley*, or *sheave*, consisting of one or more grooved wheels supported by wood or metal side plates that turn on a shaft. The block is used to change the direction of force utilized to move an object with a line. It is much easier to raise something to the grid using a block and pulling down on the line than it is to stand on the grid and pull it up. Not only is there less strain on the back but the rigger can use body weight to help raise the load.

Blocks are rated for working-load limits. Each block should have a label on its side indicating the manufacturer's name and the working-load limit. This rating indicates that all of the components of the block have been engineered to withstand the working load. Sometimes there is a code indicating the type of bearings used in the block. If the type of bearing is not evident, call the manufacturer to get a list of its codes. Do not use unrated blocks for heavy loads. If an unrated block fails while you are using it, it is your fault, and you are liable.

A. Wooden Blocks

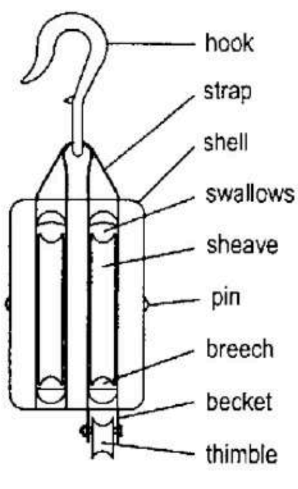


Fig. 2.2. Wooden block

Figure 2.2 shows the parts of a wooden block.

1. The wooden shell (or cheeks) keeps the rope in the sheave groove.
2. The straps, made of steel, transmit the load from the pin to the hook.
3. The sheave, or pulley, is the grooved wheel over which the rope runs.
4. The pin is the axle on which the sheaves turn. The pin supports the entire weight of the load and transmits the load from the sheave to the straps.
5. The swallows is the larger opening through which the rope passes.
6. The breech is the smaller opening at the other end of the block.
7. The becket is the attachment point of the dead end of the line.
8. A thimble is used to reduce the stress on the rope at the becket.
9. A hook or shackle is used to attach the strap to a supporting member.

B. Metal Blocks

Metal blocks, figure 2.3, are similar to wooden blocks. If the metal shell (or cheeks) is strong enough, it can actually support the

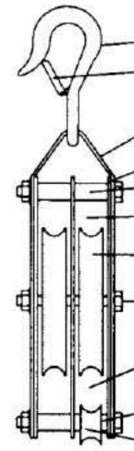


Fig. 2.3. Metal block

pin and transmit the load from the pin to the hook, and no straps are needed. In addition, metal blocks very often have some type of improved bearing to allow the sheave to turn with less friction.

C. Other Types of Blocks

Other types of rigging equipment are finding their way onto the stage. Venues close to navigable bodies of water sometimes use rated marine-grade sailing pulleys for block-and-tackle rigging. The blocks are load rated and lightweight, can be furnished with good ball bearings, and are easy to handle. Due to the small sheave diameter, they work particularly well with braided synthetic line.

For simple work lines, mountain-climbing rescue pulleys are easy to use. They are load rated, efficient, and lightweight.

2.03 Load Distribution on a Block

A. Static Load

Figure 2.4a shows a single block with a load of 100 lb. on it. A force of 100 lb. on the lead line is required to hold the load in static equilibrium. Recalling section 1.04.A, the resultant force on the block is 200 lb. A force of 200 lb. on the structural member also supports the block. When using a single block to support a load with an angle between lines of 0°, the force on the block and the supporting member is doubled.

This type of rigging is commonly found in arenas or thrust theatres with dead-hung pipe grids. Scenic units, such as head-

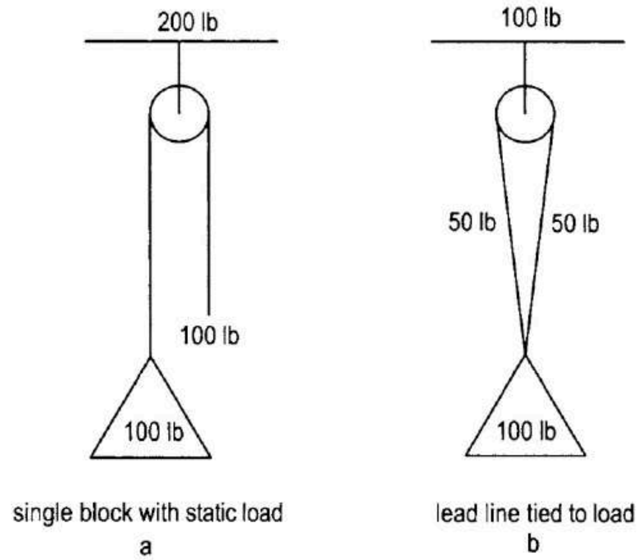


Fig. 2.4. Static load on a block

ers, are often hung from the grid. Block and tackle are used to raise the unit into position where it is dead hung with wire rope, piano wire, or some other "invisible" suspension medium. During the raising process, stagehands use single or multiple blocks to raise the unit to a working or trim height. The lead lines are often tied to the arms or legs of the auditorium seats to hold the header in position. Because seats are designed to withstand the downward load of a body, not upthrust, it is good practice to inspect the mounting bolts first to be sure that they are firmly attached to the floor, because tied-off lead lines are exerting an upthrust on the seats.

In figure 2.4b, the lead line is tied off to the load instead of to the seat. By doing this, the load is distributed equally to both lines. Because half of the load (50 lb.) is on each line, the load on the block and on the supporting member is only 100 lb. Untying the lead line from the load instantly doubles the load on the block and support.

The principle of distributing the load between two lines is used in many parts of stage rigging. One example is the difference in load distribution between a choker hitch (see fig. 2.5) and a basket hitch around a beam for arena rigging. The entire load is supported by one end of the cable in a choker hitch, while the load is split, with half on each side, in a basket hitch. A smaller-diameter wire rope can be used to support the same weight with a basket hitch. See section 4.05.D.1 for a similar example using trim chains.

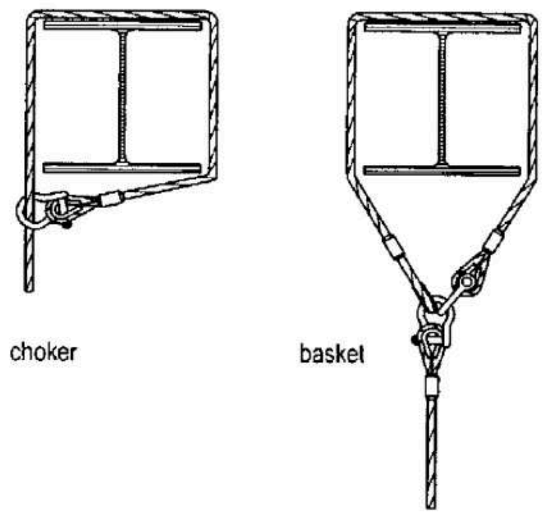


Fig. 2.5. Beam rigging

Refer to figures. 2.2 and 2.3 for the parts of a block. The entire resultant force is supported by the sheave, the pin, the attachment device, and the bearings. Half of the resultant load is supported by each side plate. Each of the components must be strong enough to do its job. If any of them are not, the component will fail, and the load can fall.

B. Dynamic Load

1. Inertia

A body at rest tends to remain at rest, and a body in motion tends to remain in motion. This tendency to resist change in acceleration is called *inertia*, and it is the principle of Newton's first law of physics. We have experienced inertia when trying to push a car on a level road. (Usually, it seems that cars must be pushed uphill, but that is a different problem.) More force is required to get the car rolling than to keep it rolling. A 100-lb. load requires a force of 100 lb. to hold it in position, but it requires more than 100 lb. to move it. In addition to overcoming the friction in the system, moving the load requires enough force to overcome the inertia, that is, to change the acceleration from zero to whatever speed we want it to move. With a block and tackle, we generally do not know the velocity that we want the load to travel. Therefore, an exact calculation of the inertial force is not practical. Even though inertia is not pragmatic to calculate, its existence causes an increase in the force required to move the load.

Once the load is moving at the desired speed, the inertial force is no longer needed. A force equal to the load plus the force of friction is required to keep it moving. The three magnitudes of force on the block and supporting member are (1) the force of the load at rest; (2) the force required to accelerate the load to the running velocity, which is a force equal to the load plus inertial and friction forces; and (3) the force required to keep it moving, which includes the load force and the friction force. These changes in force are transmitted to the block parts, to the supporting member, and to the rope and cause fatigue in all of the parts of the system.

2. Friction

When asked to solve problems of force and movement in high school physics class, we were usually told to ignore friction. In real life, ignoring friction is like ignoring the wind in a hurricane. Friction is always there. It is a real part of the system, and it is extremely hard to calculate. There are three sources of friction in a block-and-tackle system. The first is the friction of the sheave turning on the bearings. Depending on the type of bearings and how well-lubricated they are, the bearing friction can range from 1% to 10% of the load. Typical types of bearings used in blocks are

a. Common, or plain, bore. This is simply a hole drilled in the sheave for the metal shaft to rotate on, very common in wooden-sided blocks. This type of block has the high est friction factor.
b. Roller bearings.
c. Self-lubricating bronze bearings.
d. Pressure-lubricated bronze sleeves.
e. Ball bearings, usually found in boat pulleys and some stage blocks.
f. Sealed-precision ball bearings.
g. Tapered roller bearings, found in some loft and mule blocks, and all head blocks. These can be overtightened to the extent that the sheave will not move.

The friction factors for these various types of bearings are found in tables 2.1 through 2.4 in section 2.04.C.

The second source of friction is the rope. Regardless of the type of rope—synthetic, natural fiber, or wire—the strands and fibers rub against each other as they bend over the sheave. The smaller the diameter of the sheave, the sharper the bend in the rope and the more the fibers rub against each other. The recommended ratio of the sheave diameter to the rope diameter is discussed in section 3.03.G.9. The amounts of lubricant on the rope fibers and the amount of moisture in a fiber rope also affect friction. It is not practical to calculate rope friction, but be aware that it exists and requires force to overcome.

The third source of friction results when lines are twisted (see section 2.05). Additional friction can occur if the line is oversized for the sheaves and rubs on the side plates. Also, if the blocks tilt, the line can rub on the side plates and cause additional friction.

2.04 Mechanical Advantage

Mechanical advantage is the ratio, or comparison, between the force required to move a load and the force of the load. The formula is

Mechanical Advantage (MA) = Load (L) ÷ Applied Force (*AF*)

If there is a load of 100 lb. and a device requiring 10 lb. of force to move the load is used, then the MA is 10; 100 lb. ÷ 10 lb. = 10.

A. Apparent Mechanical Advantage

In order to gain any mechanical advantage in moving a load with a block and tackle, a second block attached to the load must be used. Figure 2.6a is a schematic drawing showing a two-block system with an apparent MA of 2:1. This means that an apparent force equal to half of the load is required to move the load. To determine the apparent mechanical advantage of a block-and-tackle system, count the number of ropes *supporting* the load. The number of supporting ropes is equal to the theoretical MA. Analyzing the force on the three ropes shows that there are two ropes supporting the load (S1 and S2), with half the load on each one. To hold the load in position, there is a force of ½ of the load on the *lead line*, *LL*. A second way to determine the MA is to divide the load by the force required to move the load. If the load equals 1, then L ÷ .5L = 2.

B. Actual Mechanical Advantage

In order to raise the load 1′, 2′ of rope must be pulled through the top block (fig. 2.6b). When the load is at rest, the tension in the line is equal at all points. When the load is moving, the forces

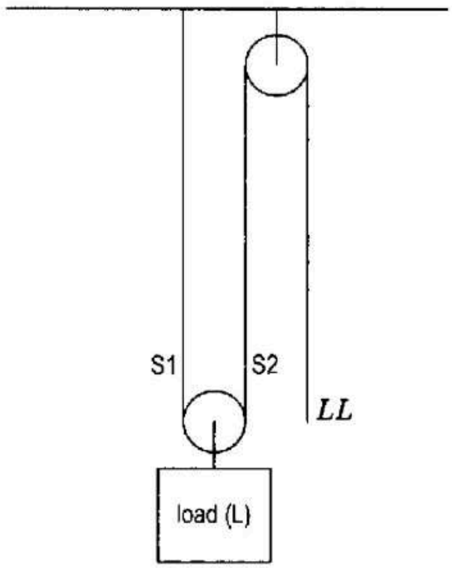


Fig. 2.6a. Two-block system

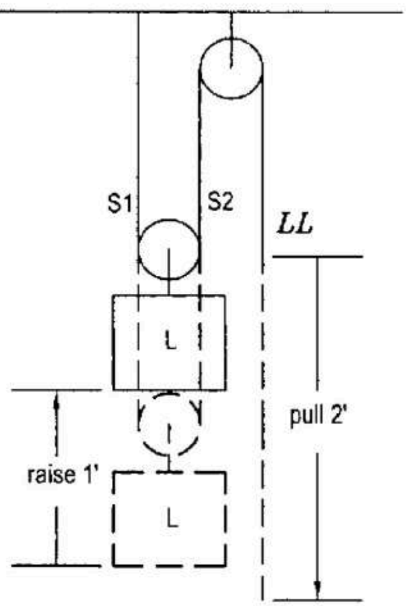


Fig. 2.6b. Raising the load 1´ by pulling 2´ of line

of friction are added to the static force in the line as it passes over a sheave, and the tension in the separate parts of the line is unequal. S1 supports half of the load when moving or static.

S2 has the added force required to overcome the friction in the lower block. Assuming that the friction factor is 10%, the tension in S2 is

$$.5L + (.5L \times 10\%) = .55L$$

The force on *LL* (the lead line pull, *LLP*) includes the friction for the upper block and is

$$.55L + (.55L \times 10\%) = .605L$$

Therefore, in order to move the load, we would need an force of .605 of the load plus the force of inertia. Using L ÷ *LLP* = MA, we have 1 ÷ .605 = 1.65. The actual mechanical advantage is somewhat less than 1.65 due to inertia.

Adding all of the force on the block and the supporting member when the load is moving, we have

S1 + S2 + *LLP* = total load on block and support
.5L + .55L + .605L = 1.655L (or, total load)

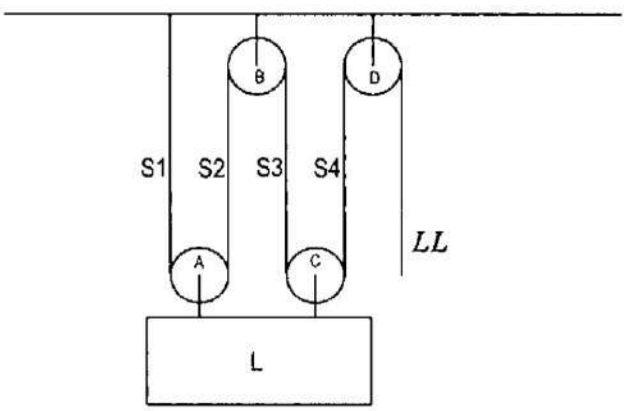


Fig. 2.7. Four-line system

Figure 2.7 is a schematic drawing of a four-line block and tackle with a static mechanical advantage of 4:1. Each of the supporting parts of line, S1 through S4, holds 0.25L when static. The amount of force on the lead line, lead-line pull (*LLP*), required to hold the load in the static position is also 0.25L. Every time the rope bends around a sheave, the friction factor for that sheave is added to the pull on the line. Ignoring inertia for the moment and assuming a 10% friction factor for bearings and rope, the actual dynamic load on each line is

$S1 = .25L$
$S2 = .25L + (.25L \times 10\%) = .275L$
$S3 = .275L + (.275L \times 10\%) = .3025L$
$S4 = .3025L + (.3025L \times 10\%) = .333L$
$LLP = .333L + (.333L \times 10\%) = .366L$

The total dynamic load on the top block and supporting member, ignoring inertia, is

$$S1 + S2 + S3 + S4 + LLP = L$$
$$.25 + .275 + .303 + .333 + .366 = 1.53L$$

If we ignored the accumulated friction factor, the apparent dynamic load would be the same as the static load, 1.25L. Taking friction into consideration, the *dynamic load* is .28L higher than the static load.

C. Calculating Lead-Line Pull

Table 2.1. Friction Factors on Sheaves with Friction Force of 10% of Sheave Load and Common Bearings (hole in the sheave)

No. of Parts of Line (N)	Multiplication Factor (M)	Actual Mechanical Advantage (ratio = N/M)
1	1.10	.91
2	1.21	1.65
3	1.33	2.26
4	1.46	2.74
5	1.61	3.12
6	1.77	3.39
7	1.95	3.59
8	2.14	3.74
9	2.36	3.81
10	2.59	3.86
11	2.85	3.86
12	3.14	3.82
13	3.45	3.77
14	3.80	3.68
15	4.18	3.66

Table 2.2. Friction Factors on Sheaves with Friction Force of 5% of Sheave Load and Pressure-Lubricated Bronze Bearings

No. of Parts of Line (N)	Multiplication Factor (M)	Actual Mechanical Advantage (ratio = N/M)
1	1.05	.95
2	1.10	1.80
3	1.16	2.59
4	1.22	3.28
5	1.28	3.90
6	1.34	4.48
7	1.41	4.96
8	1.48	5.40
9	1.55	5.81
10	1.63	6.13

Table 2.3. Friction Factors on Sheaves with Friction Force of 3% of Sheave Load and Ball Bearings or Well-Adjusted Roller Bearings

No. of Parts of Line (N)	Multiplication Factor (M)	Actual Mechanical Advantage (ratio = N/M)
1	1.03	.97
2	1.06	1.89
3	1.09	2.75
4	1.13	3.54
5	1.16	4.31
6	1.19	5.04
7	1.23	5.69
8	1.27	6.30
9	1.30	6.90
10	1.34	7.46

Table 2.4. Friction Factors on Sheaves with Friction Force of 1% of Sheave Load and Excellent Precision Ball Bearings or Perfectly Adjusted Tapered Roller Bearings

No. of Parts of Line (N)	Multiplication Factor (M)	Actual Mechanical Advantage (ratio = N/M)
1	1.01	.99
2	1.02	1.96
3	1.03	2.91
4	1.04	3.85
5	1.05	4.76
6	1.06	5.66
7	1.07	6.54
8	1.08	7.41
9	1.09	8.26
10	1.10	9.09

The previous examples illustrate a laborious method of calculating bearing-friction factors and lead-line pull. Tables 2.1 through 2.4 provide information to simplify the calculations. Each table has three numbers in each row. In the first column is the *number of parts of line (N)*, which refers to the number of supporting lines. The second number, next to the part of line, is the *multiplication factor* (M) used to calculate the load on that part of line. This factor takes into account all of the accumulated sheave friction in the system up to the point of the particular line. The third number is the *ratio* (R), or *actual mechanical advantage*, on that part of line. This is found by dividing *N* by M (or *N*/M).

To find the *LLP*, divide the load (L) by the parts of line that give the theoretical mechanical advantage, and multiply it by M.

$$LLP = (L \div N) \times M$$

Another way to find *LLP* is to divide the load by the actual mechanical advantage, R. The formula is

$$LLP = L \div R$$

Using the example in figure 2.6a, assigning a value of 500 lb. to the load and a friction factor of 10%, and using the value .605 derived for the two-line system above,

$$LLP = 500 \text{ lb.} \times .605 = 303 \text{ lb.}$$

The laborious part is arriving at the number .605. *LLP* can be calculated more quickly using the table to get the value of R.

LLP = 500 lb. ÷ 1.65 = 303 lb.

Using R to calculate LL for the four-line system,

LLP = 500 lb. ÷ 2.74 = 182 lb.

Allowable working loads for different types and sizes of rope are discussed in section 3.03.E. In all of the calculations, the friction caused by the rope rubbing against itself and the force of inertia have been omitted because of the difficulty in calculating them. The actual lead-line pull and total load on the system will be greater than the calculated lead-line pull. The design factor allows for this.

D. Mechanical Advantage of Common Systems

The most common block-and-tackle systems used for stage rigging have apparent mechanical advantages ranging from 2:1 to 6:1. There are systems used on cranes with many more parts of line, but they are beyond the scope of this book. Within the range of the systems commonly used for stage work, a number of different kinds of bearings are used. Each of the bearing types has a finite load limit and a unique coefficient of friction. The load limit is calculated in the overall rating of the block, and you can assume that the WLL has taken the bearing-load rating into account.

Many times we do not know what type of bearings the block has, so we must guess at the friction factor. Wooden blocks often have no bearings. The sheaves have a hole punched through them to allow them to turn on a steel shaft. Lubricant is the only thing that can reduce the friction on this type of block. Judging from the squeaking and groaning heard during operation, many unlubricated blocks are in use. If you are unsure of the type of bearings in a block, use the 10% friction factor shown in the tables.

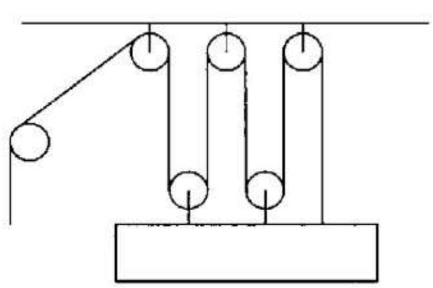


Fig. 2.8. Five-part system with mule block

Figure 2.8 shows a five-part system with a mule block added to the lead line to change the direction of the pull. The mule block adds friction to the system and decreases the MA. In this case, the actual mechanical advantage cannot be read directly from the tables. It is calculated by dividing the parts of line supporting the load (*N*) by the multiplication factor (M) for the number of sheaves the rope passes over.

$$R = N \div M$$
$$R = 5 \div 1.77 = 2.82$$

Without the mule block,

$$R = 5 \div 1.61 = 3.11$$

Therefore, *LLP* with the mule block is

500 lb. ÷ 2.82 = 177 lb.

and without the mule block is

500 lb. ÷ 3.11 = 161 lb.

Adding a block to a system always decreases mechanical advantage and increases lead-line pull.

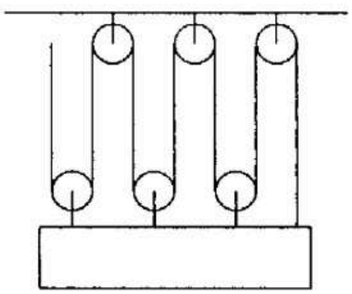


Fig. 2.9. Six-part system upside down

Figure 2.9 is a six-part system turned upside down. By reversing the position of the blocks and pulling *up* on the lead line, the lead line becomes a supporting line, the six-part system becomes a seven-part system, and the MA is increased. There are seven parts of line supporting the load but still only six sheaves. To find the mechanical advantage (R) for this system, divide the parts of line supporting the load, *N* (7) by the factor for the number of sheaves (M = 6)

$$R = 7 \div 1.77 = 3.95$$
$$LLP = 500 \text{ lb.} \div 3.95 = 127 \text{ lb.}$$

E. Calculating the Total Load on the System

The total load on the system and the supporting member is the load plus the weight of the block and tackle plus the lead-line pull. The weight of the load is either calculated or obtained by weighing the object. (If it is large, it can be weighed on a truck scale.)

The weight of the block and tackle is the total weight of the blocks and the line, and, depending on the type of equipment, it can be significant. Blocks can range in weight from a few ounces for an alloy marine block, to over 50 lb. for a 3-sheave 8″ block. If it appears that the weight is going to be a significant factor in the total load on the supporting member, weigh the block and tackle on a scale. Once done, label the set for future reference.

LLP can be calculated by using the procedures described above, which is not always possible in the field. Common sense tells us that the maximum load that can be placed on the lead line is equal to the total amount of force available to pull it. In many cases, that would equal the weight of the rigger, or riggers, pulling the line. A rule of thumb for calculating the total load on the system and supporting member is to add together the weight of the load and the block-and-tackle system and then double the total. As long as the lines are not twisted, this should provide an adequate design factor for friction and inertia. An exception to this rule is the case of a single-line block (fig. 2.4a). A single-line block system exerts a static force of twice the load on the block and supporting member. To determine the total dynamic load on the system and the supporting member and allow for friction and inertia, double the load and add 15% of the load to be raised to the doubled load.

Common block-and-tackle systems are designed to be used by hand. Attaching the lead line to a capstan winch, forklift, or other mechanical device is not recommended because of the greatly increased applied force on all of the components, which can stress them beyond their capacities.

F. Rope and Sheave Wear

Further analysis of figure 2.7, the four-sheave system, shows that to raise the load 1′, 1′ of rope passes around sheave A; 2′ of rope pass over sheave B; 3′ pass over sheave C; and 4′ pass over sheave D. This means that sheave D travels four times faster than sheave A and receives four times the wear. The lead line at sheave D has the greatest stress and travels the greatest distance. An example of this kind of stress and fatigue happens to us in everyday life. In lacing up our shoes, we pull on the ends of the laces. The greatest stress and travel of the lace is at the top eyelets, and this is where the lace almost always breaks. Re-reeving the blocks so that the fast sheave becomes the slow sheave and changing the rope end-for-end will equalize the wear on the system and extend the useful life of the rope and the sheaves.

G. Mechanical Advantage of Complex Systems

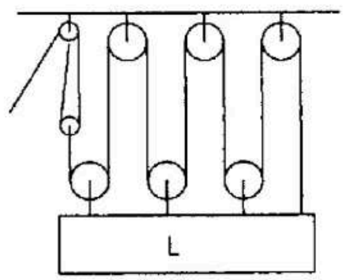


Fig. 2.10a. Two block-and-tackle systems with an actual MA of 5.92

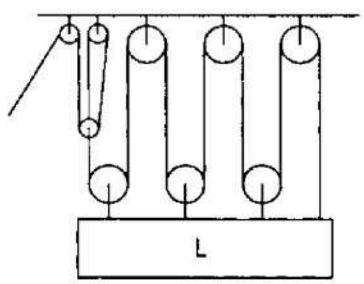


Fig. 2.10b. Two block-and-tackle systems with an actual MA of 8.11

Section 2.04.D noted that adding a sheave to a system also added friction to the system. Table 2.1, for 10% friction factor, shows that after eleven parts of line, mechanical advantage actually decreases with the addition of any more parts of line. Using two block-and-tackle systems together, as shown in figures 2.10a and 2.10b, increases the mechanical advantage significantly. The lead line from the seven-part system is attached to the fall block of a two-part system. R is calculated for each system independently: the value is 1.65 for the two-part system, and the value is 3.59 for the seven-part system. When using two systems together, the mechanical advantages are multiplied together to calculate the total mechanical advantage acting on the load. Total actual mechanical advantage is calculated as follows

R = 1.65 × 3.59 = 5.92
LLP = 500 ÷ 5.92 = 84 lb.

If two additional parts of line are added to the seven-part system making it a nine-part system in the same configuration, then

R = *N* ÷ M
R = 9 ÷ 2.36 = 3.81
LLP = 500 ÷ 3.81 = 131 lb.

In the three-part system of figure 2.10b, R is 2.26. The total mechanical advantage is

2.26 × 3.59 = 8.11
LLP = 500 ÷ 8.11 = 62 lb.

Although they take more gear and longer to set up, complex systems can significantly increase lifting capacity.

2.05 Lacing and Reeving of Blocks

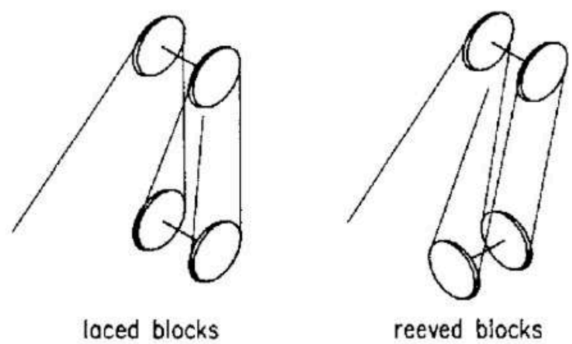


Fig. 2.11. Laced and reeved blocks

There are two ways of running the line through a set of blocks. The first, called *lacing* (fig. 2.11), runs all of the parts of line in the same direction, starting with a sheave on one side of a block and working toward the other side. Lacing tends to allow the rope to twist a great deal, and in larger systems, the block will be inclined to tilt when moving (fig. 2.12). When the block tilts, the line rubs on the cheeks of the block and adds friction. When the line twists, an enormous amount of friction is added to the system by the line rubbing against itself.

Reeving (see fig. 2.11), the second way to run a line, puts the blocks at right angles to each other. In this configuration, the two

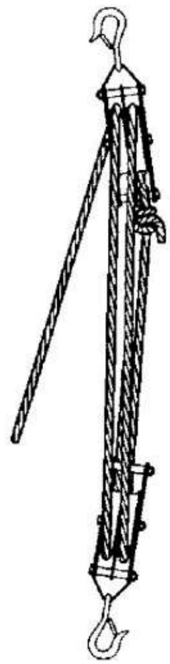


Fig. 2.12. The tendency of laced blocks to tilt

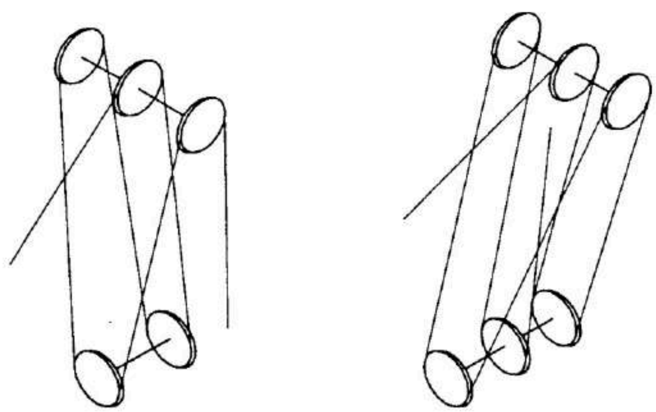


Fig. 2.13. Running of lines in five- and six-part systems of reeved blocks

sheaves on each block turn in opposite directions from each other, and this helps to decrease twisting and reduce friction. When reeving, attach the standing part of the line as close to the center of the block as possible. Also, run the lead line out of a sheave as close to the center as possible; this will reduce the tendency of the block to tilt and allow the line to run without rubbing on the side plates. Figure 2.13 illustrates how to reeve common five- and six-part systems.

2.06 Inspecting a Block-and-Tackle System

The second K, *Keep the system in safe working order*, can only be achieved by periodically inspecting the system. Every time a block and tackle is taken out of storage and set up, the rigger should inspect it. A professional, conscientious rigger inspects every piece of rigging gear before using it. Use the following checklist as a guide.

1. Check the load rating on the blocks. If they aren't rated, do not use them for heavy loads. If they are old, use a higher design factor. Because the parts are worn, they will not be as strong as when they were first made.

2. Look for frayed or worn rope. If it is old Manila or badly worn line of any type, derate the allowable load on the system. See section 3.03 for additional information on fiber rope.

3. Check to see if the rope is the right size for the sheaves. Too large a rope will rub on the side plates, adding friction and abrading the rope. Too small a rope will not be properly supported by the sheave groove. The rope may also get jammed between the sheave and the side plate.

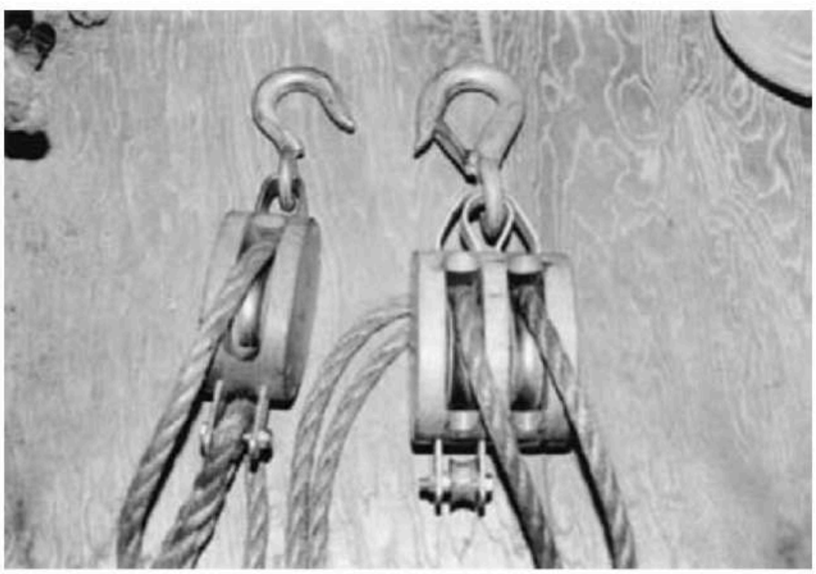


Fig. 2.14. Different-sized hooks on blocks

4. The hook or attachment device is often the weakest part of a block. Bent or deformed hooks or attachment devices on the blocks may be a sign that the blocks have been overloaded, and the block should be taken out of service. Note the different-sized hooks on the blocks in figure 2.14. The single-sheave block

is rated for a WLL of 1,000 lb., and the double-sheave block is rated for 1,400 lb.

5. Elongated straps or bent side plates are a sign that the block has been overloaded. Remove from service.

6. Cracked wooden side plates may fall apart under load. Remove them from service.

7. Turn the sheaves without a load to see if they wobble. Stick your thumb in the groove to see if the sheave moves from side to side. Wobbling can be an indication of bad bearings, an oversized hole in the sheave due to wear, or a worn-down pin. If the bearings are bad, friction and load increase on all of the components. A worn pin or enlarged hole in the sheave means a loss of strength of the component. Replace the block.

8. Check all nuts and bolts, rivets, and retaining rings for tightness.

9. Listen to the sheaves. If they squeak, lubricate them sparingly. Do not get lubricant on the line.

2.07 Using a Block-and-Tackle System

Before using a block and tackle, make a list of the items that need to be to be checked, and follow it. The user's checklist shown below is a starting point; modify it to fit your needs.

A. User's Checklist

1. The weight of the load to be lifted
2. The weight of the block and tackle
3. The capacity of the block and tackle
4. The working load limit of the rope
5. The lead-line pull
6. The load capacity of the supporting member
7. The total load on the supporting member
8. The location and capacity of the tie-off point for the lead line

B. Attaching

The standing block is attached to a supporting member. Before climbing up to make the attachment, determine to which supporting member the block will be attached as well as how it will be attached. Be sure that the supporting member will sustain the load. You may have to consult a structural engineer to help you.

Any sign of deflection in the supporting member is an indication that it may fail.

1. If a cable basket or choker is to be used, calculate the applied load, and size it accordingly. Use a minimum design factor of 5:1 for the wire rope. A minimum design factor of 5:1 is acceptable for wire rope under a static load; a design factor of 8:1 is used for running lines.

2. If the attachment fitting on the block is a rotating type, mouse it to keep it from rotating (unless for some reason you want it to rotate).

3. Hook fittings come with and without latches. If there is no latch, mouse the hook to keep it from falling. A good mousing material is solid-core electrical wire. It holds well and can be installed and removed by hand.

4. Shackles are a positive way to attach the fall block. The shackle should not have a side load on it. The pin may be either up or down.

C. Operating

1. Before operating the block and tackle, especially if multiple sets are in use on a common load, designate one person to be in charge and to give directions to keep the load balanced.

2. When operating the block and tackle, watch for any deflection on the supporting member. If it starts to deflect, stop immediately, and lower the load to the floor.

3. Keep the load balanced so that one rigging point will not have to support more than it should.

4. If the load spins, tie a tag line to the object, and have a rigger stand to the side holding the line to keep it from spinning.

5. Keep your concentration.

D. Storing

There are primarily two ways to bundle up block-and-tackle systems for storage. Once bundled, keep them in a cool, dry place away from heat sources and contaminants.

1. *Method A*. Pull the lead line until the blocks are about 3´ apart. Lay them on the floor, and coil the line around them. If you are using a right-lay twisted line, coil the line clockwise ("with the sun" as they say in the nautical-rope books). Pull the bundle together, and tie a clove hitch around the bundle in the center. The bundle may be stored by hanging by the top block.

To uncoil, lay the bundle on the floor, clove-hitch side up. Untie the knot, carefully take the coiled rope, and turn it over. Separate the blocks to the required working distance, feeding the line carefully to avoid tangling.

2. *Method B*. Separate the blocks to the full extent of the line. Tie the end of the line around the bundle of line just above the fall block. Starting at the standing-block end, coil the bundle, and using *one hand only*, pull the bundle through the loop, making another loop. Using the same hand, continue pulling the bundle through each successive loop until you reach the fall block. Pull the fall block through the last loop. The bundle may now be hung or coiled on a peg for storage.

CAUTION: If you use both hands alternately to pull the line, you create extra twists in the bundle, and it is harder to take apart. Also, be careful that you feed the fall block out *only* through the last loop. It is all too easy to put it through the second-to-last loop. If you do, you will make a series of locking knots that will have to be untied one at a time.

Part 3 Hemp Rigging

3.01 Introduction

Although hemp rigging is the simplest and oldest form of stage rigging, the word *hemp* is actually a misnomer. The term *hemp rigging* generally refers to any fiber rope used for attaching, supporting, or flying stage effects.

3.02 The Hemp Systems

A. Single-Line System

The simplest system consists of a single rope, a head block, a loft block, a load (something to fly), and a place to tie off the rope (fig. 3.1).

Rope. The rope has two ends: the load end, which is usually onstage, and the hauling end, which is usually offstage. Until the 1990s, ½″, ⅝″, or ¾″ Type M Class 1 Manila was the

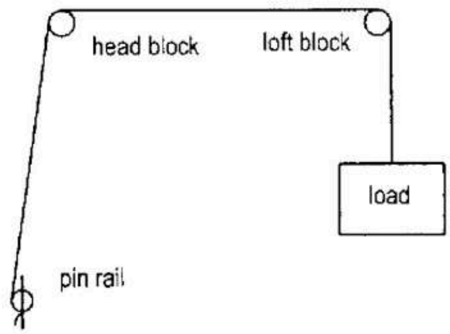


Fig. 3.1. Single-line hemp set

rope of preference. Synthetic rope will eventually replace natural-fiber rope.

Head block. The first pulley that the rope passes through, after leaving the rigger's hands, is called the head block. Usually the head block is offstage of the load. See section 3.04.C.

Loft block. The pulley that the rope passes through, directly above the load, is the loft block. It is usually onstage. Multiple-line systems have more than one. See section 3.04.D.

Spot block. A loft block that is easily movable and can be "spotted," or placed anywhere on the grid, is called a spot block. See section 3.04.E.

Pin rail. A rail with vertical pins of wood or metal, used for tying off the hauling end of hemp systems, is known as the pin rail. See section 3.05.

B. Multiple-Line System

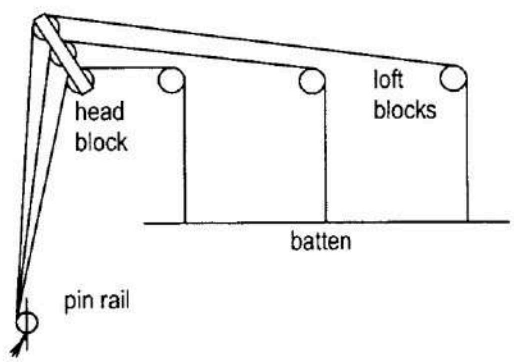


Fig. 3.2. Multiple-line hemp set

Two or more lines attached to the same load make up a multiple-line system. The ropes pass from offstage through a multi-sheave head block (see section 3.04) to individual loft or spot blocks and down to a batten or other object (fig. 3.2).

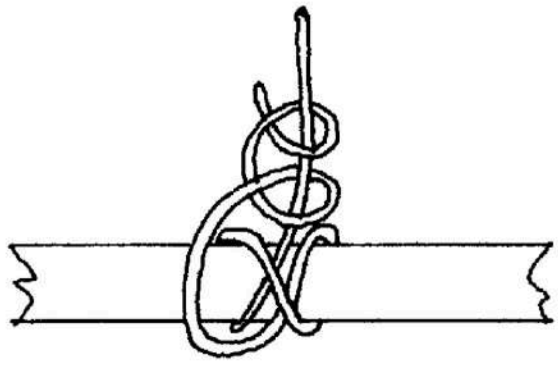


Fig. 3.3. Tying rope to a batten

Batten. A pipe or wood rail attached to two or more lines of a rigging system is called a batten. Loads are attached to the battens. Wood or pipe battens are attached to the hemp lines with a clove hitch and two half hitches (fig. 3.3).

Line identification. The lift lines or lead lines on a multiple line rigging system are identified with reference to their length from the head block. The line nearest the head block is called the *short line*; the one farther away, the *long line* (fig. 3.4).

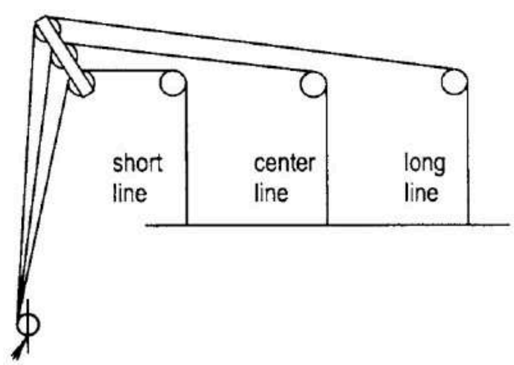


Fig. 3.4. Hemp-set lift-line identification

Starting from the loft block closest to the head block, typical line designations are

four-line set: short, short-center, long-center, long
six-line set: short-short, short, short-center, long-center, long, long-long

A more common system for numbering lines, on sets with more than three lines, is to number the lines from the head block. The short line is number one, the next is number two, and so on.

C. Sandbag and Arbor Attachment as Counterweight

If the load is too heavy for a single stagehand to move, sandbags or arbors for metal weights may be attached to the hauling line. The weight devices are attached by using either a loop of steel cable called a *sunday* (fig. 3.5) or a trim clamp (fig. 3.6). See section 3.06.

Fig. 3.5. Sandbag on a sunday

Fig. 3.6. Sandbag on a trim clamp

3.03 The Rope

Rope rigging in the theatre is generally referred to as *hemp rigging*. Several types of natural-fiber rope are casually referred to as *hemp*. This practice is confusing, because Manila, not hemp, is the preferred rope for stage rigging. As mentioned earlier, synthetic-fiber rope is being accepted rapidly as a viable alternative to natural fiber for rigging use.

A. Considerations of Rigging Rope

When choosing a fiber rope for rigging, the following characteristics of the rope should be considered.

1. Low Elongation

The rope should not be too elastic. When hauling on the line, the load should raise directly in proportion to the amount of line being pulled, rather than having the line stretch and the load bounce along behind.

2. Flexibility

The rope needs to be flexible enough to easily tie knots in and run over sheaves with a minimum amount of internal friction.

3. Durability

The rope must be durable enough to withstand the abrasion of running through blocks, being tied off, and generally being used. The rope should also be resistant to atmospheric degradation.

4. Handling Characteristics

The rope should be comfortable to handle. The operator's hands must be able to grasp the line and not slip. The line should tie and coil easily.

5. Strength

The rope must be strong enough to safely support the load and absorb the additional force of friction, inertia, and shock loading for the particular application.

6. Cost and Value

The *cost* of the rope includes the initial purchase price of the rope and the cost of installation. The *value* of the rope is a combination of initial two-part cost and the expected life of the rope before it needs to be replaced. If you pay 50% more for a good-quality rope, and it lasts three times as long as the less-expensive rope, the more-expensive rope is a better value.

B. Types of Natural-Fiber Rope

The three most common types of natural-fiber rope come from living vegetation. All natural-fiber rope has a relatively short strand. The length of strand is limited by the size of the leaf or stalk from which the fiber is made.

Hemp is a soft fiber made from the inner bark of the main stalk of the cannabis plant. Partly because of the other uses of the leaves of the cannabis, this rope is not readily available in the United States. It is not as strong as Manila.

Sisal is made from the leaf fiber of the agave plant. It is more flexible than Manila but not as strong. It is readily available, less expensive, and easy for the untrained to confuse with Manila. The sisal strands have less cohesion than do Manila strands, and, therefore, sisal is not durable enough for rigging. Because sisal is sometimes used for decorative purposes in the theatre, it is good practice to clearly mark it and store it separately from rigging rope to prevent it from ever being accidentally used for a rigging job.

Manila is a hard fiber made from the leaf of the abaca plant. To add to the confusion, it is sometimes called *Manila hemp*. It possesses the best combination of the desired characteristics of natural-fiber rope for rigging.

Manila is graded by how light it is in color and the cleanliness of its fibers. The lighter the rope, the better the grade. To determine the color of the grade, a light source is focused on the rope, and the amount of reflected light is read on a photometer. The numeric value of the reflected light is called the *Becker value*.

The cleaner and lighter the Manila rope, the longer it will last under acceptable atmospheric conditions. All grades of Manila are manufactured with the same strength rating for each size. The lower the grade, the quicker it will deteriorate and lose its strength. Do not be surprised if your local rope dealer has never heard of the Becker value. It is a term with which, for the most part, only rope experts are familiar.

When purchasing Manila, insist that it be Type M Class 1, according to federal specification T-R-605B, including Amendment 3, dated 17 April 1973. This specification indicates a minimum Becker value of 36 for Class 1 rope and has the latest mini-

Fig. 3.7. Manila rope with identification tracer

mum-strength ratings. (These are the values used in table 3.1 below.) Class 2 Manila is not graded by Becker value and generally will not last as long as Class 1. Some Manila is not manufactured to the federal specification at all, and the strength and quality vary widely. If the rope is greater than ½″ in diameter and manufactured to the federal specification, it will have a paper tracer in one strand indicating the name of the manufacturer, the year and country of manufacture, and the statement that it is Type M Class 1 Manila (fig. 3.7).

Rope can be made in several different ways. Manila rope is almost always twisted. The twisting can be done with either three or four strands, and the direction of fiber, yarn, and strand twists can vary as well. Different twist directions produce different characteristics in the rope.

The specific method of twisting for stage use is as follows. The fibers are twisted to the right, or clockwise, into yarn. Several pieces of yarn are then twisted to the left, or counterclockwise, and made into strands. Three or four strands are twisted to the right, clockwise, to make a rope. This is called a *regular-lay,* or *right-lay,* rope.

C. Synthetic-Fiber Rope

Many types of synthetic-fiber rope are available. They are braided, cored and mantled, twisted, woven, or any combination of the above. Most of them are not suitable for stage use. Nylon has too much stretch and absorbs moisture, making it difficult to handle. Polypropylene has a low melting point, low strength, and low abrasion resistance. It floats, but this is not a requirement for stage use.

Two types of polyester rope are now manufactured specifically for stage use. They have been in use long enough to have proven their worth and reliability.

1. Parallel-Core Polyester Rope

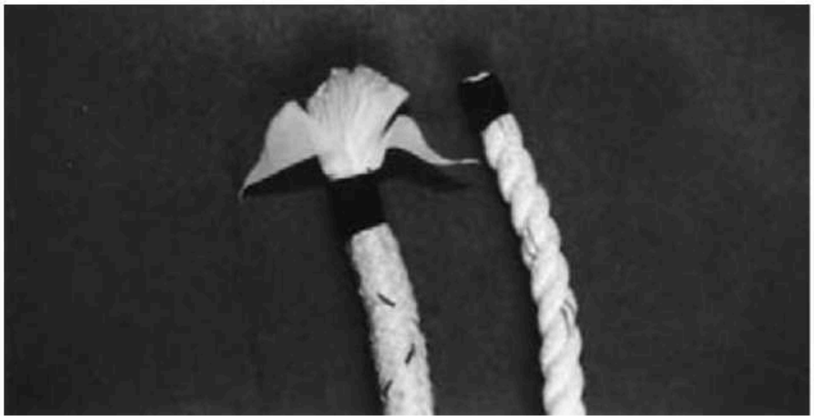


Fig. 3.8. Parallel-core and three-strand-twist polyester rope

Parallel-core polyester (fig. 3.8, left) is made of continuous parallel fibers that run the entire length of the rope. The core is wrapped in polyester tape and covered by a braided polyester jacket. Over 95% of the strength of the rope is in the core. Minor abrasion to the jacket does little to reduce the rope's strength. There are no slivers on the rope, and it does not degrade in the atmosphere. If it is not overstressed, the life of the rope is almost limitless. The strength-to-size ratio is about 3½ times that of Manila. The polyester is initially more expensive than the Manila, but it lasts much longer and is a much better value in the long run. This rope is a bit stiff for hemp systems but makes an excellent hand line for counterweight sets.

2. Three-Strand Twisted Polyester

A three-strand twisted polyester is also available (fig. 3.8, right). Sizes above ½″ diameter are made with spun-polyester fibers around a polyolefin or polypropylene core. Sizes with a diameter less than ½″ do not have the poly core. This rope has excellent handling characteristics, is easy to tie into knots, and is not susceptible to atmospheric degradation. The breaking strength is a little more than twice that of Manila. This rope is not as strong as the parallel-core polyester, but it is a bit less expensive. Because it is a three-strand rope without a jacket, any fiber breakage reduces the strength of the rope. However, unlike Manila, there is no internal organic deterioration. This rope is an excellent substitute for lines in hemp rigging.

D. Tensile Strength or Breaking Strength

Table 3.1. Comparison of Fiber-Rope Strength

Rope Diameter (in.)	Manila (lb.)	Three-Strand-Twisted Polyester (lb.)	Parallel-Core Polyester (lb.)
3/16	406		
1/4	540	1,500	
5/16	900	2,300	
3/8	1,220	3,200	4,600
7/16	1,580	4,100	6,300
1/2	2,380	5,800	8,100
9/16	3,100	6,600	
5/8	3,960	8,230	12,500
3/4	4,860	10,540	16,700
13/16	5,850		
7/8	6,950	15,500	23,000
1	8,100	18,700	32,000
1 1/16	9,450		
1 1/8	10,800		
1 1/4	12,200		

Source: Manila strength figures provided by the Cordage Institute. Polyester figures from New England Rope for Multiline II and Stage-Set X.

Tensile strength is the ultimate strength of the rope before it breaks. (See section 1.06 for a detailed discussion of tensile strength.) The breaking strength of rope should be furnished by the rope distributor. Testing is usually conducted and certified by the manufacturer. Table 3.1 is a comparison chart of tensile strength (in pounds) for Manila, three-strand twisted polyester, and parallel-core polyester. The actual breaking strength may vary slightly from manufacturer to manufacturer.

E. Strength and Allowable Working Load of Rope

1. Design Factors

The allowable working load is considerably less than the breaking strength. (See section 1.06.H for calculating the allowable load of rope.) Some of the factors affecting the strength of the rope and therefore the allowable working load are

a. *Strength reduction caused by the knots.* EVERY KNOT REDUCES THE STRENGTH OF A ROPE, SOME BY AS MUCH AS 50%. See section 3.03.F.

b. *Wearing caused by abrasion*. Rope rubbing on some part of the grid, an improperly sized sheave, or dirt on the rope will cause the fibers to break and reduce the breaking strength.

c. *The potential for shock load*. It is easier to break a piece of string with your hands by jerking than by applying steady or constant force. With stage rigging, there is always the chance of a flown piece fouling and then falling, so that a sudden shock load occurs.

d. *The length of the rope*. The longer the rope, the heavier the load. This is caused by the weight of the rope itself being added to the weight of the load.

e. *The type of use*. A dead-hung leg in the wing area has less potential for hurting someone than a working piece, such as a chandelier, over the acting area.

f. *The age of Manila rope*. Manila, or any natural-fiber rope, is an organic product made from vegetable fiber. It begins to deteriorate in the atmosphere as soon as the plant from which it is made is harvested. Even though there may be no obvious flaws in the rope, it will never be as strong as it is when it was first made. The older the rope, the greater the design factor should be.

2. Factors in Calculating the Allowable Working Load for Rope

See section 1.06.H for the formula for calculating the allowable working load.

a. *Breaking strength*. Know the rated breaking strength of the size rope being used. Remember that the breaking strength is calculated for new rope and must be derated for older Manila.

b. *Weight.* Be certain of the weight of the load. Calculate this carefully. If in doubt, weigh the object to be lifted, using truck scales if necessary.

c. *Risk.* Consider the application and degree of risk to life and property.

d. *Strength-reduction factors*. Consider the strength-reduction factors that reduce the ultimate breaking strength of the rope, such as knotting. See section 3.03.E.

e. *Load-increase factors*. Consider the load-increase factors. These are variable factors that may increase the load above its design limit, such as a curtain absorbing moisture from the atmosphere or the distribution of a load on a batten.

f. *Design factor*. Allow a minimum 10:1 design factor. The degree of risk to life and property destruction determines the design factor. If there is great risk, and the factor of ignorance is great, increase the design factor. THIS DECISION IS YOUR RESPONSIBILITY!

F. Effects of Knotting

Knotting a rope produces sharp bends and shear stresses in the rope and thereby reduces the breaking strength. The sharper the bend, the greater the stress concentration, and the greater the damage to the rope. It is interesting to note that under test, the rope will fail next to the knot rather than in the knot itself. A knot should be chosen for its strength, stability, and reduction of injury to the rope. For example, a simple overhand knot, the type that seems to get into the middle of a rope all by itself, can reduce the breaking strength by as much as 75%. If the knot is left in the rope, and stress is applied, a permanent weak spot can develop. See section 6.01.B for the efficiency of common knots.

A three-strand twisted rope is tested by attaching it to the test machine with eye splices. The breaking strength of a three-strand rope is actually the breaking strength of that rope with perfect eye splices in it. The eye splices, if properly done are, by definition, 100% efficient. The test splices are made by certified people in a consistent and specified manner. But most of us do not make an eye splice as carefully as they do. Therefore, for field use, the eye splice is derated to 95% efficiency.

G. Care of Rope

Rope is a tool made from organic or synthetic fibers. In order to perform properly within its design parameters, you must correctly care for it.

1. Balance

A rope made by twisting has a certain amount of twist built into it. If the rope has too much twist, it will kink or get a *hockle* in it. If it has too little twist, it loses strength. When the twist is just right, the rope is *in balance*. Try to avoid twisting stranded rope while working with it. If it becomes kinked from too much twist, it must be untwisted to restore proper balance. In stagehands' jargon, this is known as "taking the assholes out of the rope."

This can be done either by actually twisting the rope in the direction opposite to the final strand twist or, preferably, by hanging it vertically. If the end is allowed to hang free from the grid or fly floor, the excess twist will usually come out by itself. If the kink is not removed, and a load is placed on the line, or it is pulled through a confined space, such as a head block or loft block, permanent damage to the rope will occur. If there is too little twist in the rope, with strands hanging loose from each other, the rope has been damaged and should not be used for rigging.

2. Uncoiling Rope

New rope in a full coil is stiff and has a tendency to stay curled. The proper way to uncoil it is to lay the coil down on its side so the inside end is down near the floor. Begin uncoiling the rope from the inside end, turning it in your hand to remove the excess twist. This method will keep the rope from tangling and kinking.

3. Coiling Rope

When you are finished working with a rope, coil it properly. *Never coil a twisted rope over your hand and elbow*, as this will put excess twist in the rope and cause kinking. Right-lay rope should be coiled clockwise, or "with the sun." Care should be taken to remove all excess twist. Do this by turning the rope as it is being coiled. If the rope is properly coiled and in balance, no twisting or kinking of individual coils should occur. Rope can be coiled over an open hand, on a pin of the pin rail, or if too long and heavy, flat on the floor. When coiling a rope on the floor, be sure that the top coils do not get larger and fall around the bottom coils. This will cause kinking and tangles the next time you use the rope. When coiling a long length of rope that is to be used again immediately, let it pile up in figure-8 coils. *Do not pick up the rope when it is coiled in figure-8s.*

4. Storing Rope

On a fly floor, rope should be dressed or properly coiled and hung on a belaying pin. Do not leave it lying around on the floor. It will pick up dirt and is dangerous for people to walk on (see section 3.03.G.5).

Sometimes, rope is stored near or on the grid because spot lines must be rigged from there. Provide some method to hang the rope, preferably on wood pegs, so that air can circulate freely through it. Natural-fiber rope absorbs moisture from the air. If it is hung on a metal peg or on a metal surface, the metal can oxidize and hasten the deterioration of the rope.

5. Keeping Rope Clean

Grit and dirt work into the fibers of the rope and break them through abrasion. Dust absorbs the dressing put on the rope during manufacturing and dries the rope out, thus shortening life. When a rope gets dirty, wash it in clear water. Pass it through a tub of water, and swish it around until the dirt comes out, or hose it off. A mild dishwashing detergent can be used but should be thoroughly rinsed out.

6. Drying Rope Properly after Wetting

Because Manila is an organic substance, it will rot or mildew if stored wet. Hang it loosely where dry air can circulate, and dry it thoroughly. Inspect the rope for dryness by untwisting it a bit and touching and smelling the fibers. Wet Manila has a distinctive odor. Polyester will not rot, but it still needs to thoroughly dry after wetting.

7. Protecting Rope from Chemicals

Acidic and alkaline substances will harm Manila fibers. Grease and oil destroy the fiber friction that holds rope together. Paint solvent dries out rope. Polyester rope is not as affected by harsh chemicals. Nevertheless, keep all rope away from chemicals.

8. Avoiding Rope Overload

Once a rope is stressed beyond its elastic limit, it loses its original strength. Use the right size rope for the job at hand. If it is overstressed, take it out of service, and destroy it. NOTE: If you throw away a rope, cut it up. If someone uses your cast-off rope for load-bearing or life-line applications, and it fails, you could be liable. Always cut up old rope before throwing it away.

9. Avoiding Sharp Bends and Small Sheaves

A rope tied around a sharp corner of a heavy load can be strained at that point, which will permanently weaken the rope. Pad all sharp corners. When a rope passes around a sheave, the rope bends as it moves. Be sure that the pulley has a large enough diameter so that the rope will not be severely strained (see section 4.06.B). Maintain a minimum ratio of sheave diameter to rope diameter (D/d ratio) of 8:1.

10. Avoiding Abrasion

Do not drag rope over rough surfaces. Doing so will cause unnecessary wear. Sheaves or pulleys must be grooved for the size rope being used. If the groove is too small, the friction on the rope will cause it to wear and weaken. Be sure that blocks are aligned so that the rope does not rub on side plates.

11. Avoiding Shock Load

Jerking a rope or suddenly dropping a load (such as when a fouled piece of rigging falls free) can easily break a rope. One of the reasons that the safe working load is much less than the breaking strength of a rope is to allow for this possibility. The greater the shock load, the easier it is to break the rope. If a rope is subjected to a severe shock load, it may be stressed beyond its elastic limit. If a rope has been shock loaded, take it out of service, and destroy it.

12. Adjusting Rope for Humidity

Humidity affects Manila rope. As the humidity increases, the fibers absorb the moisture from the air and swell. The rope gets thicker and shorter. As the humidity drops, the rope dries out, the fibers shrink in diameter, and the rope gets longer. In environments with significant changes in humidity, such as theatres with intermittent air-conditioning or outdoors, multiple-line hemp sets must be trimmed before every performance. Because the lines are different lengths on multiple-line sets, they will not shrink or expand evenly. A hanging drop that is level at low humidity will get high on the long side as the humidity increases. In this case, the load is free to move, and no damage will be done to the rope.

In some instances, where the load cannot move, such as a guy rope, permanent damage to the rope may occur owing to shrinkage caused by dampness. The rope can get stretched past its elastic limit and lose some of its tensile strength. In such cases, it is important to remember to slack off the tension on the rope as it contracts. Polyester rope is not affected by humidity and therefore needs no adjustment.

13. Inspecting Rope

Using the rope until it breaks is irresponsible. As you use it, *be aware of it. Look at it; feel it!* If something does not feel or look right, replace it, rather than take a chance. *Visually inspect all rigging rope over its complete length on a regular basis.* This is best accomplished by unrigging it and inspecting the entire length by hand and eye. For multiline hemp sets, have someone on the grid at the head block inspect the line as the set is raised and lowered (see section 3.03.E).

14. Rotating Rope Position

Periodically change around the ropes. Reverse the ends, and change the jobs they do. This will lessen the chance of causing weak spots, spread the wear throughout rope, and increase the life of the rope.

THINK. All of the above recommendations for taking care of rope are common sense! Take the time to care for the rope. Replacing rope is expensive. Replacing a life is impossible.

H. Indications of Wear

When inspecting any kind of rope, look for the following.

Indentations. These are caused by a kink being pulled through a block or by excess strain.

Wear. A rough or worn spot, wear, is caused by abrasion and broken fibers and yarns. Any broken fiber in a three-strand rope or in the core of a parallel-strand rope means a reduction in strength. Open up the strands on a twisted rope. Signs of internal wear are a powdery residue or broken strands inside.

Variations in color. Color variations are indications of chemical contamination. Take the rope out of service, and destroy it.

Variation in diameter. Reduction in diameter is an indication of overloading or excessive wear on the rope.

Broken internal strands. Open up twisted rope, and look for broken internal strands. The internal strands can be the first to break when a rope has been overstressed.

High strand. If one strand is either higher or lower in a twisted rope, the load is not being evenly distributed on all of the strands, and the rope cannot sustain its rated load (fig. 3.9).

Dryness. Untwist a strand, and break a few fibers between your fingers. Overly dry rope will break easily.

Wetness. A wet rope loses a good deal of its strength. If it is wet, do not use it. Dry it well before using.

Rot. Untwist the rope in several places. Look on the inside, where the strands touch each other, for signs of mildew and rot, which is indicated by odor and darker-colored fibers.

Mildew. Smell the rope. In climates with high humidity, Manila rope is very susceptible to mildew. The strong odor of mildew is an indication that the rope should be replaced.

Fig. 3.9. Three-strand-twist Manila with high strand

Acid contamination. A dark spot or area on the rope can be an indication of acid or chemical contamination. Many of the chemicals that are used for painting, dying, and cleaning backstage contain enough acid to be harmful to rope.

All of the above conditions reduce the strength of the rope. Do not use a rope with any of the above conditions for rigging. Take it out of service, and destroy it.

I. Testing a Rope

1. Manila Rope

If you are not sure of the strength of a rope, do not guess. Manila rope loses strength every day. It is organic and gradually deteriorates even while it is just sitting there. If a nearby college or university engineering school has testing equipment, ask it to run a destructive test on a sample for you. If no free testing facility is available, contact a professional testing laboratory. The only way to determine the strength of Manila rope is to perform a destructive test on it. If that is not possible, rig the rope as it is to be used and then load it to a *minimum* of two times the anticipated working load. The rope should perform within its elastic limit and should return to its original length and show no signs of overstress after the load is removed. If the rope stretches to the point of deformation, or if there are other signs of overstress, do not use it. Although this is time-consuming, it is better than having the rope break while it is in use. Remember, the greater the risk of the situation, the greater the design factor needed. Do not keep old, unsafe rope around. Cut it up, and dispose of it so that it does not get used by a person who does not know that the rope is weak.

2. Synthetic Rope

Unless you purchased a synthetic rope and are sure of its type, strength, and history of use, do not assume the strength of the rope. Many types of synthetic rope look similar. The rope could have been shock loaded or misused without your knowledge. Test it, or get new rope that you are sure of.

J. Bo'sun's Chair

A rope that has been used for flying scenery or lifting any material should never be used for rigging a bo'sun's chair or for any type of life- or fall-protection line. To do so is against the law, as well as being highly dangerous. There are special requirements for rope used to lift or protect people. Check the current OSHA regulations.

K. Selecting the Right Rope for the Job

1. For general hemp rigging, choose Type M Class 1A Manila or polyester of the appropriate size.

2. Choose the proper diameter rope to hold the expected load, making certain that the rope is compatible with the blocks available for the job. Common sizes of blocks are ½″ and ⅝″. Half-inch rope will work quite nicely in ⅝″ sheaves, but ⅝″ rope will be chewed to shreds by ½″ sheaves.

3. Obtain test reports from your supplier.

4. Whip ends to keep them from unraveling (see section 6.01.A.1).

5. Uncoil the rope properly.

6. Post safe working loads backstage in a prominent place so all technicians will have the information available when and where they need it—working backstage with the rope.

7. Mark various lengths of rope by color-coding the whipped ends or in some other way. A 125′ rope and a 150′ rope are difficult to distinguish between when they are coiled up on a dark grid. Explain the marking system on signs posted on the grid, in the fly gallery, and on floor level.

8. Inspect all rope periodically, and replace it if you have any doubts about its condition.

3.04 Blocks

A. Hemp-Rigging Blocks

Hemp-rigging blocks are pulleys that are used to change the direction of the force that moves a load. A block consists of the following parts (fig. 3.10): (1) sheave, (2) bearings, (3) shaft or axle, (4) side plates, (5) retainers, (6) base angle, and (7) keeper pin.

1. Sheaves

The sheave is a grooved wheel. The groove should be sized to support at least ⅓ of the rope's circumference. The edges of the groove should be flared enough to allow the rope to enter and exit the groove without abrasion (fig. 3.11). As a recommended guideline, the minimum tread diameter of the sheave should be eight times the rope's diameter (fig. 3.12).

2. Bearings

The bearings reduce the friction between the sheave and the shaft. Typically, either some type of ball bearings or tapered roller bearings are used in hemp-rigging blocks. See sections 2.03 and 2.04 for detailed information on bearings and friction factors. Of the many types of bearings, some require periodic lubrication, and some are permanently lubricated and sealed. The sealed bearings may eventually dry and have to be replaced. If the sheave does not turn easily or if it squeaks, there is a bearing problem that needs to be analyzed and corrected.

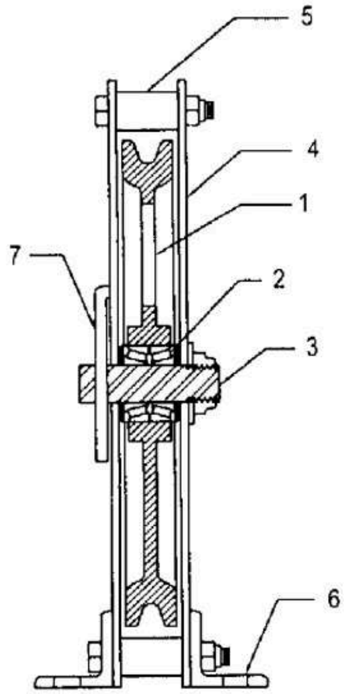


Fig. 3.10. Cross-section of a typical hemp-rigging block

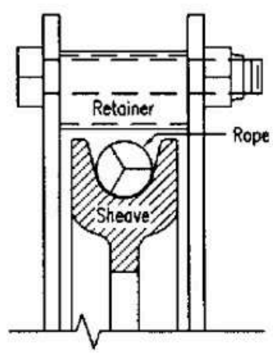


Fig. 3.11. Cross-section of a rope sheave

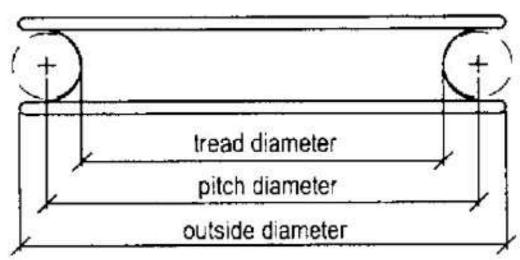


Fig. 3.12. Diameters of a sheave

3. Shaft

The shaft should be large enough to support the required load. It must be attached to the side plates by a keeper pin or other device to prevent the shaft from rotating. All rotational action should be limited to the sheave.

4. Side Plates

The side plates, made of steel, support the shaft. The retainers and other spacers keep the side plates evenly separated.

5. Retainer

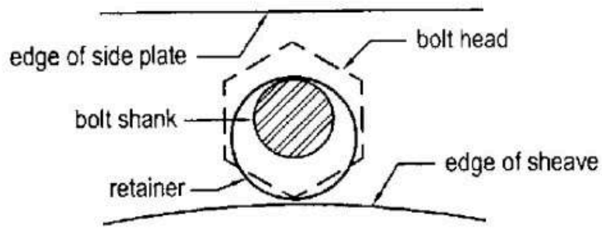


Fig. 3.13. Section through a retainer and bolt

The retainer, usually a length of pipe or tubing held in place by a bolt, prevents the rope from jumping out of the sheave groove and keeps the side plates properly spaced. The diameter of the retainer is usually larger than the bolt to allow the position of the retainer to be adjusted relative to the sheave. Retainers should not be placed too close to the sheave or they will rub on the rope or sheave. They can usually be adjusted slightly by loosening the bolt and moving it closer or farther away from the sheave (fig. 3.13).

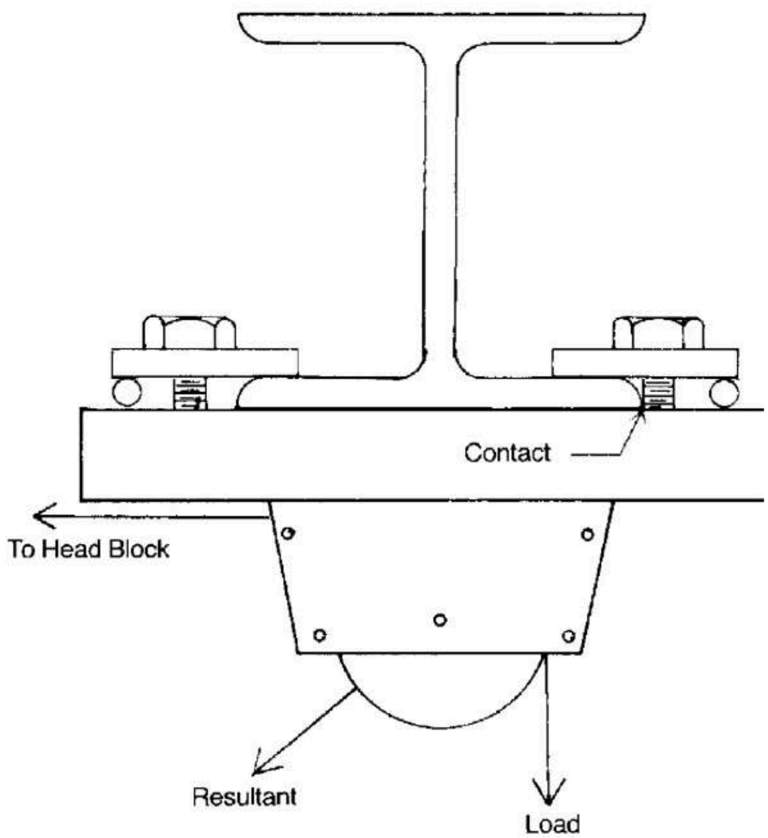


Fig. 3.14. Underhung block

6. Mounting Device

The mounting device holds the block to the support steel. A block will have a tendency to move in the direction of the resultant force (see section 1.04.A). The mounting device should provide metal-to-metal contact in the direction opposite the applied force. This is especially important in preventing horizontal movement (fig. 3.14). *At a minimum, grade 5 bolts should be used for all block mounting.*

B. Loads

In order to calculate the loading, it is necessary to understand the forces that are applied to the block.

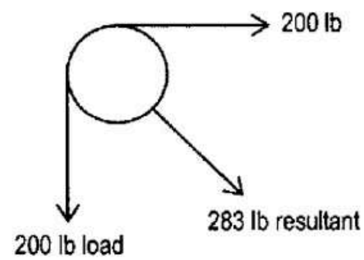


Fig. 3.15. Applied and resultant force diagram, 90°

1. Applied and Resultant Forces

Two forces are applied to a block at any given time: the force of the load and the force that holds or moves the load. These combined forces produce a resultant force (fig. 3.15). See section 1.04 for a detailed discussion on the summation of forces.

2. Batten Loading

A *batten* is a continuous beam (see section 1.03.G), and an evenly distributed load on the batten produces resultants of different magnitudes on the lift lines. The resultants can be calculated using the three-moment theorem—a very laborious process and beyond the scope of this book. Figure 3.16 shows the percentage of the total load that is applied to each loft block and lift line on a batten. The percentages are based on the assumptions that the lift lines are evenly spaced, the load is evenly distributed, and the end lines are at the end of the battens. When trimming a line set, it is possible to feel the difference in weight from line to line.

On a three-line set (second row from top in fig. 3.16), the end lines each support 18.75% of the total weight, and the center

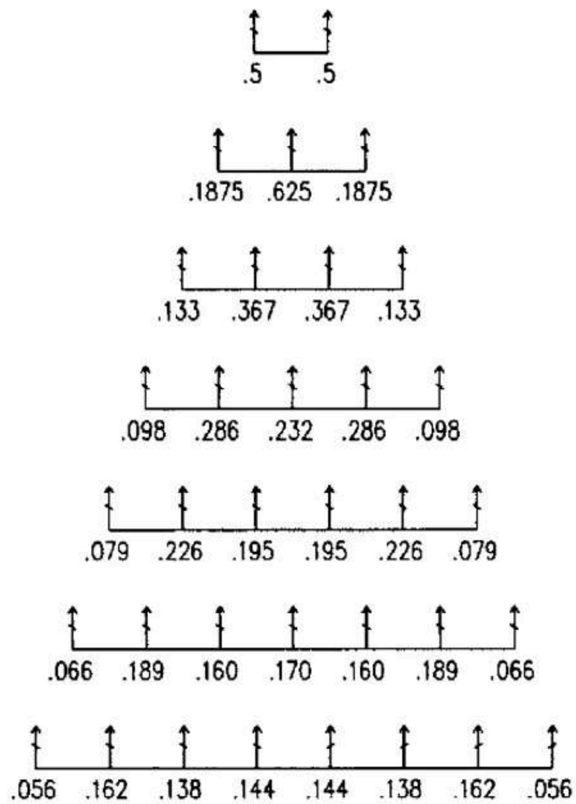


Fig. 3.16. Reactions of evenly distributed load on lift lines and loft blocks as percentages of total load on batten. Courtesy of Peter Albrecht Corp.

line supports 62.5% of the total weight. Moving the end lines in toward the center increases the load on the end lines and decreases the load on the center point. However, we do not always hang evenly distributed loads. If the batten extends too far out past the end-line and a leg is hung on the end, the batten will sag, and the curtain will not hang straight.

C. Head Blocks

Two types of *head blocks* are most commonly used for hemp sets. One type, the single-shaft head block, has all of the sheaves mounted on a single shaft (fig. 3.17). The resultant force on this type of block is similar to that on loft blocks.

The other type, the stacked head block, stacks the sheaves on separate shafts (fig. 3.18). The resultant force usually runs in a direction fairly close to the center line of the long dimension of the side plates. This places the majority of the load on the bottom block support (fig. 3.19).

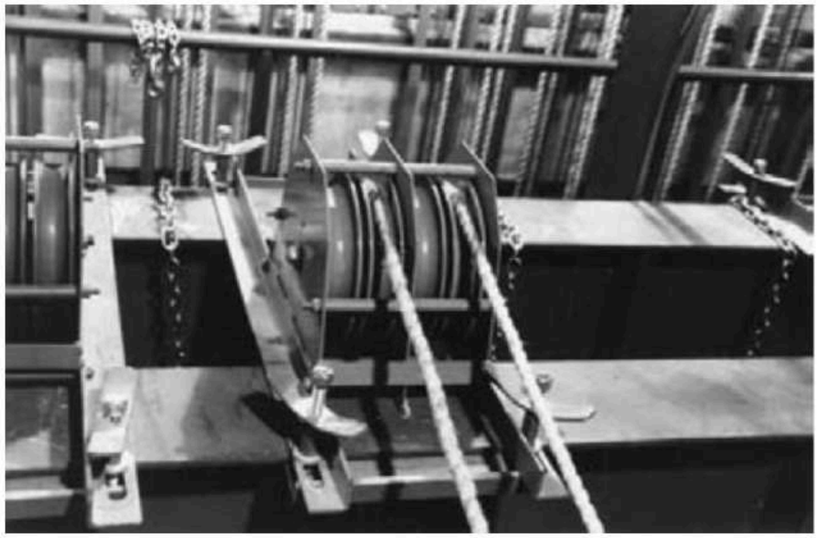


Fig. 3.17. Single-shaft head block

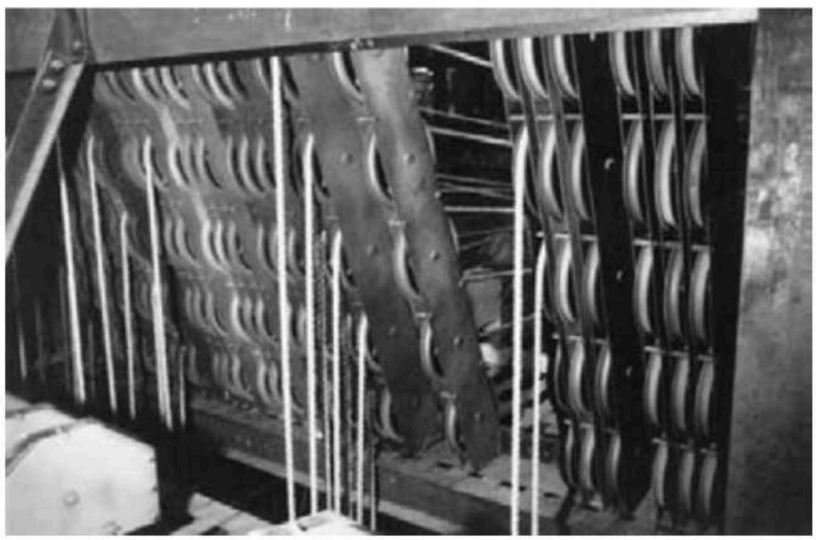


Fig. 3.18. Stacked head block

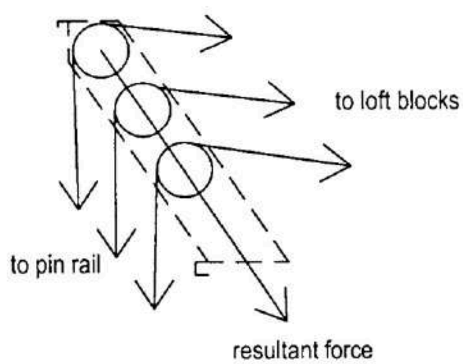


Fig. 3.19. Resultant force on stacked head block

D. Loft Blocks

Loft blocks can either be mounted on the grid (fig. 3.20) or underhung on support steel over the grid (fig. 3.21).

E. Spot Blocks

Loft blocks designed to be easily movable are called *spot blocks*. Extreme care must be taken to ensure that spot blocks are securely mounted. The V-shaped piece of steel on the underside of the block in figure 3.22 is designed to fit tightly against the grid steel to prevent horizontal slippage. The V shape allows the block to be mounted at an angle to the grid steel in order to maintain a proper fleet angle with the head block (see section 3.08.C).

F. Mule Blocks

Mule blocks change the direction of lift lines in the horizontal plane. This type of block is used when it is not possible to run the lift line straight from the head block to the loft block (fig. 3.23).

G. Idler Pulleys

Non–load-bearing blocks are called *idler pulleys*. Their function is to keep the lift lines from sagging on long runs from head blocks to loft blocks (see fig. 3.21). Idler pulleys are usually found on systems in which the loft blocks are underhung from the roof steel. Because an idler pulley does not bear any of the lifting load, it can be of a much lighter construction than a loft or head block.

H. Sag Bars

Sag bars (fig. 3.24) are used on grid-mounted systems to keep the running lines from fouling on the blocks that they have to pass. Sag bars are usually made from hardwood. Attaching a strip of ultra-high-molecular-weight plastic (UHMW) to the top of the wood greatly increases the life of the bars. The sag bars also tend to eliminate a good deal of cable noise and provide for quieter operation of the system.

I. Snatch Blocks

Snatch blocks open so that a lift line can be placed on the sheave without being threaded through from the end. Snatch blocks are

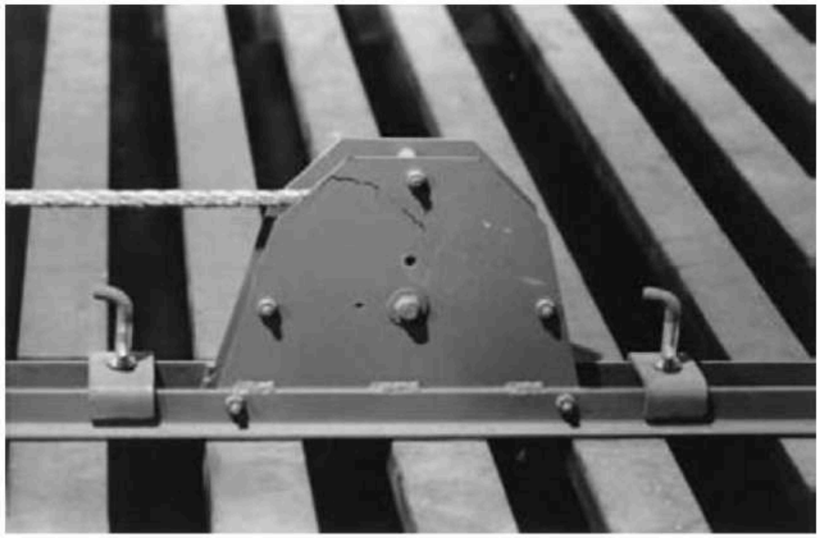


Fig. 3.20. Grid-mounted loft block

Fig. 3.21. Underhung loft blocks with idler pulleys. Courtesy of Peter Albrecht Corp.

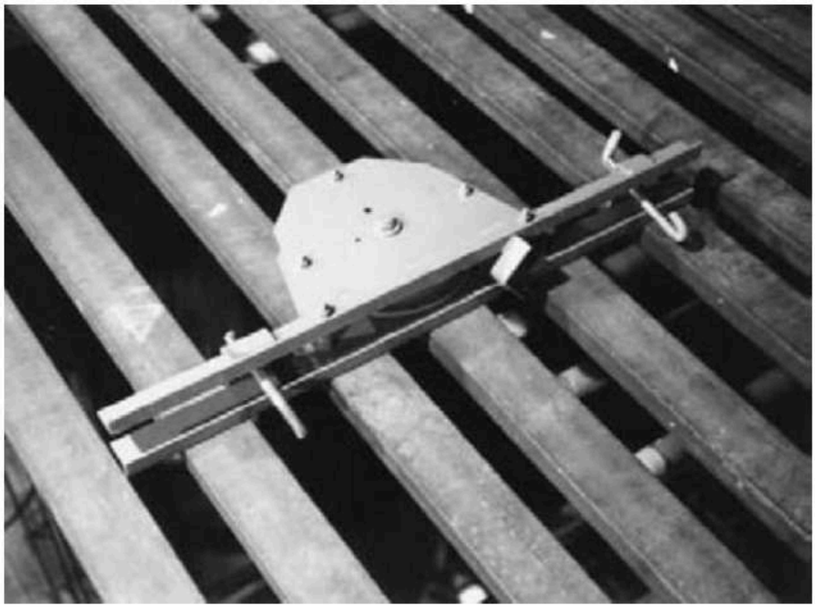


Fig. 3.22. Spot block

Fig. 3.23. Mule blocks. Courtesy of Peter Albrecht Corp.

handy for muleing or idler purposes, after the load has been attached to a lift line (fig. 3.25).

For temporary rigging, a rescue block can be used to divert or align a line (fig. 3.26). These are lightweight blocks that open easily and are found in stores that sell mountain-climbing equipment. The sheaves are made of lightweight material and should not be used for wire rope.

Fig. 3.24. Sag bars on top of grid-mounted loft blocks

Fig. 3.25. Snatch block

Fig. 3.26. Rescue block

3.05 Pin Rail

The *pin rail* is used to tie off, or *belay*, the hauling end of a hemp system. The rail is a horizontal wooden beam or large pipe that is pierced with vertical pins. The pins are made of either hardwood or pipe. They can be either fixed to the rail or removable.

A. Fixed-Pin Rail

As the name *fixed-pin rail* implies, the pins are permanently fixed and cannot be removed. This type of rail is safer than the loose pin rail for cinching a load, in that the pins cannot work their way out as the rope passes around the pin. Another advantage is that the pins cannot be lost.

B. Loose-Pin Rail

On a *loose-pin rail*, the pins are removable. It is possible to release the tie-off by pulling the pin out, which should be done only when there is no load on the line. If there is only one wrap around the pin, the pin spins as the load is eased in. Because of that spin, there is a little less friction on the rope. A second wrap around the top of the pin in the opposite direction eliminates the spin, increases the friction, and gives greater control over the load. The pins can be removed to clear space for extra-large coils of rope hanging on the rail.

C. Single-Pin Rail

A *single-pin rail* is, as the name implies, one rail. High and low trim are tied off on adjacent pins.

D. Double-Pin Rail

The *double-pin rail* consists of two rails (fig. 3.27). The top rail is usually set farther onstage than the lower rail. Tie off high trim on one rail and low trim on the other.

E. Pins

The pins can be made of hardwood or steel. Hardwood pins are easier on the rope. They do not promote rust in damp climates,

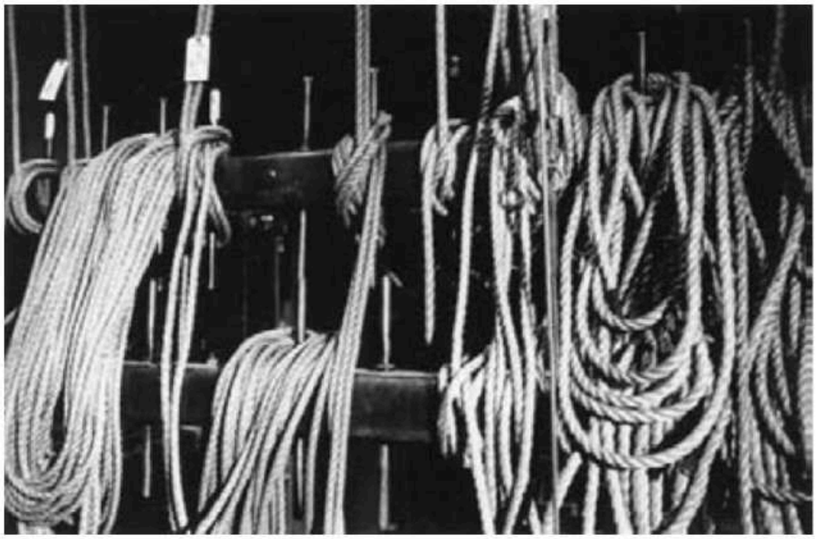


Fig. 3.27. Double-pin rail

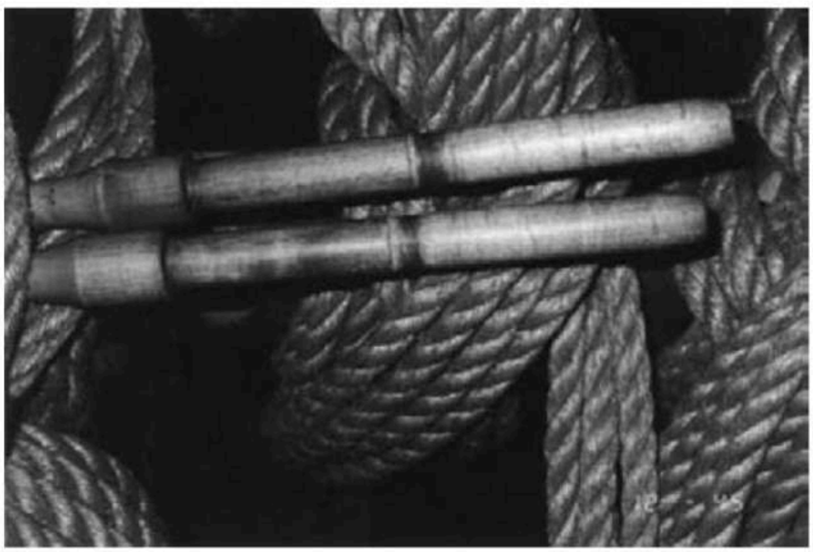


Fig. 3.28. Indented pins, lower contact point

but because they are usually loose, they spin when letting in a load. If used on a steel pin rail, hardwood pins become indented from spinning under side load and lose strength due to the broken wood fiber at the point of indentation (fig. 3.28). Examine the pins for broken wood fibers, especially at the lower point of contact with the pin rail. If they are indented, take them out of service.

Steel pins can be either solid or made from pipe. Loose steel pins will also spin but are not susceptible to the wearing that wood pins are vulnerable to. Pins made from pipe should have the ends plugged to prevent riggers from inadvertently catching their fingers in the hole. More than one rigger has missed a cue due to getting a finger stuck (fig. 3.29).

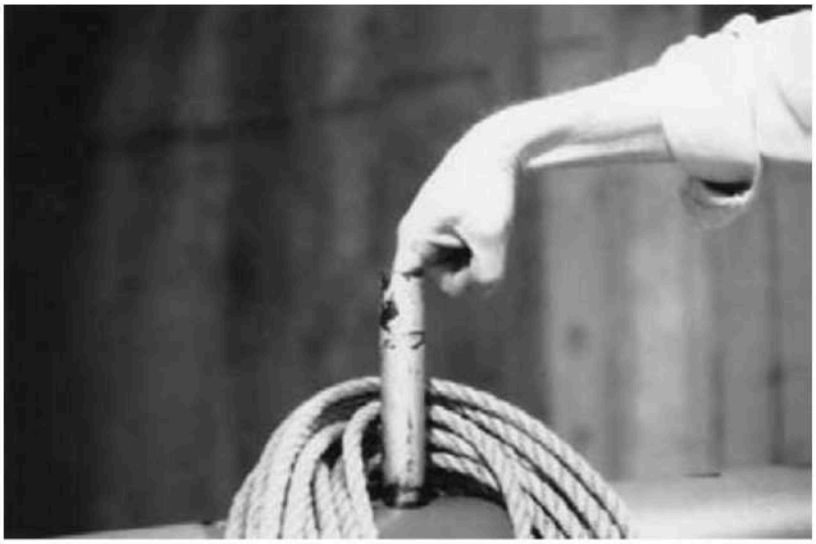


Fig. 3.29. Finger in pin. Don't do this!

F. Tying Off

There is a specific procedure for tying off a hemp line or set.

1. Take a single wrap around the underside of the pin (fig. 3.30). The friction of the rope on the pin immediately gives the operator some control of the load. It is always best to raise the load a little too high, make the wrap, and then ease it into trim position. If the load is very heavy or on a loose pin rail, two or three wraps may be necessary to control the load.
2. Cross the rope on the face of the rail, and take a wrap around the top of the pin (fig. 3.31).
3. Make another wrap around the underside of the pin, in the same direction as the first wrap.
4. Form a loop by twisting the rope. The free end goes under the standing part (fig. 3.32).
5. Put the loop over the top of the pin (fig. 3.33).
6. Pull it tight (fig. 3.34). Never tie off on the first wrap. By tying off after at least four wraps, you are able to maintain control of the load after untying the line because the other three wraps are still around the pin.

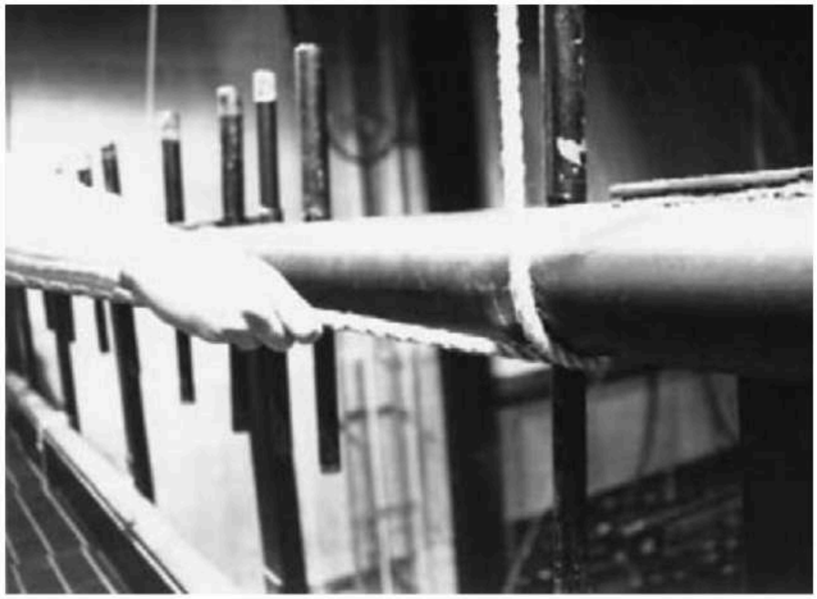


Fig. 3.30.
Tying off, step 1

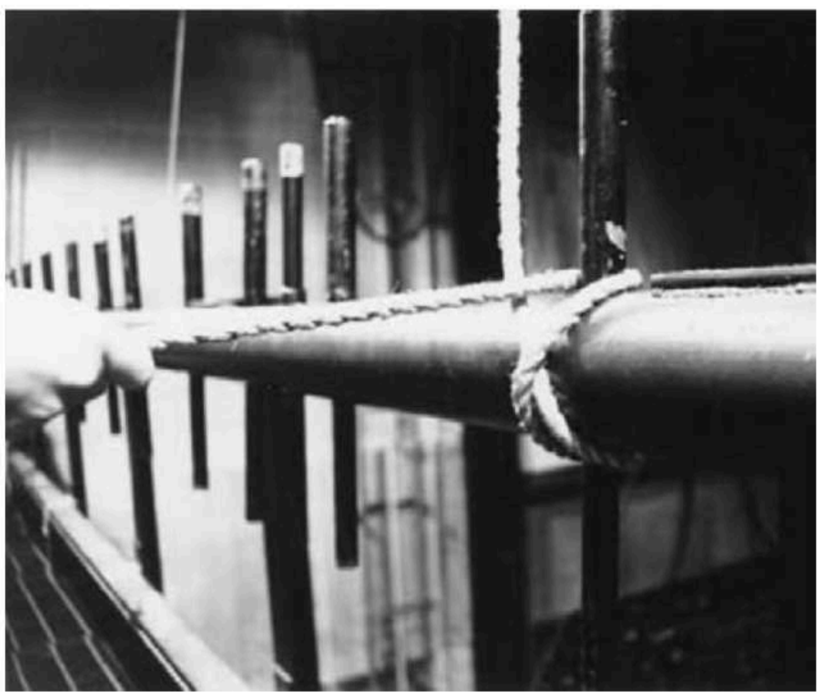


Fig. 3.31.
Tying off, step 2

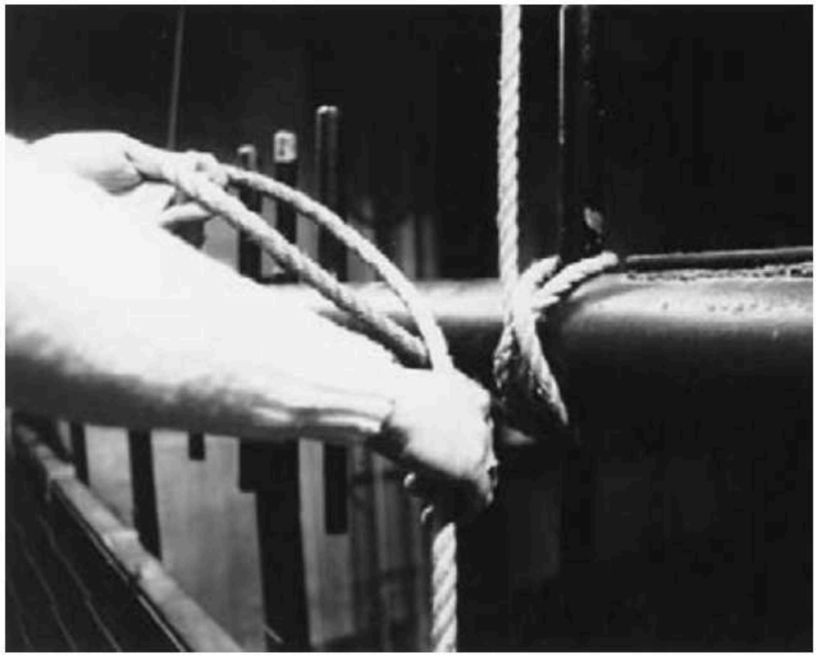


Fig. 3.32.
Tying off, step 4

Fig. 3.33.
Tying off, step 5

Fig. 3.34. Tying off, step 6

Riggers seem to enjoy heated discussions about which direction is preferable for wrapping lines around pins—to the left or to the right—and strong opinions also arise about what method to use when crossing lines on successive wraps. That debate will never be resolved. What is essential, however, is that the *direction of the wraps must be consistent in each venue.* That way, all riggers in a venue know exactly how each line set is tied off.

3.06 Sandbags and Arbors

Usually sandbags are used as counterweight for hemp rigging. They are made of heavy canvas that is reinforced with rope or nylon straps. The rope or strap has a snap hook affixed to it for easy attachment to the lift lines. Sandbags commonly range in size from 10 lb. to 150 lb. Add or remove sand from the bags as needed to match the weight of the load. A container should be on the fly floor to hold extra sand.

Metal weights on a single-rod arbor are sometimes used instead of sandbags (figs. 3.35 and 3.36). This hardware is only manufactured under special order and is not readily available. The arbor is attached to the lift lines in the same way that sand

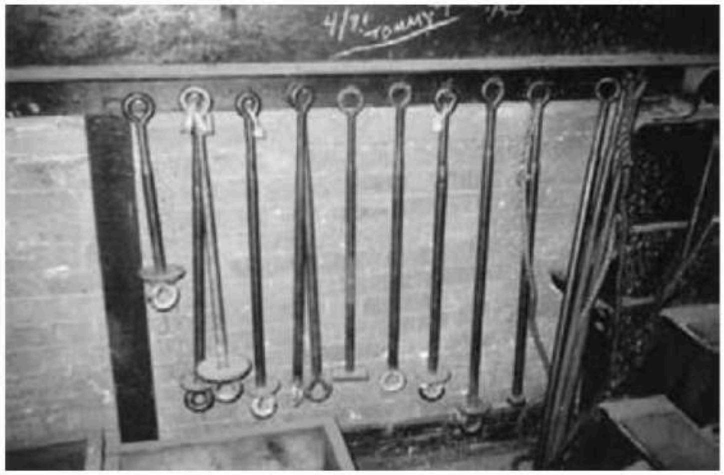


Fig. 3.35. Metal hemp arbors stored along rail wall

Fig. 3.36. Metal arbors on hemp lines

bags are attached. The weight on the arbor can be adjusted by adding or subtracting weights from the arbor rod. The rods can be tied to the lift line at the top and bottom to keep the weight from swinging.

A. Attaching Sandbags and Arbors with a Sunday

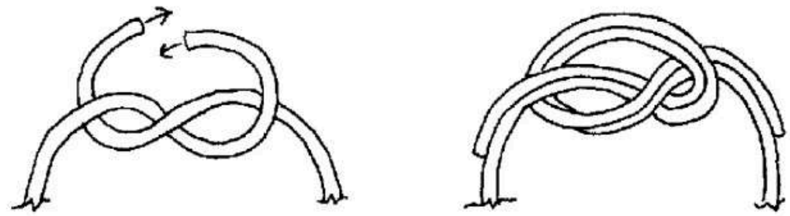


Fig. 3.37. Tying a sunday knot (water knot)

One method of attaching weight devices to the lift line is to use a loop of steel cable, called a *sunday*. A piece of ⅛″ steel cable, 3′ to 4′ long, is formed into an endless loop, either by using Nicopress sleeves (see section 6.03.B) or by tying a water knot (also known as a *sunday knot*) in it (fig. 3.37). Many theatres have started using sundays made from 5- to 6-mm Spectra rope. Spectra is stronger than steel cable. The knots are easier to tie, the rope is more flexible than cable, and the rope is easier on the hand line. Spectra rope can be purchased at sporting goods stores that carry mountain-climbing gear.

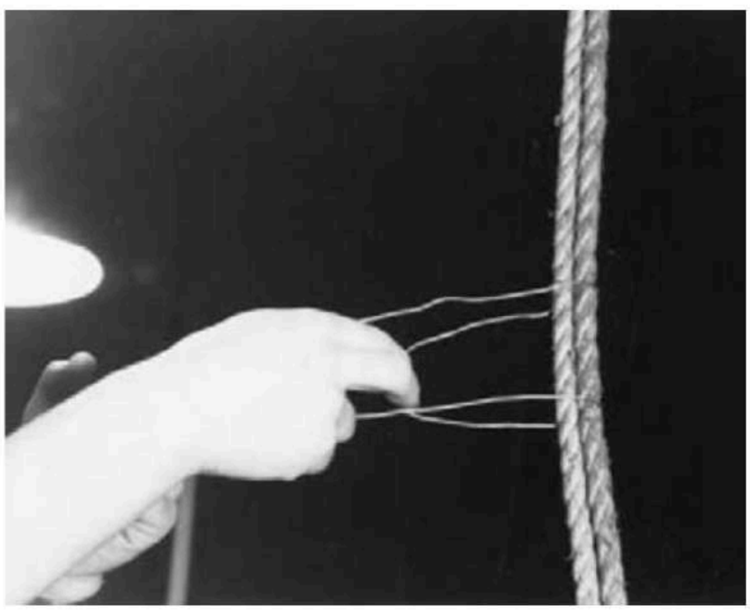


Fig. 3.38. Attaching a sunday to hemp lines

The sunday is attached to the lift line by wrapping the loop around the lift line and passing one end of the loop through the other (fig. 3.38).

The weight device is then hung on the remaining loop (see fig. 3.5).

B. Attaching Sandbags and Arbors with a Trim Clamp

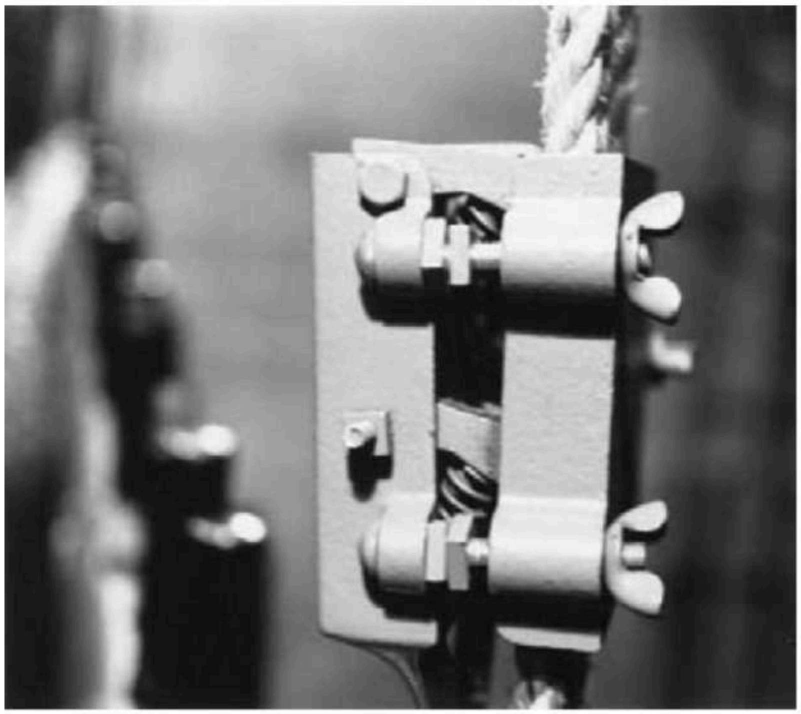


Fig. 3.39. Trim clamp

Another method of attaching sandbags and arbors to the lift lines is to use a trim clamp. The clamp is bolted over the ropes with the steel loop facing down. Sometimes, it helps to squeeze the trim clamp together with a C-clamp when putting it on. The spring-loaded jaws inside the trim clamp must be compressed in order to tighten the nuts (fig. 3.39). The sandbags are then hung on the loop (see fig. 3.6).

The advantage of using a trim clamp is that the load is easier to retrim after the trim clamp and sandbags are attached than with a sunday. This is done by pulling the longest lines through the clamp, thus raising the low points. If there is an unevenly distributed load, it may be necessary for someone on the stage floor to hold down the flown piece at the high points while the low points are raised. Instead of holding the piece directly, a rigger can tie a tag line to the batten at these points (see section 6.06.C).

3.07 Jack Line

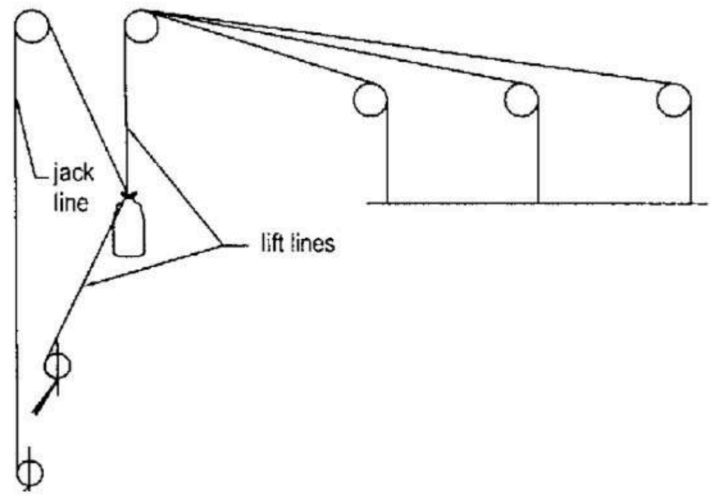


Fig. 3.40. Jack-line schematic

A *jack line* is a separate line that runs over a block on the grid. One end is tied to the sunday or trim clamp on the lift lines, and the other end is tied to a separate pin. In some theatres, the jack-line system is along the side wall of the stage, on the opposite side of the fly gallery from the pin rail. The jack line is used to let the flown piece in when it is bag-heavy. By pulling up on the jack line, the flown piece is lowered (fig. 3.40).

3.08 Spot-Line Rigging

Hemp sets can be positioned, or *spotted*, for special production needs. Either single- or multiple-line sets can be used to provide flying capability in positions and patterns to supplement permanently installed batten sets.

A. Positioning Loft Blocks

Installing a spot-line set begins with positioning the loft block. The point where the lift line must drop is usually determined on the stage floor. A target that is easily visible from the grid is placed on the floor. Using a plumb bob, a weight on the lift line, or the "spit method," position the block on the grid directly above the target (or as close as possible). The loft block is then lined up with the drop point over the target, and the sheave is aligned with the head-block position. The block is then secured to the grid.

NOTE: It is most important that the block be firmly mounted so that there is no chance of the block slipping (see section 3.04.D).

B. Positioning Head Blocks

Once the loft blocks are firmly attached, the head blocks are aligned with the loft blocks and secured in place. It is important that the rope travel in a straight line from head block's sheave to the spot block's sheave to avoid abrasion on the rope. When using the type of head block with the sheaves mounted side by side, it is sometimes necessary to angle the spot blocks slightly to align them properly.

C. Fleet Angle

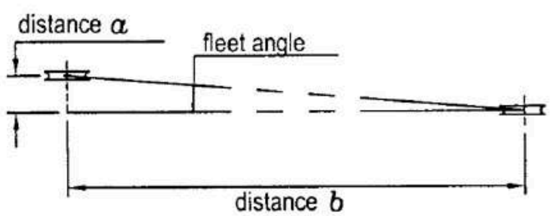


Fig. 3.41. Fleet angle of the line between offset blocks

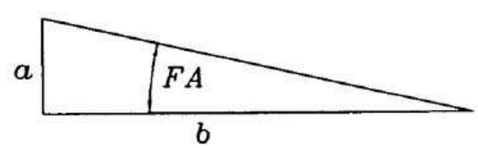


Fig. 3.42. The maximum allowable fleet angle (*FA*) is 1.5°.

The *fleet angle* is the angle the line makes when two blocks are offset from each other relative to a straight line from the center point of one sheave (fig. 3.41). For stage rigging, the maximum acceptable fleet angle is 1.5° (fig. 3.42). The formula for calculating the fleet angle is

$\tan FA = a \div b$

a = offset distance

b = distance between the pins of the sheaves

You must use the same units (inches, feet, centimeters, etc.) for both dimensions.

Using a calculator with trig functions, find the tangent according to the formula, push the inverse tan keys, and read the degrees. If the angle is equal to or less than 1.5°, the fleet angle is acceptable. If it is greater than 1.5°, there is a possibility of abrasion on the line and excessive side load on the bearings. Mule blocks may be required to correct the problem.

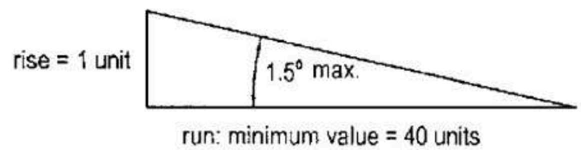


Fig. 3.43. Using slope to calculate an acceptable fleet angle

A quick rule of thumb to approximate the fleet angle is to look at it in terms of slope. The rise is the offset, and the run is the distance between the pins of the blocks. Anything less than 1 ÷ 40, such as 1 ÷ 50, is acceptable. Anything greater, such as 1 ÷ 30, and the angle is too great (fig. 3.43).

D. Aligning Blocks

Fig. 3.44. Least fleet angle for all blocks

Fig. 3.45. Greater fleet angle for long center line

When using a head block with side-by-side sheaves, align the short loft block with one of the inside sheaves. Use the adjacent inside sheave for the short center and the outside sheaves for the long center and long lines (fig. 3.44). The worst fleet-angle case is with the short line. Make that run as close to a straight line as possible. You need to calculate the fleet angle for all of the lift lines and adjust the position of the head block or provide muleing as required.

Starting with an outside sheave for the short line causes a greater offset for the long center line and could cause an excessive fleet angle (fig. 3.45).

E. Running Rope

Once the blocks are positioned, the rope is fed through the blocks from the grid. Attach a weight, or tie off the rope as soon as it is fed through the blocks to keep it from running away. Storing the rope somewhere near the grid eliminates the necessity of hauling the rope to the grid every time a spot line must be run.

F. Attaching Weight to Rope

The onstage end of the rope should be either attached immediately to the load or weighted. Weighting can be done either with a small sandbag or by running the end of the line through a short section of pipe and tying a figure-8 knot in the end of the line (figs. 3.46 and 3.47).

3.09 Operation of Hemp Rigging

The safe operation of hemp rigging requires a thorough knowledge of how the rigging system works. This knowledge includes knowing the function of each of the components and knowing how the components work together to make an integrated system. Hemp rigging requires of riggers more human physical strength to operate than do other types of rigging. At times, the operator will need to move unbalanced loads solely by brute strength. Because almost all lift-line connections are knots, the operator must also have a thorough knowledge of knot tying. Both strength and knowledge must be properly applied. Concentration and attention to detail are essential to the safe operation of hemp rigging. In brief, revisit the 4 Ks.

1. Know the rigging system you are working with.
2. Keep the equipment in safe working order.
3. Know how to use it.
4. Keep your concentration.

A. Safety Inspection of All Components

The components of a rigging system should be thoroughly inspected on a periodic basis. The resident technician, house carpenter, or technical director is responsible for maintaining the

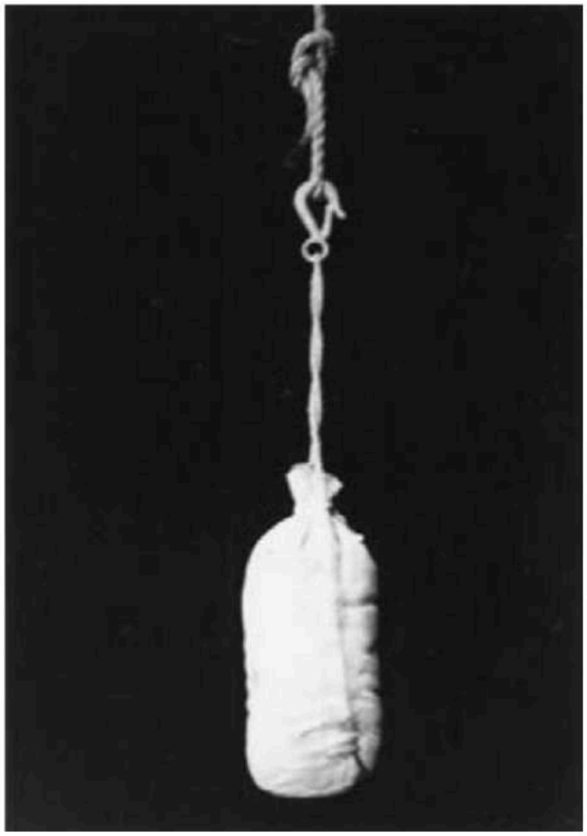


Fig. 3.46. Rope weighted with sandbag

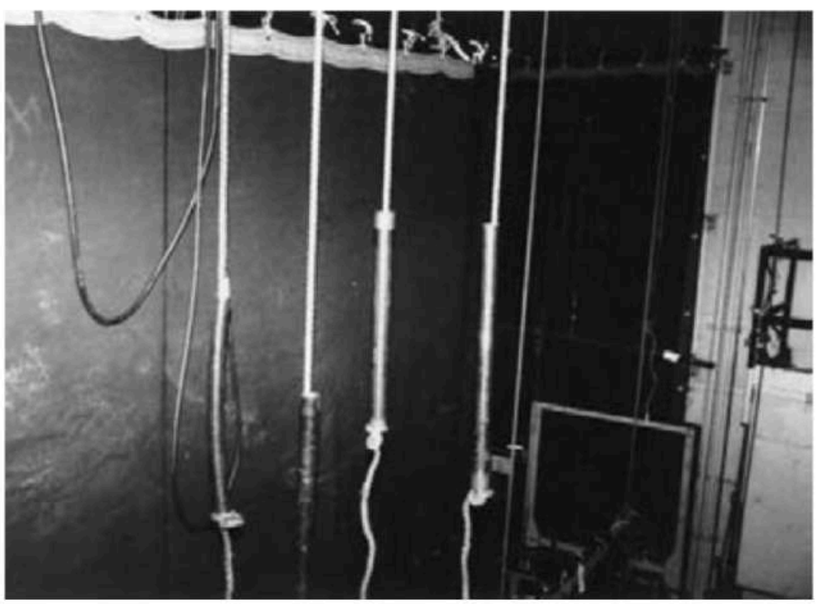


Fig. 3.47. Rope weighted with pipe

equipment. It is this person's job to see that the rigging system is in perfect working order. It is the management's responsibility to provide the time for maintenance. The system should be inspected, component by component, *at least* once a year! If the resident technician does not have sufficient expertise to conduct an inspection, it will be necessary to hire an outside expert to do it. Periodically, have an inspection performed by a competent person who is not associated with your venue; an outside set of eyes can often spot things that are missed by the people who have grown accustomed to the system (see part 7).

In a strange theatre, if there is a high degree of risk, always inspect the rigging before attaching loads. Never assume that just because it is there, the rigging is in good condition.

Knowing a rigging system goes beyond a knowledge of the parts and their locations. Every rigging system is unique and has its own feel, sound, and smell. Becoming aware of these sensory perceptions is essential so that every time the system is used, there will be instant awareness if something is out of the ordinary. A sheave with dry bearings or a rope being rubbed makes distinct sounds. It feels different. A piece of hemp with dry rot or hemp that has been charred by a lighting instrument has a distinct smell. Knowing how the system should be when it is in perfect operating condition is a prerequisite to spotting problems.

Keep the floor, grid, and fly gallery clean. Any sign of foreign substances, such as metal filings or rope fibers, is a sign that something is wearing. Keeping the work area clean makes it easier to see these signs of wear.

B. Untying a Line Set

Before untying the line on a hemp set, grasp the rope above the pin, and pull it. Get a feel of the load that is on the line before you untie it. Make this a habit. If the rope is extremely taut, it is a signal to be extremely cautious when untying the line. The load is probably very heavy. Keep several wraps around the pin so that you can safely control the line set. If the load is heavier than you are, and you untie it completely, it will be impossible to hold. If you do not let go immediately, it will haul you up to the head block. Riggers have been seriously injured and killed by having a line set run away from them.

C. Attaching Loads

Most of the time, loads are attached at stage-floor level. The rail operator should lower the load end of the rope to the stage floor.

Before moving any piece of rigging during a load-in or strike, always warn the people onstage and on the grid by yelling a warning to the stage. If the rail operator cannot see the load, a spotter should be used. The spotter watches the load and communicates directly with the rail operator. Be sure that the components are within an adequate design factor for the degree of risk. If the loads are very heavy, it may be necessary to join or marry two or more line sets. (For specific information on attaching techniques, see part 6.)

Once the load is attached, it is pulled up to the low-trim position. Several people may be required to raise the load, but one competent person must be assigned to the task of tying off the rope. At this point, multiple-line sets are *trimmed*, which means that the individual lines are pulled level to the stage floor or relevant low-trim datum point. The rope is then tied off. With the low trim tied off, the flown piece is then raised to its high-trim position and tied off again. At this point, sandbags (or an arbor) are attached, and the load is balanced. Enough weight should be added to the offstage end of ensure ease of operation. However, if there is no jack line, the line set must be slightly load-heavy in order to operate. After the weighting device has been attached, the piece should be operated to recheck high- and low-trim positions.

D. Removing Loads

The first step in removing a load from a hemp set is to be sure that the stage area underneath is clear. With the lines tied off at high trim, remove the jack line, sandbags and sunday (or trim clamp) from the rope. Untie the low trim. Sort out the rope, and be sure that it is free and clear. Untie the high trim, keeping a sufficient number of wraps around the pin to maintain control as the flown piece is lowered to the stage floor (fig. 3.48).

The friction of the rope around the pin acts as a brake. It is good practice to never unwrap the rope completely from the pin until the load is on the floor.

E. Trim Marks

Trim heights on hemp rigging may be marked on the rope by using tape. However, tape can come off or leave a sticky residue when it is removed.

Another method is to use a piece of brightly colored yarn or ribbon (fig. 3.49). Untwist the rope slightly using a splicing fid or

Fig. 3.48. Letting in an unweighted piece

Fig. 3.49. Yarn trim mark

marlinespike, and insert a piece of yarn or ribbon about 6″ long through the rope. As with tape, different colors can be used to indicate different trim positions.

F. Lashing with Small Tie Line

When tying off high and low trims on different pins, it sometimes helps to use small tie line to lash the low-trim tie-off in place (fig. 3.50). Doing so helps keep the lines from fouling on the low-

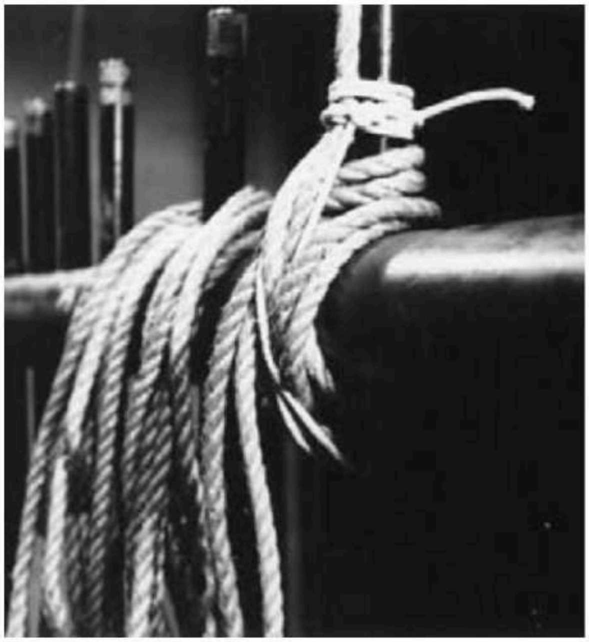


Fig. 3.50. Tie-off lashed to pin

trim pins when moving the piece from high to low trim. The small tie line also serves as a reminder not to untie the low-trim pins.

G. Retrimming

Because of the effect of moisture on Manila rope, changes in humidity affect the trim of hemp rigging. On multiple-line sets, the longest ropes change the most. Therefore, trims should always be checked before performance time.

If a multiple-line set is out of trim, the sunday must be removed to retrim. If a jack line is being used, the weight of the sand bags can be tied off with the jack line, thus allowing retrimming without removing the sunday completely. This is a time-consuming task and points to the advantage of using a trim clamp. Be sure to relevel dead-tied sets as well as those that move.

H. Coiling and Dressing

The extra rope on a fly floor should always be properly coiled and hung on a pin. This is called *dressing* the rope and keeps the rope from getting tangled and dirty from the riggers walking on it.

Keep the fly floor clean so when rope is placed on the floor, it will not get dirty (see section 3.03.G.4).

I. Showtime Operation

Operating rigging during a performance is very much like stage managing. Most of the work is in the preparation well before the performance. Knowing the rigging system, being sure that it is in good, safe condition, properly attaching the loads, clearly setting trim marks, and properly dressing the loose rope on the fly floor all contribute to an organized and reliable performance.

It is good practice to check trim marks and low-trim tie-offs before every performance. Be sure the trim marks are still in place. Be sure that tie-offs have not slipped and that humidity has not changed rope lengths.

When letting a piece in, check the load first by pulling on the standing part of the lines; then remove the coiled rope from the pin, and lay it on the fly floor. It should be placed where it cannot be stepped on so the rope will uncoil evenly and without tangling.

On the "warn" cue, find the proper rope, and review which direction it moves. On the "standby" cue, untie (if it is being let in) or get ready to pull (if it is being taken out). On the "go" cue, move the piece, being sure that either the operator or the spotter can see the piece and the stage floor under it.

3.10 Operation Summary

1. Know the rigging system. Know it well enough to detect any abnormality during operation.
2. Inspect the system thoroughly at regular intervals.
3. Be sure to use an adequate design factor for the degree of risk involved.
4. Use the correct knots for attaching loads and tying off on the pin rail.
5. Maintain visual contact with a moving piece, using a spotter if necessary.
6. Warn people on the stage and the grid before moving a flown piece.
7. Maintain control of a moving piece at all times.
8. Wear hand protection.
9. Keep the working area clean.

3.11 Historical Summary

This type of rigging has been in use since Western theatre was founded by the ancient Greeks as a part of their religious festivals. Some of the plays of Aeschylus, Euripides, and Aristophanes require characters to fly through the air. Since those theatres were open to the sky and had no grids, this effect was accomplished by a device called the *machina*. Because the most commonly flown characters were gods, the device became known later as the *deus ex machina*—a god in the machine.

The *machina* was a device consisting of a rope drawn through a series of pulleys that were mounted on a pivoting boom. The boom, in turn, was mounted on top of the *skena*—or stagehouse. A person or object could be lifted from or lowered onto the stage by stagehands working the offstage end of the rope. The boom could be rotated to move the flown object onstage or offstage.

It is generally believed that the technology that made this possible was adapted from that used by Greek sailors. Then, as now, rigging required a good knowledge of the care and use of rope as well as the ability to tie knots properly.

Today's theatres are generally enclosed structures; many of them have grids; many of them have complex, sophisticated systems for flying stage effects. But still commonly found in use is the simple technique of fastening an object to a rope, running the rope through pulleys, and raising the object into the air. There are many variations and combinations of hemp-rigging systems, but hemp remains as the most basic of all stage rigging. To be a competent stage technician, it is essential to know the correct use of hemp rigging.

Part 4 Counterweight Rigging

4.01 Introduction

The invention of counterweight rigging was the next logical step in the progression of flying equipment for the stage. It began to appear in the first quarter of the twentieth century. The early systems employed a rack, or arbor, in which to stack metal weights. This arbor was attached to the hemp lift lines, and a single hand line was attached to the arbor. The shrinking and stretching of the hemp lift lines because of changes in humidity still posed a problem. This was solved by using a wire rope for the lift lines (lead lines). Wire guides gave the arbors some vertical stability. Eventually, T-bar–guide rails appeared and have become the most common form of guide systems.

For efficiency, the counterweight system is a great improvement over hemp rigging. The onstage load can be counterweighted much faster than a hemp set can be bagged. The single hand line, wire-rope lift lines, and lock rail reduce work and thus save time.

4.02 Single-Purchase Counterweight System

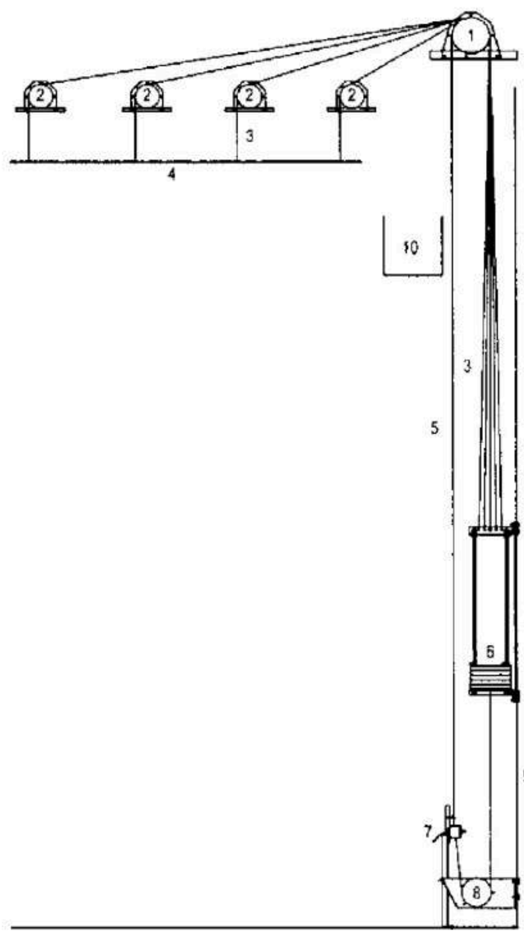


Fig. 4.1. Single-purchase counterweight set

A *single-purchase counterweight system* is used when there is clear wall space on one side of the stage from grid height to the stage floor (fig. 4.1). This system typically consists of

1. Head block for lift line and hand line
2. Loft blocks (mule blocks as needed)
3. Wire-rope lift lines
4. Batten

5. Hand line (Purchase line)
6. Counterweight arbor
7. Lock rail
8. Tension block
9. T-bar–guide rails
10. Loading bridge

Counterweights are used in a 1:1 ratio, that is, 1 lb. of counterweight is needed for each pound of load weight.

4.03 Double-Purchase Counterweight System

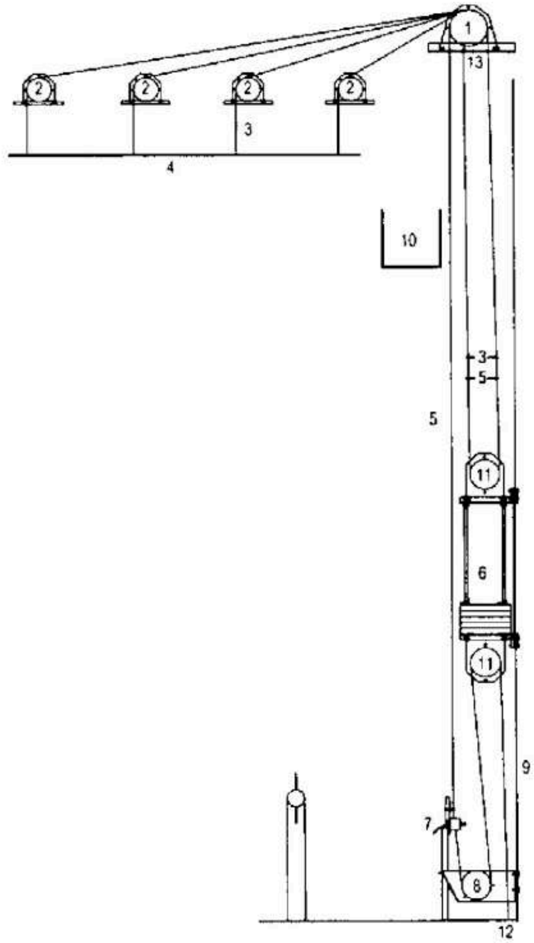


Fig. 4.2. Double-purchase counterweight set

A *double-purchase system* is used when some obstruction prevents full travel of the arbor from grid to stage floor. Note the compound rigging of both hand line and lift line in figure 4.2. The batten travels 2´ for every 1´ of travel for the arbor. Consequently, 2 lb. of counterweight are required for every 1 lb. load.

The arbors must be sized larger than a single-purchase system in order to have the same lifting capacity. Larger arbors often make loading and unloading more difficult and thus more dangerous. Quite often two loading bridges are required to safely load the longer arbors.

A typical double-purchase counterweight system consists of

1. Head block for lift line and hand line
2. Loft blocks (mule blocks as needed)
3. Wire-rope lift lines
4. Batten
5. Hand line
6. Counterweight arbor
7. Lock rail
8. Tension block
9. T-bar–guide rails
10. Loading bridge
11. Arbor blocks
12. Hand-line tie-off
13. Hand-line and lift-line tie-off

4.04 Miscellaneous Hardware

Knowing the rigging system includes knowing the capacity of every part of a system. A line set is only as strong as the weakest piece of hardware in it, and this includes the miscellaneous hardware: wire-rope clips, swage fittings, shackles, pear rings, chain, and other items used for rigging purposes but not made by manufacturers of theatrical-rigging hardware. When using this type of hardware for rigging applications, use only hardware with a manufacturer's name and load, or application, rating on it and, if possible, a *Product Identification Code* (PIC.)

When a manufacturer places its name on a product, it is willing to stand behind the product. It guarantees that the product will do the job for which it is designed. The companies that manufacturer this type of hardware have engineering departments that are willing to answer your questions about the use and application of their products.

Shackles, pear rings, chain, and other load-bearing products generally have a rated working load limit. This is a percentage of the ultimate breaking strength, well below the yield point of the material from which it is made (see section 1.06.C). Many manufacturers put the design factors in their catalogs, simplifying the task of selecting hardware with adequate design factors. The PIC tells the year that the product was manufactured, the plant where it was manufactured, and the heat number of the metal used for that particular item. The PIC, along with the manufacturer's name, assures the user of complete traceability in case of component failure and of the manufacturer's liability for the quality of its product.

By purchasing hardware that has only the country of origin stamped on it, all of the liability is placed on the user. It is impossible to trace the product in case of failure. Many of the import hardware items have a working load limit stamped on them, but there is no catalog information indicating the design factor. In fact, the design factor may be only 1:1 or 2:1, while a comparable U.S. product may be 4:1 or 5:1. With only a country of origin on the product, there is no catalog to consult or engineer to call for further information. A country, obviously, will not assume any liability if the piece of hardware fails.

4.05 Wire Rope

With the invention of the counterweight rigging system, wire rope replaced Manila as the lift-line material. Wire rope is not susceptible to stretching or shrinking from humidity changes, and it is much stronger per unit of cross-sectional area than Manila rope. Many types of wire rope are manufactured for industrial applications, and not one is designed specifically for theatrical use. Although several types of wire rope have been used for rigging over the years, some are more appropriate than others. The specific properties and types are discussed below.

A. Properties of Wire Rope for Stage Rigging

1. Reserve Strength

The outer wires of a wire rope are subject to wear and abrasion, while the inner wires are protected. The *reserve strength* is the strength of the inner wires of a wire rope with the outer wires removed. The more inner metallic area in relation to the outer metallic area, the greater the reserve strength. This property is of great interest to the elevator and crane industries, where a certain number of broken outer wires are allowed before the wire rope needs to be replaced. It is of less significance for rigging applications. For stage rigging, however, even *one* broken wire is cause to replace the wire rope immediately.

2. Flexibility

Wire rope, when used for stage rigging, is constantly being bent over sheaves and cable drums. Repeated bending and straightening requires a flexible and fatigue-resistant type of wire rope. Preforming the wire into a helix before twisting it into strands reduces internal friction and increases flexibility.

The smaller the diameter of each wire, the more flexible the wire rope. Choosing a wire rope with a greater number of wires per cross-sectional area increases flexibility and fatigue resistance. Wire rope is made of many pieces of wire. Bending a piece of wire back and forth will eventually fatigue the wire until it breaks (see section 1.06.G.1). This is true for wire rope as well. Constant bending will eventually fatigue the wires in the rope until they break. The number of repeated bends before failure is called the fatigue life cycle of the wire rope. The greater the fatigue resistance, the longer it will last.

a. *D/d ratio.* The ratio of the sheave tread diameter (D) to the wire-rope diameter (d) is called the D/d ratio. The larger the D/d ratio, the less sharp the bend over the sheave, and the longer the cable will resist fatigue failure (see section 4.06.B).

b. *Reverse bending.* Reverse bending can reduce the life of a wire rope by as much as 50%. When installing new wire rope, take it off of the spool carefully, and install it so that its major direction of bending is in the same direction as it was on the spool.

It is not always possible to avoid reverse bending. Figure 3.23 shows wire rope being subjected to reverse bends by mule blocks. If an installation requires reverse bending of the wire rope, try to place the blocks as far apart as possible, and use as large a sheave as reasonable. The reverse bends shorten the fatigue life cycle of the wire rope, thus requiring more frequent replacement.

3. Abrasion Resistance

In normal operation, a wire rope is subject to surface abrasion. Excessive fleet angles and the absence of sag bars and idler pulleys contribute to abrasive wear. The larger in diameter the outer wires are, the more the metal can wear away before the wire breaks. Larger-diameter wires generally mean greater abrasive resistance.

Another factor in abrasion resistance is the grade of the wire rope. The grade refers to the metal from which the wire rope is made. The chemical content of the steel determines the abrasion resistance and strength for a given diameter wire. Generally, the stronger the grade of wire rope, the more abrasion-resistant it is.

For outside applications, where the wire rope is being dragged over the ground, abrasion resistance is very important. For normal theatrical use, it is one of the properties that must be balanced against the others in selecting the proper wire rope for the job.

4. Size

When wire rope is manufactured, its diameter is slightly oversized. After a load is applied, it stretches, and the individual wires seat themselves closer to each other, thus slightly reducing the diameter. This stretching is called *construction stretch.* See section 6.03.A.1 and A.2 for the effect on termination devices.

Federal specification RR-W-410E specifies the dimensional and strength requirements for carbon-steel wire rope. The allowable diameter tolerances in these specifications permit a variance of –0% to +5%, thus never allowing the wire rope to be undersize, yet allowing the rope to be slightly oversize, even after construction stretch.

Imported wire rope must meet size and strength standards for theatrical use. Insist on size and strength certification from the dealer.

Any difference in diameter causes a difference in strength. The tensile strength of a material is dependent on its cross-sectional area. A smaller-diameter wire rope of similar construction and material has less cross-sectional area, thus less strength, than one of a larger diameter.

5. Strength

Strength is a major factor in selecting a type of wire rope for a rigging application. Wire-rope strength is stated in terms of ultimate breaking strength (see section 1.06). The type of material denoted by the grade determines the strength of the wire rope for a given diameter (see section 4.05.C). Wire rope should never be stressed beyond the yield point. For this reason, a minimum design factor for *running wire rope* used for theatrical purposes is 8:1. That is, the maximum allowable load is one-eighth of the breaking strength. As the degree of risk increases, the design factor must also increase. This design factor allows for the fatigue and abrasion of the wire rope.

For slings or other *static* applications, a minimum design factor of 5:1 is used. The degree of fatigue and abrasion is much less for static applications (see section 1.06.I).

B. Construction of Wire Rope

Wire rope is made of many wires twisted together in various combinations to provide a strong, flexible cable. There are classifications of the patterns that the wires are twisted in.

1. Core Construction

The *core* is the center of the wire rope around which the outer strands are wrapped. The center is usually one of three types: *fiber core* (FC), *independent-wire-rope core* (IWRC), or *wire-strand core* (WSC or SC).

The *fiber core* is made of natural or synthetic fiber. It is softer and more flexible than the IWRC and is easier to crush under load. It deforms more under compressive termination devices. Natural-fiber cores retain lubricant, which has been known to leak on the stage. They are also less strong than IWRC wire ropes. Plow-steel wire ropes are available with an FC.

Independent-wire-rope core is a separate wire rope around which the outer strands are wrapped. It resists crushing and is less flexible and stronger than a fiber-core wire rope. Galvanized aircraft cable greater than 3/8″ in diameter usually has an IWRC. Plow-steel wire ropes are available with an IWRC.

Wire-strand cores are made of the same construction as the outer strands of a wire rope. Galvanized aircraft cable below 3/8″ has a WSC.

2. Classification

Wire rope is classified according to the number of wires and strands (see fig. 4.3). For example, in a 7 × 19 classification, the first number (7) denotes the number of strands; the second number (19) denotes the number of wires in each strand. Typical classifications are 6 × 19, 6 × 37, and 7 × 19.

Plow steels for stage use are made in the 6 × category. The number of wires per strand varies, giving the user a wide choice for flexibility and abrasion resistance. Two broad construction classifications for plow steel are 6 × 19 and 6 × 37. Within the 6 × 19 classification, there are wire ropes with 19 through 26 wires in each strand. Within the 6 × 37 category, there are wire ropes with 36 to 49 wires per strand, as figure 4.3 shows. Wire

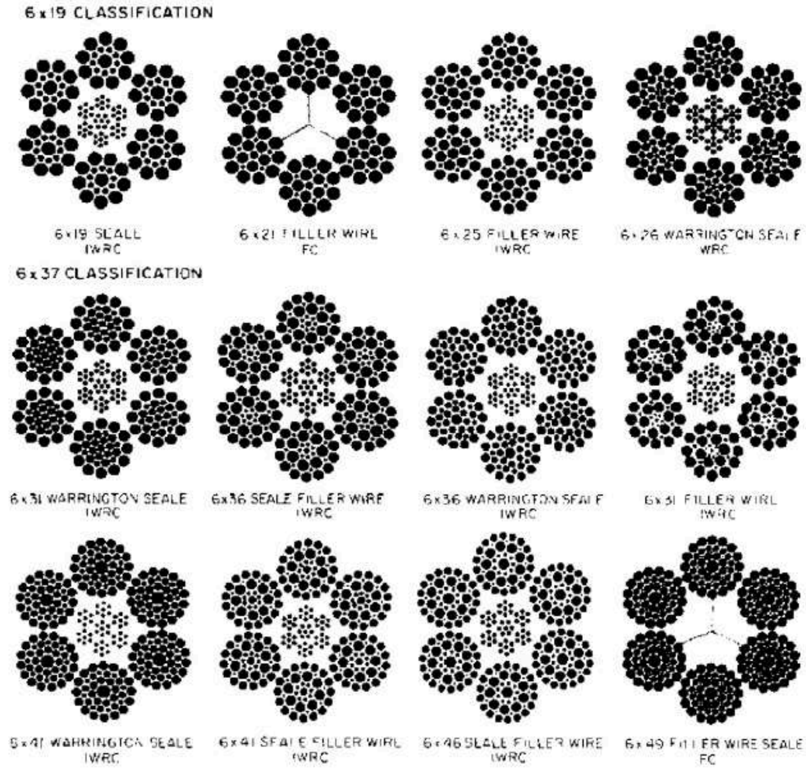


Fig. 4.3. Section drawings of 6 × 19 and 6 × 37 wire rope classifications. Courtesy of American Iron and Steel Institute, *Wire Rope Users Manual*, 4th ed.

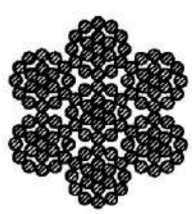


Fig. 4.4. Section drawing of 7 × 19 aircraft cable

ropes with the same diameter, core construction, and grade of wire all have the same breaking strength, regardless of the number of wires per strand.

Aircraft cable most commonly used for theatrical applications is the 7 × 19 classification. The seventh strand is the core (fig. 4.4).

C. Grades of Wire Rope

Many grades of wire rope are available. Only those found in theatrical use will be discussed here.

1. Plow Steel

Plow steel comes in four basic grades: plow steel (PS), improved plow steel (IPS), extra-improved plow steel (XIPS), and extra-extra-improved plow steel (XXIPS). (Once there was a grade called *mild plow steel* at the very bottom of the strength chart, but it has not been made for quite some time.) Plow steel is a natural-colored steel, usually not galvanized. Each grade increases its strength by approximately 15% from the one below it. PS and IPS grades can be found in older installations and are not readily available anymore. XIPS is generally used today for theatrical applications. XXIPS is available and is used for special high-strength applications.

It is impossible to distinguish the different grades of plow steel by eye. They all appear the same. Physical or chemical testing is the only way to differentiate among the various grades. To field test a piece of plow-steel wire rope to determine its grade, obtain samples of PS, IPS, and XIPS in the same diameter that you want to test. Cut all samples by hand using a cable cutter. There will be a noticeable difference in the amount of force required to make the cuts. The plow steel will cut very easily. The XIPS will require the most effort, and the IPS will fall in the middle. Cut the unknown sample, and compare the force required to the known samples. The 15% strength differential is very noticeable; one cut is usually all that is needed to make a determination. If the unknown sample is harder to cut than the known samples, it probably is XXIPS.

2. Galvanized Aircraft Cable

Galvanized aircraft cable has become the wire rope of choice for most theatrical work. It is readily available at reasonable cost and has a good balance of the properties required for theatrical use. Aircraft cable comes in both galvanized and stainless steel. The stainless is less strong and more expensive than the galvanized, and it should be used only where corrosion is a serious problem.

Aircraft cable used on the control systems of airplanes must meet the latest version of Military Specification (Mil Spec) MIL-DTL-83420M, a primary feature of which is fatigue testing. The cable used in airplanes is run over small-diameter sheaves and must be able to take repeated small-radius bending without breaking. To reduce the abrasion between wires, Mil Spec aircraft cable is heavily lubricated.

In stage applications, we have no need for this type of testing, and the heavy lubrication will drip on the stage. Instead of

Mil-Spec aircraft cable, we use *commercial grade.* Commercial grade conforms to Federal Specification RR-W-410E in size and strength but is not as heavily lubricated and does not go through fatigue testing. In order to use correct design factors and to terminate the wire rope properly, the rope must meet the size and strength criteria. Reputable suppliers can provide certification for strength and size upon request.

3. Stainless-Steel Wire Rope

Stainless-steel wire rope should be used where saltwater corrosion is a problem. It is available in two common types, 304 and 316. Type 304 is the stronger of the two; type 316 is the most corrosive resistant. Both types are less tough than galvanized aircraft cable and are susceptible to abrasion wear. Inspect the rope on a regular basis. Never use carbon-steel fittings such as thimbles, wire-rope clips, or shackles with stainless-steel wire rope. Electrolysis will cause the carbon-steel elements to rust, and the rust will migrate to the stainless wire rope, causing it to corrode.

4. Extra-Flexible Wire Rope

Applications where the wire rope is subjected to high cycles of operation or a small D/d ratio for sheaves and drums may call for extra-flexible wire rope. Extra-flexible wire rope is designed to bend over a smaller radius than either plow steel or aircraft cable.

5. Rotation-Resistant Wire Rope

For applications that require a single lift line that should not rotate, a rotation-resistant wire rope is available. The direction of twist for the core and outer strands are opposite to each other, giving it a degree of rotational stability.

6. Sash Cord

As the name implies, sash cord is a wire rope for window sashes (fig. 4.5). It is made in both a soft-iron and a steel version. The soft iron often has a copper coating to resist rust. It is made in a 6 × 7 design, has a fiber core, is extremely soft, and is very weak. Many old theatres have this wire rope on the counterweight sets. Because of its softness and low strength, soft iron does not take shock loads well and should not be used for theatrical applications.

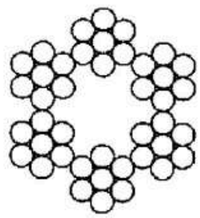


Fig. 4.5. Section drawing of 6 × 7 sash cord

7. Tiller Rope

Tiller rope is made in a 6 × 42 configuration, has a fiber core, and is usually copper coated (fig. 4.6). It is also made in both steel and iron wire and is designed for controlling the tillers on small boats. This wire rope has very low strength, low abrasion resistance, and should not be used for theatrical lifting applications.

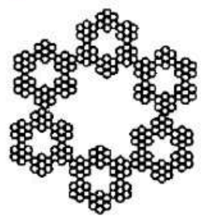


Fig. 4.6. Section drawing of 6 × 42 tiller rope

8. Strength Comparison

The following listing (from the *Macwhyte Wire Rope Catalog G-18*) is a comparison of the breaking strength of various types of 1/4″ wire rope.

Type Breaking	Strength (lb.)
Tiller rope, iron	1,168
Sash cord, bright	2,040
Tiller rope, plow steel	2,620
Plow steel IWRC	4,780
Improved plow steel IWRC	5,480
Extra-improved plow steel IWRC	6,800
Galvanized aircraft cable	7,000

9. Wire Rope for Theatrical Use

When taking over the responsibility for the rigging equipment in a facility, one of the first orders of business should be to inspect the rigging equipment. This includes finding out what type and grade of wire rope are being used. Determine if there is more than one type. Look at the outside physical appearance of the wire rope. Is it plain metal colored, copper colored, or galvanized? Determine, if possible, the approximate year the wire rope was installed. Open up an end to determine the type of core. Count the number of wires in a strand. Compare what you see to the information found in a good wire-rope catalog. Galvanized aircraft cable, tiller rope, and sash cord are easily identified. Plow steel, because of its various grades, is more difficult and may require a destructive test to determine the grade. If possible, contact the company responsible for the installation of the rigging system; it may be able to help you answer questions.

Once you determine the type and grade of the wire rope, make a written record for future use.

10. Purchasing New Wire Rope

Determine the design load for the line set and the type of use with regard to fatigue, flexibility, and abrasion. Ordinary counterweight sets and many winch sets can use galvanized aircraft cable or 6 × 19 XIPS with an IWRC. If the line set will require a high number of cycles per day, will have excessive reverse bends in the cable, or has a small D/d ratio, use a more flexible XIPS, such as 6 × 25 or 6 × 37. If the wire rope is for a permanent installation and a special application, other than a counterweight set, seek a knowledgeable person to help with the selection. Most often, the sales representative at the wire-rope store has no understanding of theatrical requirements. Talk to a theatre consultant or a stage-equipment company.

When ordering, specify the diameter, the breaking strength, the core type, number of strands and wires, and grade. Ask for a certified test report of the exact size and breaking strength. There can be a strength difference between domestic and imported wire rope. Record in the rail log the installation date and line sets for which the wire rope was used (see section 7.03.A).

D. Attaching to Batten and Arbor

Applying a load to wire rope causes it to stretch. Even if a batten is evenly loaded, the load on each lift line is not equal. Many loads are not evenly distributed, which adds to the problem of uneven cable stretch (see section 3.04.B.2). Therefore, when terminating the lift lines at arbor and batten, a method of adjustment must be provided. The adjustment device can be attached either to the batten or arbor end of the wire rope. Leveling the batten is much easier if the trimming device is attached to the batten rather than to the arbor. The batten is lowered to a point where it is convenient to measure from floor to batten. Measurements are made where each lift line is attached to the batten, and the lines are lengthened or shortened as required. If the adjusting device is on the arbor, then one person onstage must yell to the person adjusting at the arbor. This is often awkward and time consuming.

1. Trim Chain

Use trim chain that is manufactured to Federal Specifications RR-271-E and ASTM A413 to be assured of consistent strength and dimensions. The published design factor for chain meeting these specifications is 4:1. The entertainment industry uses a minimum design factor of 5:1. To obtain the allowable theatrical working load for a particular chain, multiply the published WLL by 4, and divide by 5.

Chain catalogs typically have disclaimers for welded passing-link chain, coil chain, machine chain, and grade-30-proof coil chain that indicate they should not be used for overhead lifting. These disclaimers apply to using the chain for slings and to raising or lowering loads by lengthening or shortening the chain with mechanical means, such as a chain hoist. The trim-chain application is defined as a dead hang.

Grade 8 alloy chain is recommended for overhead lifting and slings. Because of the size of the chain links in relation to the opening in the links, the bell of a properly sized shackle will not pass through a link. Using grade-8 chain is not practical for typical trim-chain use.

Today, trim chains are usually made from ¼″ proof coil chain with a breaking strength of 5,000 lb. on systems in which the WLL for the loft blocks is typically no more than 700 lb. The wire rope is terminated in an eye splice at the end of a chain, using a thimble with cable clips or a Nicopress sleeve. The trim chain is wrapped around the batten 1½ times and is secured back to the thimble using a shackle (fig. 4.7). By attaching the shackle back to the wire-rope thimble, the load is distributed between both sides of the chain (called *a basket hitch*). The effective capacity of the trim-chain assembly is doubled, thus providing a breaking strength for the chain assembly of 10,000 lb. (see section 2.03.A). When the shackle is attached to a link in the chain below the thimble, the entire load is on a single link, and the point of greatest stress is that link (fig. 4.8). This reduces the strength of the trim-chain assembly to 5,000 lb. If the chain link is side loaded, this further reduces the chain strength to 2,500 lb. Side loading reduces a chain-link strength by 50%.

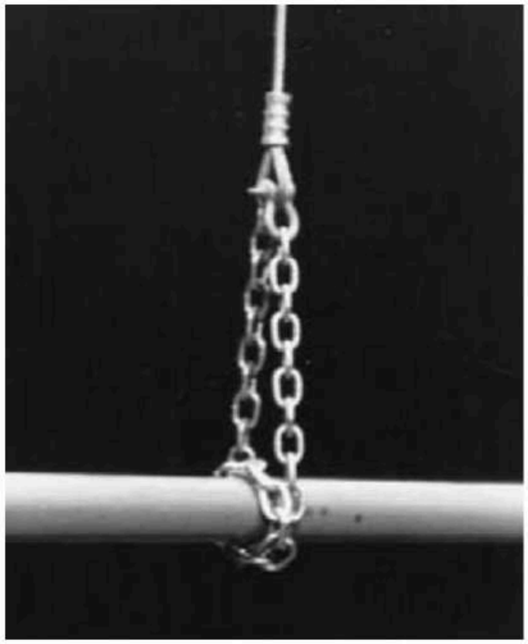


Fig. 4.7. Lift line attached to batten with trim chain; shackle through the eye of wire rope

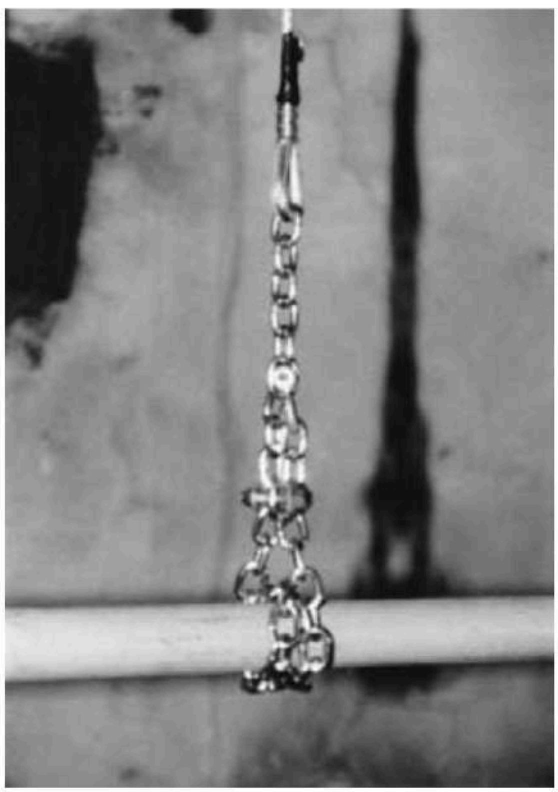


Fig. 4.8. Lift line attached to batten with trim chain; shackle through a link of the chain; the safety bolt through links of the chain

When installing trim chains, leave about four extra links hanging out of the shackle so that the batten can be lowered as well as raised without having to take the shackle out of the cable eye.

Snap hooks are often used to secure a trim chain (fig. 4.9). However, they are unrated pieces of hardware and should not be used; replace them with appropriately sized shackles. A quick temporary fix can be made by inserting a grade 5 bolt with a grade 5 locknut in the links below the snap hook as a backup device, as shown in figure 4.8.

Fig. 4.9. Broken snap hook on trim chain on arbor

Quick Links are also used with trim chains or to attach lift lines to arbors (fig. 4.10). They must be fully closed to develop their full strength. Most of them do not bear a manufacturer's name, and the design factor is unknown. Maillon-Rapide is the only manufacturer (that the author is aware of) that puts its name on the Quick Link and has a published design factor (5:1). Because Quick Links can come open as a result of vibration, they are not dependable devices. Shackles from a known manufacturer are a safer choice. If Quick Links are used on either end of the lift lines, and you notice they have a tendency to come loose, do one of the following: (1) Reinstall them so that they tighten *down*. This usually will solve the loosening problem. If changing the orientation is not possible, (2) use Loctite on the threads.

2. Clove Hitch with Wire-Rope Clips

This termination technique is a holdover from hemp rigging. The wire rope is tied around the batten with a clove hitch, just as fiber

Fig. 4.10. Loose Quick Link on trim chain

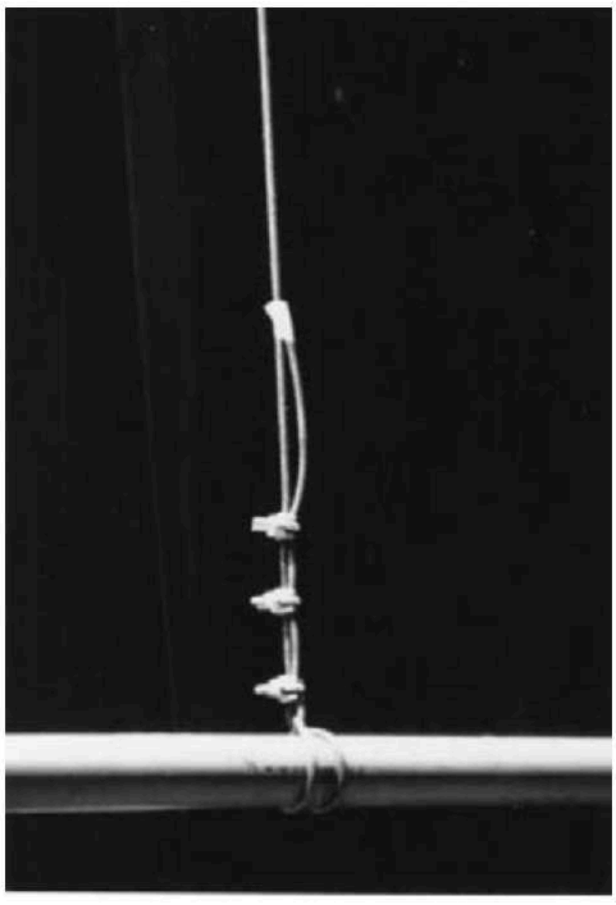


Fig. 4.11. Clove hitch with wire-rope clips

rope is. To secure the hitch, the dead end is fastened to the standing part with the recommended number of wire-rope clips (fig. 4.11). Destructive testing has shown that the weak point is just above the top clip. The wire rope breaks at this point regardless of how many clips are used. This is the point where all of the support of the load transfers from both halves of the line to just the live line. It is the point of greatest stress on the line at the batten end. From the top clip downward, the wire rope forms a basket hitch, and the load is equally divided between both halves of the line. The clove hitch supports the load on both the lines and is not the weak point of the termination. The efficiency of this termination is 80%, the same as wire-rope clips.

3. Twisted Sash Cord

In the early days of counterweight systems, 6×7 sash cord was often used for the wire-rope lift lines. As mentioned in section 4.05.C.6, this is a very weak wire rope and should not be used for stage rigging. It was often tied in a clove hitch around the batten with the dead end wrapped around the standing part. The end was taped to hold it in place. This type of termination places a concentrated stress area right where the standing part of the line makes the first bend of the clove hitch.

The photograph in figure 4.12 shows an existing system in which the rigger has replaced the tape with two cable clips; this does nothing to strengthen the termination. The entire load is still on the standing part of the line. If the dead end of the line is straight, as in figure 4.11, and the clips are applied, the wire rope forms a basket hitch, and the load is shared by both parts of the line up to the top clip. Because the dead end of the line is twisted around the live line, it does not support any of the load. In this case, the efficiency of the termination when first applied is that of a clove hitch, about 75%. Due to fatigue and shock loading over time, the wire rope can become deformed at the stress point of the clove hitch, and the termination will become even less efficient.

4. Turnbuckle

The wire rope can be attached to the end of a turnbuckle using a thimble with cable clips or a compression sleeve. Use a turnbuckle with either jaw or eye ends or a combination of both. Attach the wire rope or batten clamp to an eye with a shackle. Do not fasten the cable directly to the eye. The turnbuckle may need to be replaced, and using a shackle makes replacement easier.

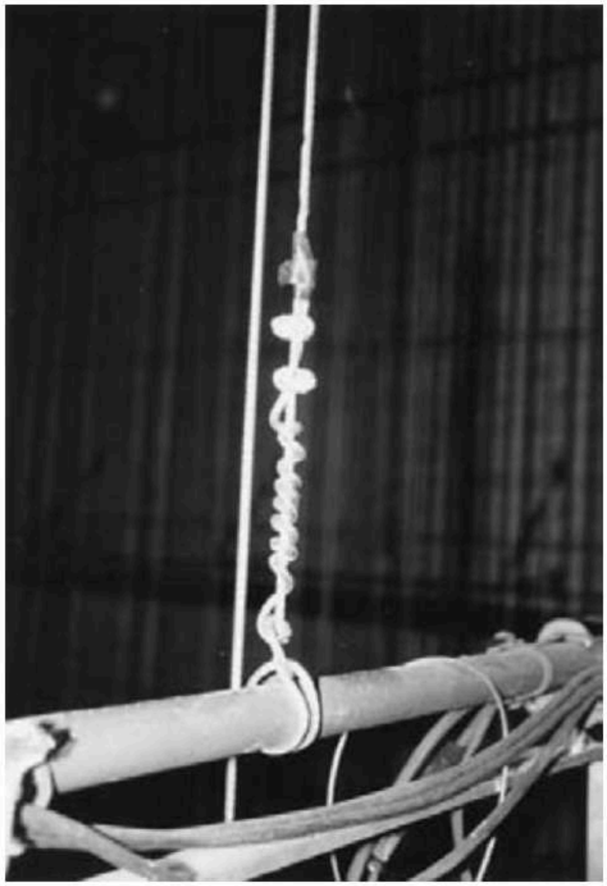


Fig. 4.12. Clove hitch with twisted dead end of wire rope; added clips of little value

A jaw end can be attached directly to the arbor, pipe clamp on the batten, or wire-rope thimble.

As wire rope runs over a sheave, the twist in the wire rope causes it to spin. Cotter pins, or No. 12 solid-core electric wire, through a hole in the rod ends or wire mousing should be used to keep the turnbuckle from turning and separating. Jam nuts do not hold. They keep the rod of the turnbuckle from closing but not from opening. All three methods are shown in figure 4.13.

E. Indications of Wear

When inspecting the lift lines for signs of wear, look for broken wires, flattened wires, separation in wire or strand, rust, signs of chemical etching, or anything unusual (fig. 4.14). Wire rope in good condition is clean, well formed, and free from dirt, grease, and other discoloration.

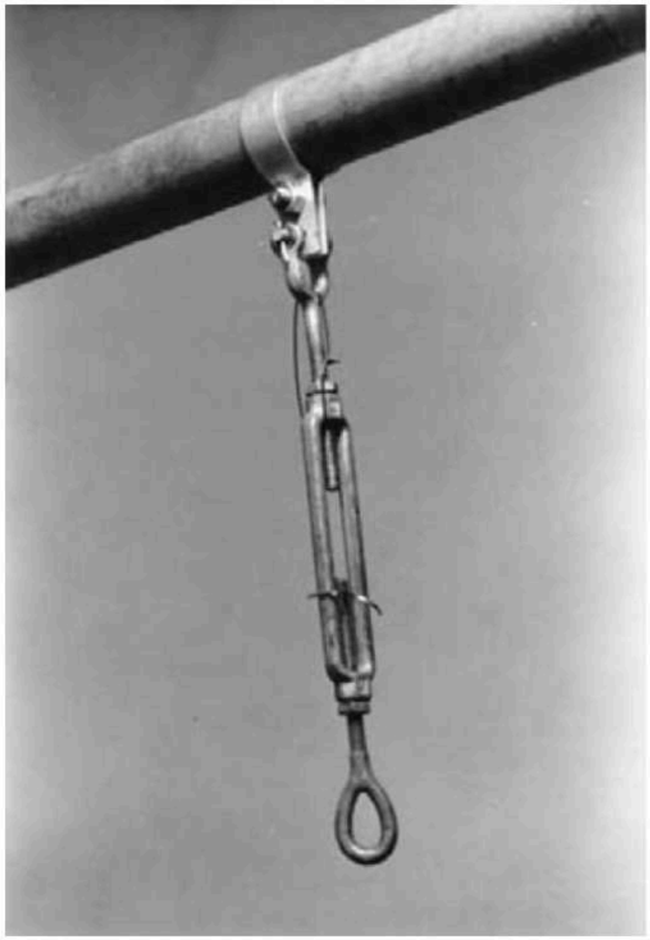


Fig. 4.13. Turnbuckle on a batten with jam nuts and two types of mousing

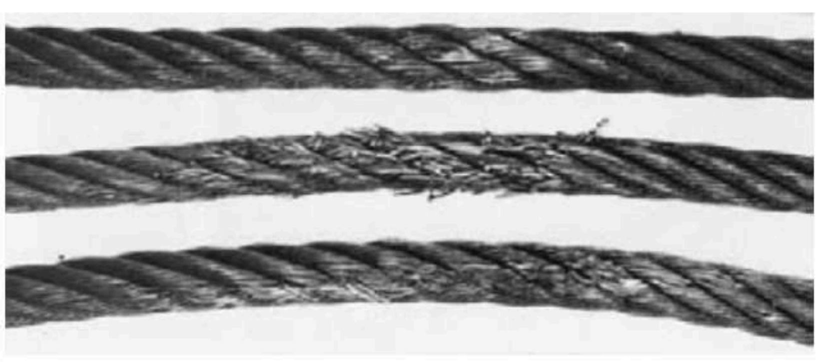


Fig. 4.14. Signs of wear and misuse. Courtesy of American Iron and Steel Institute, *Wire Rope User's Manual*, 4th ed.

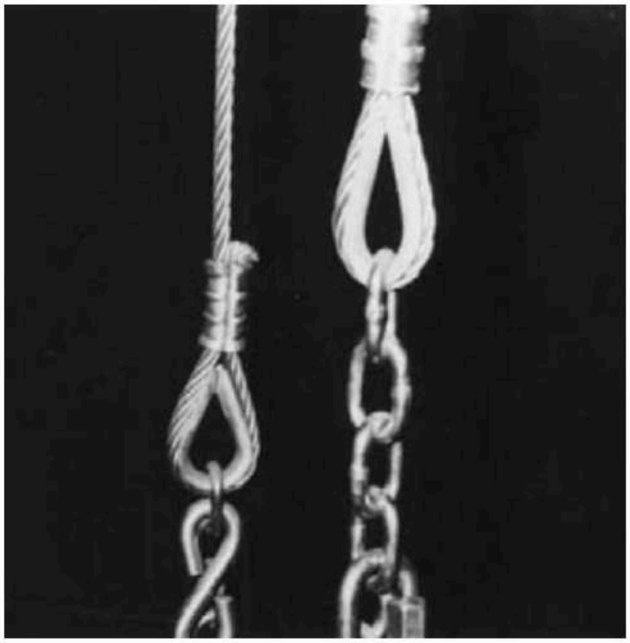


Fig. 4.15. Regular thimble (left) and deformed thimble

In particular, look closely at the wire rope next to the cable clips and compression fittings. These are points of stress concentrations and the most likely places to find broken wires caused by overloading. An elongated thimble is a sign of excessive stress (fig. 4.15). Check terminations very thoroughly.

To check for broken wire over a long run, hold a piece of terry cloth or cotton batting in a gloved hand. Wrap the material gently around the wire rope, and have someone operate the line set. The broken wires will snag the material. If using a bare hand instead of fabric, you will follow the bloody trail back to a piece of skin snagged in the broken wire.

Gun bluing or any other type of acid-based solution should never be used to color wire rope. The acid continues to eat into the metal and causes corrosion and loss of strength.

4.06 Blocks

In this section, characteristics that pertain specifically to wire rope blocks are discussed. (For general information pertaining to blocks, see section 3.04.)

A. Material

The sheaves for wire-rope blocks can be made from a variety of materials. Each material has a finite amount of compressive load that it can withstand before it fails. This compressive force is referred to as *radial pressure.* The radial pressure is dependent on the size of the wire rope (d), the magnitude of the load (L), and the tread diameter of the sheave (D). The formula for calculating the radial pressure (*RP*) is

$$RP = (2 \times L) \div (D \times d)$$

The allowable radial pressure for common sheave materials with 6 × 19 or 7 × 19 wire rope is

Material	**Radial Pressure (*RP*; lb.)**
cast iron	480
cast carbon steel	900
chilled cast iron	1,100
manganese steel	2,400
injection-molded Mylatron	500 to 700
cast Nylatron	1,000 to 2,000

The Nylatron figures vary with different manufacturers depending on molding patterns and machining techniques. Figure 4.16 shows the effect of excessive radial pressure on a sheave. This kind of scoring causes excessive wear on the wire rope. Eventually, the sheave will wear to the point of catastrophic failure.

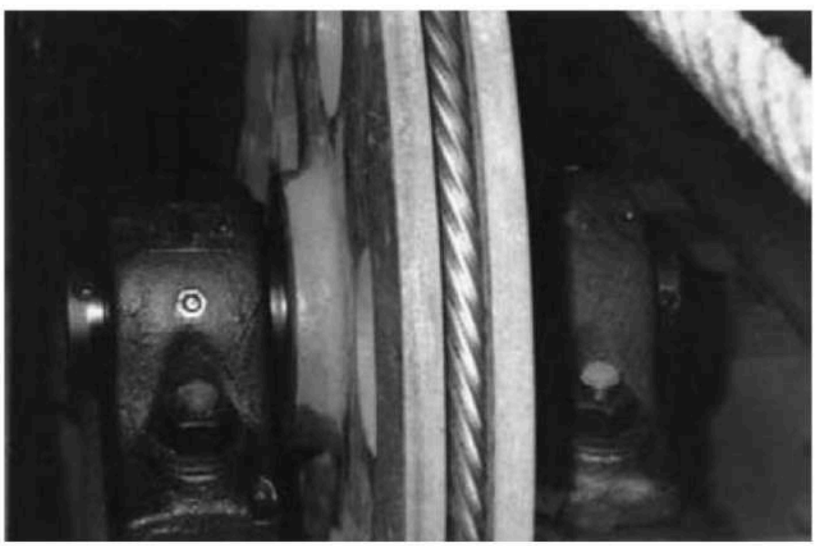


Fig. 4.16. Sheave scored by excessive radial pressure

B. Sizing

Proper sheave-diameter sizing is far more critical for wire rope than hemp rope. The recommended sheave diameter is a multiple of the wire-rope diameter called the D/d ratio (see section

4.05.A.2.a). The minimum sheave tread diameter for 7 × 19 aircraft cable and 6 × 19 wire rope is 30 times the diameter of the wire rope. Using ¼″ for example, .25 × 30 = 7.5″ minimum sheave-tread diameter. The groove of the sheave must also be properly sized for the wire rope. If it is too big, it does not support the wire rope properly, and the wire rope will flatten out and lose strength. If the groove is too small, the abrasion of the cable, rubbing the groove walls, will cause wear on both cable and sheave. A tolerance of −.00 to +.015 is acceptable. Using hemp blocks for wire rope is *never* acceptable.

C. Head Blocks

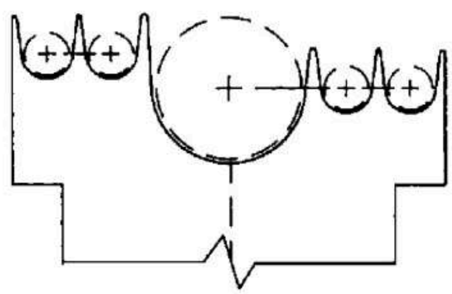


Fig. 4.17. Section of head-block sheave showing equal pitch diameter on right and unequal on left

The head blocks for counterweight sets are grooved for the wire-rope lift lines and the fiber-rope hand line. The pitch diameters for the fiber and wire ropes must be equal, or the hand line and lift lines will run at different speeds. The right side of figure 4.17 shows equal-pitch diameter for the hand line and the wire rope. The left side shows a larger pitch diameter for the wire rope. Unequal pitch diameter causes the hand line to slip in the groove of the head block, thus causing wear to the hand line and additional friction in the system. This slipping can often be felt when running the line set. Because friction is a percentage of applied force, the heavier the load, the greater the amount of friction and the greater the effort required to operate the line set. Unequal pitch diameter can be fixed only by replacing the head-block sheave or having it remachined.

When inspecting the head blocks, check to see that the lift lines are not crossed, that the fleet angle of all lines is acceptable, and that the clamps are tight and against the support steel. All head-block mounting bolts should, at a minimum, be grade 5 (see section 6.04).

D. Tension Block

Fig. 4.18. **Tension blocks**

Fig. 4.19. **Bent tension-block guide**

The tension block (fig. 4.18), found on a single-purchase counterweight set, serves two functions. First, because it can float (move up and down), it can reduce strain on the hand line if it shrinks due to increased humidity. Most types of tension pulleys require a downward pressure on the front edge before they can move up on the T-bar guides.

Second, the tension pulley allows the operator to put slack in the hand line in order to put a safety twist in it while loading or unloading (see section 4.11.A.1). The tension-block guides can become bent (fig. 4.19) from the force generated by doing this or using an Uncle Buddy. Inspect the guides at regular intervals.

4.07 Lock Rail

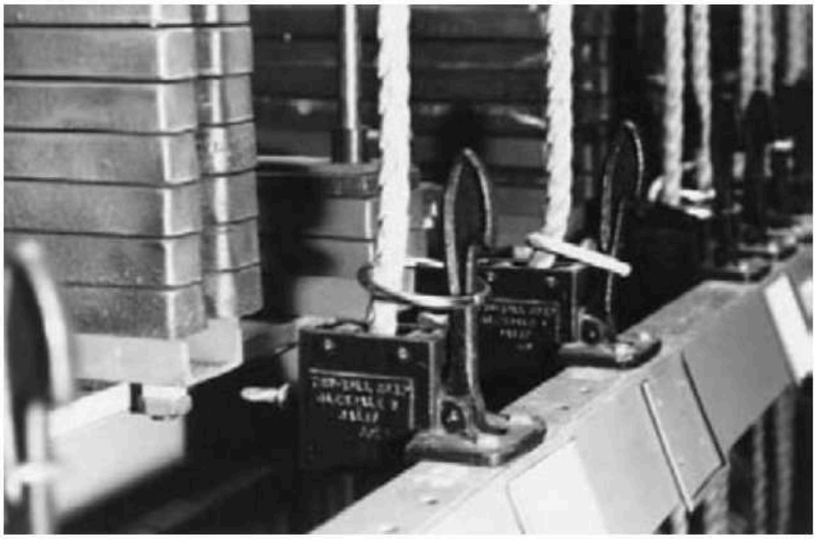


Fig. 4.20. Rope locks

The *lock rail* is a metal rail with a rope lock for the hand line of each counterweight set. The rope lock (fig. 4.20) is intended to keep the batten in a given position under a nearly balanced load condition. THE ROPE LOCK IS NEVER INTENDED TO HOLD A HEAVILY UNBALANCED LOAD WHILE LOADING OR UNLOADING. The lock rail must be firmly anchored to the floor to withstand upthrust and side load applied by stagehands climbing on it. The common upthrust design load is 500 lb. per foot.

A. Rope Lock

The lock consists of a pair of jaws and a hand-operated lever arm (fig. 4.21). The lever arm has a cam on the side that presses against the onstage jaw, forcing it against the rope thus holding the rope between the two jaws. A steel ring, which is threaded through the hand line, slips over the lever when it is in the up, or locked, position. This ring locks the handle closed and keeps the handle from accidentally falling open. When properly adjusted, the rope lock should be *self-locking*, that is, when the handle goes up 2° past the vertical position, it should stay in position. There

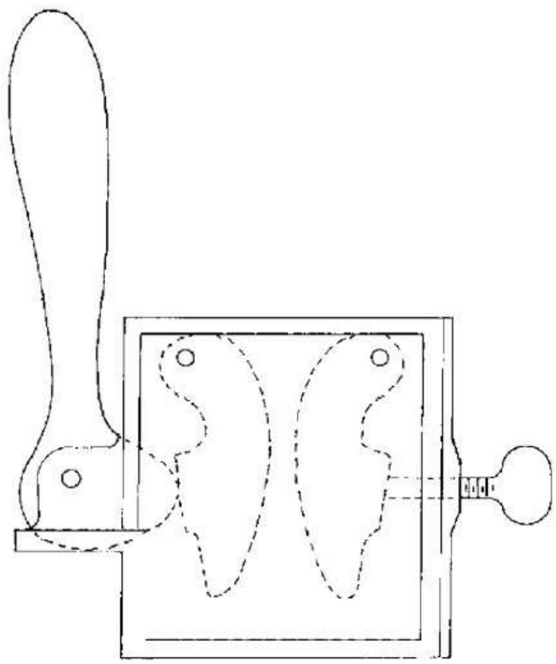


Fig. 4.21. Rope-lock detail

is a noticeable feel when the cam on the handle goes over center and into position.

B. Lock Adjustment

The pressure of the jaws is designed to be easily adjusted by turning the thumbscrew on the back side of the lock (see fig. 4.21). Missing thumbscrews should be replaced immediately. If the handle cannot be adjusted to be self-locking, the cam on the handle or the onstage jaw is worn out and must be replaced.

C. Load Limit and Identification

The lock rail is a good place to mark the load limit of each rigging set as well as to identify each set by number and purpose. Rigging sets are numbered from downstage to upstage.

4.08 Arbor

The arbor is the rack that holds the counterweights. It consists of a top plate and a bottom plate (each also called a weldment), a steel back plate, two guide shoe assemblies, and two steel rods ¾″ in diameter. Wire guide systems do not have the guide shoe assemblies and often do not have back plates. Steel plates called *spreader plates* or *spreader bars* slide on the rods. Top plates have collars and thumbscrews and are called lock plates. As weights are stacked on the arbor, the spreader bars should be distributed every 2′ to 3′. In the event that the counterweight set moves too fast, and the arbor slams into the top or bottom stops, the spreader plates keep the rods from bending so the counterweights do not fall out.

The lock plate should always be used on top of the counterweights. Its function is to keep the counterweights from falling out of the arbor in case of a crash. The lock plate can only do

Fig. 4.22. Counterweights with spreader and lock plates in place

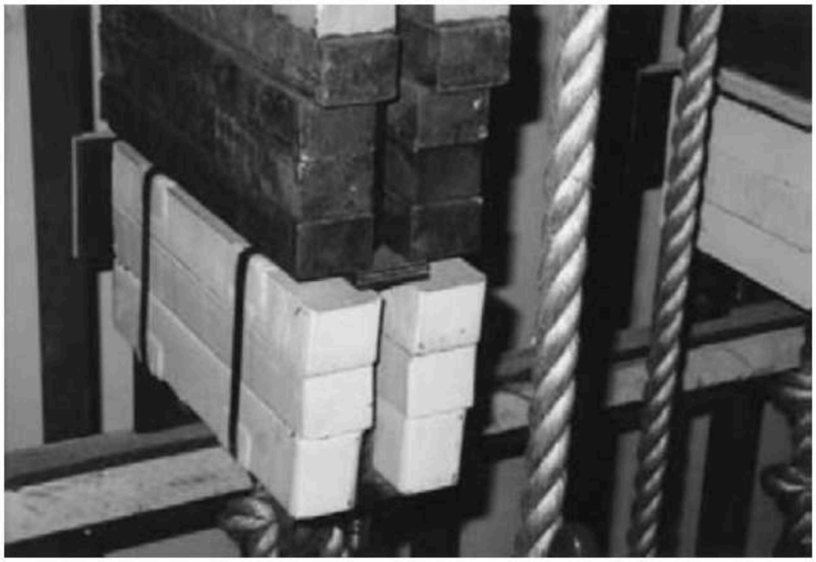


Fig. 4.23. How not to use spreader plates

this if it is in place and the thumbscrews are tight (fig. 4.22). Figure 4.23 shows how *not* to use the spreader plates. *Lock and spreader plates are like seat belts—you only need to have them in place at the moment of impact. Because you cannot know when the moment of impact will be, you need to use them all of the time.* CAUTION: If the arbor tops and bottoms are cast iron, inspect them carefully and frequently for cracks.

A. Guide Systems

There are two types of guide systems for arbors. The simplest and noisiest is a *wire-guide system* (fig. 4.24). These generally should not be used for line sets with more than 35′ of travel. No matter how tight the guide wires are, it is impossible to keep the arbor from swinging side to side. If used for systems with greater travel distances, the line sets should be spaced far enough apart so the arbors do not hit each other.

Periodically, check the wires to see that they are tight and that they are not worn. CAUTION! *Do not overtighten the guide wires*. Overtightening can bend the support steel to which the ends are fastened, whether they are part of the building or a part of the head block.

The other type of guide systems for arbors is a track system, most commonly called a *T-bar–guide system* (fig. 4.25). The name is derived from the shape of the guide rails. Typically, the T-bars

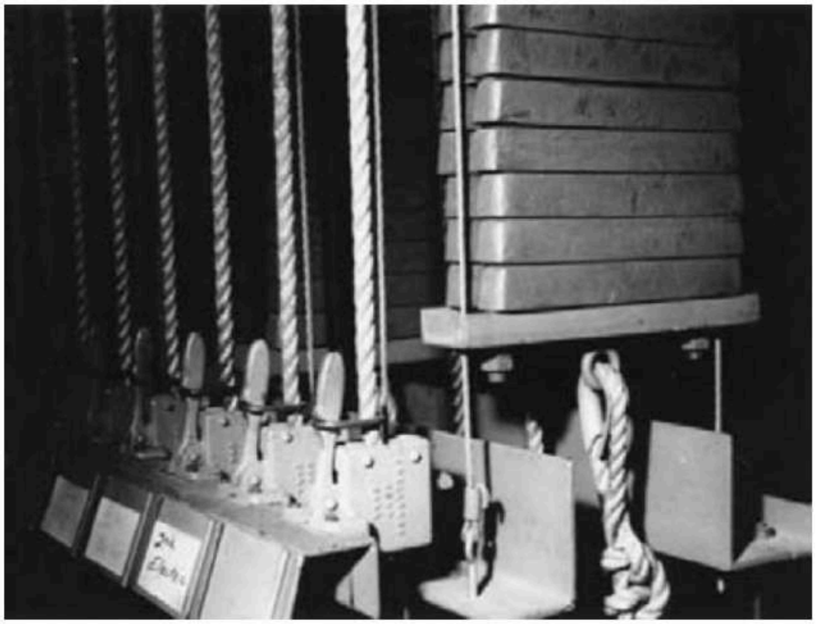


Fig. 4.24. Wire-guide counterweight set

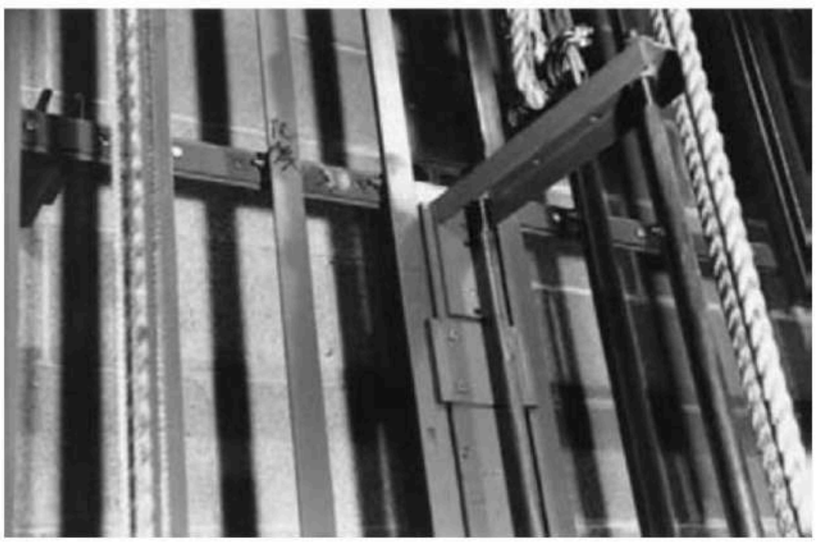


Fig. 4.25. T-bar–guide counterweight set

are made of steel. A similar guide system is made from extruded aluminum in a J-bar configuration. The J-bars are gaining popularity, as they are easier and faster to install than steel T-bars.

The arbor has guide shoes, or rollers, that run on the rails. If the arbor becomes hard to move, check the arbor guide and T-bars for proper alignment. The guide shoes may need replacement. *Never grease the T-bar*. The grease will attract dust and dirt, and it will ultimately make the arbor even harder to move.

B. Pipe Weight

Most of the time, enough weight is left on the arbor to balance the batten weight. This is called the *pipe weight*. It is good practice to paint these weights a distinctive color to aid the loaders when taking weights off the arbor.

NOTE: The spreader plates are *not* intended to mark pipe weight. Using them to mark pipe weights keeps them out of the way when loading and unloading the arbor but is of little help during a runaway.

4.09 Hand Line

Fig. 4.26. Hand line tied at arbor bottom

Once, most hand lines were Manila rope. Nowadays, three-strand twist and parallel-core polyester have become the ropes of choice. Because Manila changes its length with changes in the humidity, it should be adjusted by retying it if it becomes very tight or slack. Sometimes, it is necessary to retie polyester after the construction stretch is worked out of it. On single-purchase systems, this is done on the underside of the arbor (fig. 4.26).

The arbor is raised and locked off. The knot, usually two half hitches, is retied to adjust to the proper tension. Taping the tail of the rope to the hand line keeps it from getting in the way during operation.

On a double-purchase set, one end of the hand line is tied off on the head block beam, and the other is tied off somewhere near the lock rail. Whichever knot is most convenient to reach may be used for adjustment. Because the knot is not moving, no taping is necessary. However, the end of the rope should be taped or whipped to prevent fraying (see section 6.01).

On both single- and double-purchase systems, be sure the knot does not interfere with the arbor travel.

4.10 Loading Bridge

The loading bridge is the platform where the arbors are loaded and unloaded. A safe loading bridge is placed at a height where the arbors can be easily reached when the battens are 3´ to 5´ above the stage floor. So the loaders can safely see what they are doing, there should be adequate lighting on the loading bridge.

A. Storing Weights

Fig. 4.27. Counterweights stored on loading bridge

A kick rail should be on both edges of the loading bridge to keep the counterweights from being kicked off (fig. 4.27). *Counterweights should never be stacked higher than the kick rail!* If possible, they should be stacked on the onstage side of the bridge, so the loaders do not have to walk on them while working.

B. Loading and Unloading Weights

Usually, two people should work on the loading bridge. One person hands the weights to the other, who loads them on the arbor. To reduce the chance of dropping weights, the transfer of

Fig. 4.28. Loading counterweights

Fig. 4.29. Handing counterweights to loader

weights is done over the loading bridge, never in the open space next to the arbor. The reverse is done for unloading.

It is easiest for the person loading and unloading to grasp the weights in the middle (fig. 4.28). The person handing the weights to the loader should hold them by the ends (fig. 4.29).

C. Identifying Load Limits and Weights

It is good practice to post the weight of the variously sized counterweights in some obvious place on the loading bridge. The capacity of the batten can be indicated on the lock plate, the batten, or other convenient locations (fig. 4.30).

D. Lead Weights

Special precautions need to be taken when using lead weights. The basic rule is, *Don't lick the lead.* Be sure to use gloves, and wash your hands before smoking or eating. If you put your hands near your mouth after handling lead weights, you may accidentally get lead in your mouth and ingest it. Even a small amount of ingested lead puts you at risk of lead poisoning.

4.11 Loading and Unloading with a Loading Bridge

Counterweight sets are designed to be used in a balanced condition. This means that the load on the batten is equally balanced with the counterweights on the arbors. During the loading and unloading process, an *unbalanced* condition exists. *This condition is potentially very dangerous*! THE ENTIRE LOADING AND UNLOADING PROCEDURE SHOULD BE HANDLED WITH GREAT CARE. The basic rule for working with an unbalanced load is KEEP THE WEIGHT DOWN. Never depend on the lock or the lock rail to hold weight in the air.

A. Crew Responsibilities

In order to avoid holding weight in the air, it is essential that a proper loading-and-unloading sequence be followed. In addition, it is essential that the crews loading weights, working the lock rail, and attaching scenery or lights to the battens thoroughly know their jobs.

1. The Rail Operator

The operator on the lock rail directs the loading and unloading. The operator controls the sequence by giving directions for attaching or removing loads, as well as adding or removing counterweights on the arbor. If a heavy show is being set in or taken out, assistant flymen control the hand lines while the head flyman directs the operation. When loading or unloading, ALWAYS

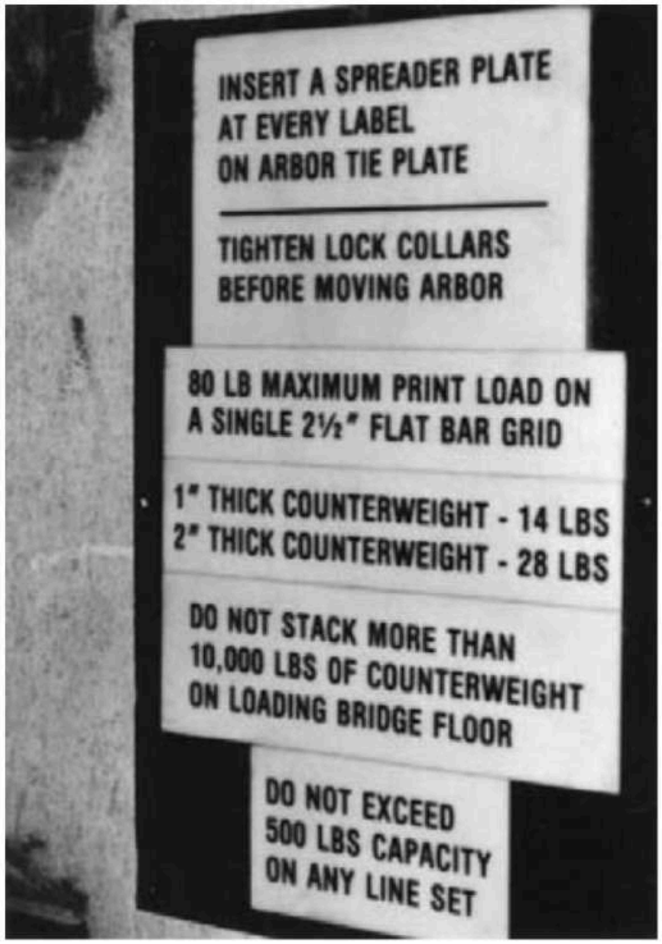


Fig. 4.30. Loading-bridge sign, for which "Maximum print load" should read "Maximum point load"

HAVE A SAFETY WRAP ON THE HAND LINE. There is always a chance of the counterweight set becoming unbalanced with the load in the air. Therefore, one of the methods of putting a safety wrap on the line should be used (see figs. 4.31 through 4.38).

Method 1. Twist the hand line. Step down on the front of the tension pulley, and pull up on the back hand line. This will create slack in the hand line. Twist one rope around the other, four or five times. Apply tension to the front rope by hand (fig. 4.31), or place a belaying pin in the ropes for ease in holding (fig. 4.32). *Never rely on the rope lock to hold an unbalanced load!* Twisting the hand line will cause the tension block to pull up in the front, which puts a great deal of strain on the tension-block guides and may cause them to bend (see section 4.06.D, fig. 4.19). Once the load is attached, and the arbor is loaded, hold onto the front line while keeping the hand lines twisted. Allow the line to slip as the

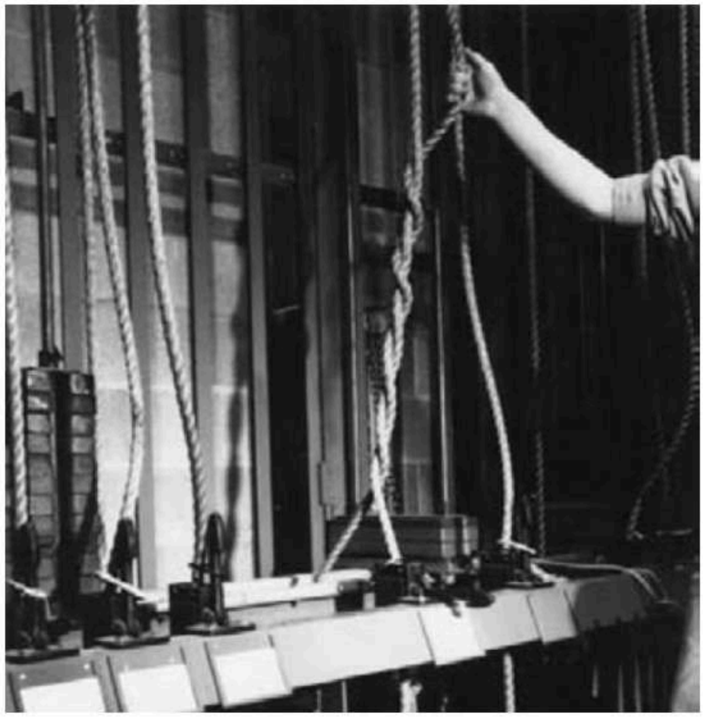


Fig. 4.31. Safety twist in hand line

Fig. 4.32. Belaying pin in hand line

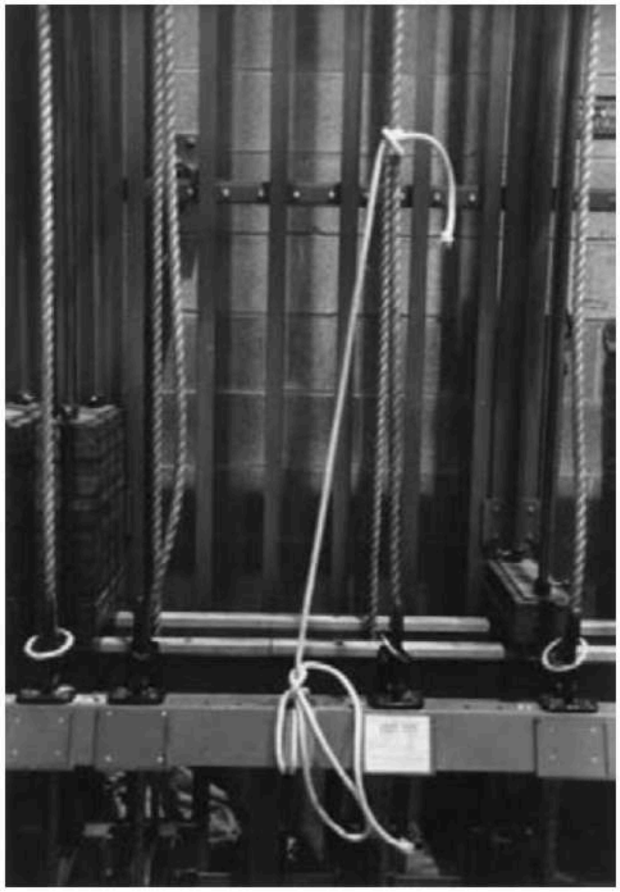


Fig. 4.33. Safety hitch on hand line

load is raised off the floor. When the load is clear of the floor, if the load feels balanced, untwist the line and operate normally. If the load is not balanced, pull the arbor to where the weight can be adjusted, and do it.

Method 2. Tie a safety hitch from the hand line to the lock rail. In the past, it was common to use a piece of Manila or cotton sash cord to tie off the hand line (fig. 4.33). With the introduction of polyester hand line, 8 or 9 mm nylon and Spectra mountain-climbing accessory cord is coming into use (fig. 4.34). Spectra is much stronger than nylon. Two knots that work well for attaching the safety line to the hand line are the stopper hitch and the prusik knot (see sections 6.01.B.3 and 4). The smaller diameter of the synthetic tie-off line grips the synthetic hand line better and gives more secure holding power than Manila. The synthetic line also works well on Manila hand line. Tying off the hand line places all of the stress on the tie-off line and not on the tension block. This method is the easiest on the tension-block guides.

Fig. 4.34. Prusik knot in synthetic safety line

Fig. 4.35. Slipping the knot on the safety line

Quite often the load—a piece of scenery or a curtain—will be on the floor after it is attached to the batten. The arbor is weighted, and the line set is out of balance until the load is lifted clear of the floor. If the tie-off is removed while the weight is on the floor, the overweight arbor can run away, jerking the load into the air. Both the stopper hitch and the prusik can be slipped on the hand line, allowing the operator to control the load until it is balanced. Get some help to pull down slightly on the tied-off hand line. When there is a bit of slack on the tie-off line, place your hand on top of the knot, and slide it down the hand line (fig.

4.35). Ease the hand line up a bit, and continue this process until the load is clear of the floor. Check the balance by pulling on the hand line. If the load is balanced enough to control, remove the tie-off line.

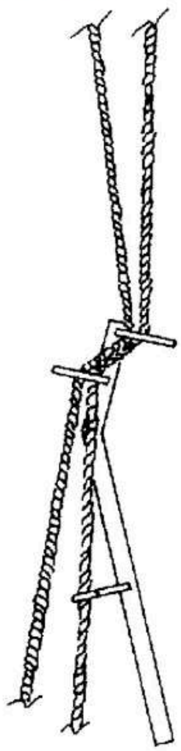


Fig. 4.36. Drawing of Line Lok

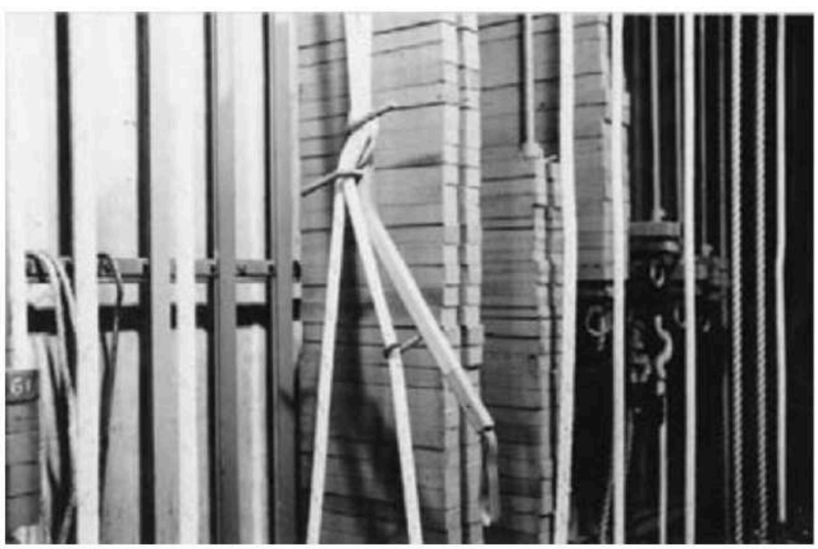


Fig. 4.37. Line Lok

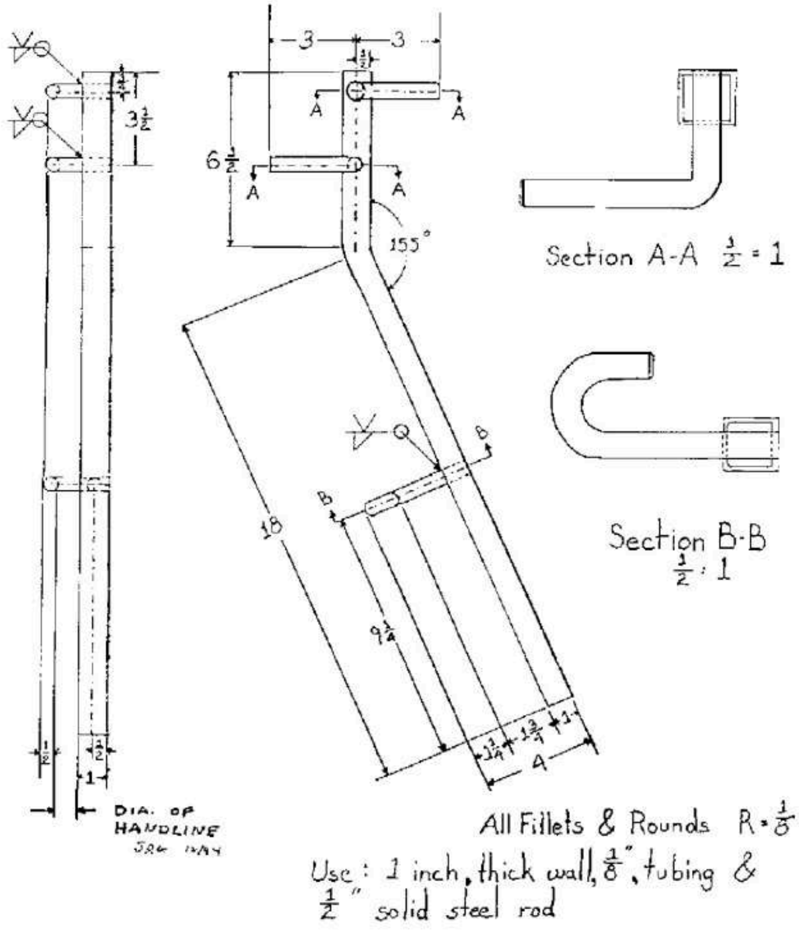


Fig. 4.38. Line Lok detail. Courtesy of Wes Jenkins

Method 3. Use a Line Lok (Uncle Buddy). I first saw a Line Lok (figs. 4.36 and 4.37) in a theatre in Calgary, Canada. Some months later, while doing a rigging seminar at the Banff Center, I mentioned the Line Lok. The technical director not only had some in the theatre but gave me the drawing in figure 4.38 to make one. He mentioned that the device first appeared in Canada with a touring U.S. road show. After the first edition of this book was published, I moved to Seattle and found that the device was originally made by a Seattle stagehand. In his honor, it is called an *Uncle Buddy*. This is a typical example of how information on rigging is passed along from one place to another in the theatre.

NOTE: The drawing of how to make a Line Lok, or Uncle Buddy, that appeared in the first edition contains a dimensional error and has been corrected in this edition. The original drawing indicates a space from the inside of the hooks to the front of the steel tube of 1″. This dimension should be the same as the diameter of the hand line. If manufactured as drawn and used on a line less than 1″ in diameter, the Line Lok could slip. The slack space can be taken up by attaching a plate of the correct thickness on the inside of the tube, as shown in figure 4.37.

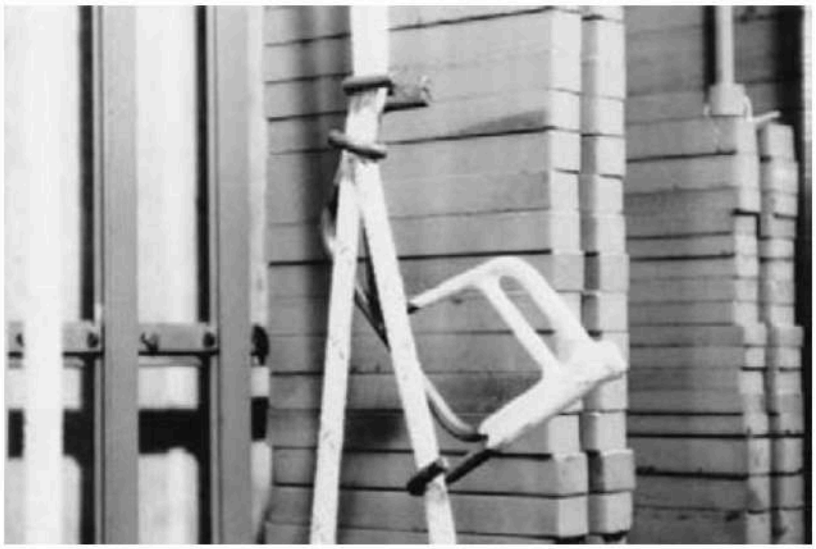


Fig. 4.39. Commercial line holder

Figure 4.39 shows a commercially manufactured device that works in a similar manner to the Line Lok. Both devices can be used as a brake to move an unbalanced load, similar to slipping the tie-off knot above. This is done by releasing the bottom hook, placing one hand at the top of the device and rocking the bottom with the other hand.

Method 4. Use a bull line. See section 4.12.B.2.

Method 5. Use a bull winch or capstan winch. See section 4.12.B.3.

Method 6. Use a block and tackle. See section 4.12.B.4. *Never leave the hand line unattended when a counterweight set is being loaded or unloaded.*

2. Loading-Bridge Crew

The loading-bridge crew should add or remove weights only when instructed to do so by the rail operator. Adding weight to an arbor before a load is attached to a batten can cause an unbalanced condition. This could leave the counterweights hanging in the air, supported only by the hand line. Follow safe procedure for loading weights, using spreader bars and lock plates (see section 4.10).

3. Stage Crew

The crew onstage attaches the load to the batten. The head carpenter or head electrician supervises batten and spot-line loading and unloading. The head flyman gives the order to the stage crew to attach or remove the load. Removing the load from a batten before the arbor is unloaded is dangerous.

When scenery or curtains are resting on the floor while being attached or removed from a batten, their full weight is not offsetting the counterweights needed to balance them. The stage crew may have to hold the batten down as counterweights are being added or removed. They do this either by holding the batten with their hands or with a bull line (see section 4.12.B). *When holding a batten by hand, never lean over the batten. It may be necessary to let go quickly if the batten begins to run away.*

B. Communications

The crews onstage, on the loading bridge, and at the lock rail must be able to hear the directions given by the rail operator. If, for any reason, the flyman has difficulty being heard, electronic voice reinforcement should be used.

Often, many people are working on and above the stage. It is important to shout a warning to all before moving a batten in or out. The normal warning is to shout, "Heads up," "Heads," or "Line set number ___ moving." It is also helpful to indicate where the piece is moving (e.g., "Upstage, heads up"). *When working on the stage, never stand or walk under a moving rigging set. Never move a rigging set when someone is under it.*

C. Runaway Set

If crew members involved in loading or unloading a counterweight set lose their concentration, it is possible for them to make a mistake and for the set to become unbalanced and run away. This happens when the weight in the air is so heavy that it cannot be held by the rope lock. If it starts to creep, it may be possible to stop it by brute strength and quickly correct the situation. However, if the set begins to move rapidly, indicating a very heavy out-of-balance condition, DO NOT ATTEMPT TO STOP IT! To do so could cause serious injury. If a runaway should occur, *shout a warning to all crews, and take cover*. Crew members should take cover to protect themselves from flying counterweights and objects falling from the grid.

The arbor will either crash down or up, depending on which part of the line set is heavy; and the chance is great that counterweights and smashed head blocks, tension blocks, or other hardware will fly through the air. The batten will either go up or down, and the possibilities of adjacent flown objects being hit, lift lines snapping, loft blocks smashing and falling, and sprinkler systems being activated are all very real. The only reasonable course of action is to get quickly out of harm's way. *Runaways are caused by human error. Concentration on the task at hand is essential to using rigging safely.*

D. Loading

The loading procedure is as follows.

1. Attach load to batten. If a great deal of weight is resting on the floor, make provision for holding the batten down until the counterweight has been loaded.
2. Load counterweight arbor.
3. Slowly raise the batten to test for balance, keeping it under control at all times.
4. Add or subtract weight as needed for final balancing.

E. Unloading

1. Unload weight from arbor first.
2. Remove weight from batten.

4.12 Loading and Unloading without a Loading Bridge

Some facilities do not have loading bridges, or the arbors cannot be reached from the loading bridge when the batten is down. This is particularly true with lighting battens. The electric-cable cradle often restricts the full travel of the battens and arbor.

A. Partial Loads

Where it is possible to attach partial loads to the batten, such as a lighting batten, the procedure is

1. Put a small amount of weight on the arbor—enough so that the operator can safely raise the arbor to a height where the batten can be reached.

2. Add part of the load to the batten, overloading the batten slightly.

3. Lower the arbor so more weight can be added. This procedure is followed back and forth until both batten and arbor are fully loaded and balanced. Needless to say, the rail operators must be strong and in good physical condition for this work.

4. For unloading, the procedure is reversed. Do not remove all of the load or counterweights at one time. This could result in a runaway set.

B. Unbalanced Large Loads

Sometimes, it is necessary to attach large loads as a single unit. This requires moving either the arbor or batten with a great deal of weight in an unbalanced condition. Although this is difficult, with proper techniques and planning, the danger can be minimized. Sufficient force must be used to move the unbalanced load to a point where it can be balanced. Several options are possible.

1. Human Method

Weight permitting, a group of people operate the hand line by brute strength.

2. Bull Line

A *bull line* (fig. 4.40) can be used on the batten. A bull line is a long piece of rope, ⅝″ to ¾″ diameter, that is doubled over the batten near one of the lift lines. The stage crew can then pull on this line and aid the operator in raising or lowering an overweight arbor. The line is doubled so that it can be pulled free once the load is balanced. The bull line must be placed near a lift line or the batten can be bent. More than one bull line can be used on a batten.

3. Capstan Winch and Bull Winch

A *capstan winch* (fig. 4.41) is a movable winch that aids in pulling the arbor down or keeping the arbor from rising too rapidly. A rope is attached to the bottom of the arbor. It is then wrapped several times around the capstan of the winch, and the winch is turned on. Applying tension to the free end of the rope causes it to tighten around the capstan and allows the winch to help move the unbalanced load.

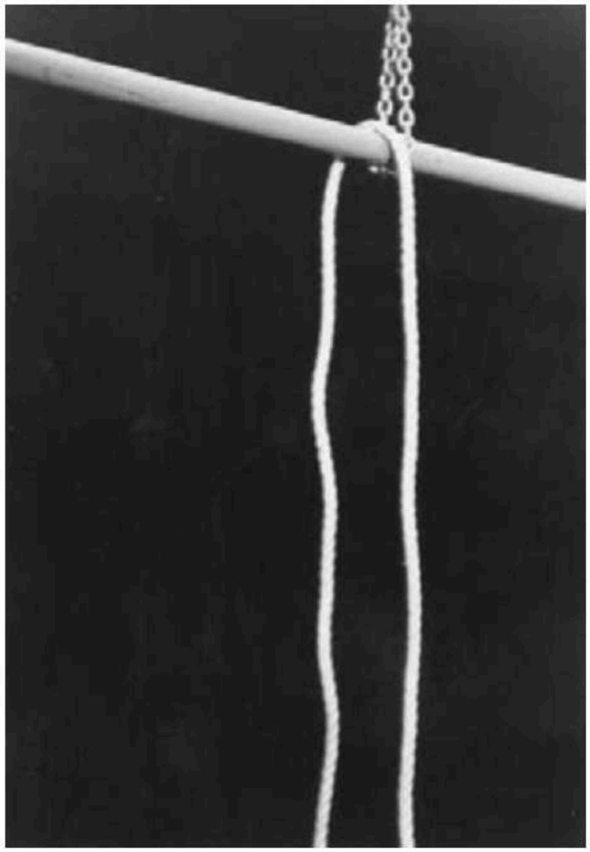


Fig. 4.40. Bull line on a batten

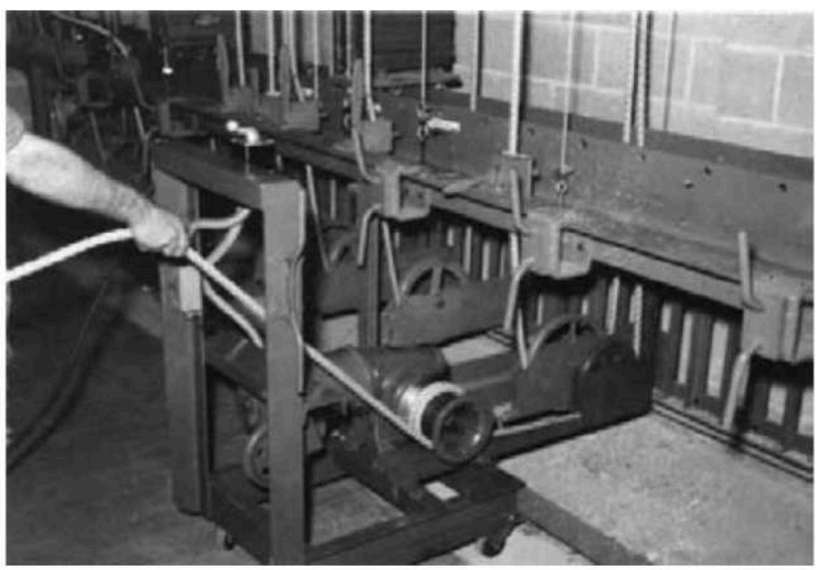


Fig. 4.41. Capstan winch. Courtesy of Peter Albrecht Corp.

Fig. 4.42. Bull winch used to load arbor in a facility with no loading bridge

A movable winch with a wire-rope drum is called a *bull winch* (fig. 4.42). All of the pulling force is applied by the winch. No pulling by hand on the line is necessary.

4. Block and Tackle

A block and tackle can be used to raise or lower an unbalanced load. It can be rigged to the head-block beam and the top of the arbor to help lift an arbor-heavy load; or it can be rigged to the lock rail and the bottom of the arbor to help raise a batten-heavy load. The fall block can also be attached to the hand line using a sunday with a prusik knot.

5. Sandbag Substitution

When battens are used to store scenery during a performance, there may not be time to unload the arbor when the scenery is removed from the batten. In order to keep the counterweight set in balance, a sandbag may be moved onstage on a dolly and attached to the batten near one of the lift lines. The weight of the sandbag will compensate for the weight of the removed scenery.

If the weight is heavy, the sandbag must be attached near one of the lift lines, or it will bend the batten. Remember, attach the sandbag before removing the scenery.

6. Carpet Hoist

The *carpet hoist* (fig. 4.43) is also used in situations in which the load will be removed from the batten during performance. To make and use a carpet hoist,

a. Bolt a bracket to the bottom of the arbor. The bracket should extend out from the arbor far enough to prevent the adjacent arbor from passing it. The bracket must be strong and rigid enough to move the scenery arbor without bending or breaking. Many different types of arbor bottoms are in use. It is beyond the scope of this book to try to detail a bracket that would work for each type. The bracket must be designed to support the applied load and not come loose during operation. The bottom of the second arbor rests against the top of the bracket.
b. The batten and lift lines must be removed from the second arbor.
c. The scenery arbor is loaded only to pipe weight.
d. The second arbor is loaded with enough weight to balance the scenery.
e. To lower the scenery, pull the hand line to raise the scenery arbor. The weight on the second arbor will follow along and balance the load.
f. When the scenery is at the point where it will be removed from the batten, lock off the hand line on the second arbor. Secure a safety hitch between the second arbor hand line and lock rail. Remove the scenery from the batten. Take the batten out by using the hand line on the scenery arbor.
g. After the scenery is reattached to the batten, release the safety hitch and the rail lock on the second arbor. Raise the scenery by pulling on the scenery arbor hand line.

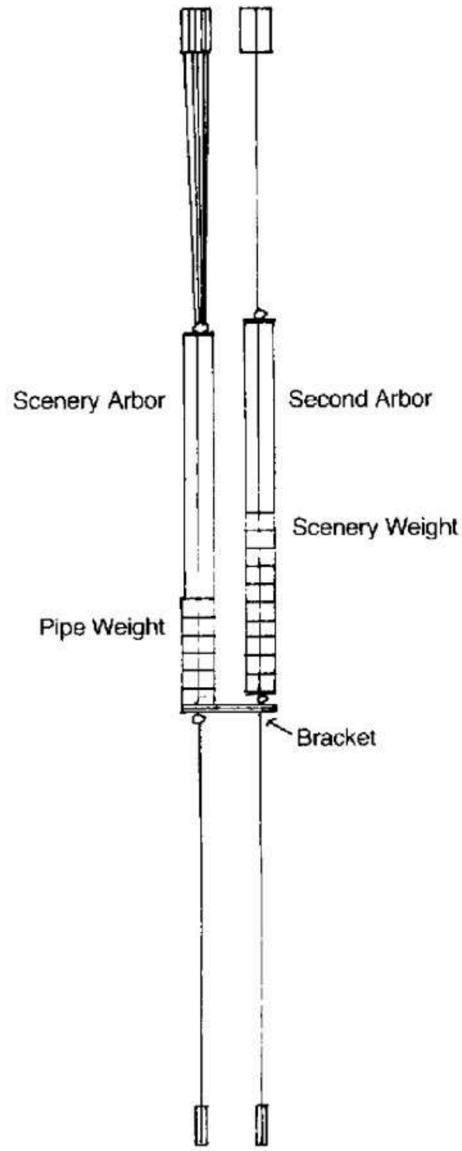


Fig. 4.43. Carpet hoist

NOTE: When the scenery is removed from the batten, the second arbor is out of balance and held in the air by the safety hitch. *Be sure the hitch is well tied. Never depend on the rail lock alone to hold the arbor!* A block and tackle can also be used to hold the second arbor in lieu of the safety hitch. With a sunday, secure the fall block to the hand line that raises the arbor, and secure the standing block to the lock rail. Tie off the lead line to the lock rail to hold the arbor in position.

4.13 Showtime Operation

The reason that scenery, curtains, and lights are flown is so that they can be used during a performance. Some flown objects do not move at all, while others move in and out one or more times during a performance. It is essential to make sure that the flown objects will function as they should for every performance.

A. Label Lock Rail

Each counterweight set in use for a production should be clearly labeled on the lock rail. Sets that are storing objects not currently in use should also be labeled. When releasing the lock on the lock rail, the rail operator should know what is hanging on that batten.

B. Use Trim Marks

All rigging sets used during a performance should have trim marks on the hand lines. Tape, ribbon, yarn, or string can be used for this purpose (fig. 4.44). If the piece must move quickly during the performance, winding the tape down the rope or inserting a warning yarn of a different color will indicate that the trim mark is approaching.

Ribbon trim marks can be pulled through the mantle of a parallel-core polyester line by using a crochet hook, tire-repair tool, or a small screwdriver with a slot cut in the blade. Do not go through the center of the line (fig. 4.45).

Pieces that do not move during a performance should also be marked so that if they have to move for maintenance purposes, repositioning to performance trim is simplified.

C. Knuckle Buster

Accurate and fast positioning of a moving piece can be accomplished by using a knuckle buster on the hand line (fig. 4.46). This clamp is designed to fit on the hand line without damaging the rope lock. However, in the dim light of performance, a rail operator's knuckle or hand may be hit—hence the name.

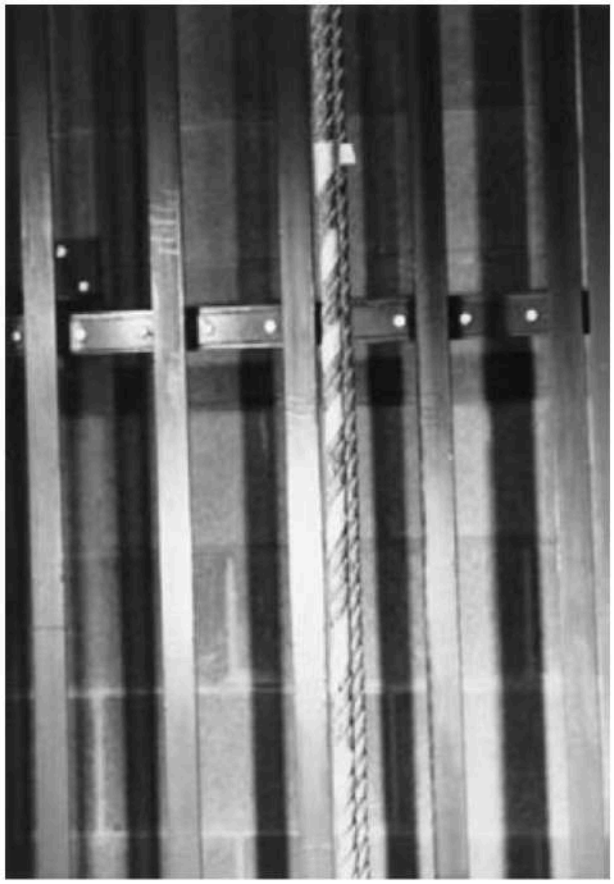


Fig. 4.44. Tape trim mark

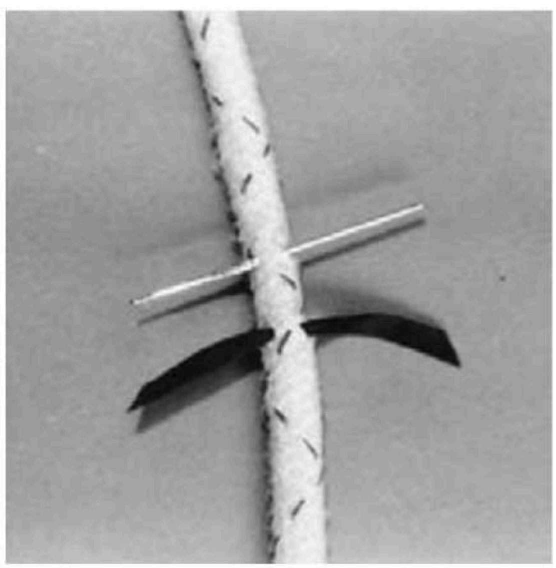


Fig. 4.45. Ribbon trim mark on parallel-core polyester line

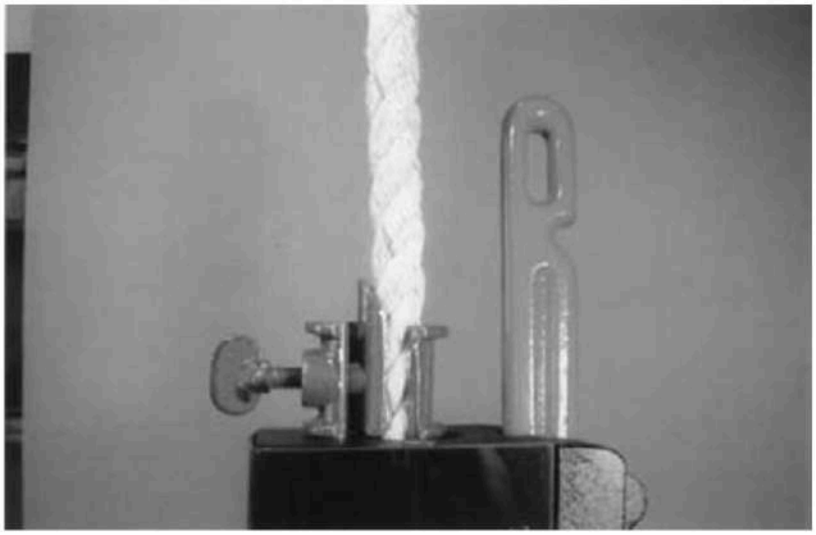


Fig. 4.46. Knuckle buster

D. Preshow Testing

Make a habit of running each moving piece before every performance. Test for balance, clearance, and ease of running. If the pull on the hand line feels different, find out why—before the performance!

Because soft goods absorb moisture from the air, the weight of a curtain or drop can change drastically with a change in humidity. Adjusting the counterweight on the arbor may be necessary on a daily basis in some theatres.

E. Cuing

Be absolutely sure of the signals for all cues during a performance. A *normal cue sequence* consists of three parts, the *one-minute verbal warning*, or *cue*, gives the operator time to find the proper hand line and determine what is supposed to happen. Does the piece move in or out? Are there special timing problems?

The next part is the *standby cue*, which occurs about three lines before the go cue and is often done by turning on a cue light. At this point, the rope lock is released, and the operator is ready for the go.

Finally, the *go cue* is given. Because it is impossible for a person to watch two things at once, the operator generally watches the moving piece to be sure that there are no clearance problems. If the moving piece is masked from the operator's view, a spotter should be used to ensure that the piece is moving safely.

If you feel any unusual resistance, stop moving the piece immediately. Chances are that it is fouled on another batten or flown object. The air currents in many theatres are different when the theatre is full (performance) and when the theatre is empty (rehearsal). Soft goods can blow and foul on adjacent objects. If you feel a problem, determine what it is before moving the piece. A powerful flashlight is a useful tool to have backstage for seeing into the dark flies.

4.14 Special Counterweight-Rigging Problems

A. Lighting Battens

Lighting battens frequently change weight as they are raised or lowered. This is caused by the border light cable, which is attached to the batten. In some rigging schemes, the cable is supported by a cradle attached to the lift lines. As the batten is raised, more weight is added to the batten. As the batten is lowered, weight is removed from the batten. In this circumstance, try to balance the batten for the performance trim height.

B. Variable Load

Flying framed wall units with hinged side panels is one situation in which a change in load on the batten occurs. As the wall unit touches the floor, and the hinged panels open, the floor—not the batten—is supporting the weight. The wall tends to bounce off the floor, leaving a gap at the bottom of the set. Here are three suggestions for dealing with this problem.

1. Block and Tackle

Use a block and tackle. Attach as described in section 4.12.B.4. As the flown piece touches the floor, the block and tackle is used to raise the arbor and take the strain off the batten. This method requires the use of two operators. One operator operates the hand line, and the other operates the lead line of the block and tackle.

2. Batten Tie-Down

Attach wire or hemp ropes to the batten near the lift lines. As the flown piece nears the floor, the free ends of the ropes are tied off to brackets firmly attached to the stage floor or to a sandbag. Using a trucker's hitch for hemp or a lever-type load binder for cable usually gives the mechanical advantage needed to hold the batten in the desired position (figs. 4.47 and 4.48).

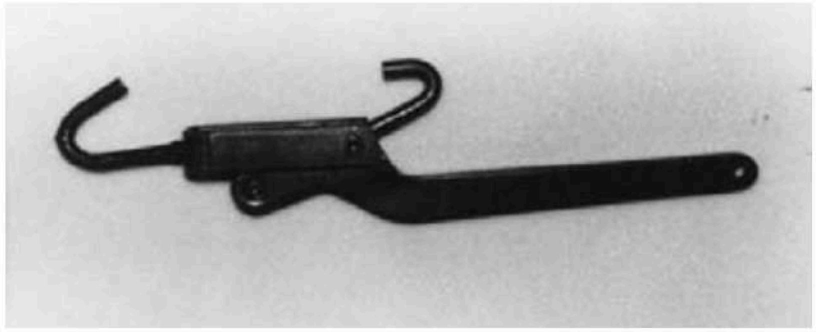


Fig. 4.47. Load binder

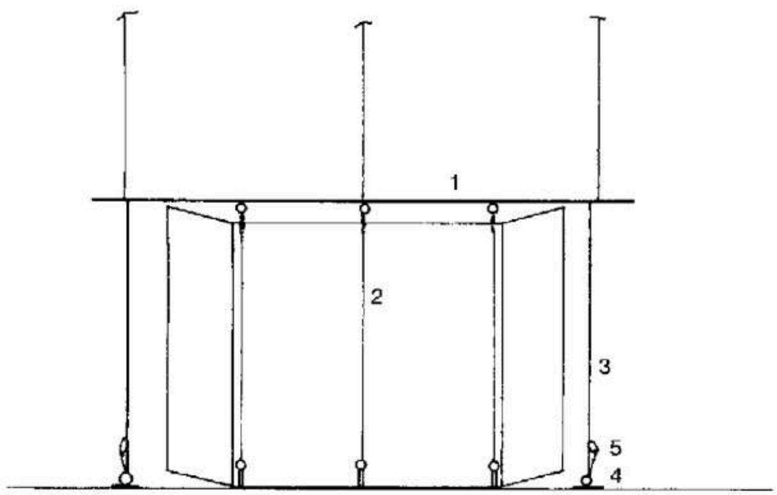


Fig. 4.48. Batten tie-down
1. Batten
2. Attachment line
3. Tie-down line
4. Ceiling plate
5. Trucker's hitch

3. Use a Carpet Hoist

See section 4.12.B.6.

C. Increasing Counterweight Capacity

There may be times when an arbor will not hold enough counterweight to balance a heavy load. Do not use lead weights or an arbor extension without first checking the capacity of all of the components, including the support steel. The line set was designed as a complete system, quite often with the arbor being the limiting factor in terms of applied weight. Using lead or an arbor extension may overload components beyond their working load limits. Suggested solutions to increase load capacity include:

1. Join two or more adjacent battens together, and use more than one line set. When doing this, be sure that the load is firmly attached to all of the battens and that the counterweight is evenly distributed among all the arbors. More than one operator may be required to move the battens. This solution distributes the load among the blocks and lift lines of several line sets and keeps all of the components within their working load limits.

2. After a careful analysis of the line set components (i.e., cable size, loft block, head block, support steel, attachment devices, etc.) to be certain they can sustain the added weight, you may substitute lead weights for steel weights. The density of lead is approximately 1.45 times that of steel.

3. Install a larger arbor or an arbor extension *after* analyzing the rest of the components to be sure that they can safely support the added load.

4. If there is room on the grid and in the flies, an additional free-hanging arbor may be used.

  a. Mount additional loft blocks over the batten. The blocks can be evenly spaced between the permanently mounted loft blocks or placed near the point of attachment of a concentrated load. A head block or a group of loft blocks is mounted on the grid in an area where the arbor has clear travel. Have the load capacity of the support steel checked to see if it can support the concentrated load of the loft and head blocks.
  b. Attach lift lines from the batten to the arbor.
  c. Since the arbor may not be near a loading bridge, a safe method of loading the arbor will have to be devised.
  d. Arbor guide cables can be attached from grid to stage floor if necessary.
  e. The area under the arbor must be roped off to keep people away during performance.

CAUTION: In items 2 and 3 above, the flown object is solely supported by a single set of lift lines and blocks. *It is absolutely necessary to be sure that the rigging set and support steel can hold the concentrated load.* Hire a structural engineer to make an analysis before attempting to increase the arbor load on any counterweight system.

4.15 Operation Summary

1. Safety inspect all components at regular intervals.
2. Know the feel, sound, and smell of the system.

3. Know the weight capacity of the system.

4. Always follow safe practice when loading, unloading, and operating the system. Keep unbalanced loads down.

5. Always appoint someone to maintain visual contact with a moving piece.

6. Be sure the deck is clear before moving a line set.

7. Always warn people on the stage and grid before moving a batten during set-in and load-out.

8. Before each cue, check the cue sheet to be sure which set to move, which direction, and any special timing problems.

Part 5 Motorized Rigging

5.01 Introduction

The basic hemp rigging used for the stage changed little from the time of the Greeks until the twentieth century. The need for greater efficiency prompted the modification of hemp to counterweight, which is still the most common type of rigging equipment in use. Today, the desire for increased efficiency and more dynamic scenic effects is fueling a greater use of motorized equipment.

Stage-rigging manufacturers combine industrial-grade motors, speed reducers, brakes, controls, and special components to produce motorized rigging equipment for the entertainment industry. A motorized system must be properly designed for its application by a competent engineer. Because motorized rigging equipment is used to suspend objects over people, it requires operational safety devices not found on winches used in industry. Truck winches, industrial hoists, and boat winches are extremely dangerous to use for stage rigging as are homemade systems, unmodified industrial systems, and Rube Goldberg equipment. DO NOT USE THEM.

Most theatrical rigging-equipment manufacturers offer motorized equipment as standard products (figs. 5.1 and 5.2). Escalating labor costs and the equipment's versatility have helped hasten the acceptance of motorized equipment. Broadway, touring productions, and regional professional companies use motorized equipment as a matter of course.

As the cost of motorized equipment has come down in relation to counterweight systems, more and more high school, college, and regional theatres are installing motorized equipment. There is a safety element that appeals to high schools in that motorized systems eliminate the need to load and unload counterweight. Motorized systems are the state of the art in rigging equipment today.

It is beyond the scope of this book to describe all of the types of systems in existence. Instead, you will find descriptions of the most common systems in the United States and their specific operating procedures.

The operator of motorized rigging does not have physical contact with the moving object that is present when using hemp and counterweight systems. You cannot feel when something changes or goes wrong. *Special operating procedures and precautions for motorized rigging must be followed.*

5.02 Systems Descriptions

The following descriptions are of general system types. Some of the advantages and problems are listed for each system.

A. Motorized Counterweight Systems

A *motorized counterweight system* is basically a counterweight set that uses a motor to do the pulling. The motors do not need to be as large in horsepower as a dead haul (noncounterweight) motorized rigging system. One type requires counterweights to balance the load, so the same basic loading and unloading procedures used for a counterweight set should be followed. Another type of motorized counterweight system is designed to run out of balance, with the counterweight balancing only part of the load.

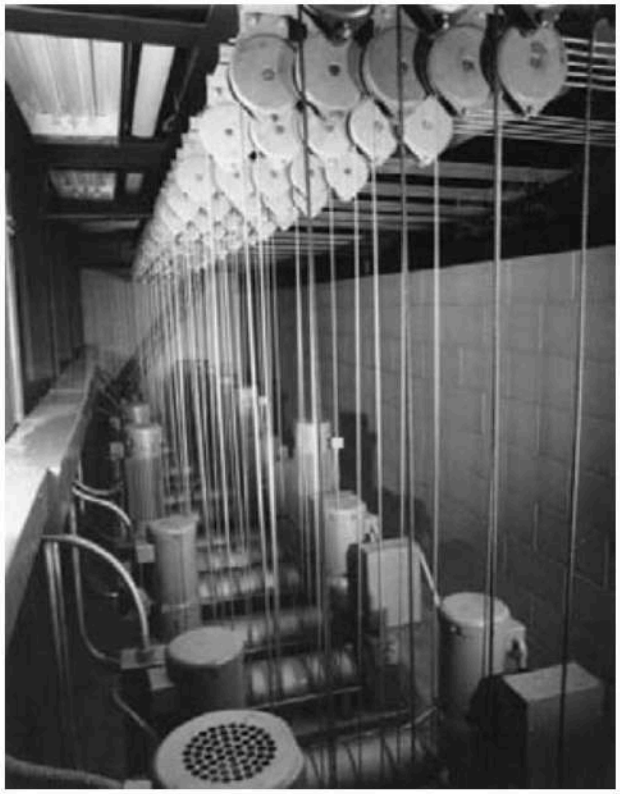


Fig. 5.1. Electric motorized winches. Courtesy of Peter Albrecht Corp.

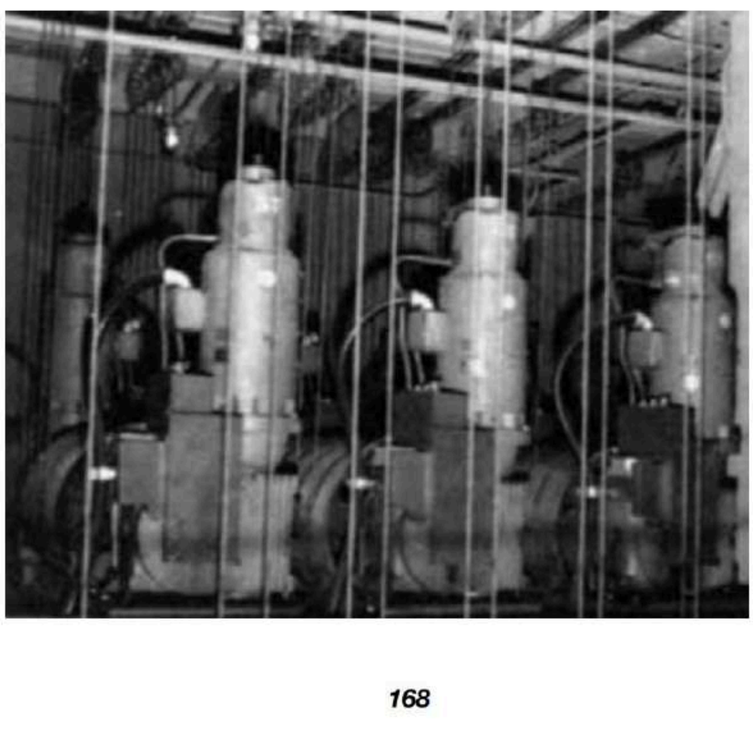


Fig. 5.2. Electric motorized winches. Courtesy of Peter Albrecht Corp.

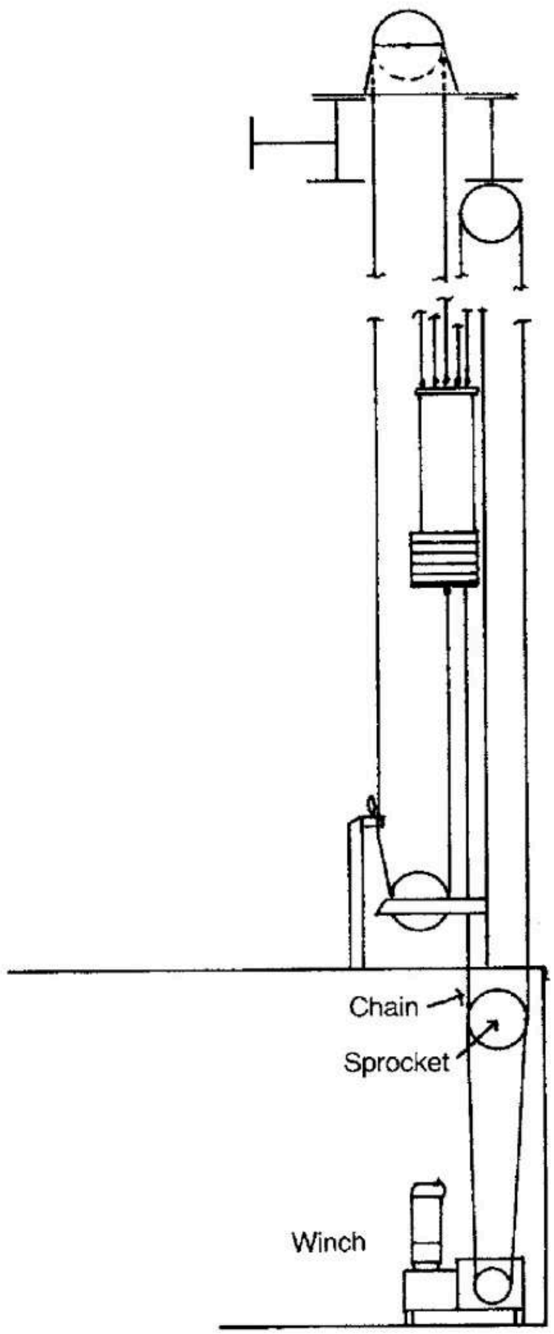


Fig. 5.3. Chain-drive motorized counterweight set

1. Chain-Drive, Wind-on-Wind-off Systems

Chain-drive systems (fig. 5.3) use a roller chain attached to the arbor, very much the same way that the hand line is attached to the arbor of a manual counterweight set. The chain goes from the top of the arbor, over a head-block sprocket, down around a sprocket below the arbor, and finally to the underside of the arbor where it attaches.

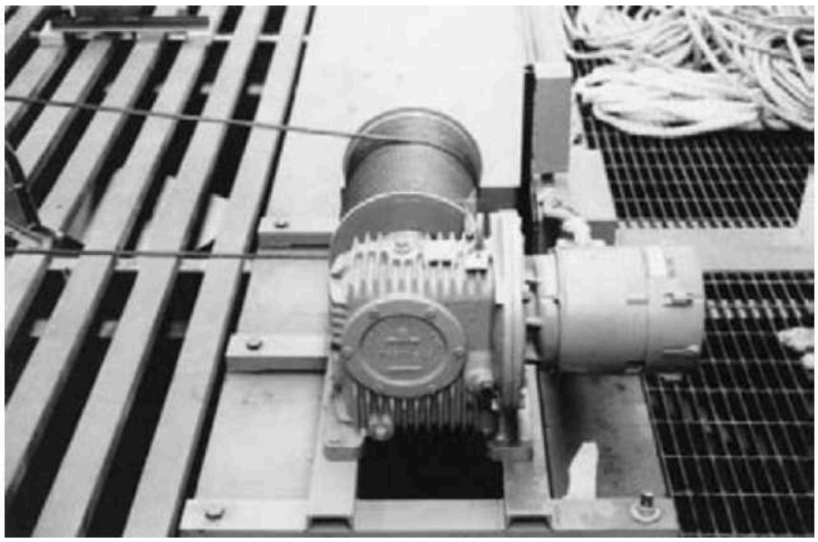


Fig. 5.4. Wind-on wind-off winch

The winch is usually mounted on the stage floor, the grid, or below the stage-floor level. The *wind-on-wind-off winch* uses a drive cable in place of a roller chain, but the basic operation principle is the same. One end of the cable is attached to the bottom of the arbor, and the other end to the arbor top. One end of the cable winds on the drum as the other winds off (fig. 5.4). Both of these systems are typically used for unbalanced applications, such as electric battens and lighting bridges. This type of system can be designed so that the winches can be moved from one line set to another.

2. Power-Assist Units

Power-assist units are packaged units that attach to counterweight systems to automate particular line sets, especially electric and orchestra ceiling sets (fig. 5.5). They are designed either for new construction or existing counterweight systems as retrofits and are *not* designed to be moved from set to set. They eliminate the need for loading weight on electric sets and make heavy sets much easier to move.

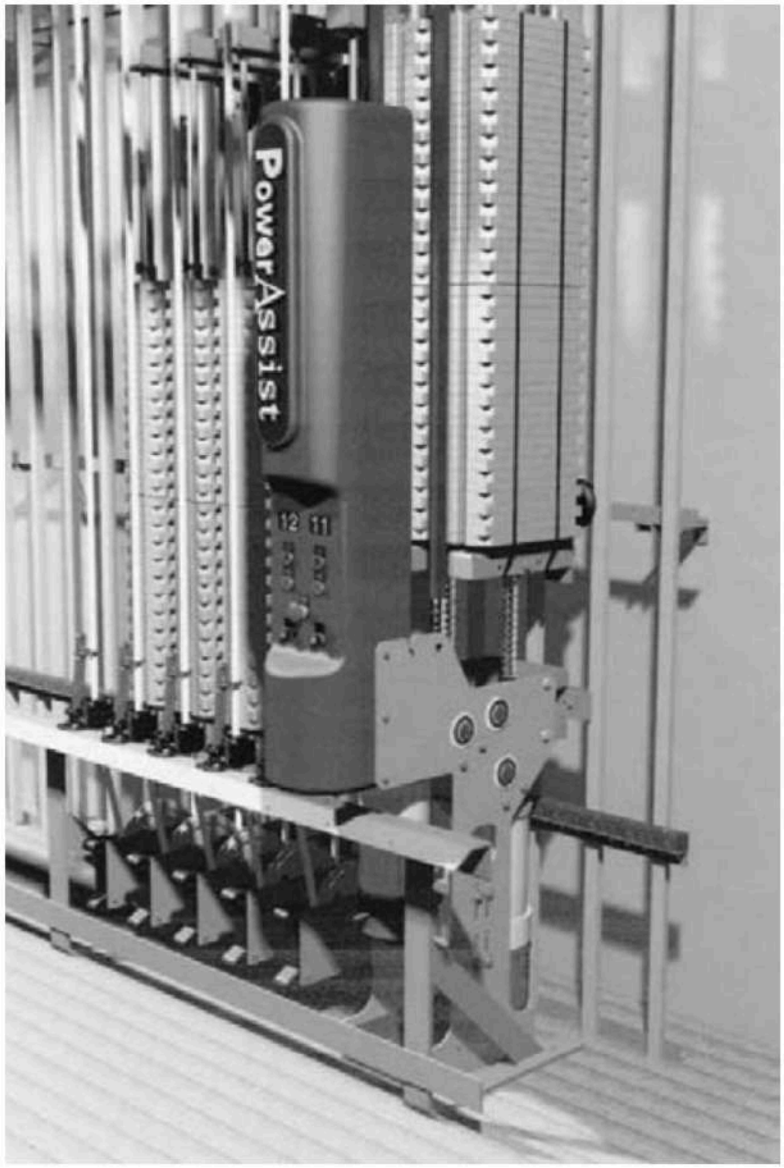


Fig. 5.5. Power-assist unit. Copyright © J. R. Clancy

3. Traction-Drive Systems

Traction-drive systems are generally used for constant-weight systems, such as acoustical reflectors, speaker clusters, large fire curtains, and movable ceiling panels (figs. 5.6 and 5.7). Once the arbor is loaded and the weight balanced, the weight is never changed. In this system, the head block is usually machined with tight V-shaped grooves for the lift lines. The head block is driven by the motor and provides the force to move the load. As the

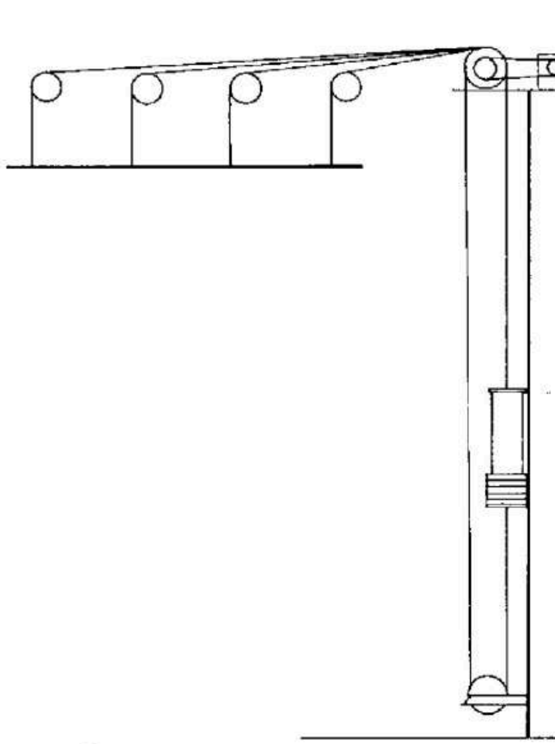


Fig. 5.6. Traction-drive motorized counterweight set

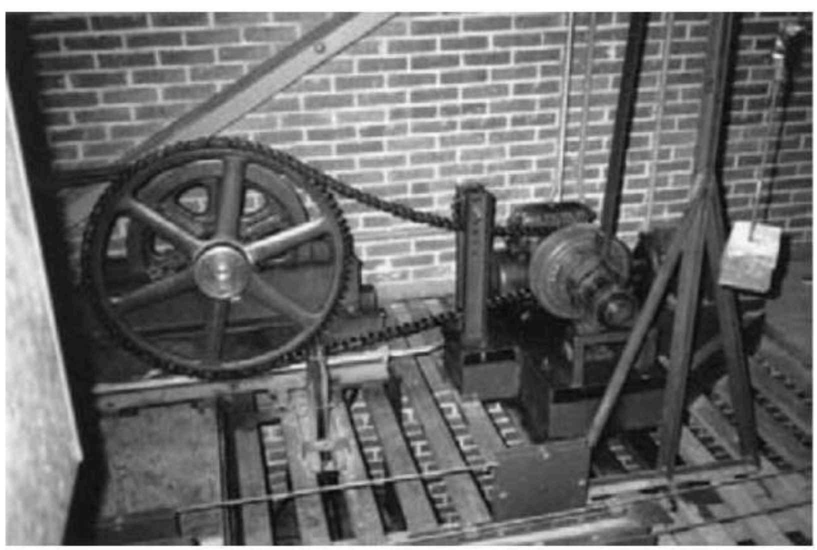


Fig. 5.7. Traction-drive fire-curtain winch

head block turns, the V grooves grip the cable and move the load. Special care should be taken to inspect the cable and traction head blocks for wear.

B. Dead-Haul Winch Types

Dead-haul winch systems use only the winch to move and hold the load. This type of system usually requires a larger motor and gear reducer than does a motorized counterweight system. It is very efficient on rigging sets with changing loads. Setup and take-down are greatly reduced, because no counterweights need to be loaded or unloaded.

1. Drum Winch

The simplest dead-haul winch is a drum type (fig. 5.8). All of the lift lines wind on a single drum. This is the least-expensive type of dead haul winch but can have the greatest fleet-angle problems.

Fig. 5.8. Constant-speed electric winch. Courtesy of Peter Albrecht Corp.

2. Line-Shaft Systems

Line-shaft systems use a grooved drum at each lift line instead of running all of the lines back to a single drum (fig. 5.9). The drums are connected to the motor and to each other by a common shaft. If the lift lines drop straight down from each drum, there are no horizontal forces on the support steel, and fleet-angle problems are minimized.

Fig. 5.9. Line-shaft winch

3. Packaged-Hoist Systems

Packaged-hoist systems are self-contained winch units, such as Vortek, developed by Hoffend, or Power Lift, manufactured by J. R. Clancy (fig. 5.10). The winch unit is mounted to a frame with the head blocks attached. These units are fast and efficient to install and have no fleet-angle issues. Because they are manufactured as standardized units, they are less expensive than custom-designed winches.

Fig. 5.10. Packaged hoist system. Copyright © J. R. Clancy

5.03 Motor Types

There are several types of motors that are generally used for motorized rigging. Each has characteristics that make it more useful for some applications than others.

A. AC Electric Motor

AC motors are the least expensive and easiest motor to operate. Until a few years ago they were mainly used for fixed-speed applications. With the great improvement in variable-frequency drives, they are now the preferred motor for both fixed-speed and variable-speed applications.

B. DC Electric Motor

For years, *DC motors* were the only reliable variable-speed electric motors and were almost exclusively used for electric variable-speed applications.

C. Servo Motor

Servo motors are a fairly new product in the entertainment industry. They can be either AC or DC, and at this time, they are being used for special production applications. Compared to standard AC and DC motors, they are small and compact. They have rapid response to control commands and are very accurate. The small diameter of the motor provides low inertia for fast starts, stops, and reversals. They operate at a range of speeds without overheating and, like any closed-loop AC or DC motor, have the ability to operate at zero speed and retain sufficient torque to hold a load in position.

D. Hydraulic Motor

Two types of rotary hydraulic motors are used for theatrical applications (fig. 5.11). The most common has an impeller blade mounted on a shaft that can either be a direct drive to the output shaft or be coupled to a speed reducer to increase the output torque. Pressurized hydraulic fluid is forced through a valve, into an input port (making the impeller turn), then out through a return port. Reversing the direction of the fluid flow reverses the direction of the motor. The speed is controlled by operating the valve to regulate the flow of the hydraulic fluid.

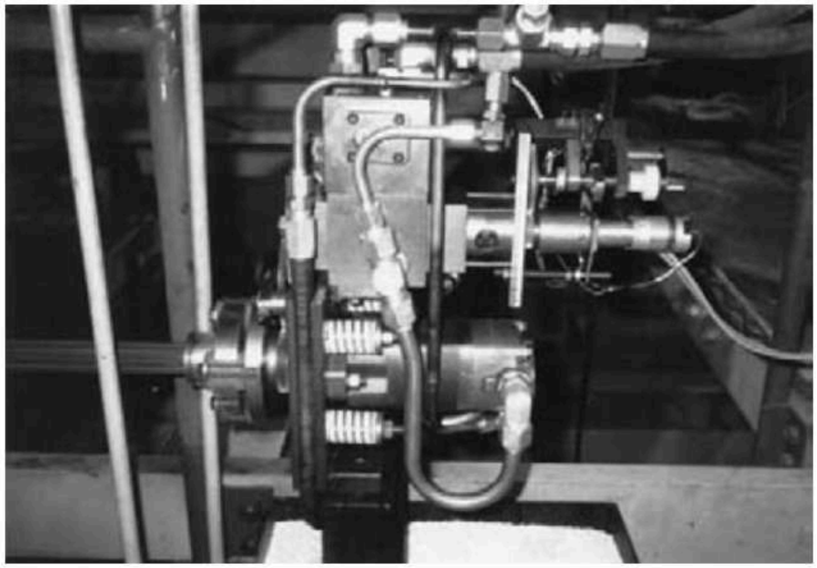


Fig. 5.11 . Hydraulic motor on line-shaft winch

A *radial hydraulic motor* is somewhat more complex, operating like a rotary aircraft engine. A number of pistons are mounted radially around the drive shaft. Fluid is forced sequentially into the cylinder heads, forcing the pistons toward the drive shaft.

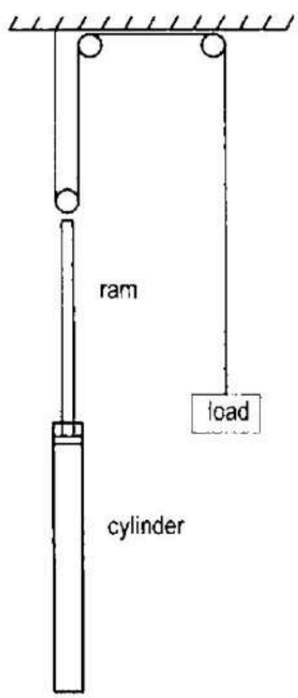


Fig. 5.12. Hydraulic ram. Load moves 2′ for every 1′ of ram movement

As the pistons move toward the shaft, they force the shaft to turn and produce rotary motion to turn a cable drum.

Another type—the *linear hydraulic motor*, or hydraulic ram—consists of a cylinder with a piston inside. Fluid is pumped through a valve on one side of the piston, forcing the piston to move along the length of the cylinder. The end of the piston is connected by a rod to the object that is to be moved. The most common use of the hydraulic ram is for stage and orchestra lifts, in which high speed and heavy load capacity are required. For rigging purposes, the end of the rod can be attached to a multi-sheave block, allowing a travel greater than the stroke of the piston (fig. 5.12). With sufficient pressure, very high speeds can be attained with this type of system.

5.04 Electric-Winch Components

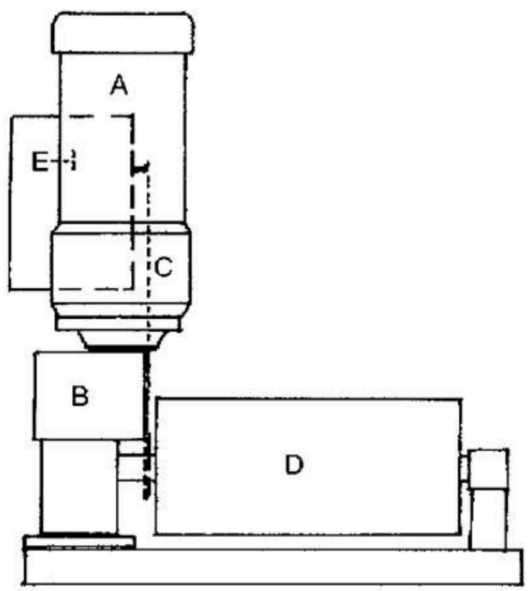


Fig. 5.13. Electric-winch components

Electric winches usually consist of the following components (fig. 5.13): (A) motor, (B) gear reducer, (C) brake, (D) drum, and (E) controls.

A. Motor

The *motor* is the device that converts electrical energy into mechanical energy. The motor is either AC or DC.

B. Gear Reducer

The *gear reducer* converts a high number of revolutions with low torque into a lower number of revolutions with high torque (or lifting power). For many applications, self-locking gear reducers are preferred. These reducers require power to lower an object as well as to raise it. Some gear ratios are high enough so that the load cannot exert enough force on its own to move the gears, even if no motor brake is attached to the system. The self-locking feature should never be used alone. A properly sized brake is always required on a motorized rigging system.

Non–self-locking, or overhauling, gear reducers work conversely. These reducers are often used where very high efficiency is required or where the winches are self-climbing, such as in television studios. In this case, when the brake is released on the system, the load is capable of back-driving the gears, and the load descends without the motor running.

C. Brakes

Most electric winches use a *motor brake*, which is electrically held open when the winch is running. When the power is turned off, the brake closes and holds the load in place. The brake must be properly sized for the application, usually with a minimum retarding torque of 200% of the motor torque to ensure that the load can be both stopped and held in place. The brakes supplied on theatrical winches are usually a fast-acting type to ensure that they release quickly on startup.

Some winch systems employ a second brake system on the outboard end of the drum. This serves as a backup brake. There are three types. One is similar to the motor brake. It is electrically held open when the winch is running and only sets when power to the machine is turned off. There have been some problems with this type of brake being synchronized to operate properly. Another type is an overspeed brake. This is a centrifugal brake that only kicks in if the winch starts to run past a preset speed and brings the load to a controlled stop. This brake is not a parking brake and only operates in a runaway condition.

Recently, some manufacturers have started using a drive-through brake. This brake is engaged when the load is being lowered or at rest and is released only when the load is being raised. When the load is being lowered, the winch is driving through the brake.

D. Drum

On a dead-haul electric winch, the lift lines wind on a *grooved drum*. The drum's grooves match the size of the cable being used. A minimum of two dead wraps of cable should be maintained on the drum.

Nongrooved pile-on drums, such as those found on hand winches, are sometimes used. As the wire rope winds on successive layers, the wire rope underneath is subjected to abrasion and crushing. Inspect the wire rope carefully, and replace it at the first sign of wear.

The *yo-yo drum* is another type of pile-on drum. This drum has a narrow groove that guides the wire rope to pile up on top of itself, just like a yo-yo. Because the radius from the wire rope to the center of the drum is constantly changing, the torque on the drum and speed of the wire rope are also constantly changing, thus making it a poor choice for variable-speed systems. Yo-yo drums are often found on self-climbing battens and motorized acoustic-curtain systems. The main advantage of the yo-yo drum is that it eliminates any fleet-angle problems.

E. Controls

Motorized rigging can be controlled in a number of different ways. Some of the typical components and methods are as follows.

1. Limit Switches

All winches should have a set of four hard-limit switches. The primary limits are adjusted for the maximum high and low trims. Once the limit has been reached, the winch can travel in the opposite direction. The second set of limits are overtravel switches that serve as backups for the limit switches in case the primary limits fail. Should the limit switch fail, the overtravel switch will stop the movement of the winch before damage can occur. Overtravel limits are wired to the emergency-stop contactor, and when activated, the winch cannot back off the overtravel without manually resetting the system. This type of circuitry serves as an indicator that the primary limit switch has failed. Figures 5.14 and 5.15 show two types of rotary limit switches. There are several other types of direct-struck limit switches that are activated by a moving part of the load physically striking an arm or button.

Soft-limit switches are programmable limits that are set through the operation software when a programmable logic con-

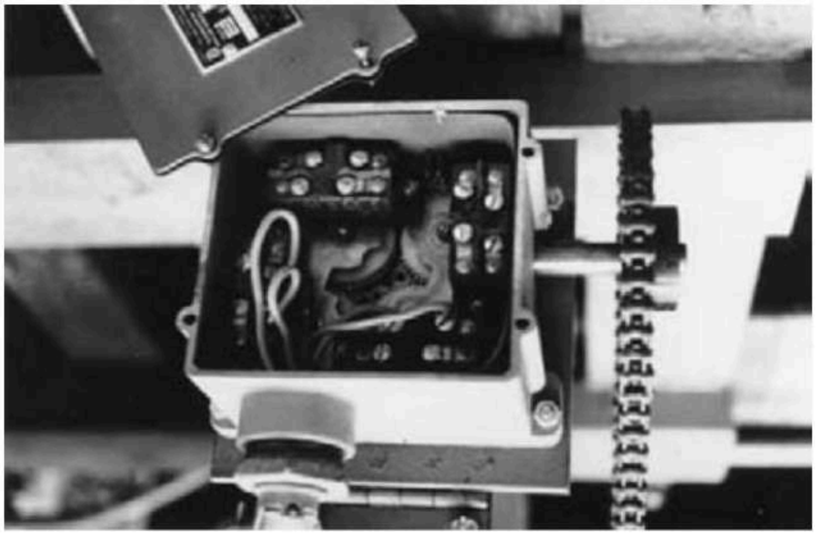


Fig. 5.14. Four-element rotary limit switch

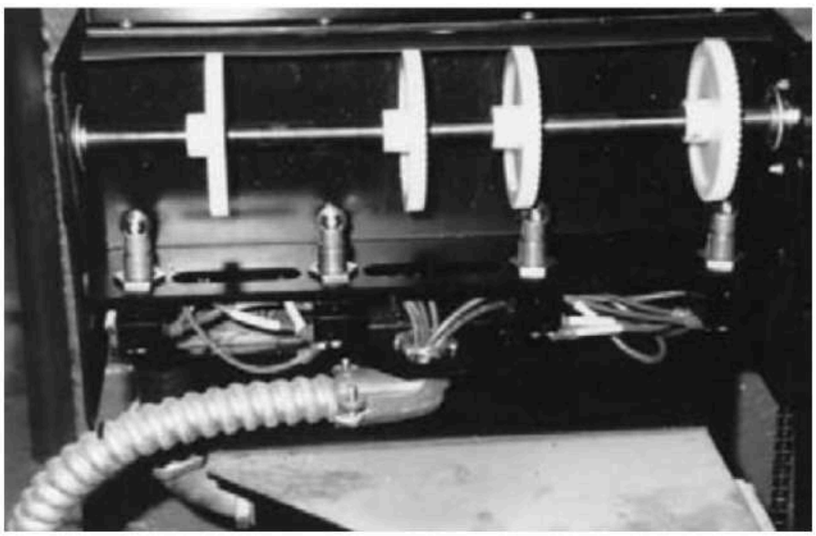


Fig. 5.15. Traveling-nut limit switch

troller (PLC) or computer is used to operate the line sets. The soft limits can be set for any number of intermediate positions.

2. Movement Controls

These controls can be categorized in two groups: *hold-to-run* (or deadman) and *latching*. The hold-to-run type requires constant hand pressure on the switch to keep the winch running. If pressure is removed, the winch stops. This type of control is the

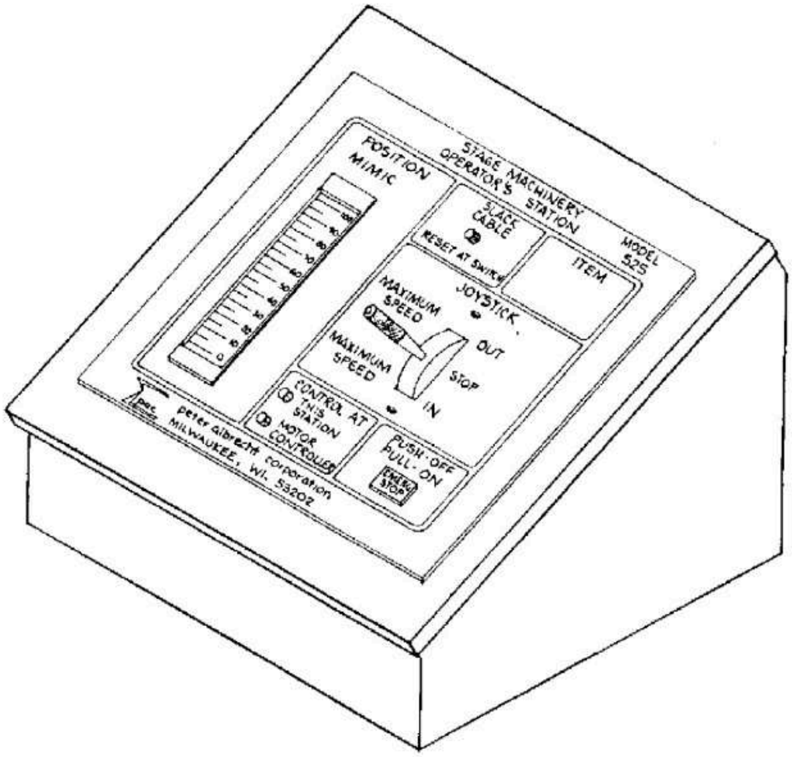


Fig. 5.16. Joy-stick winch control. Courtesy of Peter Albrecht Corp.

safest. Hold-to-run controls can be the push-button type or the joystick type. The push-button type is self explanatory. The joy stick is usually found on variable-speed systems. The farther the stick is pushed, the faster the winch runs (fig. 5.16). Pushing the stick in the opposite direction moves the winch in the opposite direction. The center position stops winch movement and sets the brake.

Latching-type controls require only that the control is activated to start the action. The control then is "latched in," and the winch will run until a preset limit is reached. A separate control must be activated to stop the winch in case of an emergency. Latching controls require extra attention when the winch is operating because the operator needs more time to stop the winch than with the hold-to-run type: the operator must find the stop button and hit it. Using the hold-to-run control, the operator merely releases pressure. It may appear that a motorized rigging set runs very slowly, but when something fails, and an object falls, it is extremely fast. It takes only about 2.5 seconds for something to fall from a 90-foot-high grid to hit the floor.

3. Emergency-Stop Button

All motorized winch systems should have an *emergency-stop button* (E-stop). The button should be large, easy to see, easy to reach, and require pressure to activate. This switch should *not* require electrical power to operate. The E-stop should operate a contactor that removes power from all of the winches. On hydraulic systems, it should stop the pumps, thus removing power from the winches. An E-stop control that only removes power to the control circuit is not reliable. Electronic-control circuits can fail in such a way that the E-stop will not work. The E-stop is fail-safe only when it is on the power side of the system, not on the control side. On multiwinch systems, a single E-stop button should stop *all* of the machines.

4. Speed Controls

With variable-speed systems, you can select and adjust the speed of the winches. They must also have a tachometer that shows how fast the winch is turning. Some systems are designed to allow the synchronizing of several machines.

5. Position Control

Many systems have some sort of device to allow for stopping the batten at a particular position. The important feature of positioning is repeatability. The load must stop every time at the same place when coming from the same direction. This feature is essential for the proper running of shows.

6. Other Safety Features

The *slack-cable switch* detects any slack cable on the winch set and stops the movement of the machine. These devices are difficult to use and often not reliable. They are prone to false tripping.

A *load-sensing device* measures the weight of the load on the batten through two or three cycles after the line set is loaded. It will then automatically stop the system if the load is increased or decreased beyond the programmed parameters.

7. Computer Control

A number of different computer-control consoles are available for motorized rigging systems. Some of them use Programmable Logic Controller (PLC) technology, while others use specially designed software. All computerized systems require the winch components listed above, including limit switches, a tachometer, a position-feedback device, and so on, as well as the computer. No attempt is made here to describe the current computer-control systems available. The design of these systems changes as quickly as new advances are made in computer technology, so any description written today will be out of date by the time this edition is published.

For safe operation, there must be E-stop buttons located at strategic places. With computer controls, the operator has a wealth of information available on the monitor screens, but none of it is as critical as watching the moving object. If the operator cannot see the object that is moving, spotters must be used, and they must have the ability to communicate quickly with the operator or stop the object themselves in case of emergency. Video monitors are not substitutes for direct visual contact. The resolution on the monitor is so low that an accident can occur without the operator being aware of what is happening.

F. Rigging Components

The rigging components of motorized systems (the loft blocks, cables, battens, etc.) are the same as those used in counterweight rigging. The same care and precautions should be used on these components as on a counterweight system (see parts 4, 7, and 8).

5.05 Hydraulic-Winch Components

Hydraulic power for the stage is transmitted by controlled circulation of pressurized fluid in a closed system (fig. 5.17). In addition to the required rigging components, a hydraulic system used for theatre work usually consists of

1. Electric power supply
2. Hydraulic pump
3. Hydraulic-fluid feed line
4. Hydraulic-fluid return line
5. Forward-reverse speed-control manifold
6. Hydraulic motor
7. Forward fluid line
8. Reverse fluid line
9. Control wiring to manifold
10. Control panel
11. Control wiring to pump

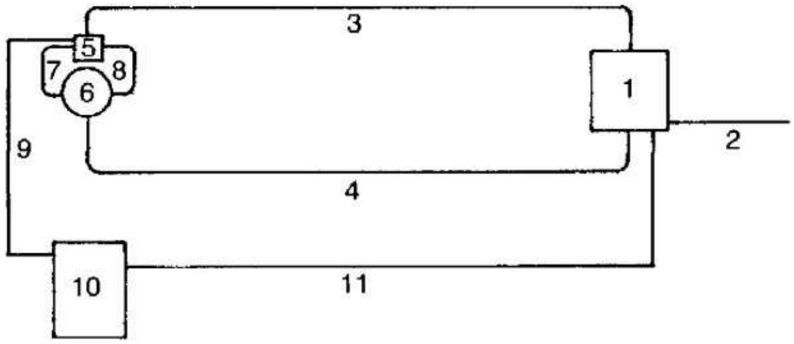


Fig. 5.17. Hydraulic-system components

These systems are very efficient, but they require more maintenance than electric motors. Particular care should be given to filters, fluid, valves, and hoses.

5.06 Hand Winch

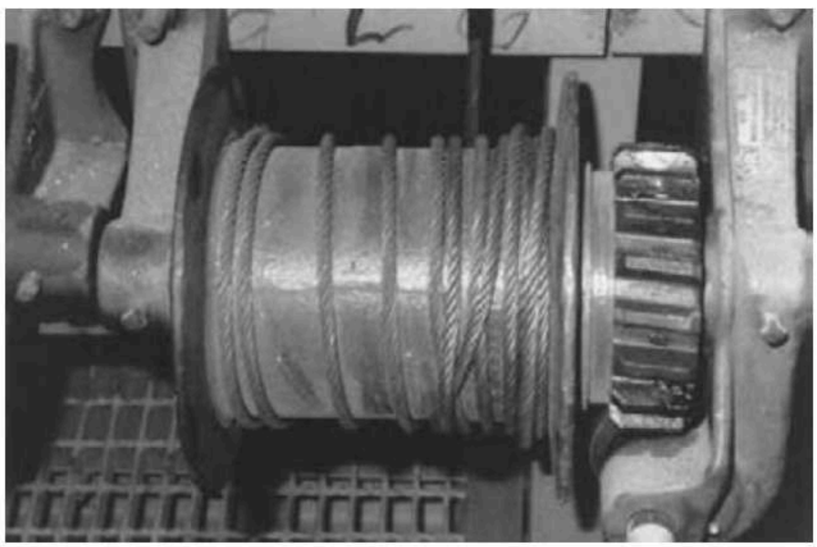


Fig. 5.18. Hand winch with wire rope wound the wrong way

Many different types of hand winches are on the market. They are used for pulling boats onto trailers, raising basketball nets, and various other nontheatrical things. Most of them are not designed to hold objects safely over people's heads. Be sure that the hand winch that you are using is designed for both the load and the application for which you are using it.

Some hand winches are designed to be run with drill motors. Most are not. Running a hand winch with a motor produces operating speeds that are much faster than the gears were designed for. The gears will wear faster and eventually break, causing the load to fall. If the wire rope on your hand winch looks like figure 5.18, it is not wound on the drum in the correct direction. This leads to excessive crushing and reduces the life span of the

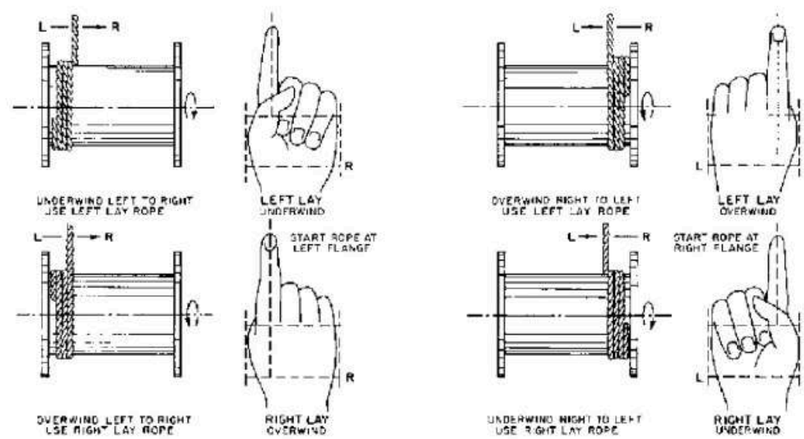


Fig. 5.19. Winding wire rope on a smooth drum. Courtesy of American Iron and Steel Institute, *Wire Rope Users Manual*, 4th ed.

wire rope. See figure 5.19 for the proper winding directions.

5.07 Operation of Motorized Rigging

A single person can simultaneously operate many motorized rigging sets. This is both an advantage and a danger. Because the operator does not have physical contact with the moving load through a hand line, it is imperative that visual contact with the moving load be maintained. If this is not possible, because of control location or because of the number of winches operating at one time, spotters—in audio contact with the winch operator—*must* be used.

It is absolutely necessary that the operator knows the motorized equipment thoroughly. Answers to the following questions are essential before using any motorized system safely.

1. What is the capacity of each winch?
2. Are the gear reducers self-locking or overhauling?
3. Are there overtravel switches on the limit switches?
4. How do the controls work? (Hold-to-run? Latching?)
5. How does the emergency-stop switch work? (Disconnect the power to the winches or only to the controls?)

A. Safety Inspection of All Components

As with any rigging system, motorized rigging sets must be periodically inspected. In addition to inspecting the normal rigging components (see part 7), check the following:

1. Be sure the correct size of fuse is installed.
2. Check all limit and overtravel switches.
3. Maintain oil in gear reducer or hydraulic systems according to manufacturers' instructions. Change the oil when necessary.
4. Test all controls for proper functioning.
5. Inspect winch mounting devices. They can pull loose!
6. Check the brake. If it chatters, or the drum continues to turn after the winch is stopped, the brake may need adjustment.

B. System Capacity

It is essential to know the designed capacity of a motorized rigging set. Most are designed with the motor as the weakest part of the system. Any attempt to overload the system should result in the motor stalling out. However, not all systems are designed in this manner. Overloading the system can result in deflecting support steel or straining a component beyond its limit. FIND OUT THE CAPACITY OF THE SYSTEM; DISPLAY IT WHERE IT CAN BE SEEN, AND STAY WITHIN IT!

C. Loading and Unloading

1. Motorized Counterweight System

With a balanced-load motorized counterweight system, it is necessary to balance the load with weight on the arbor before operating the line set. As with a counterweight system, keep the weight down when loading or unloading. With this type of system, there is usually a clutch that will slip, or the motor will quickly overheat and cut out if the system is out of balance. Listening to the motor run in both directions can help determine whether the system is balanced or not. Using an amp probe to measure the current draw in both directions is more accurate.

With a line set that is designed to run out of balance, the motor is the limiting factor. You should know the load capacity of the line set and the weight of the load that you place on it. If the line set is severely out of balance, a great deal of strain is placed on the drive chain or cable and motor. Overloading this type of system usually causes the motor to overheat, tripping the overload relay.

2. Dead-Haul Motorized System

Calculate the weight of the load before attaching it to the winch. If the machine stalls or the overload relay trips or sounds as if it is straining, the winch is overloaded. Do *not* use it in this condition.

D. Showtime Operation

When the equipment is in safe operating condition, the operator thoroughly understands the controls, and all loads have been correctly attached, the motorized equipment is ready to be used during performance.

If there are severe air currents backstage or tight clearances that may cause problems, do a preshow check of any pieces that might foul. Either maintain visual contact with the moving pieces, or use a spotter. Read the cue sheets carefully! Be sure the right piece is moving on cue.

Listen carefully for any unusual sounds. Stop the moving piece immediately if a strange noise is heard.

Most motorized systems will stop much faster than a person can stop a counterweight system. This is a safety advantage in case of fouling.

5.08 Operation Summary

1. Know the system.
2. Safety inspect all components at regular intervals.
3. Always follow safe practice when loading and unloading.
4. Be sure that everyone and everything is clear before moving a piece.
5. Maintain visual contact, or use a spotter.
6. Always warn people onstage and on the grid before activating a winch during set-in or strike.
7. Before each cue, check your cue sheet to see which piece to move, which direction, and any special concerns.

5.09 Safety-Inspection Summary

1. Check all rigging components (see part 7).
2. Check all lubricated parts on the winches: (a) gearbox, (b) pillow blocks, and (c) motor bearings. CAUTION. DO NOT OVER-LUBRICATE.

3. Check all hydraulic connections, fluid level, filters.
4. Check limit and overtravel switches.
5. Check the control system.
6. Check the brakes.
7. Check the emergency-stop controls.

Part 6 Cutting and Terminating Rope, Attaching Loads, and Dealing with Special Problems

6.01 Fiber Rope

Fiber rope is made of natural or synthetic fibers that are either twisted or braided into yarns and then into rope.

A. Cutting

There are specific procedures for cutting different kinds of rope.

1. Natural Fiber

Twisted natural-fiber rope should be taped with electrician's friction tape before cutting. This tape is easy to remove and will keep the ends from fraying. Tape about a 2″ length of rope where the cut is to be made. Use a pair of garden pruning shears to cut the rope in the center of the tape (fig. 6.1). After the rope is cut, remove the tape, and whip the end, using small twine (fig. 6.2).

Fig. 6.1. Cutting fiber rope

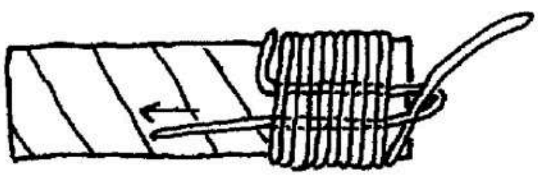


Fig. 6.2. Whipping fiber rope

Braided natural fiber, such as cotton sash cord, need not be taped for cutting; pruning shears work best for the job. If the rope is to be used for a long time, whipping, dipping the ends in glue, or taping will keep the ends neat. Braided rope is not as susceptible to fraying as twisted rope.

2. Synthetic Fiber

Synthetic-fiber rope is best cut with a heated knife designed for the purpose. Live flame can be substituted if the knife is unavailable. Hold the rope in both hands, and rotate it over a flame. Gently pull it apart as you rotate it. The ends can be shaped before they completely cool by pushing them against a hard surface. This method not only cuts the rope but binds the fiber ends together to prevent unraveling (fig. 6.3).

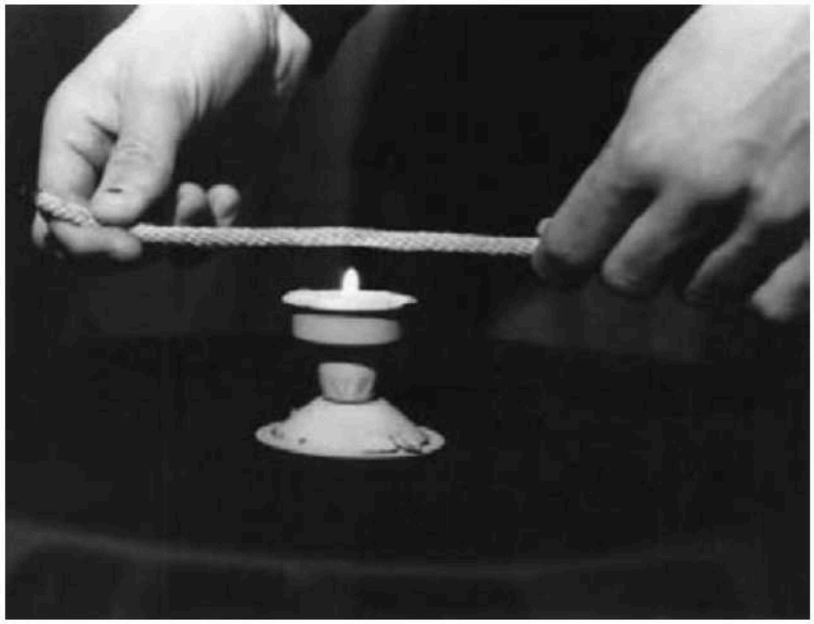


Fig. 6.3. Cutting nylon rope

B. Knots

A knot is used to attach a rope to an object. Knots reduce the breaking strength of rope and can slip or come untied if misapplied. Therefore, the proper knot for a specific application must be used. *Knot efficiency* is the remaining strength of a rope after a knot has been tied in it. Table 6.1 is a list of the efficiencies of common stage knots. These are average values and will vary depending on a number of conditions.

Table 6.1. Knots and Their Efficiencies

Knot Type	Efficiency (%)
Bowline	60
Figure-8	64
Two half hitches	
around a 15-mm-diameter ring	60
around a 96-mm-diameter post	65
Square knot	43
Clove hitch	75
Clove hitch with two half hitches	65
Eye splice with thimble	95

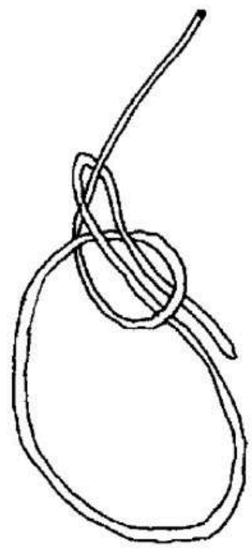


Fig. 6.4. Bowline

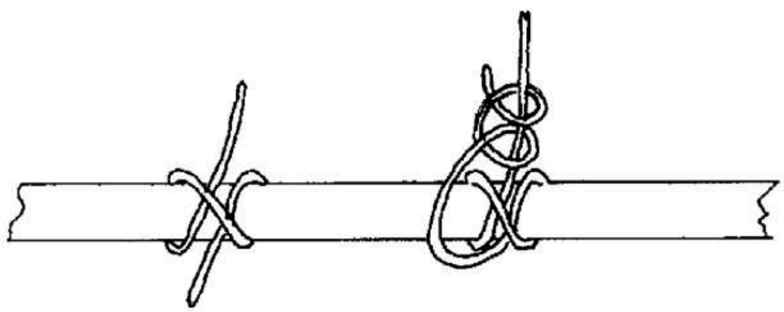


Fig. 6.5. Clove hitch with two half hitches

Fig. 6.6. Stopper hitch

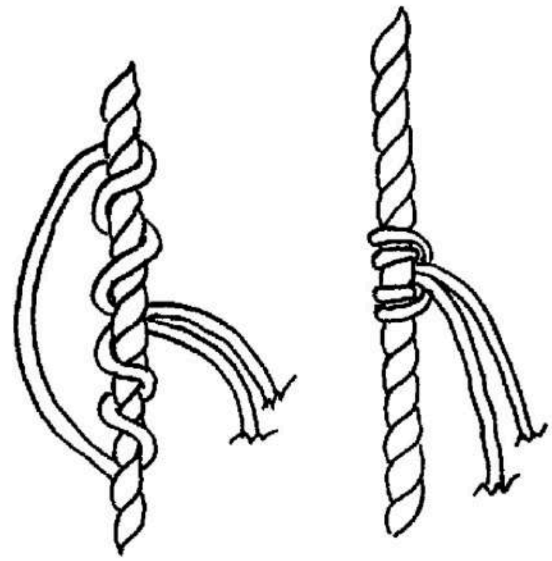


Fig. 6.7. Prusik knot

1. Bowline

Use this knot (fig. 6.4) when tying a loop in the end of a rope.

2. Clove Hitch

This knot is used for tying a rope to a rigid object, such as a batten. When properly tied, it does not slip sideways (fig. 6.5).

3. Stopper Hitch

A stopper hitch (fig. 6.6) is used to tie the safety rope on a counterweight hand line (see section 4.11.A.1).

4. Prusik

Another knot used to tie a safety line on a counterweight hand line is a prusik. It can also be used to attach a rope sunday to a hand line for use with a block and tackle (fig. 6.7).

5. Half Hitch

The half hitch (fig. 6.8) can be used to secure the counterweight safety rope to the lock rail.

6. Figure-8

The figure-8 knot (fig. 6.9) is used at the end of a spot line to hold a length of pipe as a weight (see section 3.08).

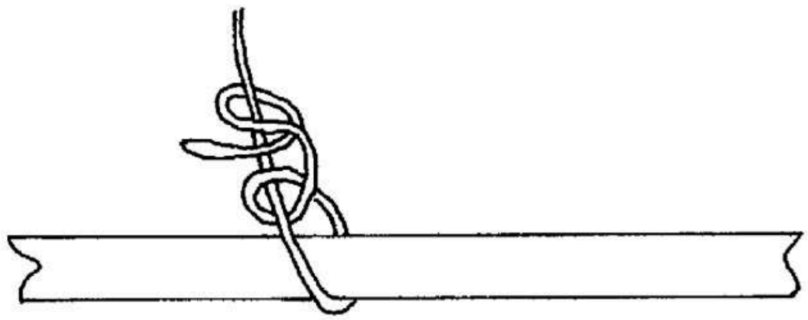


Fig. 6.8. Two half hitches

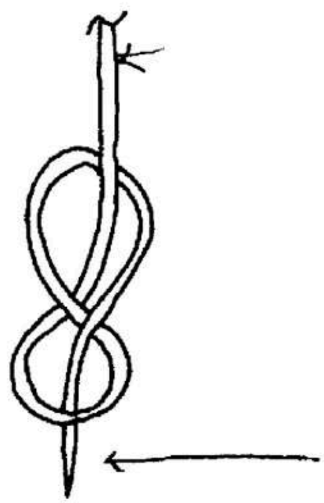


Fig. 6.9. Figure-8 knot

7. Trucker's Hitch

The trucker's hitch (fig. 6.10) is used when flying framed scenery with hemp or when tying a batten down to a floor hold. Figure 6.10 shows one of many ways to tie this knot.

6.02 Wire Rope

Cutting, handling, and terminating wire rope all require special care. Carelessness can result in damage and loss of strength to the wire rope.

A. Cutting

Several different kinds of wire-rope cutters are available on the market. For sizes up through ⅛″, small hand-held cutters can be

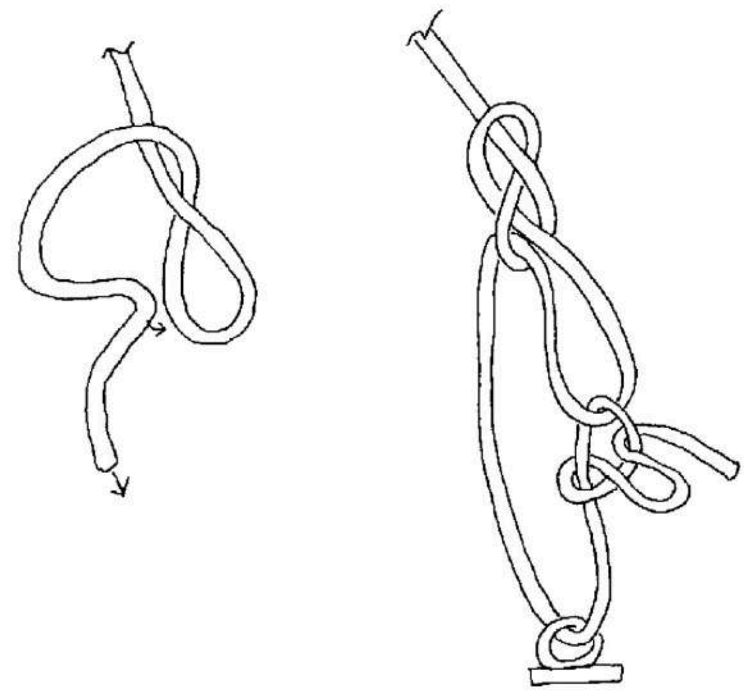


Fig. 6.10. Trucker's hitch

used (fig. 6.11). For larger sizes, two hand cutters or a cold chisel must be used (fig. 6.12).

NEVER try to use a standard pair of wire cutters! Not only will they do a poor job but they will be ruined in the process.

Tape the wire rope before cutting. If the wire rope is to have a free end, *seizing* is required. Seizing is whipping the end with thin wire (fig. 6.13).

B. Unreeling and Uncoiling

Great care should be taken when unreeling or uncoiling wire rope. Carelessness can cause kinking. A kink can never be removed and must be cut out. When taking wire rope from a reel, place the reel on an axle so that it can rotate. Grasp the wire rope, and walk away from the reel. Take care that the reel does not turn too fast and dump wire rope in a pile on the ground.

If the reel is too large to be supported by an axle, let the end of the wire rope rest on the floor, and roll the reel away from the end.

Coiled lengths of wire rope must be handled carefully. Unroll the coil in your hand as you walk along, or roll it along the floor. DO NOT UNCOIL BY PULLING ONE END.

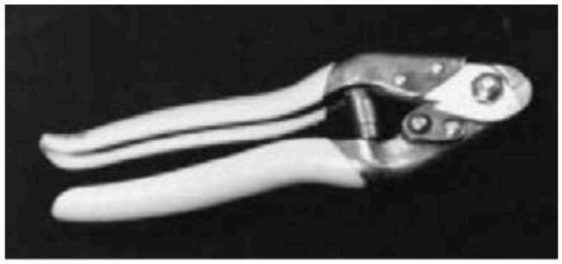


Fig. 6.11. Small-wire-rope cutter

Fig. 6.12. Large-wire-rope cutter

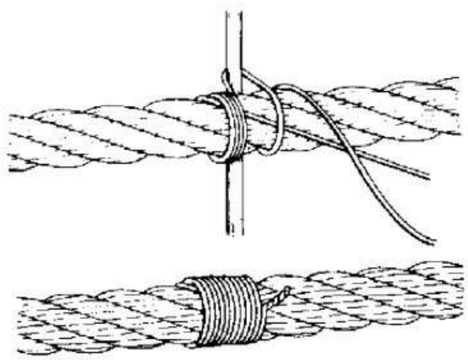


Fig. 6.13. Seizing wire rope. Courtesy of American Iron and Steel Institute, *Wire Rope Users Manual*, 4th ed.

6.03 Terminating

Terminating (attaching the end of wire rope to an object) must be done carefully. It is important to maintain maximum wire-rope strength. It is also necessary to be sure that the termination will not slip.

A thimble is always used when forming a loop in the end of a wire rope. The rope is fastened using either wire-rope clips or compression sleeves.

A. Wire-Rope Clips

Wire-rope clips are manufactured from two types of material: forged steel or cast malleable iron (fig. 6.14). For load-bearing applications, use only forged clips.

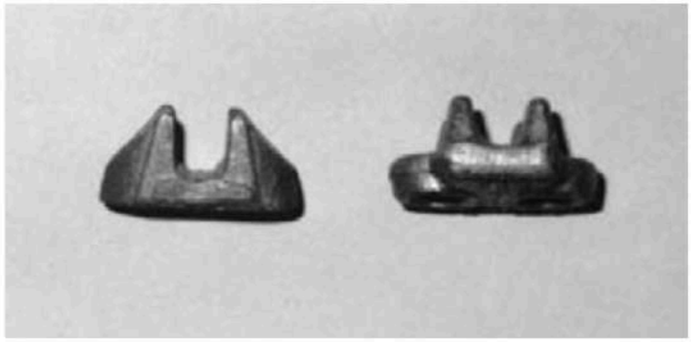


Fig. 6.14. Malleable clip saddle (left), forged clip saddle

Fig. 6.15. Two malleable saddles—note differences in size and quality

The saddles for *malleable clips* are cast, and the quality of the castings varies widely (fig. 6.15). The casting process can produce hidden voids, which cause weaknesses and are not visible to the naked eye. The hidden voids usually cause failure when the clip is being tightened or, more seriously, under shock load. Only one U.S. company manufactures malleable clips domestically and puts its name on the product. All other malleable clips are manufactured offshore and have only the country of origin stamped on them, making it impossible to trace or obtain application information about them.

Malleable clips are *not* rated for load-bearing application and should not be used for rigging applications. They are designed for non–load-bearing uses, such as guy wires.

Forged clips are designed to be used for load-bearing applications. Hot steel is beaten into shape by forging dies to form the saddle, eliminating any chance of hidden voids. The U-bolt and nuts are larger than those used for the malleable clips.

The number of clips, the spacing of the clips, and the proper tightening of the clips are necessary to make a correct termination. If you use the correct number of clips and the proper tight-

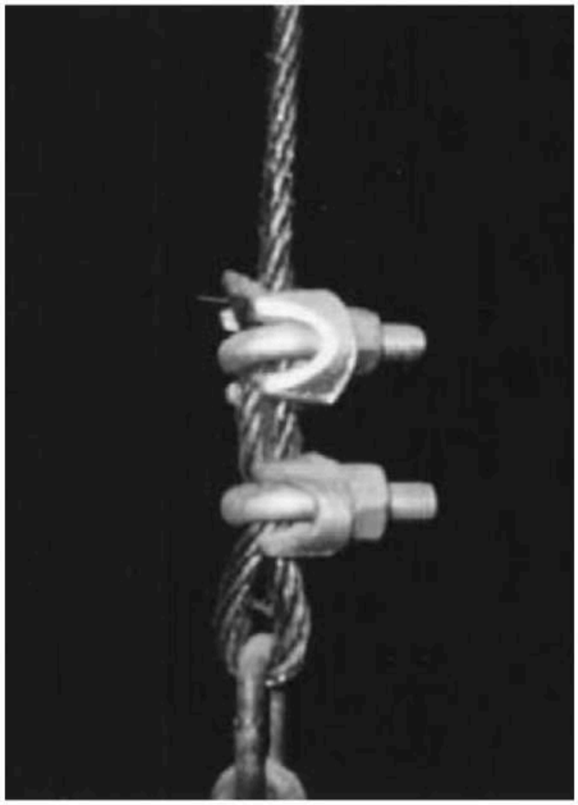


Fig. 6.16. Clips installed too close together

ening torque, you reduce the tendency for the clips to slip under load. The proper spacing on the clips is necessary to keep the clips from slipping if the top clip is pulled up into a sheave or against some other object (fig. 6.16). When pulled against an object, the top clip tends to slip along the live line, and the dead end tends to bend out and pook away from the live line. The resulting kink helps keep the dead end of the line from pulling out of the clips.

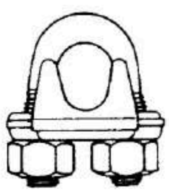


Fig. 6.17. Forged U-bolt wire-rope clip. Courtesy of American Iron and Steel Institute, *Wire Rope Users Manual*, 4th ed.

Two types of forged wire-rope clips are commonly used for stage rigging: *U-bolt* (fig. 6.17) and *fist grip* (fig. 6.20). The efficiency of both types is the same.

When using U-bolt clips, extreme care must be exercised to make certain that they are attached correctly; that is, the U-bolt must be applied so that the U-section is in contact with the dead end of the rope and the saddle on the live end. REMEMBER, NEVER SADDLE A DEAD HORSE. Also, the tightening and retightening of the nuts must be accomplished as required.

1. *How to apply U-bolt clips*. The following steps are the recommended method of applying U-bolt clips to get maximum holding power of the clip. Refer to figure 6.18 for the proper installation order, to figure 6.19 for the proper orientation of the clips, and to table 6.2 for parameters.

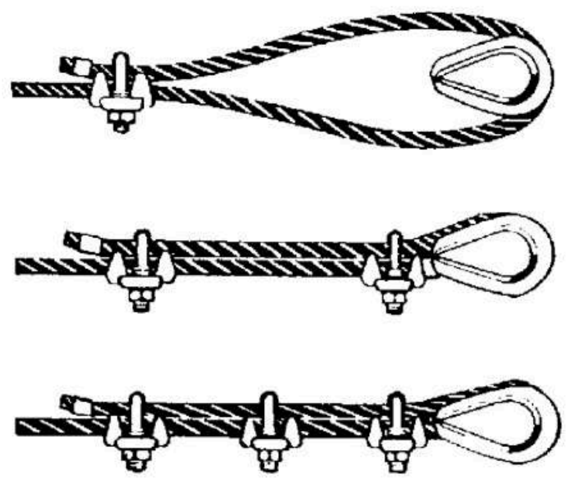


Fig. 6.18. Order of installing clips. Courtesy of Columbus McKinnon Corp.

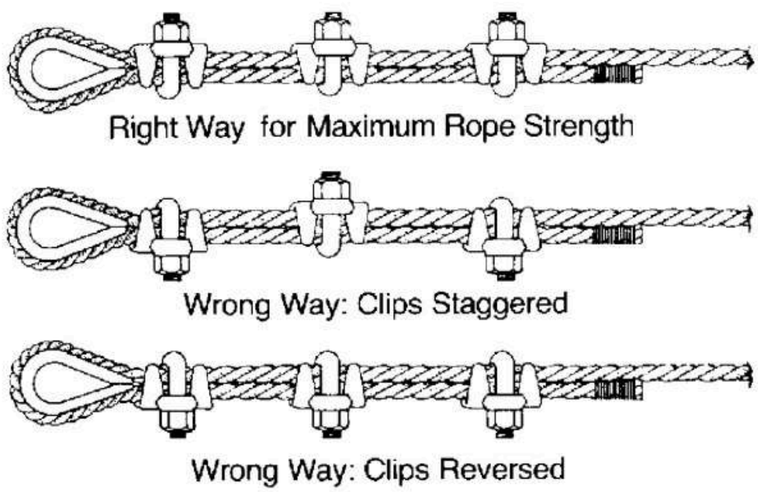


Fig. 6.19. Clip application. Courtesy of American Iron and Steel Institute, *Wire Rope Users Manual*, 4th ed.

Table 6.2. U-Bolt Clip Installation Parameters

Clip Size (in.)	Minimum No. of Clips	Amount of Rope to Turn Back (in.)	Torque (lb./ft.)
1/8	2	3 1/4	4.5
3/16	2	3 3/4	7.5
1/4	2	4 3/4	15.0
5/16	2	5 1/4	30.0
3/8	2	6 1/2	45.0
7/16	2	7	65.0
1/2	3	11 1/2	65.0

Source: From the Crosby Group. Refer to the Crosby general catalog for more information.

a. Turn back the specified amount of rope from the thimble. Apply the first clip one base-width from the dead end of the wire rope (U-bolt over dead end; live end rests in clip saddle). Tighten the nuts evenly.

b. Apply the next clip as near to the loop as possible. Turn nuts firmly but do not tighten.

c. Space additional clips, if required, equally between the first two. Turn nuts, take up rope slack, and tighten all nuts evenly on all clips to recommended torque.

d. NOTICE: *Apply the initial load, and retighten nuts to the recommended torque. Rope will stretch and be reduced in diameter when loads are applied. Inspect periodically, and retighten to recommended torque.*

A termination made in accordance with the above instructions and using the number of clips shown has approximately an 80% efficiency rating. This rating is based on the catalog breaking strength of wire rope. If a pulley is used in place of a thimble for turning back the rope, add one additional clip.

The number of clips shown is based on using right regular-lay or lang-lay wire rope, 7 × 19, 6 × 19, or 6 × 37 class, fiber-core or IWRC, IPS or XIPS. If Seale construction or similar large outer-wire–type construction in the 6 × 19 class is to be used for sizes 1″ and larger, add one additional clip. The number of clips shown also applies to right regular-lay wire rope, 8 × 19 class, fiber-core, IPS, sizes 1 ½″ and smaller; and right regular-lay wire rope, 18 × 7 class, fiber-core, IPS or XIPS, sizes 1 ¾″ and smaller (see table 6.2).

For other classes of wire rope not mentioned above, it may be necessary to add additional clips to the number shown.

If a greater number of clips is used than shown in the table, the amount of rope turn-back should be increased proportionately. THE ABOVE IS BASED ON THE USE OF U-BOLT CLIPS ON NEW WIRE ROPE.

IMPORTANT: Failure to make a termination in accordance with the aforementioned instructions or failure to periodically check and retighten to the recommended torque will cause a reduction in efficiency rating.

2. *How to apply fist-grip clips*. The following steps are the recommended method of applying fist-grip clips (fig. 6.20). Refer to table 6.3 for parameters.

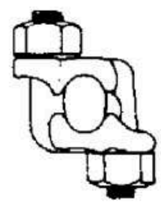


Fig. 6.20. Forged fist-grip wire-rope clip. Courtesy of American Iron and Steel Institute, *Wire Rope Users Manual*, 4th ed.

Table 6.3. Fist-Grip Clip Installation Parameters

Clip Size (in.)	Minimum No. of Clips	Amount of Rope to Turn Back (in.)	Torque (lb./ft.)
$^3/_{16}$–$^1/_4$	2	4	30
$^5/_{16}$	2	5	30
$^3/_8$	2	5 $^1/_4$	45
$^7/_{16}$	2	6 $^1/_2$	65
$^1/_2$	3	11	65

Source: From the Crosby Group. Refer to the Crosby General Catalog for more information

a. Turn back the specified amount of rope from the thimble. Apply the first clip one base-width from the dead end of the wire rope. Tighten nuts evenly to recommended torque.
b. Apply the next clip as near to the loop as possible. Turn nuts firmly, but do not tighten.
c. Space additional clips, if required, equally between the first two. Turn nuts, take up rope slack, and tighten all nuts evenly on all clips to recommended torque.
d. NOTICE: *Apply the initial load, and retighten nuts to the recommended torque. Rope will stretch and be reduced in diameter when loads are applied. Inspect periodically, and retighten to recommended torque.*

A termination made in accordance with the above instructions and using the number of clips shown has an efficiency rating of approximately 80%, based on the catalog breaking strength of wire rope. If a pulley is used in place of a thimble for turning back the rope, add one additional clip.

The number of clips shown is based on using right regular-lay or lang-lay wire rope, 7 × 19, 6 × 19, or 6 × 37 class, fiber-core or IWRC, IPS or XIPS. If Seale construction or similar large outer-wire–type construction in the 6 × 19 class is to be used for sizes 1″ and larger, add one additional clip. The number of clips shown also applies to right regular-lay wire rope, 8 × 19 class, fiber-core, IPS, sizes 1 ½″ and smaller; and right regular-lay wire rope, 18 × 7 class, fiber-core, IPS or XIPS, sizes 1 ¾″ and smaller.

For other classes of wire rope not mentioned above, it may be necessary to add additional clips to the number shown.

If a greater number of clips are used than shown in the table, the amount of rope turn-back should be increased proportionately. THE ABOVE IS BASED ON THE USE OF FIST-GRIP CLIPS ON NEW WIRE ROPE.

IMPORTANT: Failure to make a termination in accordance with aforementioned instructions or failure to periodically check and retighten to the recommended torque will cause a reduction in efficiency rating.

Fist-grip clips do not damage the wire rope the way U-bolt clips do. For this reason, fist-grip clips are preferred for temporary uses, such as hanging scenery.

B. Compression Sleeves

When properly applied to 7 × 19 galvanized aircraft cable or 6 × 19 IWRC classification plow-steel wire rope, copper compression sleeves, also called Nicopress sleeves (Nicopress is a registered trademark of the National Telephone Supply Company), provide an eye-splice termination equal to the breaking strength of the wire rope. That is, the wire rope will break usually at or above the catalog breaking strength, and the sleeve will not slip.

The telephone companies use compression sleeves for terminating steel cable to support large multicable telephone lines. The aircraft industry uses the termination method on control cables on airplanes. To ensure uniformity, copper sleeves and plated, copper sleeves used on airplane control cables are manufactured to Mil Spec MS 51844. Aluminum sleeves are softer and can slip, especially under shock load. They are not allowed in the aircraft

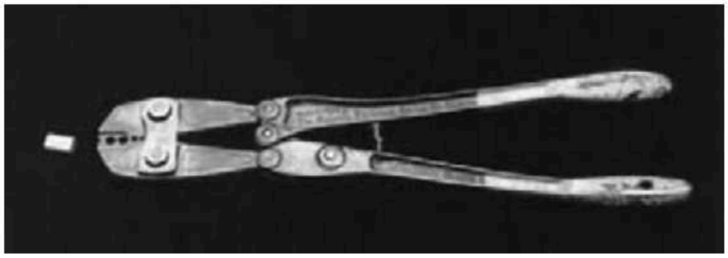


Fig. 6.21. Nicopress crimping tool and sleeve

industry because they not manufactured to any standard. Do not use aluminum sleeves for stage-rigging applications.

The sleeve must be crimped to the proper tightness in order to prevent slipping (fig. 6.21). If the tool is not adjusted properly, thereby not supplying the proper amount of force, the wire rope can slip out of the sleeve. Always do a test crimp, and check the tool adjustment before starting on a load-bearing termination. If the crimp does not pass a go-gauge test, adjust the tool per the manufacturer's recommendations, and test again. As shown below, it is also important to use the specific gauge that is furnished with the crimping tool to test the compressions. The thickness of the jaws on the tools varies, and each tool requires a specific number of crimps to achieve a 100% efficient termination.

A number of manufacturers make compression tools. The two most popular and reliable brands are Nicopress, made by National Telephone Supply Co., and LocoLoc, made by Loos & Co. These two companies manufacture the tools that conform to the Mil Spec and FAA standard and put their guarantees in writing. It is not a good idea to use any swaging tool that does not come with a go-gauge and does not state the efficiency of the termination in writing.

1. Nicopress Tools

National Telephone Supply developed the compression-sleeve termination system (marketed under the trade name Nicopress) for the telephone industry, so its parts-numbering system is a bit confusing to us in the entertainment industry. Listed below are the numbers of the nonhydraulic tools, both hand held and bench mounted, used for the common sizes of wire rope, as well as the required number of crimps for each tool. The hydraulic bench-mounted tool No. 635 and hand-held hydraulic tool No. 3512 require separate sets of dies for each wire-rope size. The hydraulic tools each crimp the entire sleeve with a single compression (fig. 6.22).

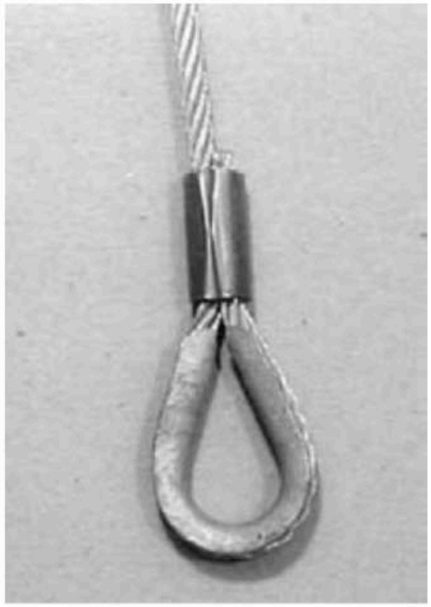


Fig. 6.22. Hydraulically swaged sleeve

Nicopress sleeves are made of various materials and designed for different purposes. The Nicopress part-number prefixes in table 6.4 indicate the material of which a given sleeve is made. Stage use usually requires either galvanized aircraft cable or non-galvanized wire rope—not stainless steel.

Table 6.4. Nicopress Sleeves, by Material and Use

Type of Sleeve	Use
18-xx copper	preferred for stage use
28-xx zinc-plated copper	OK for stage use
168-xx stainless steel	Only for stainless-steel wire rope
188-xx aluminum	not for use in overhead applications
428-xx tin-plated copper	OK for stage use and stainless wire rope
871-xx copper stop sleeve	OK for stage use
878-xx aluminum stop sleeve	not for use in overhead applications

Source: National Telephone Supply Co.

The tool head numbers listed in table 6.5 can be either hand held or bench mounted. The number of compressions are clearly visible on a crimped sleeve (fig. 6.23). Larger sizes of wire rope require the use of a hydraulic swaging tool.

Table 6.5 Presses and Tools for Nicopress Sleeves

Cable Size (in.)	Material	Tool No.	Tool Groove	No. of Presses
$^1/_{16}$	stainless	51-B4-887	oval B4	1
	all others	51-C-887	oval C	1
	all others	64-CGMP	oval C	1
	all others	3-C-887	oval C	1
	all others	3V-CGMP	oval C	1
$^3/_{32}$	stainless	51-C-887	oval C	1
	all others	51-G-887	oval G	1
	all others	64-CGMP	oval G	1
	188-3-VG	51-G-887	oval G	2 overlapped
	188-3-VG	64-CGMP	oval G	2 overlapped
	stainless	3-C-887	oval C	1
	all others	3-G-887	oval G	1
	all others	3V-CGMP	oval G	1
	188-3-VG	3-G-887	oval G	2 overlapped
	188-3-VG	3V-CGMP	oval G	2 overlapped
$^1/_8$	stainless	51-G-887	oval G	1
	all others	51-M-850	oval M	3
	all others	64-CGMP	oval M	3
	all others	63V-XPM	oval M	3
	all others	51-MJ	M	2
	stainless	3-G-887	oval G	1
	all others	3-M-850	oval M	1
	all others	3V-CGMP	oval M	2
	all others	3V-XPM	oval M	2
	all others	3V-F6:X:M	oval M	2
	all others	3-MJ	M	2
$^5/_{32}$	stainless	51-M-850	oval M	3
	all others	51-P-850	oval P	3
	all others	64-CGMP	oval P	3
	all others	63V-XPM	oval P	3
	stainless	3-M-850	oval M	1
	all others	3-P-850	oval P	1
	all others	3V-CGMP	oval P	2
	all others	3V-XPM	oval P	2

3/16	stainless	51-P-850	oval P	4
	all others	51-X-850	oval X	4
	all others	63V-XPM	oval X	4
	all others	3-X-850	oval X	2
	all others	3V-XPM	oval X	2
	all others	3V-F6:X:M	oval X	2
7/32	all others	51-F2-850	oval F2	4
	all others	3-F2-850	oval F2	2
1/4	all others	3-F6-950	oval F6	3
	all others	3V-F6:X:M	oval F6	3
5/16	all others	3-G9-950	oval G9	3
	188-10-VG	923-G9-950	oval G9	4

Source: National Telephone Supply Co. Nicopress is a registered trademark of the National Telephone Supply Company.

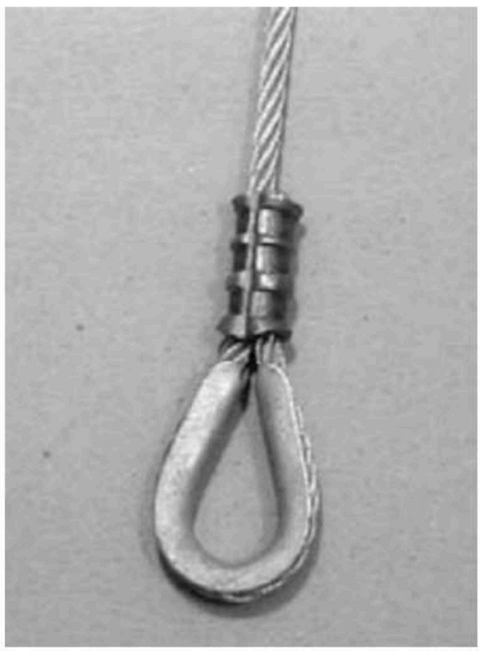


Fig. 6.23. Hand-swaged sleeve

As oval sleeves are crimped, the length of the sleeve increases. Table 6.6 shows the unpressed length and the pressed lengths for the various-sized oval copper sleeves.

Table 6.7 shows the number of presses required for copper and aluminum stop sleeves using Nicopress tools. The table shows the results of holding strength tests performed by Nicopress to determine the approximate holding strength of the stop sleeves. The approximate holding power indicates where the wire rope pulled out of the sleeve. STOP SLEEVES ARE NOT 100% EFFICIENT AND WILL NOT FORM A TERMINATION EQUAL TO THE RATED BREAKING STRENGTH OF THE WIRE ROPE. Contact Nicopress for additional information concerning the use of these sleeves.

Table 6.6. Oval Copper Sleeves, Unpressed and Pressed Lengths

Size (in.)	Unpressed Length (in.)	Pressed Length (in.)
$^{1}/_{16}$	$^{3}/_{8}$	$^{7}/_{16}$
$^{3}/_{32}$	$^{3}/_{8}$	$^{7}/_{16}$
$^{1}/_{8}$	$^{9}/_{16}$	$^{3}/_{4}$
$^{5}/_{32}$	$^{5}/_{8}$	$^{7}/_{8}$
$^{3}/_{16}$	$^{15}/_{16}$	$1\ ^{3}/_{16}$
$^{7}/_{32}$	$^{7}/_{8}$	$1\ ^{1}/_{16}$
$^{1}/_{4}$	$1\ ^{1}/_{8}$	$1\ ^{1}/_{2}$
$^{5}/_{16}$	$1\ ^{1}/_{16}$	$1\ ^{3}/_{8}$
$^{3}/_{8}$	$1\ ^{1}/_{4}$	$1\ ^{5}/_{8}$
$^{7}/_{16}$	$1\ ^{3}/_{4}$	$2\ ^{5}/_{16}$
$^{1}/_{2}$	$1\ ^{7}/_{8}$	$2\ ^{1}/_{2}$
$^{9}/_{16}$	2	$2\ ^{5}/_{8}$
$^{5}/_{8}$	$2\ ^{3}/_{8}$	$3\ ^{1}/_{8}$

Source: National Telephone Supply Co.

Table 6.7. Presses Needed for Copper and Aluminum Stop Sleeves

Size (in.)	Tool No.	Tool Groove	No. of Presses	Approximate Holding Power (lb.) Copper	Aluminum
$^{1}/_{16}$	51-C-887	oval C	1	430	250
	32-VC:VG	VC	1		
	33V-CGB4	VC	1		
	64-CGMP	oval C	1		
	3-C-887	oval C	1		
	3V-CGMP	oval C	1		
	3-Q-929	Q	1		
$^{3}/_{32}$	51-MJ	J	1	600	300
	51-Q-929	Q	1		
	3-MJ	J	1		
	3-Q-929	Q	1		
$^{1}/_{8}$	51-MJ	J	1	900	350
	3-MJ	J	1		

$^{5}/_{32}$	51-MJ	M	1	1,200	500
	3-MJ	M	1		
$^{3}/_{16}$	51-MJ	M	1	1,600	500
	3-MJ	M	1		
$^{7}/_{32}$	51-MJ	M	2	2,500	
	3-MJ	M	2		
$^{1}/_{4}$	3-F6–950	oval F6	2	3,500	1,500
	3V-F6:X:M	oval F6	2		
$^{9}/_{32}$	3-F6–950	oval F6	2	4,000	
	3V-F6:X:M	oval F6	2		
$^{5}/_{16}$	3-F6–950	oval F6	2	4,000	1,500
	3V-F6:X:M	oval F6	2		
$^{3}/_{8}$	3-F6–950	oval F6	2	5,000	
	3V-F6:X:M	oval F6	2		

Source: National Telephone Supply Company. Used with permission.

For sizes $^{3}/_{32}$″ and below, the ratings are for 7 × 7 galvanized aircraft cable. For sizes $^{1}/_{8}$″ and above, the ratings are for 7 × 19 aircraft cable.

The only way to tell if a swaging tool is properly adjusted and the crimp is properly made is to check the crimps with a go-gauge (fig. 6.24). Each type of Nicopress tool is designed to provide a fixed amount of compression. There is a difference in the diameter of the finished compression-sleeve size between the hand

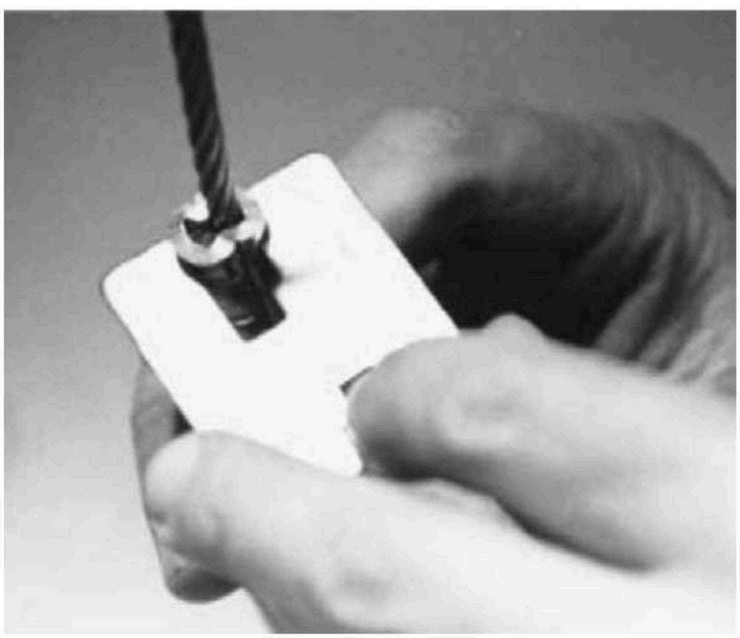


Fig. 6.24. Checking crimp with go-gauge

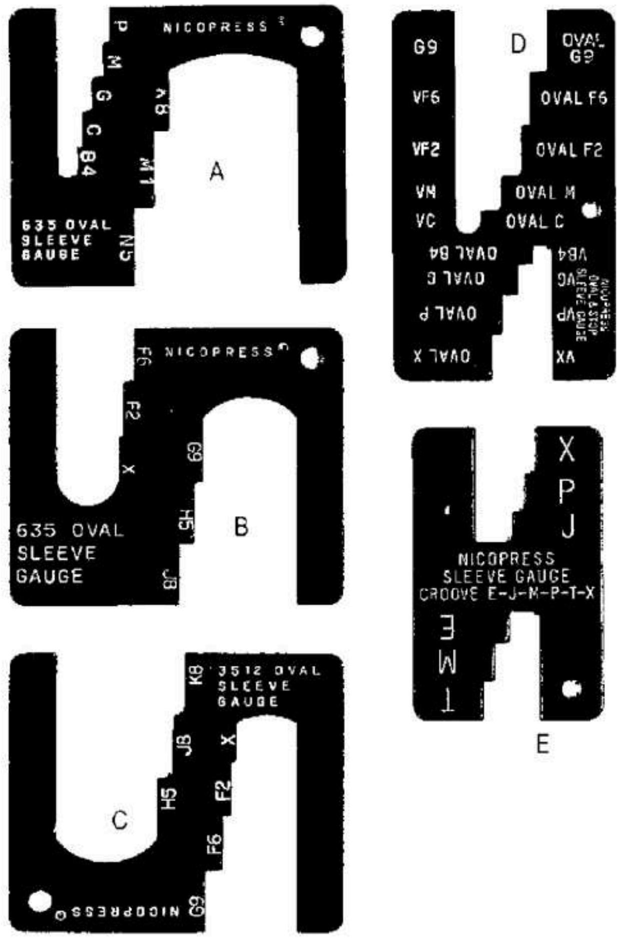


Fig. 6.25. Nicopress gauges

and bench mounted tools and the hydraulic tools. Figure 6.25 shows five typical Nicopress gauges. Use the slot in the gauge that matches the tool groove number. Gauges A and B are furnished with the 635 hydraulic tool and should be used on sleeves swaged with that tool. Gauge C is furnished with the 3512 hand-held hydraulic tool and should be used on sleeves swaged with that tool. The compressions made with the hydraulic tools are a few thousands of an inch larger in diameter than the compressions made with the hand-operated tools, and the slots in the gauges are sized for those compressions. Gauges D and E should only be used on swages made with hand-operated tools. They will not fit swages made with a hydraulic tool.

Nicopress tools have two recessed allen-adjustment screws on the handle. The lower screw is a lock screw. To adjust the tool, loosen the lower lock screw two turns, tighten the upper-adjustment screw a quarter-turn, and make a test compression. Repeat adjusting the top screw in quarter-turn increments until a compression passes the go-gauge test. Tighten the locking screw. Continually monitor the adjustment by testing the competed crimps with the go-gauge. Adjust the tool as needed.

2. Locoloc Tools

Loos & Co. makes very good swaging tools under the brand name Locoloc that will produce terminations conforming to the military and FAA standards. Table 6.8 shows the number of compressions required on copper or aluminum sleeves for Loos hand-operated tools.

Table 6.8. Compressions Required on Copper or Aluminum Oval and Stop Sleeves, Hand-Operated Tools

	No. of Presses	
Size (in.)	Oval Sleeves	Stop Sleeves
1/16	2	1
11/32	2	2
1/8	3	2
5/32	3	2
3/16	4	2
7/32	4	2
1/4	4	3
9/32	4	3
5/16	4 copper	3
5/16	5 aluminum	n.a.

n.a., not available.
Source: National Telephone Supply Co.

The notches in the Locoloc gauges shown in figure 6.26 are slightly different from the notches in the Nicopress gauges by a few thousandths of an inch. Locoloc gauges should be used only on swages made with Locoloc hand tools. The labels on the Locoloc gauges tend to wear off, so it is a good idea to engrave the size information on a new gauge so that when the label wears off, you will still be able to identify the proper slot on the gauge.

The Locoloc hand tools have one adjustment screw on the handle. Adjust the tool by tightening the allen screw in quarter-turn increments until a compression passes a go-gauge test. Locoloc makes hydraulic swaging tools. Use only the gauge supplied with these tools to test compressions.

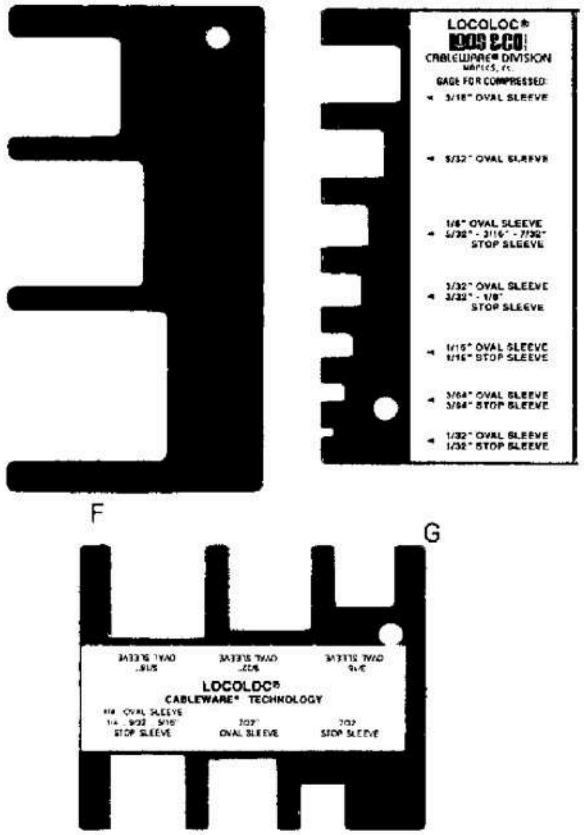


Fig. 6.26.
Locoloc gauges

To make a proper termination using any tool:

a. Use the correct-size copper sleeve.
b. The wire rope must extend all the way through the sleeve.
c. The sleeve should be spaced far enough from the thimble so the thimble will not deform when the sleeve is crimped.
d. The crimping tool must be properly adjusted.
e. Use the correct number of compressions.
f. Make the first crimp, and test with a gauge.
g. Make the required number of crimps in the proper order (fig. 6.27).

One of the corrections made in this edition of *Stage Rigging Handbook* is the order of making crimps in a sleeve. Three correct crimping-sequences are shown in the top row of figure 6.27. The author was taught to make the crimps in the order shown in previous editions. However, after a great deal of discussion with engineers at both Loos & Co. and Nicopress, one of the orders

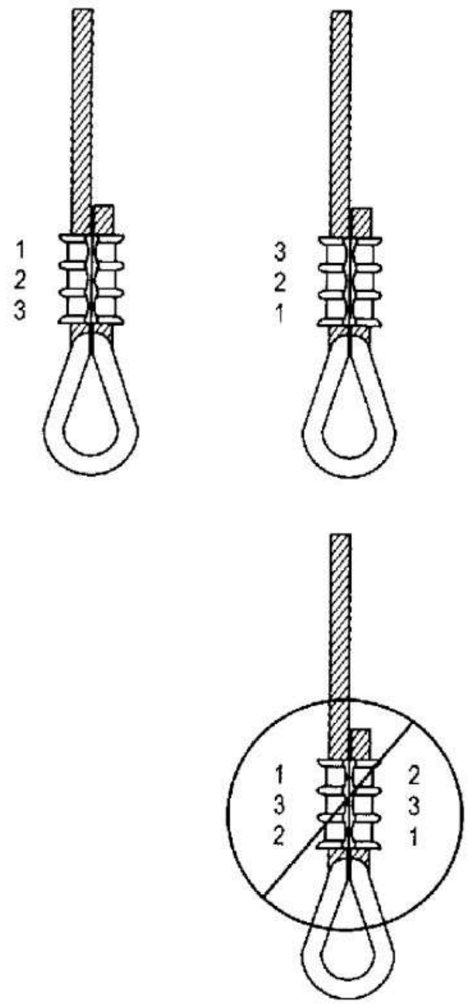


Fig. 6.27. Three correct orders of crimping (top); incorrect order (bottom)

of compressions shown in figure 6.27 (the bottom one) is *not* recommended, due to the elongation of the sleeve that occurs during this swaging process.

At the beginning of this section, it was stated that properly applying compression sleeves to 7 × 19 GAC or 6 × 19 classification wire rope will produce 100% efficient eye splices. Other constructions of wire rope such as 1 × 19 may not have deep enough grooves to hold the sleeve from slipping. In case there is any doubt, apply two sleeves as shown in figure 6.28. The order of compressions shown will prevent the elongating sleeves from running into each other and causing stress in the wire rope.

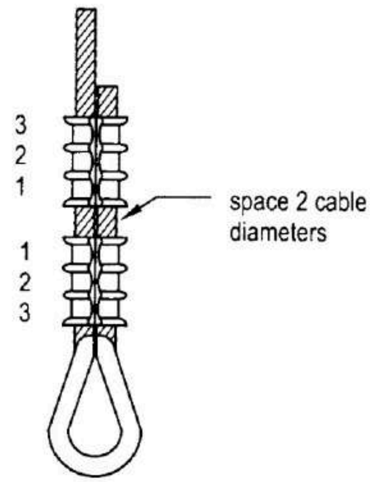


Fig. 6.28. Correct order of crimping two sleeves

If you have any doubt about the strength of the termination, have a sample tested.

3. Quarter-Inch Terminations

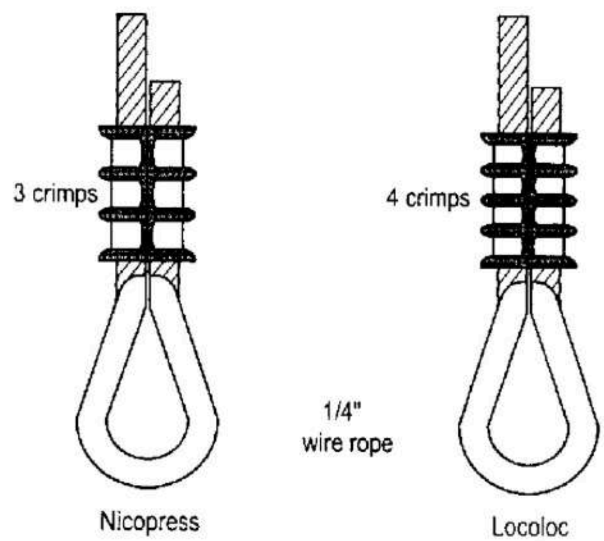


Fig. 6.29. Number of crimps for 1/4″ wire rope

Quarter-inch galvanized aircraft cable is one of the most common sizes of wire rope terminated with compression fittings. It is important to remember that the Nicopress hand tool requires three crimps and the Locoloc hand tool requires four crimps (fig. 6.29).

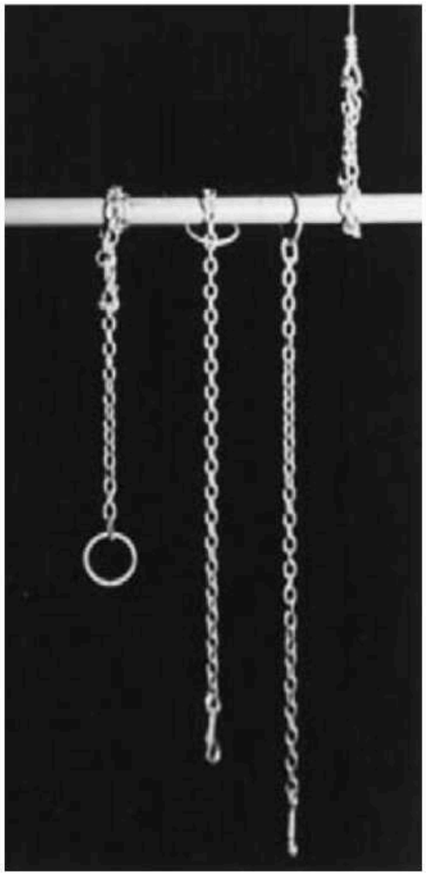


Fig. 6.30. Trim chains on a batten

C. Trim Chains

Trim chains are used in many ways to attach loads to battens. A typical scenery trim chain consists of a welded or forged steel ring, a length of chain, and a device to attach the chain to itself (usually a snap hook).

Take care to find out the safe working load of a trim chain before using it. Manufacturers' catalogs will usually give that information on the chain and the ring. It is almost impossible to find a rating for snap hooks. Because snap hooks are unrated, they should not be used for any heavy load. Many theatres are replacing the snap hooks with shackles. The chain can either be attached to the batten by sliding the ring on the batten between the lift lines, passing the chain around the batten and through the ring, or wrapping the chain around the batten 1½ times and attaching it to itself (fig. 6.30).

If the strength of the trim chain is in doubt, do not use it, or use more chain to distribute the load. If the strength of the snap hook is in doubt, use a shackle.

6.04 Bolts

A great deal of rigging hardware is clamped together by bolts. One of the primary examples of this is clamping head and loft blocks to the support steel; and an examination of any rigging system will reveal many other examples of bolts clamping components together. In a clamping application, as the nut is tightened, the bolt is put in tension and actually stretches. The nuts are made of a slightly softer material than the bolts. There is a tolerance between the threads of the nut and the threads of the bolt. You can feel the slop by wiggling a new nut on a new bolt. As the nut tightens, the threads of the nut deform and become fully engaged with the threads on the bolt. This maximum contact allows enough force to stretch the bolt. Once the threads in a nut have been deformed, they are never as strong again because they have been stretched past their yield point. If you are "kicking sheaves" or have to disassemble a component that has been clamped together, it is a good idea to replace the nuts. The bolt manufacturers purposely make the nut the softer material because it is easier and cheaper to replace than the bolt.

Bolts are tightened with a torsional force that is far more destructive than the compression force on the pieces of metal that they are clamping together. If the bolt and the metal pieces being clamped are the same strength material, it is fairly easy to strip the bolt or wring the head off. There are three major grades of bolts readily available, and using the right grade for a specific application is essential to having a safe rigging system. The grade is based on the ultimate breaking strength of the material from which the bolt and nut are made. *The nut and bolt must be the same grade*. If you mix the grades, the weakest component will easily strip, and you will not be able to get the proper tension in the bolt.

Figure 6.31 shows the markings for the three grades of nuts and bolts. Grade 2 bolts are the common variety found in local hardware stores. These work fine for clamping legs on platforms or any wood-to-metal application. *Grade 5 bolts should usually be used for all rigging components*. Grade 8 bolts are used for clamping high-strength steel together and special applications.

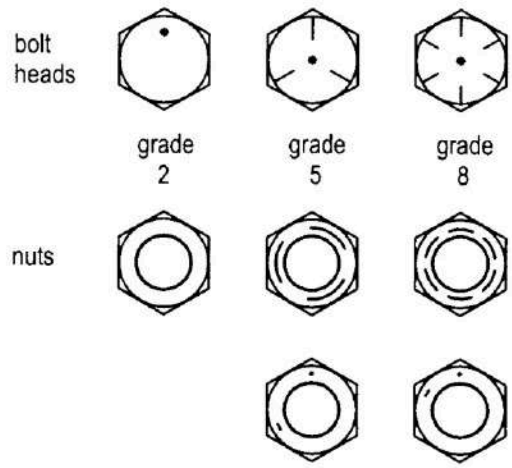


Fig. 6.31. Nut and bolt-head markings (the asterisk [*] is a manufacturer's identification mark)

6.05 Attaching Loads

A. Curtains

Curtains are attached to battens by using tie lines. Some of the standard procedures for tying curtains follow.

1. Knots

Always use bow knots. This knot will securely hold the load, and untying the curtain will be easy.

2. Full-Stage-Width Curtains

On full-stage-width curtains, start tying in the center of the batten.

3. Excess Curtain Width

Fold excess curtain back on the offstage side.

4. Overlap Panels

Overlap panels by at least one tie line. Overlapping by two will ensure a less obvious break in the panels.

5. Tied-In Fullness

When tying fullness into a flat-sewn curtain, tie the ends first (fig. 6.32). Then tie the center tie to a center point on the batten between the two end ties. Continue tying the center tie of the remaining section of curtain to the center of the remaining spaces. This will produce even fullness in the goods.

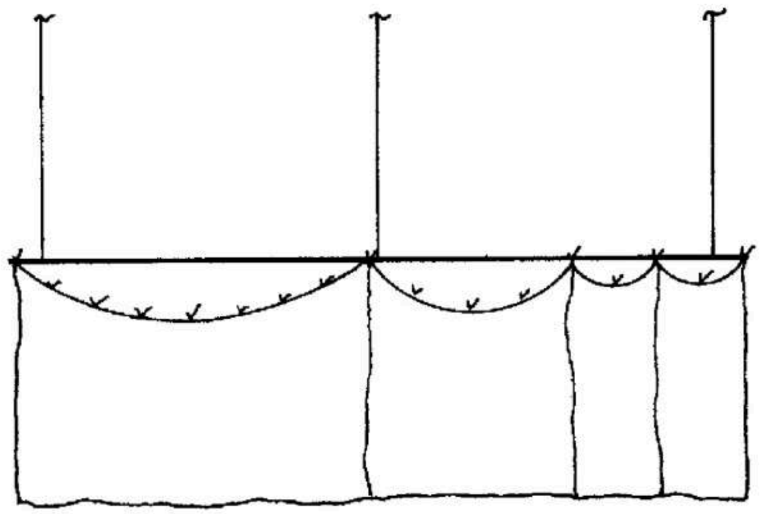


Fig. 6.32. Tying fullness in a curtain

6. Soft-Edge Legs

For a softer look on the onstage edge of legs, fold the sewn edge back one or more ties.

7. Bent Batten

If the legs on the batten are very heavy and bend the batten, apply weight to the center of the batten; sandbags or a length of pipe can be tied, chained or clamped to the batten.

B. Drops

If drops are not made with grommets and ties, sandwich battens must be used along the top edge.

1. Grommets and Ties

Tie a drop to a batten the same way that a full-stage-width curtain is tied. Start at the center point, and work toward the offstage ends.

2. Sandwich Batten

The top of a drop can be sandwiched between two pieces of 1″ × 3″ pine that are screwed together. The drop is pierced just below the sandwich batten near the ends and about every 10′. Trim chains can then be used to attach the drop to the pipe batten.

The chains are attached to the pipe batten by passing the free end around the batten and through the ring. The chains are pulled snug to the pipe batten. The free end is then passed through the drop and attached back on the chain. This method allows easy leveling of crooked drops.

An alternate method is to drill ½″ holes through the sandwich batten and use no. 8 sash cord to tie the drop to the pipe batten.

3. Pipe Weight

A common method of adding weight to a drop is to sew a pocket into the bottom and insert a length of ½″ pipe as a weight. Be sure the ends of the pipe are secured to the drop to prevent the pipe from slipping out if one end of the drop should foul.

4. Pipe-Weight Safety

Use small-diameter wire ropes for safety if the drop requires a pipe larger than ½″, and it is so close to another object that there is danger of the pipe pocket tearing and the pipe falling out.

Attach $^{1}/_{16}$″ or $^{1}/_{8}$″ wire rope to the pipe batten every 10′ or 12′ and near the ends of the drop. Let the wire ropes hang down on the back side of the drop. Pierce the pipe pocket on the back side, then secure the other end of the wire ropes to the batten weight pipe, using a clove hitch and wire-rope clip. Even if the drop tears completely away, the safety wire ropes will hold the weight pipe. SAFETY CABLES ARE A MUST FOR ALL DROPS USED IN A VISTA CHANGES. Wire rope $^{1}/_{16}$″ is usually strong enough and, if painted black, is not be noticeable even through a scrim.

C. Vertical Framed Scenery

Vertical framed scenery is anything that has a rigid frame and hangs in a vertical plane.

1. Hardware Attachment

Put at least one bolt through every piece of hardware on a flying unit. This is especially important on all hanger irons used to attach the unit to fly lines.

2. Calculate Load

The load will probably not be evenly distributed to all support lines (see figure. 3.16). Be sure the support lines have a minimum design factor of 5:1. If people must move under the load while it is moving, increase the design factor to 10:1.

3. Point of Attachment

Traditionally, the point of attachment for hard-framed scenery has been at the bottom for two reasons. First, it is easier to level the unit if the adjustment devices are at the bottom. Second, by attaching at the bottom, the framing members are in compression instead of tension. With wooden flats held together with nails and corrugated fasteners, having the joints in compression provides added strength to the joints. The disadvantage of attaching the support lines at the bottom is that the scenic unit tends to tilt and not hang plumb.

Placing the point of attachment at the top requires using a ladder to level the unit. It also places the framing members in tension and adds stress to the joints. With proper design of the framing members and joints, issues of strength can be resolved. The advantage of top attachment is that the unit generally will not tilt.

4. Attaching with Rope

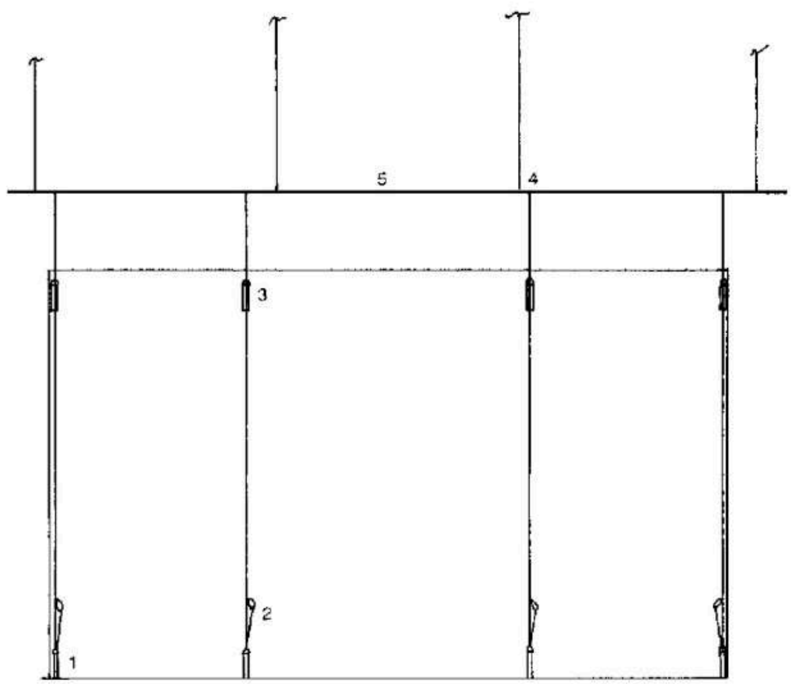


Fig. 6.33. Framed scenery attached to batten with fiber rope
1. Bottom hanger iron
2. Trucker's hitch
3. Top hanger iron
4. Clove hitch
5. Batten

Rope is used when the weight of the unit is within the load limits of rope and when the attaching lines will not be visible (fig. 6.33). Tie the rope to the batten with a clove hitch and two half hitches. Pass the rope through the top hanger irons (fig. 6.34). Attach it to the bottom hanger irons (fig. 6.35) using a trucker's hitch. The hitch will allow easy adjustment for leveling the unit. If the unit is properly designed, the hitch can be applied to the top hanging hardware.

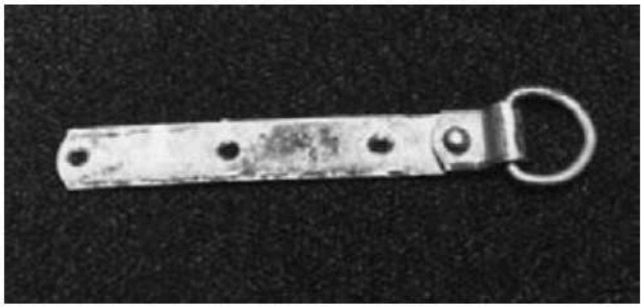


Fig. 6.34. Top hanger iron

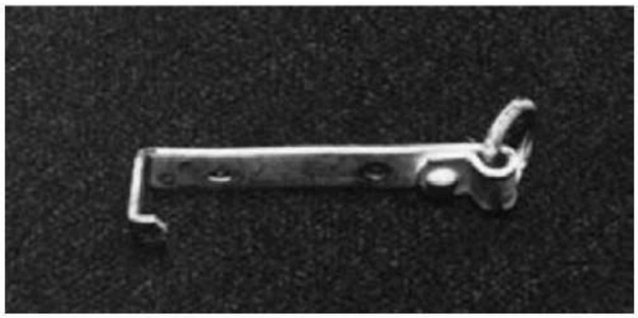


Fig. 6.35. Bottom hanger iron

5. Attaching with Wire Rope

Attach the wire rope to the batten by wrapping it around the batten with a clove hitch and fastening the end with clips. An alternate method is to make a loop around a thimble, using wire-rope clips or compression sleeves. This loop is then attached to a trim chain on the batten. The wire rope is then run through a boat eye (fig. 6.36) and attached to a jaw-eye turnbuckle.

The jaw end is attached to the bottom hanger iron. Leveling of the piece can then be easily accomplished from the bottom (fig. 6.37). The wire rope can also be attached to a properly designed top hanger. For attaching at the top, the turnbuckle can be either at the scenery or batten end of the wire rope.

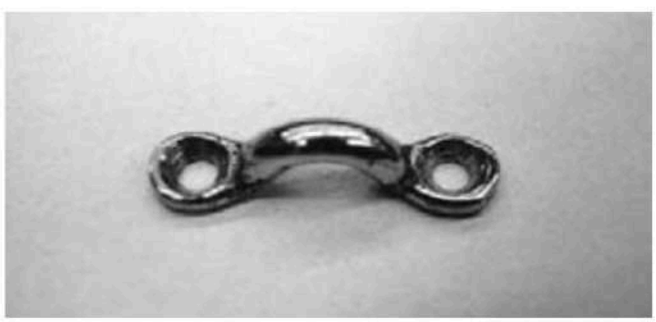


Fig. 6.36. Boat or line eye

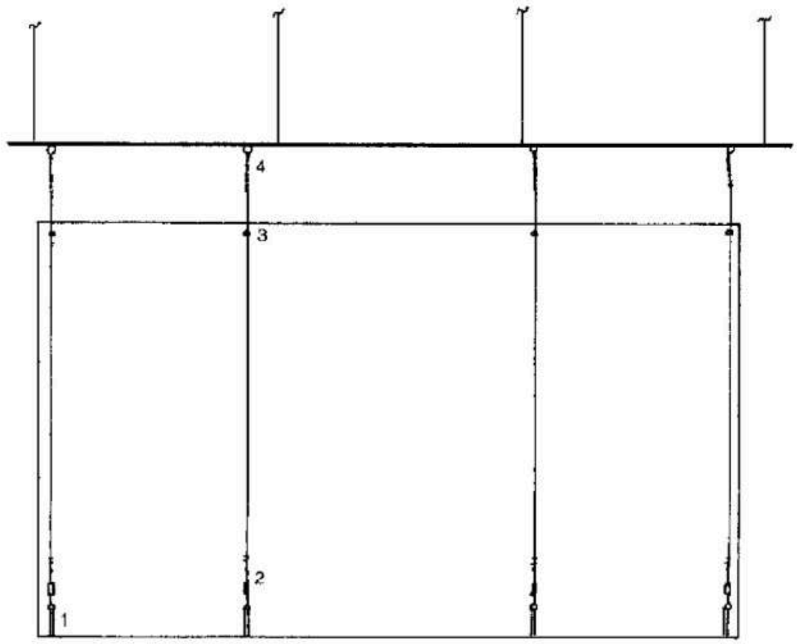


Fig. 6.37. Framed scenic unit hung with wire rope
1. Bottom hanger iron
2. Turnbuckle
3. Boat eye
4. Trim chain

D. Horizontal Framed Scenery

Horizontal framed scenery units (fig. 6.38), such as ceilings, hang parallel to the stage floor. It is important to have enough pickup points to distribute the load on the frame. Ceiling plates (fig. 6.39), bolted to the frame, are used to attach pickup lines of either hemp or wire rope.

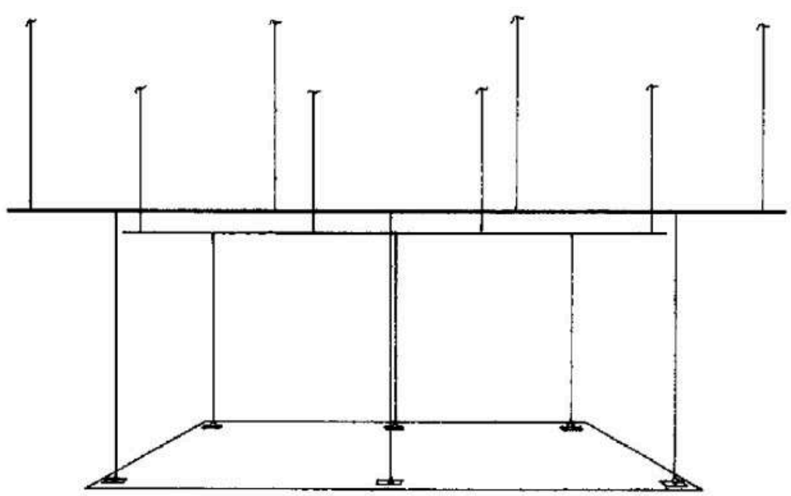


Fig. 6.38. Horizontal framed scenery

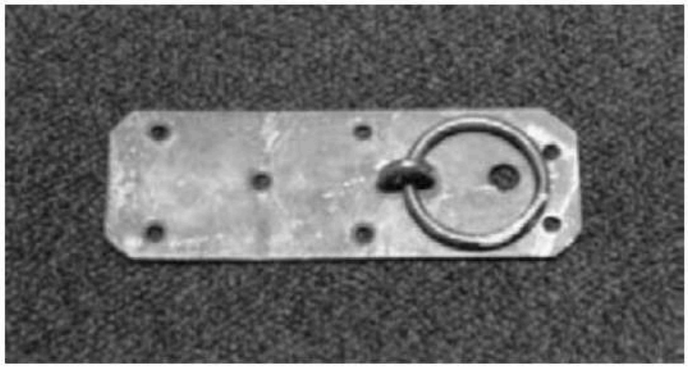


Fig. 6.39. Ceiling plate

E. Point Loads

A *point load* is the load on a single support point (fig. 6.40). The point must be capable of supporting the load imposed on it. When attaching a load to a batten, it is best to keep the attachment points as close to the lift lines as possible. This will keep the batten from bending and lift line wire ropes from becoming slack (fig. 6.41).

1. Truss Batten

One method of distributing the load more evenly is to use a *truss batten* (fig. 6.42). The truss is made of two battens (spaced from several inches to a foot apart) with welded or bolted support members. If the truss is overloaded, the top member will tend

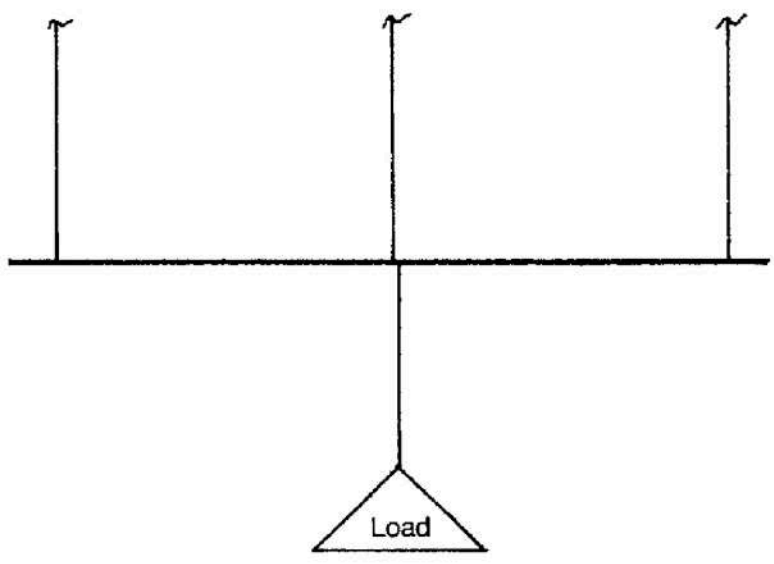


Fig. 6.40. Point load on a batten

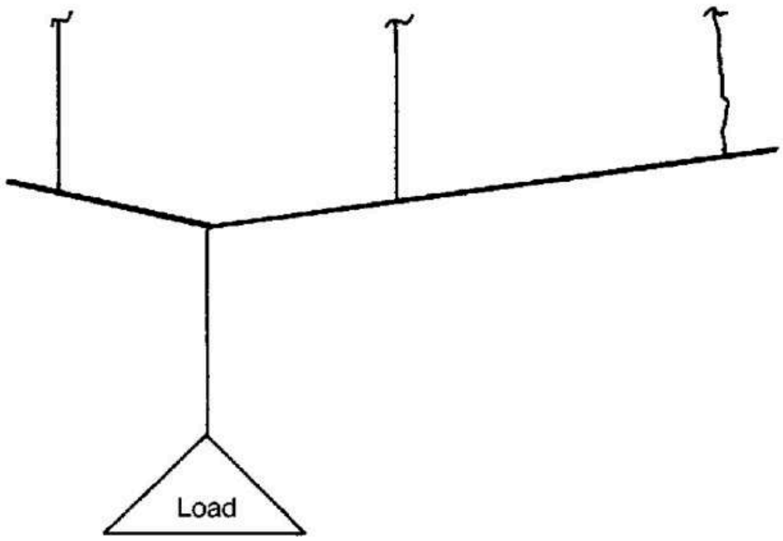


Fig. 6.41. Point load bending a batten

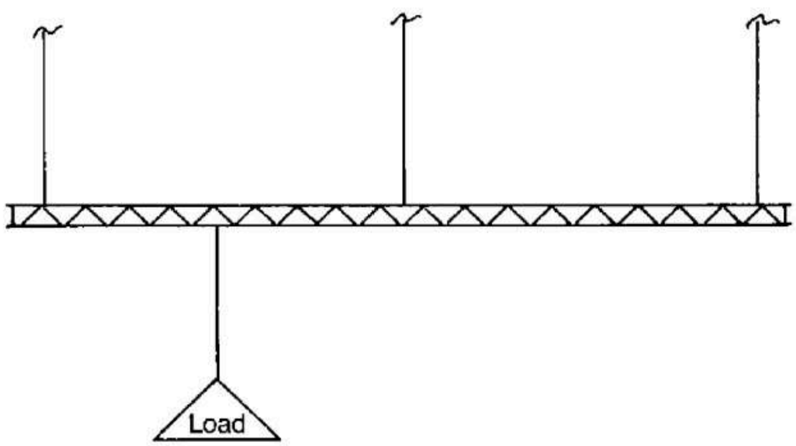


Fig. 6.42. Point load on a truss batten

to buckle and bend outward. A box or triangular truss is more resistant to buckling and can generally hold heavier loads than two-dimensional trusses.

2. Bridling

Bridling is another way to distribute the load (fig. 6.43). The same technique can be used to distribute dead-hung loads attached to the grid (fig. 6.44). See section 1.05 for load-calculation information on bridles.

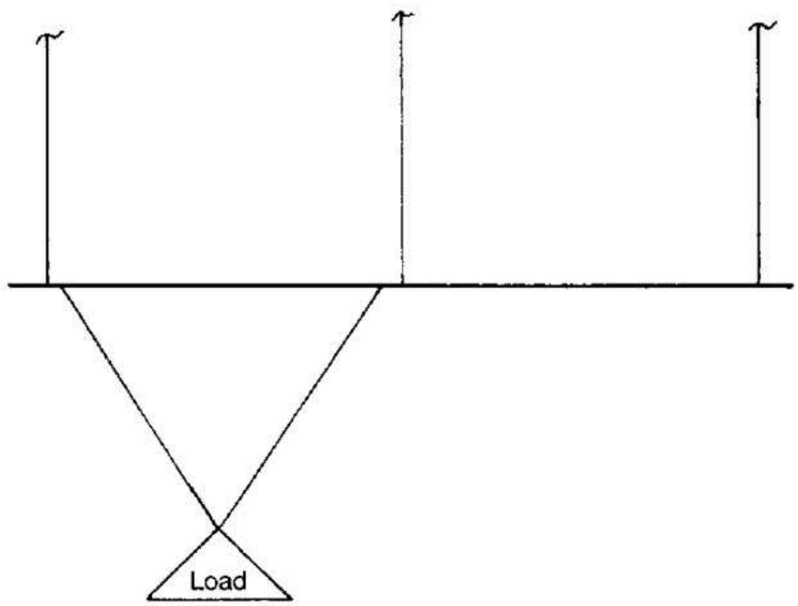


Fig. 6.43. Load on a bridle

Fig. 6.44. Bridle-line detail

6.06 Special Problems

A. Breasting

There are times when it is necessary to move a flown piece in a horizontal, as well as a vertical, direction. This can be done by breasting the piece (fig. 6.45). *Breasting* is a form of bridling, and the loading must be calculated accordingly.

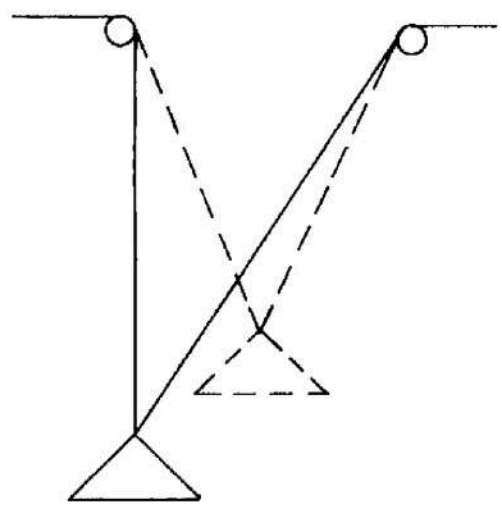


Fig. 6.45. Breasting

B. Tripping

Tripping is a method of flying a very high drop where the grid is too low (fig. 6.46). A second set of lift lines is attached to the weight pipe in the bottom of the drop. As the trip lines are raised, the load on the main flying set is reduced. The hand line of the main flying set should be tied off with a safety hitch before raising the trip lines.

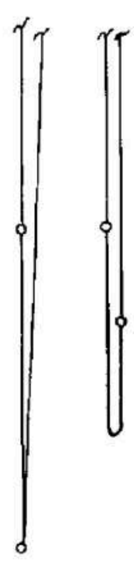


Fig. 6.46. Tripping

C. Guiding

In very close quarters, a drop or piece of scenery may require guide cables to keep from fouling (fig. 6.47). If guide cables are not possible, lengths of rope, called *tag lines*, can be attached to the end of the batten or an adjacent batten (fig. 6.48). As the piece is moving in or out, crew members guide it with the tailing ropes.

D. Dead Hanging

Units may be dead hung from the grid. When necessary, distribute the load to more than one grid member (fig. 6.49). If bridling is not possible, pass the support line through the grid, and attach it to a piece of steel or wood that has been placed on the grid. This will help to distribute the load. Typically, a piece of 3″ pipe about 30″ long is used to support a chain hoist in this configuration.

E. Flying People

Flying people for the entertainment industry is a very special skill. If the goal of flying people is to just lift them up in the air, then mountain-climbing, rescue, or fall-protection techniques can be used. Contact experts in those fields for assistance. But if the goal is to create magic and give the illusion that a person is flying through space with no visible means of support, then the services, expertise, and special equipment of a company specializing in flying people are required.

The rigging equipment used for these special effects is not for sale from theatrical-supply houses. Much of it is designed and manufactured by these specialized companies. The equipment is designed to be used under very strict supervision. It is rigorously tested before installation and meticulously inspected before every performance. Because of the high degree of risk involved with flying people, only professionally manufactured equipment installed under the supervision of an experienced flying technician should be used.

Never use homemade equipment for flying people. Standard heavy-duty traveler-track hardware, blocks, and other components will not stand up to the complex dynamic forces of flying a person. A number of former Peter Pans and ex–Santa Clauses still suffer from the injuries they sustained while being flown on homemade equipment.

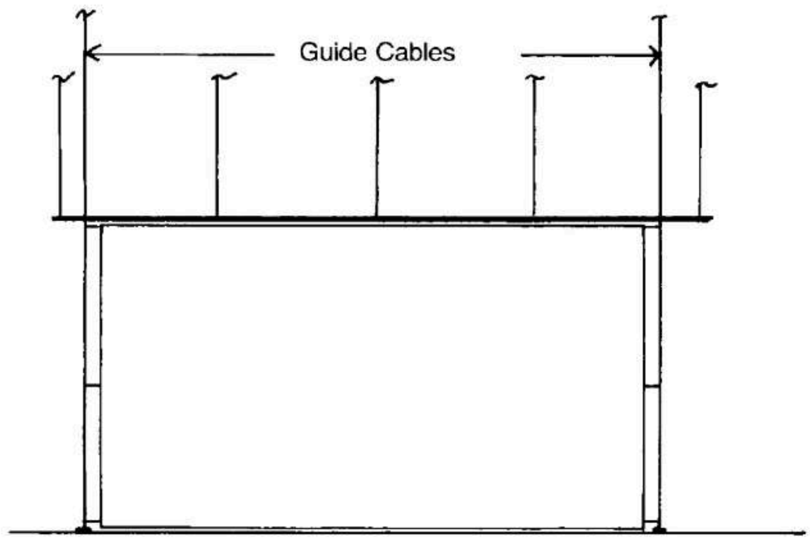


Fig. 6.47. Guide lines on a drop

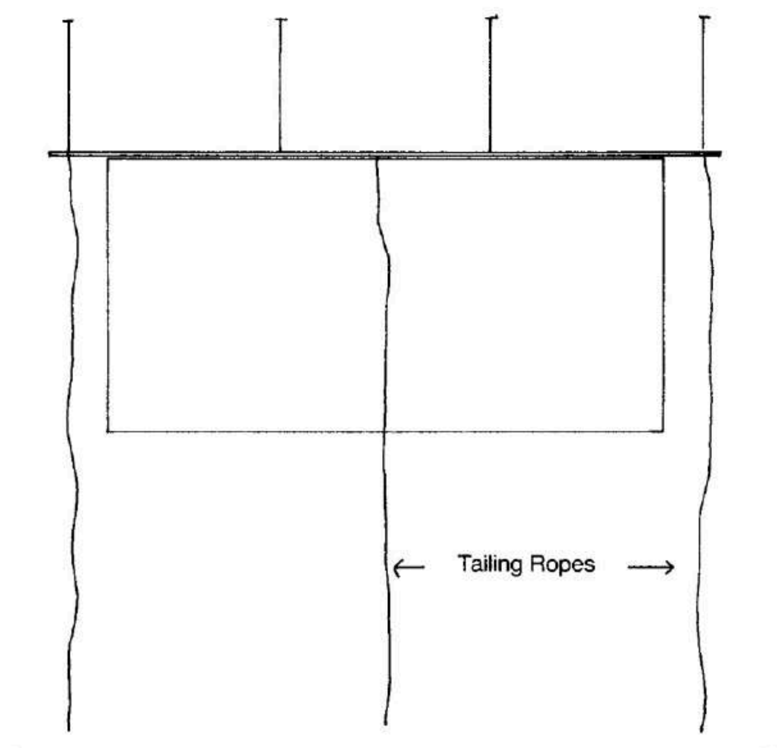


Fig. 6.48. Tag lines on a batten

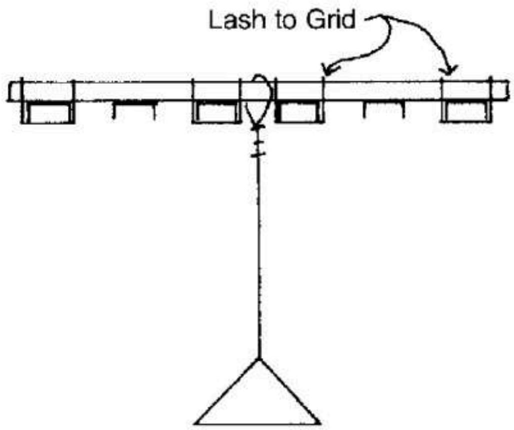


Fig. 6.49. Distributing a dead-hung load on a grid

Part 7 Inspection of Rigging Systems

7.01 Keep the Equipment in Safe Working Order

One of the questions asked after an accident is whether the rigging equipment has been inspected and maintained on a regular basis. *Rigging equipment is machinery and, as such, requires care and maintenance*. Because it suspends objects over the heads of people, it poses a high degree of risk to life and limb. Failure to care for rigging equipment is negligent behavior. Performing regular inspections and correcting problems as they occur are required procedures to ensure the safety of everyone working on the stage or under any suspended object.

7.02 Frequency of Inspection

How often you should inspect the rigging depends on the usage and degree of risk it poses.

A. Daily

Every time you use a line set, be aware of anything that sounds, feels, or smells out of the ordinary. As Wally Blount said when teaching classes on chain hoists for Columbus McKinnon, "If it looks bad, if it sounds bad, it *is* bad."

Always investigate a strange noise, feel, or smell to find out what is causing the problem. Then, if necessary, immediately repair it, or take the line set out of service. The problem may require canceling a performance, which can be a tough decision to make. Remember, *the show does* NOT *have to go on.* No performance is so important that a performer, crew member, or audience member be put at risk. If the rigging equipment is properly maintained, canceling a performance because of unsafe rigging should never need to happen.

B. Scheduled

Thorough inspections must be performed on a regular basis to find any worn parts or potential problems, and repairs should be done before parts break, pose a risk, or endanger a person. The more the rigging system is used, the more frequently the equipment needs to be inspected.

1. Every rigging system, regardless of number of performances, should have a thorough inspection at least once a year.

2. Equipment in busy roadhouses—those with several hundred performances a year—should be inspected more frequently. This is especially true if line sets have been taken out for a show and reinstalled. When line sets are hurriedly restored early in the morning after an all-night load-out, it is very common to miss something. Before the next show is loaded in, carefully inspect every restored set from arbor to batten.

3. Long-running shows with heavy rigging use require more frequent inspection. Thoroughly inspect a line set at least every 300 cycles. The number of cycles is the number of times the line set is used, not the number of performances. If a blackout curtain is run in and out 8 times during a performance, then the line set should be inspected every 38 performances.

4. Flying performers poses a much-higher degree of risk than almost any other type of flying. The entire flying-rig should be inspected before *every* performance.

7.03 Preparation

To inspect the rigging efficiently and thoroughly, take some time to prepare. It is important to have a guide to the inspection, a record of the inspection, and a record of any repairs that need to be made. Here are three documents that will help with the inspection process.

A. Rail Log

Memories fade, and people change jobs. The rigging equipment remains in the theatre, but no one can remember what was done when. A rail log is a record of anything and everything that happens to the rigging system.

A simple but effective way to create a rail log is to use a looseleaf notebook. On the first page, list the manufacturer, installer, and their contact information. Include the date that the equipment was installed. Using a separate sheet of paper for each line set, list every problem, repair, and component replacement that has affected that line set. Set up a separate section to list every inspection of the equipment. List the dates of the inspections and the names of the people conducting them.

The sheets can be prepared on a computer, but printing out hard copies to put in a binder makes them more accessible to the entire rigging crew. (The other advantage of paper records is that they do not crash.)

B. Repair List

As you inspect, create a list of the items requiring repair or replacement. Create a second list of those items not sufficiently worn to require immediate replacement but that bear watching. As items are repaired, enter the information on the appropriate line-set sheets in the rail log.

C. Inspection Checklist

The inspection checklist is a list of all of the components you are going to inspect. It is a guide to the inspection and helps ensure that you do not forget anything. See the sections below for sample check sheets.

7.04 What to Look For

You will look for typical things as well as unusual things. A good rule-of-thumb for an inspection is to remember what you may have learned watching *Sesame Street*, "One of these things is not like the other, one of these things just doesn't belong." Always look for the "something" that seems out of place. Several of the more typical things to look for are listed below.

A. Overstressed Components

When a component has been loaded beyond its elastic limit, it can become permanently deformed. Any deformed piece of hardware or support member is suspect. Radial pressure marks on loft blocks are also typical signs of overloading. See Section 4.06.A.

B. Impact Loading

Inspect the crash bars for broken wood fibers and bent steel angles. A severe crash could bend arbors and shock load lift lines, battens, and the entire system.

C. Fatigue

Fatigue is the equivalent of carpal-tunnel stress for rigging components. Repeated bending of wire rope over sheaves eventually weakens the wire, and the strands will begin to break. Bearings eventually wear and cause excessive play in sheave rotation on head blocks and loft blocks.

D. Loose or Missing Bolts

Look for loose and missing bolts.

E. Defective Hardware

Sometimes, defective hardware gets installed. Believe your eyes. If something does not look right, take a second look. When you install hardware, inspect it before you install it. You are the final inspector of all of the hardware that you install.

F. Corrosion

Look for signs of corrosion, or rust, on components. If you can rub it off with your fingers, it is surface rust. Sometimes, applying a coat of rust inhibiting paint or light oil will stop the oxidation from continuing. If you cannot rub it off with your finger, it may be penetrating rust, which can be very dangerous. As rust penetrates a component, the surface of the metal expands, causing microscopic cracks in it. Deeply corroded components should be replaced.

G. Incorrectly Installed Hardware

Examples of incorrectly installed hardware include running rope or cable over retainers, misaligned blocks and guides, improperly installed wire-rope clips, Nicopress sleeves, and any other type of termination. The list of incorrectly installed hardware is almost as long as this book. Use the other sections for reference.

H. Wrong Hardware for the Job

Some examples of the wrong hardware include undersized components, such as wire rope, incorrect sheave diameter, and incorrect sheave-groove size. All of these things will usually cause the hardware to wear out more quickly.

I. Organic Degradation

Organic degradation occurs any time you use natural-fiber products, such as Manila rope and cotton curtains.

7.05 Inspection Procedure

The inspection will be efficient and thorough if you start with a plan. The object of the inspection is to look at all of the parts and components of each line set. One way of doing this is to use a checklist roughly organized in the same order that you are going to perform the inspection. Sample checklists for different types of rigging systems are listed below.

It is critical that you operate each line set during the inspection to determine if there are any operational problems. Conduct the inspection when the theatre is quiet, so you can hear the sounds the rigging makes. Performing an inspection correctly takes concentration and the use of all of your senses. Begin at one end of the line sets, and work your way through the entire system. A good method is to begin with the battens. Use a Genie to access any battens that cannot be lowered in.

A word on using Genies—*always use the outriggers!* Every year, stagehands are injured—even killed—by Genie lifts tipping over. The decision not to use the outriggers is generally made in the name of convenience and speed. After the accident, it is obvious that the decision to hot-wire the outriggers or move the lift with someone in it was a stupid one. The erroneous assumption is that if the Genie falls, the stagehand can hold onto the batten until rescued. But think about it for a moment. If the Genie tips over, how will the rescue take place?

Before going up in the lift and volunteering to be pushed around, do a little self-test. Lower a batten so that it is just about 6″ higher than you can reach. Snub the hand line to the lock rail so it will not slip through the lock. Jump up and hang from the batten, and time yourself to see how long you are comfortable hanging there waiting to be rescued. More than likely, there will be a curtain hanging on the batten that will make climbing up on the batten difficult, if not impossible. You will probably decide at this point that your rescue plan is flawed. The few extra minutes using the outriggers and lowering the lift is time well spent.

After checking all of the battens that cannot be lowered, start letting in each line-set. If done with bare hands, you will be able to feel problems with the hand line before you see them in the dim light of the theatre (your hands may be uncomfortable, however). Your senses of touch and sound will tell you if the line set is running smoothly. On counterweight sets, as soon as you release the rope lock, the feel of it will indicate if it adjusted correctly. If the hand lines are Manila, your sense of smell will tell you if mildew or rot is in the rope.

Use the following checklists as a guide to creating venue-specific checklists. Add or subtract items to reflect the system under inspection. The details of how hardware should perform, be selected, and installed are in the other sections of this book. Section 7.04 lists typical things to look for with most of the components. Be familiar with these details before starting the inspection. Although every effort has been made to make the information in this book as complete and accurate as possible, you may come upon situations for which there is no reference. In that situation, contact a reputable rigging inspector, manufacturer, or installer.

7.06 Fire-Curtain-Inspection Checklist

A. Lower the curtain manually, or run it with the motor. It should seal to the floor with no gaps for smoke to leak through.

B. Perform a drop test by releasing the emergency-release line. It should come in smoothly and stay down.

C. Fire curtain
   1. Tears or holes
   2. Curtain guides
   3. Yield pad
   4. Top smoke seal

D. Batten
   1. Straight
   2. Level
   3. Terminations

E. Guides
   1. Loose cable or turnbuckles
   2. Loose or bent track

F. Arbor
   1. Lock plate
   2. Guides
   3. Terminations
   4. Rods

G. Arbor guide track
   1. Plumb
   2. Loose fasteners
   3. Arbor stops
   4. Terminations

H. Overbalance system
   1. Not installed
   2. Out of adjustment

I. Release system
   1. Inaccessible
   2. Inoperable
   3. Improperly secured
   4. Fusible links missing
   5. Signs missing
   6. Rate-of-rise device not working

J. Checking device
   1. Not installed

2. Inoperable
3. Leaking fluid
4. Improperly adjusted

For motorized systems, also check each of the following items to see that they are working properly.

K. Limit switches
   1. Up and down limits
   2. Overtravel limits

L. Emergency-stop button

M. Clutch-release device

N. Clutch adjustment (fire curtains)

O. Drive chain and sprockets

P. Motor brake

Q. Drum brake

R. Oil in gearbox

7.07 Hemp-System-Inspection Checklist

A. Batten
   1. Level
   2. Straight
   3. Terminations
   4. Splices

B. Rope
   1. Frayed or worn
   2. Rotting
   3. Out of balance

C. Loft blocks
   1. Mounting
      a. Base angles
      b. Clips
      c. J-bolts
      d. Support steel (bent, deformed)
   2. Sheave groove
      a. Size
      b. Excessive radial pressure
   3. Sheave bearings
   4. Side plates

5. Retainers
6. Alignment

D. Head blocks
   1. Mounting
      a. Base angles
      b. Clips
      c. J-bolts
      d. Support steel (bent, deformed)
   2. Sheave groove
      a. Size
      b. Radial pressure
   3. Sheave bearings
   4. Side plates
   5. Retainers
   6. Alignment

E. Pin rail
   1. Mounting bolts
   2. Rail
      a. Wood split
      b. Bent
   3. Pins
      a. Wood worn from spinning
      b. Bent
      c. Missing

F. Sandbags and weight pipes
   1. Holes or leaking
   2. Missing hooks

G. Sundays
   1. Knots secure
   2. Kinked
   3. Proper size

H. Trim clamps
   1. Missing bolts
   2. Missing jaws
   3. Cracked casting

7.08 Counterweight-Inspection Checklist

A. Batten
   1. Level or bent
   2. Size

3. Splices

B. Wire rope
   1. Type and size
   2. Kinked
   3. Worn, abraded, broken wires
   4. Bird cage opening up
   5. Rubbing on obstructions
   6. Corrosion

C. Terminations
   1. Wire-rope clips
   2. Nicopress sleeves
   3. Trim chains
   4. Turnbuckles
   5. Batten clamps

D. Lock rail
   1. Mounting bolts
   2. Uprights
   3. Diagonal braces
   4. Cardholders

E. Rope locks
   1. Housing
   2. Handles
   3. Jaws
   4. Mounting bolts (all 4)
   5. Adjustment

F. Hand line
   1. Terminations
   2. Undersize
   3. Worn
   4. Rot

G. Tension blocks
   1. Sheave
   2. Bearings
   3. Side plates
   4. Guides
      a. Missing bolts
      b. Bent
      c. Will not move
      d. Moves too freely

H. T-bar guides
   1. Missing bolts
   2. Bent
   3. Bad splices
   4. Horizontal supports
   5. Wall knees

I. Arbor stops
   1. Broken wood
   2. Bent angle supports
   3. Missing bolts
   4. Missing neoprene pads
   5. Incorrect position

J. Loft blocks
   1. Mounting
      a. Base angles
      b. Clips
      c. J-bolts
      d. Support steel (bent, deformed)
   2. Sheave groove
      a. Size
      b. Radial pressure
   3. Sheave bearings
   4. Side plates
   5. Retainers
   6. Alignment
   7. Idler pulleys
   8. Sag bars

K. Mule blocks
   1. Mounting
      a. Base angles
      b. Clips
      c. J-bolts
      d. Support steel
   2. Sheave groove
      a. Size
      b. Radial pressure
   3. Sheave bearings
   4. Side plates
   5. Retainers
   6. Alignment

7. Idler pulleys
8. Sag bars

L. Head blocks
   1. Mounting
      a. Base angles
      b. Clips
      c. Support steel (bent, deformed)
   2. Sheave groove
      a. Size
      b. Radial pressure
   3. Sheave bearings
   4. Side plates
   5. Retainers
   6. Alignment

M. Arbor
   1. Guides
   2. Rods
   3. Rod nuts
   4. Bottom plate
   5. Top plate
   6. Terminations
   7. Lock plate and collars
   8. Spreader plates
      a. Insufficient quantity
      b. Not used properly

7.09 Motorized-Inspection Checklist

A. See the counterweight section above (7.08) for rigging components.

B. Mounting
   1. Mounting bolts
   2. Support steel

C. Motor—is bearing lubricant required?

D. Gear reducer
   1. Check oil
   2. Leaks
   3. Change oil

E. Pillow blocks
   1. Housing

2. Bearings
3. Lubrication (do not overlubricate)

F. Motor brake
1. Worn shoes
2. Adjust release

G. Drum brake

H. Limit switches
1. Primary limits
2. Overtravel limits

I. E-stop
1. Check connection. The E-stop should disconnect power to the winch, not low-voltage control power. If it does not disconnect power to the winch, there may be a code violation. See Section 5.04.E.3.
2. Test the switch.

J. Overload indicator

K. Slack-cable switch

L. Other control devices

7.10 Installation Checklists

This section is intended as a guide for installers and makes no claim to being complete. You may photocopy the checklists or use them as guides to create your own job-specific checklists.

The goal for installing the rigging system should be a *no note punch list*. Redoing parts of the installation is time consuming and expensive. Doing it right the first time saves the installer time and money and produces client confidence and satisfaction.

Usually, the installer hires a local labor force, frequently made up of people with no experience installing stage rigging and no idea how the equipment will be used after it is installed. Following these checklists will help ensure that rigging is installed properly and safely.

Set an attitude for excellence. By your tone and actions, you convey to the crew what kind of work you expect from them. Set your sights high. The crew will never perform better than your expectations.

One of the most common errors in installations is improper wire-rope terminations. To avoid having a termination fail or having to redo the terminations, follow section A, Termination Instructions.

A. Termination Instructions

1. Wire-Rope Clips

a. Show the installers the proper amount of turn-back.
b. Show them which side of the cable the U-bolt goes on.
c. Devise a method to properly tighten the clips. See Section 6.03.A.1 and tables 6.2 and 6.3 for the proper torque rating for various-size clips.

2. Nicopress Sleeves

a. Verify the proper size and type of sleeve for the job. Usually, only copper or plated copper sleeves are used. Aluminum sleeves should not be used for overhead installation.
b. Check the tool and the instructions to determine how many crimps are required. See the tables in Section 6.03. B.1 and tables 6.4, 6.5 and 6.6 on Nicopress fittings.
c. Do a test sleeve before starting to be sure the tool is properly adjusted.
d. Give the installers a gauge, and show them how to use it.
e. Check the first few sleeves to be sure they are correct.
f. As the installation progresses, periodically check the sleeves to see that the tool has not gotten out of adjustment. Have the installers tell you when the tool needs adjustment. Improperly crimped sleeves are one of the most common problems on new installations, and recrimping them is expensive and time consuming. If the sleeves are not crimped properly and the wire rope pulls out, the installation company owns the liability.

B. Counterweight-System Checklist

1. Run each batten to low trim. Operate the line sets before any curtains or other objects are attached to the battens.

__ Check the rope lock for proper adjustment. It should not bind the rope during operation.
__ Close the lock and make sure the rope will not pull through.
__ Run each batten all the way in to check for smooth operation.

__ Listen for strange noises and find the cause.
__ Fix any arbor that is binding on the T-bars.

2. While the battens are down, do the following.
   __ Check to see that the lift lines are in the correct position on the batten.
   __ Check to see that the trim chains are not crossed.
   __ Check to see that the wire-rope clip quantity, spacing, and torque are correct.
   __ Check to see that the ends of wire rope are either taped or heat-shrunk.
   __ Do a random check of Nicopress sleeves with gauge.
   __ Check to see that all turnbuckles are moused.
   __ Check to see that all shackles are tightened and moused.
   __ Check to see that all safety bolts have washers and Nylock nuts.
   __ Check batten splice-bolts.
   __ Check to see that all battens are level and straight.
   __ Check batten end-caps.

3. At the lock rail, do the following.
   __ Check all mounting bolts and welds. Check bolts for tightness.
   __ Check all rope-lock mounting bolts.
   __ Check that there are no cracks in the tops of the rope lock housings.
   __ Check that tension blocks float.
   __ Check that hand line is run properly around tension blocks.
   __ Hit T-bars with the heel of your hand, and listen for loose bolts.
   __ Check bottom arbor stop.

4. On the loading bridge or grid, do the following.
   __Check that arbor-rod nuts on underside of arbor top are tight.
   __ Check hand line and wire-rope terminations.

5. Check the head blocks.
   __ Check that all rope and cable are inside the retainers.
   __ Check wire-rope alignment.

6. Check the loft blocks.
   __ Check mounting bolts.
   __ Check that cable is inside the retainers and idlers.
   __ Check that cable is not rubbing on side plates.

7. Raise the battens. Stop the arbors high enough so that you can easily see the bottom of the arbors. Have three or more people spread out on the grid in a line near the set to be run. Have someone operate each line set and run the battens back up to high trim. Listen for strange noises and determine their cause. Do this for each line set.

After all the sets have been run, go to one side of the grid, and sight down the line of lift lines for each line set. This checks the alignment for the loft blocks for each line set.

__ Check to see that all idlers are turning and all cables are in the proper groove.
__ Check to see that all cables are above the sag bars.
__ Check all lift lines to be sure they are not cutting into grid hangers, sprinkler pipes, multi-cable, or other obstructions.

8. While all arbors are down, do the following.

__ Hit the T-bars at the loading bridge level, checking for loose bolts.
__ Check the top arbor stop.
__ Using a flashlight, look up from the loading bridge to check that all head block mounting bolts have been installed.
__ Check all electric-cable pickups.
__ Check all orchestra-shell and lighting sets to be sure additional arbor stops have been installed where needed.
__ Check hand-line terminations on arbor bottoms.
__ Check that all spreader plates are on top of the counterweights and not marking pipe weight.
__ When loading the arbors after hanging curtains and lighting battens, be sure the spreader plates are properly positioned.

C. Motorized-System Checklist

1. Operate each winch before any curtains or other objects are attached to the battens. Listen. Lower the battens to low trim. Find the source of any strange noise.

__ Check for proper fleet-angle for each cable coming off the drum.
__ Check winch-mounting bolts and support steel.
__ Check fleet angle for each loft block.

__ Check to see that the arbor does not bind on motorized counterweight sets.
__ Check all limit switches.
__ Check overtravel switches by tripping them and trying to move the batten in the opposite direction.
__ Check all E-stops.

2. When the batten is down, follow the appropriate parts of the counterweight checklist in Section 7.10.B.

D. Hand-Winch Checklist

1. Operate each hand winch before any curtains or other objects are attached to the batten. Lower the battens to low trim. Listen for any strange noise.
__ Check clew travel and guides.
__ Check terminations at clew.
__ Check winch mounting bolts.

2. See above counterweight section for batten, wire rope terminations, loft, and head-block checklists.

E. Fire-Curtain Checklist

1. Operate the fire curtain manually, either by hand or with the up and down push-button controls if it is motorized. Bring it all the way in.
__ Check for proper balance with manual operation.
__ Check yield-pad seal at floor.
__ Check smoke seal at top of curtain.
__ Check curtain-guide–system for smooth operation.
__ Check arbor for smooth operation.
__ Check arbor stops on lattice track.
__ Check lattice-track mounting bolts.
__ Check arbor for loose bolts.
__ Check arbor spreader plates and lock plate.
__ Check cable terminations at arbor.
__ Check mousing on turnbuckles.
__ Check mousing on shackles.
__ Check smoke pockets for gaps between the pocket and the wall.
__ Check lift lines on batten for position.
__ Check lift line terminations at batten.

__ Check safety-stay–chain terminations at grid and batten.
__ Check all bolts on chain to see that they have two flat washers and lock nuts.
__ Check hand-line tension.
__ Check tension-block mounting bolts and operation.
__ Check to see that hand line does not run over head- and tension-block retainers.
__ Check head-block mounting and operation.
__ Check lift lines to be sure they are not cutting into loft-block retainers, side plates, or other obstructions.
__ Check loft-block–mounting bolts and operation.
__ Check fire-line–pulley operation and mounting.
__ Pull out curtain. It should be properly balanced and able to be pulled out with a reasonable amount of force.

2. Operate fire-curtain emergency-release system on both sides of the stage. The curtain should come in within 30 seconds and stay in with no gaps between the yield pad and the floor. Most codes require the curtain to take at least 5 seconds to travel the last 8′ before hitting the floor.

__ Check that fire-line release signs are installed.
__ Test rate-of-rise release system.
__ Check deceleration device for proper adjustment.
__ Check overbalance system.

3. For motorized systems, run the curtain from all control stations.

__ Check winch mounting bolts.
__ Check push-button controls.
__ Check E-stop.
__ Check clutch-reset operation.
__ Do a test drop from both sides of the stage.

F. Brail–Fire-Curtain Checklist

1. Lower the fire curtain.

__ Check yield pad seal at floor.
__ Check smoke seal at top of curtain.
__ Check curtain-guide system for smooth operation.
__ Check smoke pockets for gaps between the pocket and the wall.
__ Check lift-line position on batten.
__ Check lift-line terminations at batten.
__ Check safety-stay-chain terminations at grid and batten.

__ Check all bolts on chain to see that they have 2 flat washers and lock nuts.
__ Check all turnbuckles to make sure they are moused.
__ Check all shackles to make sure they are tight and moused.
__ Check head-block mounting and operation.
__ Check head blocks to be sure that all cables are within spacers.
__ Check loft-block mounting bolts and operation.
__ Check lift-line travel to be sure that lines are not cutting into side plates or retainers.
__ Check clew travel.
__ Check clew guide-cables.
__ Check wire-rope terminations at clew.
__ Check winch mounting bolts.
__ Check mounting bolts on fire-line pulleys.
__ Check fire-line pulley operation and mounting.

2. Test the curtain-release system by operating it from both sides of the proscenium. The curtain should come in within 30 seconds and not bounce. Most codes require the curtain to take at least 5 seconds to travel the last 8′ before hitting the floor.

__ Verify that the fire-line release signs installed.
__ Test rate-of-rise release system.
__ Check hydraulic speed governor for leaks and proper adjustment.
__ Listen for any strange noise, and locate its source.
__ Check trigger-release system.
__ Check brake-line counterweight travel.
__ Check mounting bolts on round weight guard.

Part 8 Operation and Training

8.01 ETCP Certification

In the fall of 2005, the first national certification examination in the entertainment industry was given to riggers (arena) and flymen (theatre). The examination was part of the Entertainment Technician Certification Program (ETCP), a voluntary process that grants recognition to individuals who have demonstrated certain abilities, skills, and knowledge as riggers and flymen. The ETCP is widely supported and funded by many groups and individuals in the entertainment industry, including the Alliance of Motion Picture and Television Producers (AMPTP); Canadian Institute for Theatre Technology (CITT); Clear Channel; International Alliance of Theatrical Stage Employees (IATSE); International Association of Assembly Managers (IAAM); InfoComm International; League of American Theatres and Producers; Production Resource Group (PRG); Themed Entertainment Association (TEA); and United States Institute for Theatre Technology (USITT). The ETCP is under the supervision and auspices of the Entertainment Services and Technology Association (ESTA).

The tests can now be taken at various testing centers throughout the country. Applicants must prove that they have had a certain amount of work experience as riggers or flymen before they are eligible to take the test. It is the goal of the industry to eventually have a certified rigger as a lead in every major venue in North America. Contact ETCP on its Web site (http://etcp.esta.org) for additional information about the test.

8.02 Venue-Specific Training

All of the flymen in a venue need not be certified by the ETCP. However, the rigging equipment in each venue is unique, and operating it safely requires *venue-specific training*. Even though the hardware in two different venues may be from the same manufacturer, the rigging may operate differently due to the unique structure of each theatre. To ensure that the crew in your theatre can operate the rigging system safely and efficiently, a training program for your venue should be set up and implemented.

Creating a training program sounds daunting. The suggestions that follow may help to take some of the anxiety out of the process. The list is a suggestion only. Add items not listed that pertain to your venue, and delete items that are not relevant.

First, determine where the specific work stations are. Then decide what job skills are needed to work at each station, and list those job skills. Try to limit the checklist to no more than the two sides of a sheet of paper. Put a line on the top of the checklist for the trainee's name. As the person demonstrates knowledge and proficiency for each item, check it off. When all the items are checked, the person should be a proficient flyman for that venue.

8.03 General Subjects for All Rigging Systems

Every person working with the rigging system on a regular basis should be familiar with the following information. Take time to acquaint the new person with this information. You might consider assigning new hires the responsibility for keeping the rail log and writing the line set schedules and cue sheets to help them really learn your system.

A. Paperwork

1. Rail log. See Section 7.03 for a description of a rail log. Every person working with the fly system on a regular basis should be familiar with the contents and location of the rail log.

2. Inspection reports. These should be available to all regular hands so they can quickly determine if a strange noise or an odd-looking piece of hardware has been noted before.

3. Line set schedule. This is a listing of all of the line sets, their location from the plaster line, their use, and their capacity. This list serves as a reference for what can be hung for a show and where. A line-set schedule is created for each production.

4. Cue sheet. It is a good idea to have a standard way of writing cue sheets for every show. All rail operators should be familiar with the format for your theatre.

5. Repair and project list. Keep an ongoing list of items that require repair, as well as other projects to maintain and improve the operation.

6. Hardware shopping list. Keep an ongoing, written list of items that need to be purchased. Teach the new hires the pet names for things that you use so that they will know what you are talking about.

B. Rail-Operation Checklist

__ 1. Rope-lock adjustment
__ 2. Moving the tension block
__ 3. Adjusting the hand line
__ 4. Identifying the line sets on the rail
__ 5. Verbal commands/communication
__ 6. Order of loading and unloading
__ 7. Securing the hand line for loading and unloading

C. Operating a Line Set

1. Cue sequence
2. Cue sheet
3. Setting trim marks
4. Pull line in and out to trim marks

D. Loading-Bridge Procedure

1. Commands, when to load and unload
2. Responses to commands

3. Reaching the arbor
4. Lock-plate and spreader-plate use
5. Loading weight
6. Unloading weight
7. Stacking weight
8. Fall-protection system

E. Mid-Rail (Jump-Rail) Operation

1. Rope-lock operation (open locks at floor)
2. Tag lines on arbors
3. Setting trim marks
4. Loading and unloading weights
5. Hemp-set operation (see section 8.03.K)

F. Motorized Rigging Operation

1. Visual contact or spotters
2. Control-panel operation
3. Limit switches
4. E-stop
5. Trim marks or position indicator
6. Special controls

G. Runaway Procedure

(See also section 4.11.C.)

1. Shout a warning.
2. Get out of the way, and do not try to stop the line set.
3. Leave the stage.
4. Drop and cover on the loading bridge.

H. Knot Tying

1. Bowline
2. Clove hitch
3. Figure-8
4. Half hitch
5. Snub or prusik

I. Fire-Curtain Operation

1. Manual operation

2. Emergency release
3. Automatic release
4. Fire alarm
5. Resetting curtain

J. Grid Operation

1. Kicking loft blocks
2. Using diverter rollers
3. Spot-line rigging
4. Setting up chain hoists

K. Hemp-Set Operation

1. Attaching load to batten
2. Removing loads
3. Bagging a set
   a. Using sundays
   b. Using trim clamps
4. Tying off on the rail
5. Setting high and low trims
6. Show time operation

8.04 Keep Your Concentration

A part of any rigging-competency training program should include training in developing good work habits. The fourth and final K—*Keep your concentration*—is a learned skill. Insisting that the flyman operate the rigging for a number of performances without an error before certification is one way of accomplishing this. One facility requires 100 consecutive perfect shows before issuing a competency certificate. If the flyman blows a cue on the 99th show, it's back to the beginning of the count for that crew member. This is a true test of keeping concentration while running a show.

Part 9 Fire Curtains

9.01 Introduction

A proscenium theatre of a certain size generally requires a *fire curtain* or, as it is referred to in the various codes, a *proscenium curtain*. The primary purpose of the fire curtain is to contain an onstage fire (and its resultant smoke) long enough for the audience to evacuate safely. The fire curtain has been a standard fire-protection device in theatres for more than 100 years, but the sad reality is that many curtains in existing theatres do not work. *If a theatre has a fire curtain, it must work!* If it does not work, the theatre can be closed for failure to comply with the fire code. Ongoing discussion continues in the entertainment industry about the need to revise codes to provide for alternate fire-protection systems, but in the meantime, this book focuses on types of fire curtains that are currently in use.

A specific fire curtain must comply with the governing code at the time of its installation. However, if architectural modifications have been made to the stage, the fire curtain most probably will be affected by newer codes.

9.02 Codes and Regulations

The design and operation of fire curtains are governed by a number of codes.

A. Building Codes

Until the year 2000, several building codes were used in the United States, including the Uniform Building Code (UBC), the Standard Building Code (SBC), and Building Officials and Code Administrators code (BOCA). The UBC and SBC were similar, both giving specific requirements as to how the fire-curtain system was to be constructed. The BOCA code differed from the other two in a number of ways, and the differences caused so many problems that a new code, the International Building Code (IBC), was written to replace them all.

The IBC is a general performance code and does not go into detail of how the fire curtain is constructed. It states, "The curtain shall be designed and installed to intercept hot gases, flames and smoke, and to prevent a glow from a severe fire on stage from showing on the auditorium side for a period of 20 minutes" (section 410.3.5). It also gives test criteria for the curtain fabric. Individual states and municipalities are free to adopt any, or none, of the codes, and to modify them as they see fit.

All building codes require the use of a fire curtain in proscenium theatres meeting certain criteria. Older codes specified the type and size of theatres that required fire curtains, how the curtains should operate, and criteria for the materials from which they were made. Over the years, as codes were revised and changed, design criteria have also changed. Main operation parameters have not changed, however.

1. The curtain must prevent smoke, hot gases, and flame from reaching the audience.
2. The curtain must be able to be closed manually. This can be accomplished by pulling a hand line or operating the controls on a winch-driven system.
3. The curtain must close automatically and require no electrical power when fire-detection devices are activated.

4. The curtain should close within 30 seconds but take at least 5 seconds to travel the last 8′.
5. Scenery and other items must not be placed so as to prevent the curtain from closing, unless the local authority having jurisdiction (AHJ) has given permission (see 9.02.C below).
6. Most fire curtains have some sort of emergency-release device to quickly lower the curtain, even though not specifically required in the new code.

The various fire-curtain systems are described in detail in sections 9.03, 9.04, 9.05, and 9.06.

The fire curtain may also be designed to operate in conjunction with other fire-and smoke-control systems, such as a smoke-evacuation system, or a sprinkler system over the stage. Those systems are beyond the scope of this book.

B. Life Safety Code

The National Fire Protection Association (NFPA) publishes a number of codes including NFPA 101, Life Safety Code. The description of the design and operation of the fire curtain is more detailed in this code than in other building codes. One major difference is cited in section 12.4.5.7.2-G of the 2003 NFPA 101: "All proscenium curtains shall be in the closed position except during performances, rehearsals, or similar activities." That sentence is restated in section 13.4.5.7.4.

Few theatres follow this rule for two reasons: (1) water-deluge curtains and brail curtains do not lend themselves to being closed on a daily basis, and (2) most theatres with straight-lift curtains are unaware of this code requirement. One of the main advantages of keeping the fire curtain closed is to limit smoke damage to one side of the curtain in case a fire occurs when the stage is not in use. Another advantage to closing the curtain daily is to exercise the hardware regularly, ensuring that the curtain will at least operate manually.

C. Authority Having Jurisdiction

Because there is no national enforcement agency for the codes, enforcement is by local jurisdiction, in the hands of the local inspectors referred to as the *authority having jurisdiction* (AHJ). Unfortunately, many of the local inspectors are not aware of the codes governing fire curtains, so they neglect to inspect them. This does not relieve the theatre from the responsibility of having a working fire curtain that complies with the local regulations.

9.03 Water Curtains

Two types of water curtain devices used to separate the stage from the auditorium in case of fire are (1) water-deluge system and (2) water-spray system. Both devices release large quantities of water on the stage at the proscenium line. Accidental activation of the devices can cause substantial water damage, so insurance premiums may be affected by the presence of a water-curtain system in the theatre. If you are contemplating installing a water curtain system in your theatre and are not self-insured, check with your insurance company to get a premium estimate before making a final decision.

A. Water-Deluge System

The *water-deluge system* has open sprinkler heads, or water cannons, that dispense a large volume of water, creating almost a wall of water all across the proscenium opening. Working in conjunction with smoke hatches or other types of smoke-evacuation systems, the deluge system prevents fire and smoke from crossing the opening. This system is a good choice where it is impossible for a curtain to close off the proscenium opening due to architectural design, or when scenery or other objects must block the curtain travel.

B. Water-Spray Curtain

The *water-spray curtain* requires a noncombustible, opaque, fabric curtain to close automatically without power. A fixed-spray system that soaks the fabric is automatically activated and must be capable of keeping the fabric wet for at least 30 minutes.

C. Maintenance and Testing

The water-flow systems, including activation devices, sensing devices, deluge valves, and alarms, should be tested annually by a qualified person. This can be done without turning on the water. The automatic mechanical operation of the fabric curtain should also be regularly tested but only after determining that the water-spray activation system has been bypassed.

9.04 Fabric Curtains

Traditional fire curtains are made from fabric and operate without a water spray. There are several types of fabrics, and some versions of the codes require the curtain to be framed if it is over 50′ wide or 30′ high.

A. Types of Fabrics

1. Asbestos

Until the 1970s, asbestos was the traditional fabric used for fire curtains. The asbestos fibers were encapsulated to prevent them from becoming airborne. It was also common practice to paint the fire curtain with a noncombustible paint that further encapsulated the asbestos. An asbestos curtain usually poses no danger unless the fabric is torn or the curtain rubs against the wall or smoke pockets when it is operated. Quite often the stuff you see floating in the air when the curtain runs is dust and contains no asbestos fibers. If you are in doubt, contact an independent testing laboratory to have the curtain tested.

2. Fiberglass

Currently, most fire curtains are made from fiberglass. Many are coated with a vermiculite slurry during manufacturing. Painting the curtain or getting it wet may remove the coating. Painting it voids the certified listing of the curtain. If the curtain has gotten wet or been painted, contact the manufacturer or installer.

B. Types of Curtains

There are several types of construction for fabric fire curtains. The most common types are brail and straight-lift curtains.

1. Brail Curtains

Brail curtains are used when there is not sufficient room over the stage for a straight-lift curtain (fig. 9.1). The lift lines run through rings or battens on the curtain to gather it up like a furled sail on a ship. As the curtain is raised, it becomes heavier and heavier,

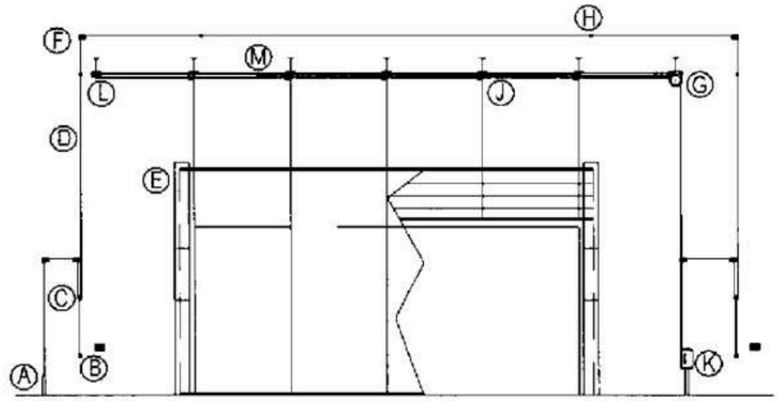


Fig. 9.1. Brail curtain schematic. Courtesy of Dan Culhane and SECOA

A - ROUND WEIGHT AND GUARD
B - RING AND PIN STATION WITH SIGN
C - 4" FLOATING PULLEY
D - RELEASE LINE
E - SMOKE POCKET
F - MULE BLOCK
G - HEAD BLOCK
H - FUSIBLE LINK RELEASE
J - LOFT BLOCK
K - BRAIL WINCH
L - MULE BLOCK
M - HORIZONTAL BRAIL CLEW

thus making it almost impossible to raise by hand. Typically, a hand-operated *brail winch* is used to lift and control the curtain operation.

The brail-winch device consists of several parts, including a gear reducer and a chain drive that rotates a drum with a single cable attached (fig. 9.2). This cable goes to a clew that attaches

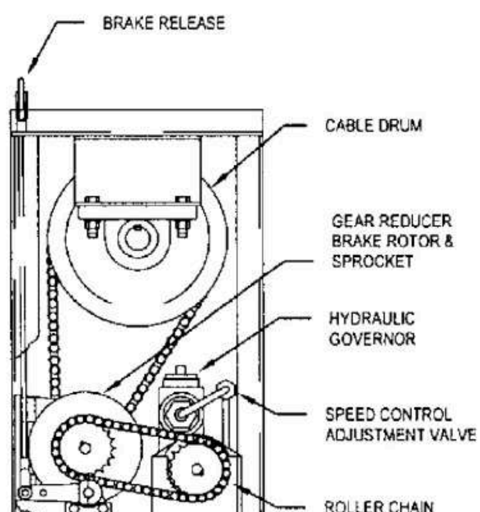


Fig. 9.2. Brail winch. Courtesy of H & H Specialties, Inc.

to the lift lines. A brake locks the drum and keeps it from turning. The operation arm of the brake is held in the *on* position by the curtain-release line. When the line is released, the brake lets go and the curtain falls. A small, closed-loop hydraulic governor is connected to the drum by a roller chain. The hydraulic governor controls the descent of the curtain. A valve in the hydraulic line controls the rate of flow of the hydraulic fluid and thus controls the speed of the drum as it unwinds.

When resetting this device, be sure to turn the hand crank in the proper direction to raise the curtain. If it is turned in the other direction, the cable will wind in the wrong direction on the drum. Then, when the curtain is released, oil will flow backwards through the hydraulic governor and cause the curtain to rapidly descend completely uncontrolled. The brail curtain is difficult to raise and therefore not practical to be closed on a daily basis.

2. Straight-Lift Fire Curtains

Most fire curtains are the straight-lift type (see figs. 9.7, 9.11, and 9.14). The straight-lift curtain is used when there is sufficient height over the stage to store the curtain in the open position. If the curtain is not framed, it usually is operated manually. In some cases unframed curtains are operated with a winch, but all framed curtains are heavy enough to require a winch.

C. Curtain Construction

Fire curtains are constructed to prevent smoke and hot gases from crossing the proscenium line and entering the auditorium, which can impede the audience's evacuation from the premises. The curtain fabric must meet the code requirements for flame retardancy and have the required perimeter devices attached to contain the smoke and gases.

1. Smoke Seal

The *smoke seal* is a two-part device at the top of the curtain. One part is attached to the wall above the proscenium. The second part is attached to the top of the fire curtain. When the curtain is in the down position, the two parts of the seal interlock and prevent smoke from passing over the top of the curtain.

2. Yield Pad

The *yield pad* is a thick, soft pad of fireproof material sewn into the bottom of the curtain. The curtain has a heavy pipeweight in the bottom pocket above the pad. When the curtain is lowered to the floor, the weight of the pipe pushes down on the yield pad and creates a seal to prevent smoke from passing under the curtain. Obviously, in order for this to work, the bottom of the curtain must be level with the floor, and the curtain must close all the way. Any obstruction such as scenery, electric cords, props, musical instruments, or anything else that prevents the curtain from sealing to the floor is a violation of the fire code.

3. Smoke Pockets and Curtain Guides

The steel pockets on the sides of the proscenium in which the edges of the curtain run are called *smoke pockets*. Inside the smoke pockets are either guide tracks or taut steel cables that run from the floor to the top of the pockets. Guides on the sides of the curtain fit into either these cables or the tracks. Smoke pockets and side guides keep smoke and heat pressure from blowing the sides of the curtain out into the house, thus preventing smoke from passing around the sides of the curtain. There should be no obstructions inside the smoke pockets, such as sound or electric cables.

9.05 Operation Devices

If fire curtains were operated only manually, rigging them would be as simple as running a standard counterweight set. Requiring the fire curtain to close automatically if fire is detected backstage makes its operation a good deal more complicated. Generally, the curtain is either overweighted and held open by an automatic-release device, or the release device causes the curtain to be overweighted and come in. A number of the release devices are discussed below.

The codes do not specifically detail the precise construction of fire-curtain-operation devices. Their design has been left to the rigging manufacturers, and consequently, many different systems exist. It is impossible to discuss them all, but the most common types are covered here.

A. Release Lines

All fire curtains have release-line systems that serve two purposes: (1) they are part of the primary automatic-release mechanism for lowering the fire curtain, and (2) they provide a quick way to manually release the fire curtain from either side of the proscenium in case of an emergency. You can use the release system to test the automatic drop of the curtain. Typically, the release line is anchored to one side of the proscenium about 5′ above the floor and runs up the side of the proscenium, across the top of the stage slightly above the grid, and down the other side of the proscenium to another termination. Various devices are installed on the release line to hold the fire curtain open. Some release systems include a weight device in the release line to provide enough tension for it to work properly (see item A in fig. 9.1.) The line contains various devices that automatically brake it in case of fire, releasing tension, and allow the curtain to come in by itself. These devices are discussed later in section 9.05.C.

B. Manual-Release Devices

In older systems, the release line, called a *cut line*, is made from Manila rope and tied to anchor points on either side of the stage. A knife, or other type of cutting device, should be chained to the wall near the termination with a sign that reads "In case of fire, cut rope." Often, the knives have disappeared or are so dull that they cannot cut the rope. If you have one of these cut lines in your theatres, replace it with a release device that does not require a knife. Some of the newer devices are described under 1. ring-and-peg release, 2. pull-pin release, and 3. latching release device.

1. Ring-and-Peg Release

Replacing the release line with ⅛″ wire rope eliminates the problems associated with organic rope. Because knots do not work well in wire rope, a different type of release device must be used. The simplest device is the *ring-and-peg release* (fig. 9.3). The end of the release line is attached to a steel ring with a thimble and Nicopress sleeve. A steel peg is welded to a plate and bolted to the wall. The ring is hooked over the peg. The wire rope has the usual automatic-release devices on it. To manually release the curtain, the ring is pulled off the peg.

2. Pull-Pin Release

The *pull-pin release* uses a pair of steel plates with holes drilled in them (fig. 9.4). The ring is brought down between the steel plates, and a pull-pin is inserted into the holes in the plates. Pulling the pin releases the release line.

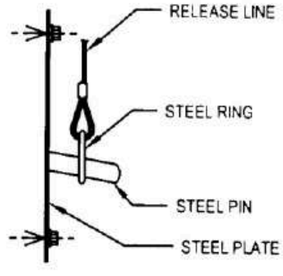


Fig. 9.3. Ring-and-peg release

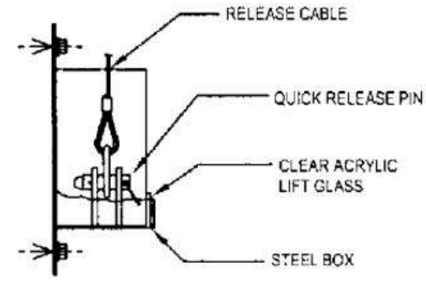


Fig. 9.4. Pull-pin release. Courtesy of Dan Culhane and SECOA

This type of release can be open construction or enclosed in a box with a glass faceplate. The open construction, like the free-end ball and the ring and peg, can be prone to unwanted release. They are not recommended for schools. Enclosing the pull-pin release with a glass-plate cover reduces the chance of unwanted release, because the glass must be broken in order to reach the pull pin. Instead of a knife, a small hammer or steel bar is tethered to the box for breaking the glass. The glass can be removed with a screwdriver for testing.

3. Latching Release

A third type, the *latching release* device, has a hinged release held in place by the glass faceplate. When the glass is broken, the latch is free to pivot up, and the line is released. Again, remove the glass with a screwdriver to test.

4. Signage

Regardless of the type of release employed, a wall-mounted sign should be at each release station indicating the type of action required, and the area around the releases must be kept clear. If breaking glass is a required part of the release, teach the crew members to shield their eyes.

C. Automatic-Release Devices

The codes require that the fire curtain will automatically close in case of a fire. This action is accomplished by installing devices that automatically open the release line when the temperature reaches a certain point backstage.

1. Fusible Links

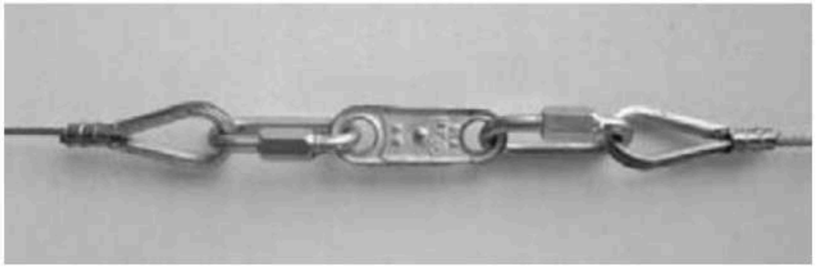


Fig. 9.5. Fusible link. Courtesy of Dan Culhane and SECOA

The oldest device is a *fusible link* (fig. 9.5). This consists of two pieces of metal held together with a solder that will melt at or above a certain temperature. For theatrical use, that temperature is usually between 135° and 165° F. When the ambient temperature reaches the critical point, the solder melts, and the links separate, effectively dropping the fire curtain. Typically there are six fusible links in the release line, two along the top and two on both sides of the stage. There are several limits to this type of link. First, the heat must be generated near the proscenium to trigger them. Even if there is a lot of smoke, the fusible links may not get hot enough to part if the fire starts upstage. Second, the solder on these devices deteriorates with age. Fusible links have been known to open and lower the curtain at inappropriate times. The manufacturer recommends replacing them annually. It is a good idea to have some spare fusible links on hand.

The links typically found in the theatre are rated for about 30 lb. of tension. Higher load ratings are available. If the links are breaking due to overstress, use two or more together. Devices are also available that provide a mechanical advantage to increase the holding power of the fusible link.

2. Electrothermal Links (ETL)

Electrothermal links operate by having an electric current melt the solder holding the link together (fig 9.6). The links are activated through the alarm system, which receives a signal from rate-of-rise heat sensors deployed throughout the stage. If the sensors determine a temperature rise of 15° to 20° F. within one minute, they activate the alarm system and send the melting current to the thermal links. One advantage of this system is its ability to sense fire upstage, away from the proscenium, and activate the fire curtain without waiting for the flame to spread downstage. Some theatres incorporate smoke sensors in the alarm system. Select them carefully so they are not activated by stage smoke and fog effects.

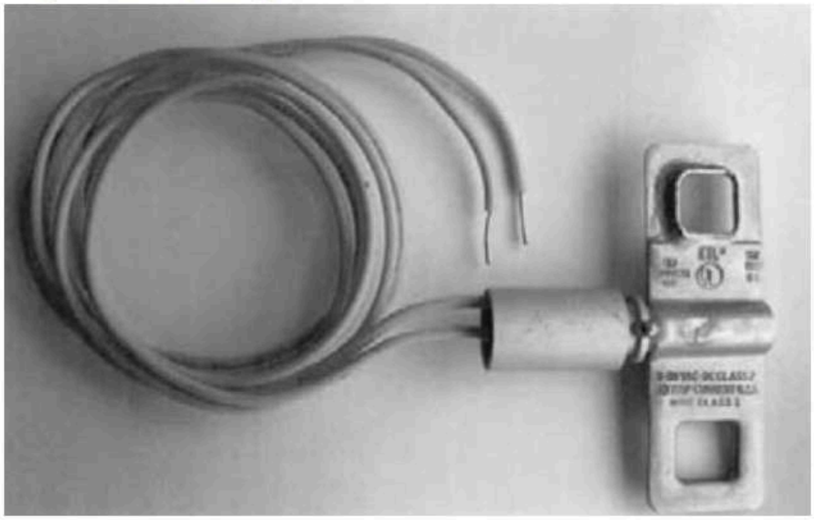


Fig. 9.6. Electrothermal link. Courtesy of Dan Culhane and SECOA

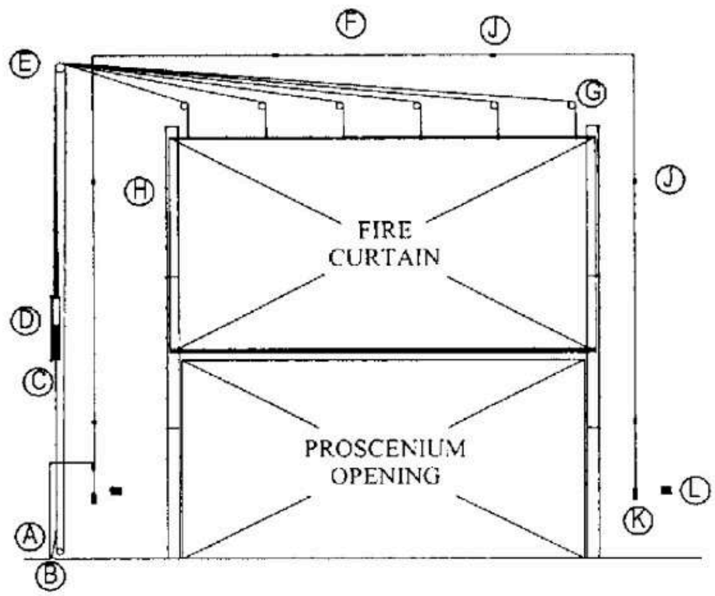
3. Resettable Thermal Release

The Sur-Guard, manufactured by J. R. Clancy, is a resettable thermal release device. It connects to the alarm and heat-sensing system in the same way as an ETL. The advantage of the Sur-Guard is that it can be tested and reset.

D. Overbalance Systems

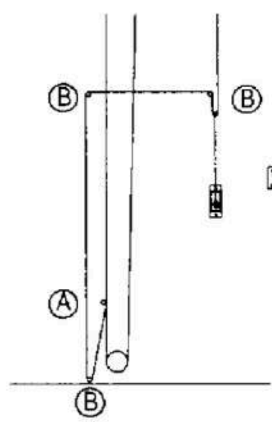
1. Free-End Ball Release

This system requires that the fire-curtain side of the system be heavier than the arbor side (fig. 9.7). A heavy ball made of steel or lead is affixed to the end of the release line and is tied to the operating line to keep the curtain open (figs. 9.8 and 9.9). When one of the automatic devices in the release line opens, the slack in the line allows the ball to fall to the floor releasing the knot on the operating line, and the overweighted curtain comes in. The release line has emergency-release devices on either side of the stage. Releasing the ball by hand allows manual operation of the curtain. There are weight limitations to this type of curtain, and they are very hard to properly balance. Fire curtains can absorb moisture out of the air. Changing humidity can change the weight of the curtain and affect balance of the system. If the arbor side is too heavy, the curtain can bounce and not stay down. Usually, this system does not use a dashpot (see 9.05.E), so if the cur-



A - FREE END BALL RELEASE
B - RELEASE LINE PULLEY
C - LIFT LINE
D - COUNTERWEIGHT ARBOR
E - HEAD BLOCK
F - RELEASE LINE
G - LOFT BLOCK
H - SMOKE POCKET
J - FUSIBLE LINK
K - MANUAL RELEASE STATION
L - SIGN

Fig. 9.7. Straight-lift curtain with free-end ball on release line. Courtesy of Dan Culhane and SECOA



A - FREE END BALL RELEASE
B - RELEASE LINE PULLEY

Fig. 9.8. Rigging detail for free-end ball. Courtesy of Dan Culhane and SECOA

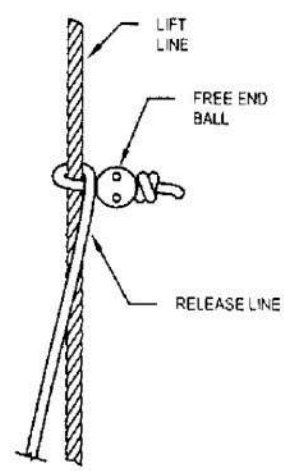


Fig. 9.9. Free-end ball knot. Courtesy of Dan Culhane and SECOA

tain side is too heavy, it can come in dangerously fast. And because the curtain side is always heavy, it can be very hard to raise the curtain.

Another dangerous problem with this type of release is that many stagehands do not know how to tie off the release line with the proper ball knot. *Do not tie the line around both sides of the operation line*, as that will cause it to slip and not hold the curtain. *Do not use any knot* (including an overhand knot or a clove hitch) *other than the one shown in figure 9.9*, or it will not release properly. Figure 9.9 shows the proper way to tie off the release line to the operating line.

2. Lever-Arm Release

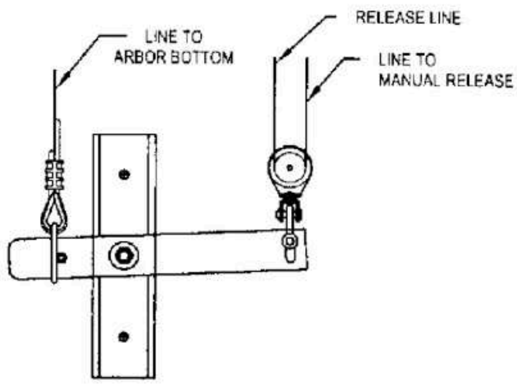


Fig. 9.10. Lever-arm release system. Copyright © J. R. Clancy

The *lever-arm release* in figure 9.10 is an alternative to the free-end ball system. A separate cable is attached to the bottom of the arbor (in addition to the hand line) and runs down the wall to a convenient height. The free end is attached to a D-ring that slips over a pivoting lever mounted on the wall. Tension is applied to the lever by the release line, which holds the arbor in the down position. When the release line goes slack, the lever rotates, releasing the D-ring and allowing the overweighted curtain to come in.

Resetting the fire curtain requires at least two people. If the curtain is well balanced, one person raises the curtain, and a second person secures the free-end ball on the lift line. If the curtain is not well balanced, more than one person may be required to raise the curtain.

3. Overbalance Bar

To solve the problem of raising an out-of-weight curtain, several methods of overweighting the curtain can be used. For these systems, the curtain and arbor are balanced, allowing easier manual operation of the curtain. One method, called the *overbalance bar*, uses a weight bar above the curtain that is guided by the center lift lines (figs. 9.11 and 9.12). When the release line loses tension, the bar is released, slides down on top of the curtain, and makes the curtain heavy. This extra weight provides a force to get the curtain moving. The chains supporting the overweight bar are attached to the grid to prevent the bar from riding the curtain all the way down and to facilitate resetting it. A lever system can be used to release the chain from its stored position to allow it to fall on the curtain (fig. 9.13).

Resetting this system requires two or more people, depending on the weight of the bar. The curtain is raised, and the release line is reset at stage level. One or more persons on the grid pull the chains attached to the bar up and reconnect them to the release mechanism.

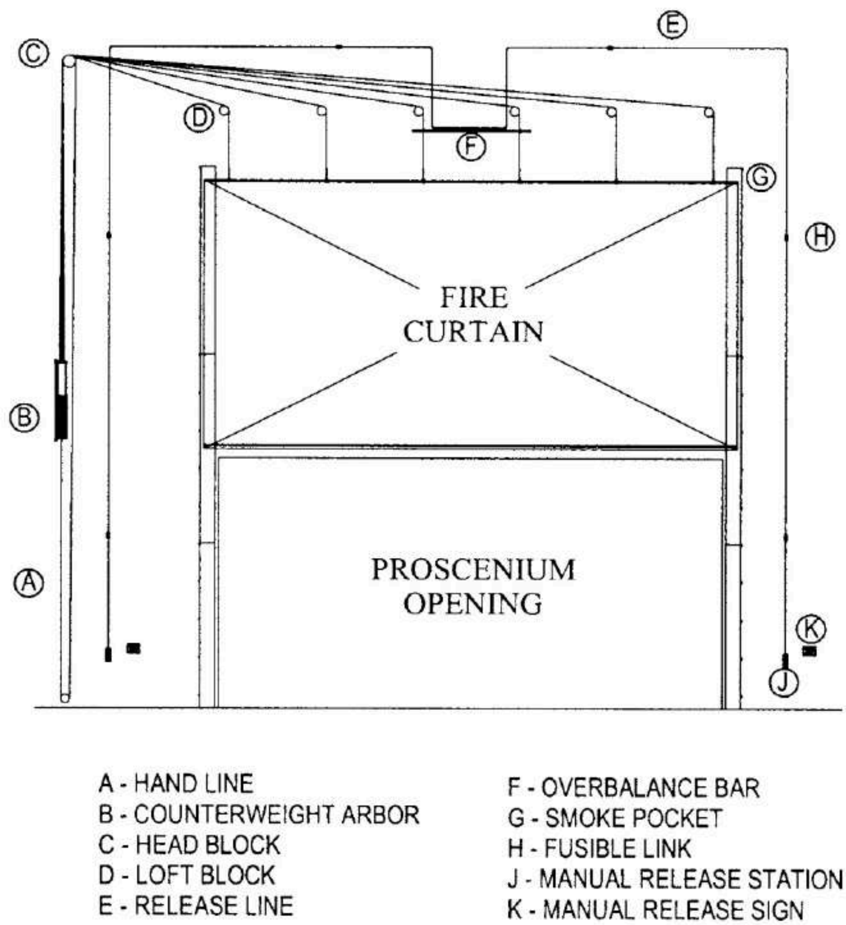


Fig. 9.11. Straight-lift curtain with overbalance bar. Courtesy of Dan Culhane and SECOA

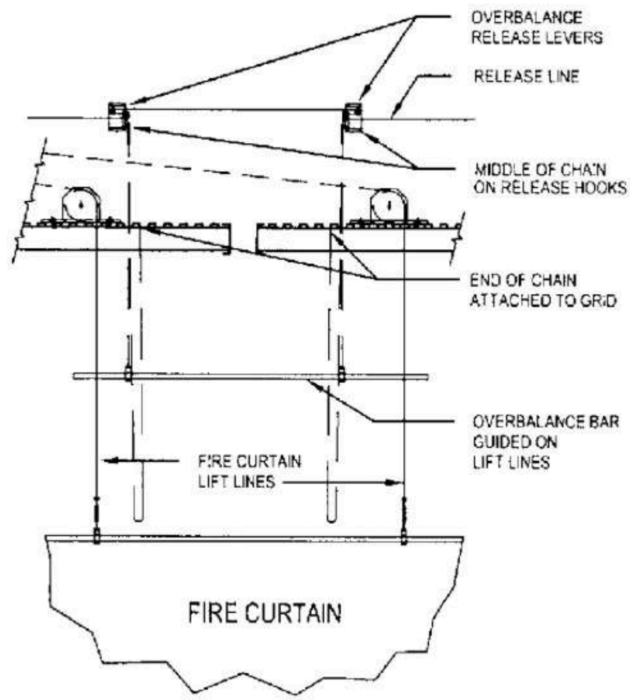


Fig. 9.12. Overbalance-bar detail. Courtesy Dan of Culhane and SECOA

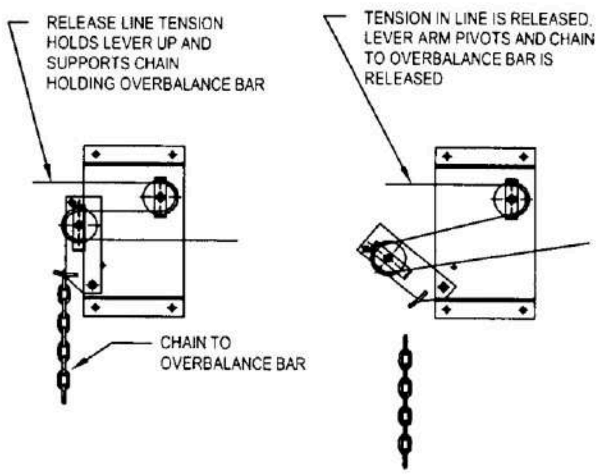


Fig. 9.13. Lever-release system. Courtesy Dan of Culhane and SECOA

Another version of the overbalance-bar system has pulleys attached to the top of the overbalance bar. The release line runs through the pulleys holding the bar in the stored position. When the release line is let go, the bar falls and operates as above. This system can be reset from the floor by pulling the release line. It is a good idea to tie a decent-sized rope to the release line when testing this type of system. It is very difficult to raise the weight bar by pulling on 1/8″ wire rope.

4. Overbalance Arbor

The *overbalance arbor system* employs a second, small, wire-guide arbor, usually mounted high on the stage wall (fig. 9.14). This arbor has two parts. The lower section has a cable attached that travels up through the top section, through the weights, through a block, and over to another block that attaches to the top of the main-curtain arbor (fig 9.15). There is just enough weight on the lower arbor section to keep tension on the cable.

The upper section of the wire-guide arbor is located below the grid and is held in place by the fire-release line. When the line goes slack, the upper arbor falls on the lower arbor, which pulls up on the curtain arbor and adds weight to the equation

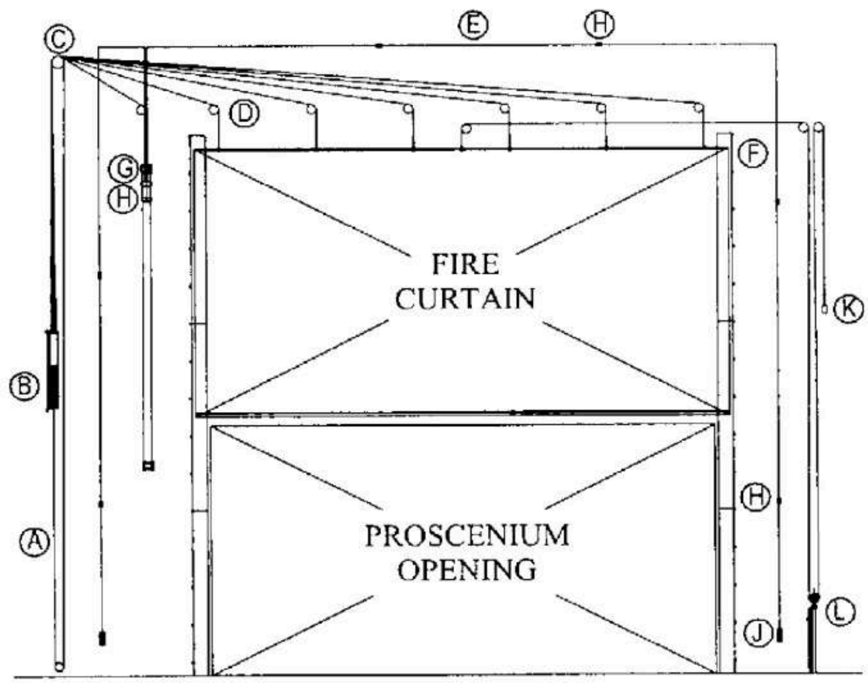


Fig. 9.14. Straight-lift curtain with overbalance arbor. Courtesy of Dan Culhane and SECOA

A - HAND LINE
B - COUNTERWEIGHT ARBOR
C - HEAD BLOCK
D - LOFT BLOCK
E - RELEASE LINE
F - SMOKE POCKET
G - UPPER OVERBALANCE ARBOR
H - LOWER OVERBALANCE ARBOR
H - FUSIBLE LINK
J - MANUAL RELEASE STATION
K - DASH POT TENSION WEIGHT
L - DASH POT

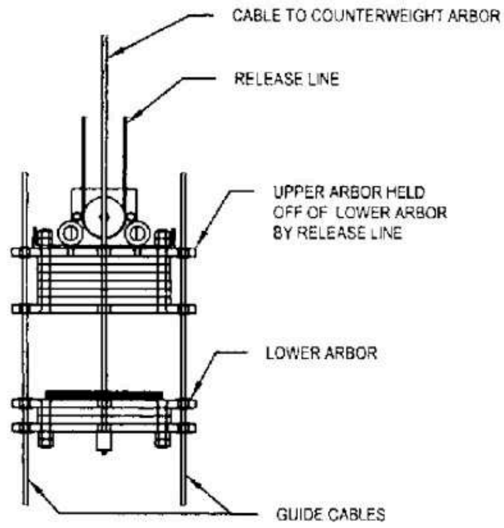


Fig. 9.15. Overbalance-arbor detail. Courtesy of Dan Culhane and SECOA

on the curtain side. Overhauling the curtain raises the overbalance arbor near the stored position, enabling the release line to be reset. Again, when testing the system, it is a good idea to tie a piece of rope to the release line to aid in resetting.

E. Deceleration Devices

When automatically released, the codes require that the last 8′ traveled by the fire curtain must take at least 5 seconds. On brail curtains, the closed-system hydraulic motor controls the rate of descent. They are also occasionally used on straight-lift curtains.

More commonly, a *dashpot* is used to control the deceleration of a straight-lift curtain (figs. 9.16 and 9.17). The dashpot is a closed-loop hydraulic cylinder that has an internal plunger with a sheave attached to its top. A cable is attached either to the bottom of the arbor or to the curtain batten. The cable runs over blocks, down to the sheave on top of the dashpot plunger, up to the grid, and over a head block. It has a weight attached to the free moving end. As the curtain descends, the weight travels up until it is stopped by the grid or sheave. This causes the plunger to be pulled upward, forcing the hydraulic fluid toward the top of the cylinder and through the return pipe and back into the bottom of the cylinder. A valve on the return pipe controls the rate of descent. Slowing the curtain in its deceleration allows time for someone under the curtain to get out of the way and reduces the chance of the curtain bouncing when it hits the floor.

Look for signs of leaks round the dashpot. The seals can dry out if the device is not operated regularly.

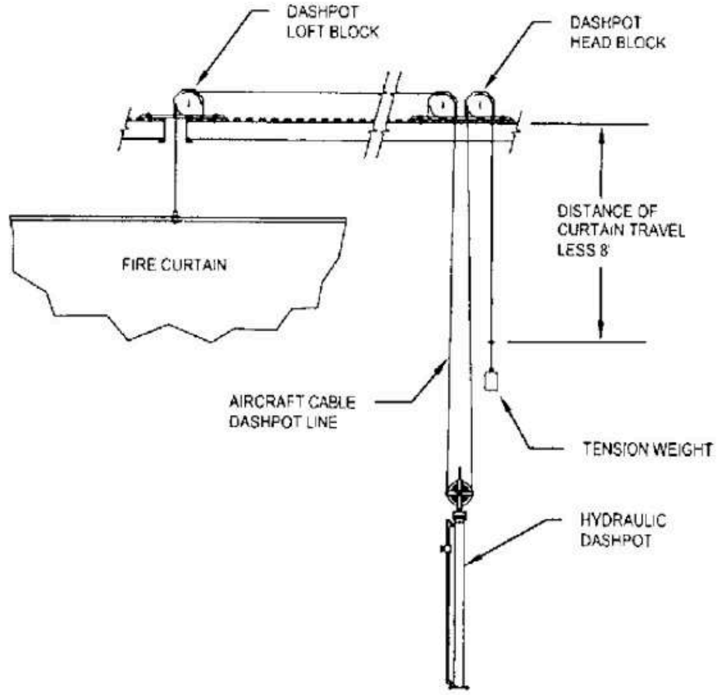


Fig. 9.16. Dashpot-system drawing. Courtesy of Dan Culhane and SECOA

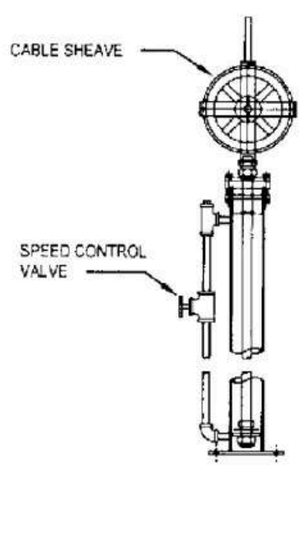


Fig. 9.17. Dashpot detail. Courtesy of Dan Culhane and SECOA

9.06 Motorized Fire Curtains

Large fire curtains, especially the framed units, are heavy. When a curtain gets too big to easily raise by hand, it is motorized. Usually, a traction drive winch is used to power the head block that raises the curtain (see part 5.02.A.3 and fig. 5.6). In recent years, line-shaft systems have sometimes been used on fire curtains. The release line is used to hold a clutch in place. When the line goes slack, a captured falling weight releases the clutch, allowing the curtain to close. The release line has the required automatic heat- and emergency-release devices described above (see section 9.05.E). Manual operation is by pushbutton control.

Follow the normal maintenance procedures associated with a winch. The clutch must also be properly adjusted. Signs of a slipping clutch include the curtain slipping when it is being raised, the curtain not going out when the winch is running, or the curtain coming in by itself without the release line being activated. There are various ways to adjust a clutch. Find out how to do this before you need to, and have the proper tools on hand.

9.07 Maintenance

Like all rigging equipment, the fire-curtain system requires regular inspection and maintenance so it will work when needed. Operate it on a regular basis. No matter how hard it is to raise, operating it at least every 60 days will help keep the sheave bearings lubricated and the cables from getting a permanent set. A test drop should be performed at least once a year. If rigging or construction work has been performed near any of the operating parts, the curtain should be tested. A common practice in some professional theatres is to do a test drop before the opening night of every show. Allow sufficient time to repair it if needed.

If the curtain is easy to operate, comply with the Life Safety Code (see 9.02.B). Keeping the curtain closed when the stage is not in use is a responsible way to be sure that the curtain operates properly in the manual mode.

Glossary
Selected Bibliography
Index

Glossary

act curtain. Also called a *front curtain* or *main curtain*; the curtain closest to the proscenium that opens and closes to expose the stage area to the audience.

apron. The area of the stage that is in front of the proscenium.

arbor pit. An open space in the floor directly under the counterweight system that allows the arbors to travel below floor level.

arbor stop. See **crash bar**.

auditorium. The area where the audience is seated; also called the *house*.

a vista. A scene change that occurs in full view of the audience.

batten. A steel pipe or wooden bar used to support scenery, curtains, and lights, usually suspended from the grid or roof structure on the lift or lead lines of a rigging set.

bridge. A movable steel structure suspended over the stage or audience area, usually used for suspending lighting instruments.

captured stage equipment. Machinery that is part of the structure of the building or is contained in a temporary stage floor, such as electromechanically or hydraulically driven wagons or turntables.

catching device. A protective shield that prevents the system operator from injury should a counterweight become dislodged and fall from the counterweight arbor.

catwalk. A steel structure over the stage, the audience area, or both, used by stage personnel to access lighting, rigging, or other stage equipment.

clew. A metal plate with several holes on one side and a single hole on the other, used to join several lift lines on one side to a single tow line on the other.

competent person. A person who is capable of identifying existing and predictable hazards or dangerous conditions in the rigging equipment.

controlled stop. A timed deceleration of a moving device.

counterweight carriage. A metal frame that holds the counterweights used to balance the weight of flown scenery; also referred to as the *arbor* or *cradle*.

counterweights. Cast iron, steel, or lead weights placed on the arbor to balance the load on the batten.

crash bar. A horizontal member, usually attached near the top and bottom of the T-bars, that limits the travel of the arbors. Also called an *arbor stop*.

dead hung. Battens or similar equipment that is permanently supported from the grid and cannot be easily lowered to the stage floor.

deflecting device. Same as *catching device*.

fid. A tapered pin (usually wood) used in opening the strands of a rope.

fire curtain. A nonflammable curtain immediately behind the proscenium, contained in the smoke pocket, used to protect the audience from possible smoke and fire originating from the stage area.

fly. To move scenery or similar devices vertically on the stage.

fly gallery. A platform attached to the side wall of the stage house used to operate the rigging devices.

fly loft. The space above the grid and below the roof.

grid. A steel framework above the stage area that is used to support the rigging system; short for *gridiron*.

hard contact. A sudden or uncontrolled stop of the counterweight carriage caused by hitting the upper or lower crash bars.

hemp system. A system of hemp (Manila fiber) ropes used for support to raise or lower scenery.

house. See **auditorium.**

line set. A unit of rigging consisting of the batten and all other support cables, sheaves, and mountings.

loading gallery. A platform used for the loading or unloading of the counterweight carriages.

loft block. The pulleys or sheaves directly above the batten used to change the direction of the working lines from horizontal to vertical.

marlinespike. A metal (usually iron) version of a fid.

motorized rigging. A system of electric or hydraulic motors used to raise and lower battens or counterweight carriages.

mouse. (1) To wire the throat of a hook to prevent a cable or line from jumping out of the hook; (2) to interweave the barrel of a turnbuckle with wire to keep it from unscrewing; (3) to place wire or cotterpins through holes drilled in the endfittings of a turnbuckle or shackle pins.

orchestra lift. An elevator in the orchestra pit used to raise and lower the floor of the pit.

pin rail. A part of a hemp system consisting of a metal pipe or wooden rail attached to the fly gallery and fitted with removable steel or wooden pins used in tying off the working lines.

pit. A recessed area in front of the stage used principally by musicians; can also be covered and used as an extended forestage.

proper training. Training from a reputable school, college, university, venue, or IATSE local that has a formalized apprentice program.

proscenium. The wall between the stage and the audience containing the proscenium arch.

proscenium curtain. See **fire curtain.**

qualified person. A person with a recognized degree or professional certificate and extensive knowledge and experience in the subject field who is capable of design, analysis, evaluation, and developing specifications in the subject work, project, or product.

rigging. The general term describing systems used to raise, lower, or move the stage equipment overhead.

set. See **line set.**

sheave. A grooved wheel in a block or pulley.

spreader plates. Movable steel plates on a counterweight arbor used to keep the arbor rods from spreading and counterweights from falling out in case of a sudden stop.

stage house. That portion of a theatre building containing the stage area, fly loft, grid, and galleries.

supervisor. A person charged with the responsibility of directing the work of others and the safe operation of stage equipment.

technical stage equipment. A general term referring to the equipment or machinery used on a stage to support the movement of scenery, lighting equipment, or people.

thrust stage. An extension of the stage floor into the auditorium, allowing the audience to be seated on three sides.

traps. Sections of the stage floor that can be removed to access the understage area.

turntable. A rotating platform or portion of the stage floor.

wagon. A movable platform usually on casters or wheels.

well. The space between the beams on the grid over which the loft blocks and the working lines are placed to drop to the batten.

winch. A manual or power-operated device used to wind cable to raise and lower stage equipment.

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Index

Jay O. Glerum has worked in theatre and the entertainment industry for more than fifty years. During that time, he has worked as a stagehand, designed scenery and lighting, taught technical theatre at several universities, consulted on numerous theatre and television studio projects, and worked as a systems designer for a major theatre-equipment company. Glerum regularly teaches classes on stage rigging throughout the United States, Canada, and Europe. He is the president of Jay O. Glerum and Associates, Inc., a firm that specializes in theatre consulting, rigging inspections, and accident investigation for the entertainment industry.

THEATRE

"*Stage Rigging Handbook* should become a standard text for advanced technical students and all individuals concerned with the safe and proper maintenance and operation of stage-rigging systems."
—Derek Hunt, *Theatre Design and Technology*

"*Stage Rigging Handbook* clearly explains the basics of how to maintain your rigging system and operate it safely. This manual can also be a ready reference and friend when rigging a show. This is a book to always keep handy in a cubbyhole at the end of your pinrail."
—Steve Nelson, *Dramatics*

Succinct and jargon free, *Stage Rigging Handbook* remains the only book in any language that covers the design, operation, and maintenance of stage-rigging equipment. It is written in an at-a-glance outline form, yet contains in-depth information available nowhere else. This fully indexed third edition includes three new parts: the first, an explanation of inspection procedures for rigging systems; the second, a discussion of training in the operation of rigging systems; and the third, essential information about fire curtains. The remaining six parts, as well as the glossary and bibliography, have been updated. This edition also contains a new preface and many new illustrations.

Jay O. Glerum holds seminars on stage rigging throughout the United States, Canada, and Europe. A fellow of the United States Institute for Theatre Technology, he has served as chair of the Rigging and Stage Machinery Standards Committee of the Institute and has taught at Seattle University, Marquette University, and the University of Washington. He is president of Jay O. Glerum & Associates, Inc., a firm specializing in consulting for the entertainment industry.

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