CHAPTER 15

MATERIALS HANDLING

15-1 INTRODUCTION

Materials handling is the lifting, moving, and placing of items in various forms. It may be done manually or with equipment. Materials handling is one of the leading causes of disabling occupational injuries. According to the National Safety Council, 20% to 25% of all disabling occupational injuries result from materials handling.

Materials handling includes the use of many kinds of equipment designed to help in the tasks. Manipulators, jacks, hoists, derricks, industrial trucks, cranes, backhoes, conveyors, rigging, escalators, elevators, and other equipment are part of the materials handling arsenal. There are many kinds of objects and materials to handle, each posing different hazards. There may be individual objects or groups of objects in boxes, bins, totes, or on pallets. We use buckets and scoops of various types to handle bulk materials, like grain, gravel, earth, and loose parts.

This chapter discusses many of these activities and types of equipment used in them. Included will be a discussion of storage of materials and excavation and trenching.

Hazards

There are many kinds of hazards for materials handling activities and equipment. Some are unique to particular activities, equipment, or kinds of materials. Manual materials handling poses dangers that may be different from the use of cranes or hoists. Electrically powered equipment has some hazards resulting from electricity that are different from those powered by other energy sources. Mobile equipment has hazards different from fixed equipment. Lifting and moving a coil of steel has different hazards from loading grain into a bin. Materials may be flammable or toxic.

Environments may contribute to hazards in materials handling. Good lighting, sufficiently wide aisles, good ventilation, traffic controls and visibility, and uncongested and unobstructed pathways are important. So is keeping lift zones clear of people. Proper maintenance of materials handling equipment is essential. Failure of structural elements, brakes, controls, and other components can lead to accidents. Training is also important. Workers must learn how to lift items to minimize the chances of injury. Operators must learn how to operate materials handling equipment, to properly plan a safe lift, to understand what can go wrong and how to protect themselves, others, and property. Other participants in materials handling operations must know procedures, such as hand signals, staying out from under loads and away from elevated loads, and use of proper rigging. It is also important to plan materials handling jobs and instruct participants in the steps that will be taken.

One major class of hazard in materials handling is failure of the lifting equipment. The failures are often the result of overloads for certain lifting conditions. For example in

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humans, we see sprains and strains of backs, arms, and legs. A crane boom may buckle, a chain or wire rope that is part of the lifting device may break, rigging that restrains load may fail, or a conveyor support may collapse.

Another class of hazards is falling loads. Materials may fall on people and cause injury or they may fall on property and cause damage. A load may shift and tip over. A load may be inadequately rigged, restrained, or anchored.

Another class of hazard is material in motion. The speed and mass of materials and equipment are important considerations. Objects may strike something else and cause damage or strike a person and cause injury. One may operate equipment too fast, tip it over, and be out of control or unable to stop it quickly. People may be run over or have their hands or bodies caught, crushed, or pinched. The rate of flow is important, particularly when materials are handled in different ways in an overall process. Unless there is balanced flow, materials will pile up at certain points, possibly causing workers to rush and do things in an unsafe manner.

Controls

There are many different controls for preventing materials handling accidents. Controls are related to kind of activity, kind of equipment, and kind of material. There are also controls for the environments where material handling occurs.

Eliminate Handling Analysis of operations may identify ways to eliminate material handling tasks. If material handling steps are eliminated, there are fewer opportunities for handling hazards, which makes sense from a safety point of view as well as making good economic sense. Material handling takes time, costs money, and increases the likelihood of damage to items handled.

Planning If materials handling is needed, one should plan the details. Handling locations should be clear of hazards. Planning should include selection of correct equipment, identification and analysis of steps that may go wrong, and establishment of procedures for dealing with contingency problems. Hand signals, two-way radio systems, and other means of communication must be arranged, and participants must understand the plans. Even a seemingly simple, two-person lift requires planning. Participants should, as a minimum, go over how they will proceed from start to finish, what they will do if something starts to go wrong, and how they will communicate during the process. Mechanical handling is generally preferred to manual handling. Manual handling is usually more expensive than mechanical handling.

Design and Selection Materials handling tools, devices, and equipment require proper design. Standards from various sources may be applicable. Design considerations must include structural strength, operational features, control systems, visibility, failure modes, incorporation of safety features, and other factors. Even permanently installed materials handling equipment must have safety features. For example, conveyors that move above workers in a factory must have overhead protection for the people below to prevent objects and materials from falling on them. Some materials handling equipment must have access ways and guardrails for maintenance and lubrication tasks. There may be a need for exhaust ventilation or sprayers to isolate or control dust. Power equipment may need emergency shutoff controls and guards may be required. Each design requires analysis of uses and use environments. Selection of equipment must match use requirements to availability of necessary features to ensure safe use.

Selection of the right handling equipment for a job also is important. Specific jobs require particular handling equipment. Special features may be needed for certain uses. Whoever makes the selection must know the task, the equipment, and the use environment.

Use People must use equipment correctly. Many examples of proper and safe use can be cited. Loads on materials handling equipment must not exceed safe load limits. Operators must drive mobile equipment safely. Cranes should not be operated within certain distances of power lines.

Training The use of each kind of materials handling equipment requires particular knowledge and skill. Operators and those involved in the area of use must learn what hazards equipment and its use impose and how to control the hazards. They need to develop skill in operating controls, to develop skill in recognizing when things could and do go wrong, and to be knowledgeable of the suitable action to take. They must develop skill in the procedures and judgments related to planning and executing materials handling tasks. They must know what conditions in the use environment add to the hazards of the material handling task, and they must know when stopping the activity is more important than loss of equipment or materials or more important than injury or loss of life.

Environments There are many different and important use environment factors. Lighting, visibility, weather, terrain, properties of materials (weight, toxicity, stability, etc.), and location of people on or near a site must be evaluated. Proper controls must be in place before handling tasks start. Even communication means have to be worked out on loading docks where workers do not speak the same language.

15-2 MANUAL MATERIALS HANDLING

Manual materials handling accidents result in a variety of injuries. Objects and loads may fall and injure hands, feet, and legs. Lifting may cause muscle strains and joint injuries. By far the most common injuries from manual materials handling are back injuries. According to several studies, low back injuries account for approximately one quarter of all workers' compensation claims.

Back claims and complaints are widespread among people and occupations. They are not limited to industrial or construction activities. They are common among hospital employees, often resulting from lifting of patients. Back complaints are even prevalent among office workers. Results of one national survey estimated that more than half of all office workers have back complaints at some time. Another study notes that four of every five Americans will experience at least one episode of lower back pain between the ages of 20 and 60 years.

Hazards

Many things contribute to manual materials handling injuries. Included are materials handling techniques, job design, and physical condition and characteristics of individuals.

A biomechanical analysis of lifting gives us insight into some of the problems. When a person lifts and carries an object, the load must be counteracted by the back muscles. The spine is the fulcrum (see Figure 15-1) and the back muscles are a fixed, short distance from the spine. The load in front of the body is much farther from the spine, at minimum nearly the thickness of the trunk. The moment created by the load is greater when a load is held far from the body compared with holding it close to the body, whether standing,

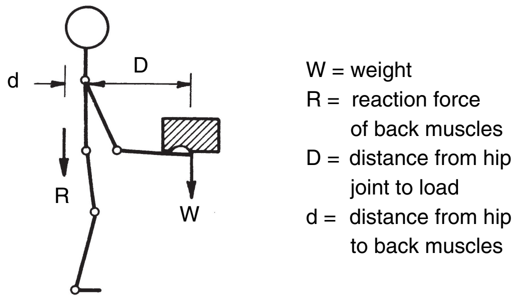

Figure 15-1. Biomechanics of manual lifting. The moment ($W \times D$) created by the load being lifted must be counteracted by the muscles of the back ($R \times d$).

sitting, or stooping. The moment created by the load must be counteracted by the back muscles.

Stooping to raise a load creates even greater moments because of the trunk length. To keep the moment small, the load must be held close to the body. In general, women have a slightly longer torso length relative to their body height than men do. As a result, a woman will experience a greater moment for a lifting task than will an man of equal height. Because there is considerable variability in body dimensions, this generalization may not apply to every woman.

The size of a load can contribute to the moment. A large object cannot be held as close to the body as a small object. Depending on its distance away from the body, a large but relatively light object may produce a greater moment than a small heavy object. The inertia created by acceleration during lifting can add to the static load and can increase the moment.

The length of a lift (vertical distance) can increase the potential for injury. Lifting overhead involves other muscle groups that may have less capacity than the back. Reaching while picking up an object or putting it down is more likely to result in dropped loads and to produce greater moments.

The weight of an object being lifted is also important. One study of 550 workers over a 2-yr period found that few injuries resulted when loads were kept to less than 45 lb. Other factors beside the weight of the object affect lifting stress. There are software programs, for example, that estimate the compressive load on the lumbar area of the back during lifting activities.

Frequency of lift is also important. Continuous lifting activity may exceed the physical work capacity of an individual and lead to fatigue, error, and injury. Because the body is not well suited to asymmetrical loads or rotation, lifting with one hand or twisting during a lift add to the likelihood of injury.

People vary in size, weight, strength, physical condition in general, physical condition of muscles, condition of joints, and other factors. Back muscles reacting to a lifted load compress the vertebrae of the spine. Some studies have estimated the compressive load limits of spinal elements, but the capacity for an individual and particular spinal locations varies. It is difficult to predict where and under what conditions an individual will experience pain, a strain of a muscle, or other form of injury.

Controls

Administrative Controls Administrative controls include selection and training of workers. Selection includes physical assessment, strength testing, and testing for aerobic work capacity. Training involves recognition of dangers in manual materials handling, how to avoid unnecessary stress, and what a person can handle safely. Table 15-1 lists recommendations for lifting techniques compiled from various sources.

Engineering Controls Engineering controls are divided into (1) mechanical, visual, and thermal environments, (2) alternatives for materials handling systems, and (3) potential safety and ergonomic problems. The mechanical environment includes unit size of load, container design, handle and handhold designs, and floor–worker interfaces. The visual environment refers to lighting, color, and labeling. Materials handling system alternatives involve materials handling equipment and job aids, like hooks, bars, rollers, and other devices. Other chapters discuss many environmental controls further.

The Revised National Institute for Occupational Safety and Health Lifting Equations

The National Institute for Occupational Safety and Health (NIOSH) studied many of the factors just discussed, and it combined much of the information into a guide called the *Work Practices Guide for Manual Lifting*.[1] The guide reviewed epidemiological, biomechanical, physiological, and psychophysical literature and recommended controls for minimizing lifting injuries. Later, NIOSH updated the study[2] and revised the lifting recommendations to incorporate additional lifting factors: asymmetrical lifting tasks and lifts of objects with less than optimal couplings between the object and the worker's hands.[3] The revised lifting equations compute two values: recommended weight limit (RWL) and lifting index (LI), based on seven lifting factors.

The RWL aids in decisions to separate an acceptable lifting condition from a hazardous lifting condition for which some redesign of the condition is required. If the weight of an object to be lifted is greater than the RWL, engineering or administrative controls are needed to reduce the weight or to increase the RWL.

Because the LI is simply a ratio of the weight of an object and its RWL, the LI provides an estimate of the hazard of overexertion injury (or degree of stress) for a manual lifting job.

There are limits for the applicability of the revised lifting equations. In summary, they do not apply if any of the following lifting/lowering conditions occur:

- with one hand
- for more than 8 hours

TABLE 15-1 Frequently Recommended Lifting Procedures

Get a firm footing. Make sure the floor is not slippery.
Size up the load. Determine what it weighs.
Spread your feet for a stable stance.
Get a firm grip. Use handles, gripping, or other lifting tools that will help.
Make sure the load is free, not locked down or stuck.
Keep your back straight. Keeping your chin tucked in will help keep your back straight.
Lift with your legs.
Tighten your stomach muscles.
Accelerate the load slowly. Don't jerk.
Hold the load close to your body. Position a load close to your body before lifting.
Watch out for your fingers and hands when carrying a load so you don't strike them against something.
Don't twist during lifting. Turn with your feet, not with your back.
Set the load down gently. Use your legs. Keep the back straight.
Watch your fingers so you don't pinch them.

- while seated or kneeling
- in a restricted work space
- unstable objects
- while carrying, pushing, or pulling
- with wheelbarrows or shovels
- with high speed motion (faster than approximately 30 in/s)
- with unreasonable foot/floor coupling (<0.4 coefficient of friction between sole and floor)
- in an unfavorable environment (temperature outside the ranges 66°–79°F [19°–26°C] and 35%–50% relative humidity)

For these conditions, a more comprehensive ergonomic evaluation of the activity is recommended.

The seven lifting task multipliers involved in the computations are presented in Table 15-2. The load constant (LC) is the maximum weight that can be lifted safely for a lift in which the lifting conditions are optimal (10 in horizontally from the body and 30 in vertically from the floor). The multipliers (which range between 0 and 1) reduce the load constant, depending on lifting conditions.

Associated with a lifting task are the load weight (weight of object lifted), L, and the following task variables:

H Horizontal location: distance of the hands away from the midpoint between the ankles, in inches or centimeters, measured at the origin and destination of a lift.

V Vertical location: distance of the hands above the floor, in inches or centimeters, measured at the origin and destination of a lift.

D Vertical travel distance: absolute value of the difference between the vertical heights at the destination and origin of the lift, in inches or centimeters.

A Asymmetry angle: angular measure of how far the object is displaced from the front (midsagittal plane) of the worker's body at the beginning or ending of the lift in degrees measured at the origin and destination of a lift. The asymmetry angle is defined by the location of the load relative to the worker's midsagittal plane (front-rear plane separating left and right) as defined by the neutral body posture, rather than the position of the feet or the extent of body twist.

F Lifting frequency: average number of lifts per minute over a 15-minute period.

C Coupling classification: coupling quality ratings are good, fair, or poor, depending on the quality of the hand-to-object coupling (see Table 15-4). The classification is necessary to use Table 15-5.

TABLE 15-2 The Seven Lifting Task Multipliers

Abbreviation	Term	English Units	Metric Units
LC	Load constant	51 lb	23 kg
HM	Horizontal multiplier	10/H	25/H
VM	Vertical multiplier	$1 - (0.0075\|V - 30\|)$	$1 - (0.003\|V - 75\|)$
DM	Distance multiplier	$0.82 + (1.8/D)$	$0.82 + (4.5/D)$
AM	Asymmetric multiplier	$1 - (0.0032A)$	$1 - (0.0032A)$
FM	Frequency multiplier	From Table 15-3	From Table 15-3
CM	Coupling multiplier	From Table 15-5	From Table 15-5

TABLE 15-3 Frequency Multiplier

Frequency Lifts/min (F)[a]	Work Duration					
	≤1 hour		<1 but ≤2 hours		>2 but ≤8 hours	
	$V < 30$ in	$V \geq 30$ in	$V < 30$ in	$V \geq 30$ in	$V < 30$ in	$V \geq 30$ in
≤0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

To enter the table, first measure the number of lifts in a sample 15-minute period and divide by 15 to obtain the lifting frequency, *F*. Then select the applicable FM value from this table based on the length of the lifting task.
[a] For lifting less frequently than once per 5 minutes, set $F = 0.2$ lifts/min.

Recommended Weight Limit (RWL) The RWL for a specific set of task conditions is the weight of the load that nearly all healthy workers (free of adverse health conditions that would increase the risk of musculoskeletal injury) could perform over a substantial period of time for up to 8 hours without an increased risk of developing lifting-related lower back pain. The RWL (lb) is defined as

$$\text{RWL} = \text{LC} \times \text{HM} \times \text{VM} \times \text{DM} \times \text{AM} \times \text{FM} \times \text{CM}. \tag{15-1}$$

Lifting Index The LI provides a relative estimate of the physical stress associated with a manual lifting job. As LI increases, the level of risk for a given worker increases, and a greater percentage of workers are likely to be at risk for developing lifting-related lower back pain. LI is computed as

$$\text{LI} = \frac{\text{load weight}}{\text{RWL}}. \tag{15-2}$$

Procedures The first step is to analyze a lifting task to define the load weight, *L*, and the task variables for both the origin and destination where applicable. The next step is to determine the task multipliers and then use them to compute RWL and LI. Then LI is used to make decisions about a lifting task and its design. RWL and LI guide the ergonomic design of a lifting task:

- Individual multipliers help to identify specific job-related problems
- RWL can help guide the redesign of an existing or new lifting task

TABLE 15-4 Hand-to-Container Coupling Classification

Good	Fair	Poor
For containers of optimal design, such as some boxes, crates, etc., a "good" hand-to-object coupling would be defined as handles or hand-hold cutouts of optimal design (see notes 1, 2, and 3).	For containers of optimal design, a "fair" hand-to-object coupling is defined as handles or hand-hold cutouts of less than optimal design (see notes 1, 2, 3, and 4).	Containers of less than optimal design or loose parts or irregular objects that are bulky, hard to handle, or have sharp edges (see note 5).
For loose parts or irregular objects, which are not usually containerized, such as castings, stock, and supply materials, a "good" hand-to-object coupling is defined as a comfortable grip in which the hand can be easily wrapped around the object (see note 6).	For containers of optimal design with no handles or hand-hold cutouts or for loose parts or irregular objects, a "fair" hand-to-object coupling is defined as a grip in which the hand can be flexed approximately 90° (see note 4).	Lifting nonrigid bags (i.e., bags that sag in the middle).

Select the classification that best fits the lifting task to enter Table 15-5.
Notes:
1. An optimal handle design has 0.75 to 1.5 in (1.9–3.8 cm) diameter, ≥4.5 in (11.5 cm) length, 2 in (5 cm) clearance, cylindrical shape, and a smooth, nonslip surface.
2. An optimal hand-hold cutout has the following approximate characteristics: ≥1.5 in (3.8 cm) height, 4.5 in (11.5 cm) length, semioval shape, ≥2 in (5 cm) clearance, smooth, nonslip surface, and ≥0.25 in (0.06 cm) container thickness (e.g., double thickness cardboard).
3. An optimal container design has ≤16 in (40 cm) frontal length, ≤12 in (30 cm) height, and a smooth, nonslip surface.
4. A worker should be capable of clamping the fingers at nearly 90° under the container, such as required when lifting a cardboard box from the floor.
5. A container is considered less than optimal if it has a frontal length >16 in (40 cm), height <12 in (30 cm), rough or slippery surfaces, sharp edges, asymmetric center of mass, unstable contents, or requires the use of gloves. A loose object is considered bulky if the load cannot easily be balanced between the hand grasps.
6. A worker should be able to wrap the hand comfortably around the object without causing excessive wrist deviations or awkward postures, and the grip should not require excessive force.

TABLE 15-5 Coupling Multiplier

	Coupling Multiplier	
Coupling Classification	$V < 30$ in (75 cm)	$V \geq 30$ in (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Select the coupling multiplier for the coupling classification and vertical location.

- LI helps estimate the degree of physical stress for a lifting task
- LI can help prioritize redesign of various lifting tasks based on rank order of LI values

Figure 15-2 provides a sample form for managing the analysis for a single task.

References provide examples of various lifting tasks, both for single tasks and for multiple tasks. They also explain how to deal with special circumstances.

JOB ANALYSIS WORKSHEET
Single Task - NIOSH Revised Lifting Equations

Department		**Description of Job**
Job Title		
Analyst	**Date**	

Step 1. Measure and record task variables

Object Weight (lb)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Freq Rate	Duration	Object Coupling
		Origin		Destination			Origin	Destin.	lifts/min		
L (Avg)	L (Max)	H	V	H	V	D	A	A	F	Hrs	C

Step 2. Determine the mulitpliers and compute the RWL's
RWL = LC x HM x VM x DM x AM x FM x CM

Multiplier	LC	HM	VM	DM	AM	FM	CM	RWL
ORIGIN								
DESTINATION								

Step 3. Compute the Lifting Index (LI)
LI = Object Weight (lb) / RWL

ORIGIN	Object Weight =	RWL =	LI =
DESTINATION	Object Weight =	RWL =	LI =

Figure 15-2. Job analysis worksheet for the revised NIOSH lifting equations.

Example 15-1 A worker parks a hand truck near a mixing hopper to be able to stand somewhat between the hand truck and the hopper. The task is to lift each of the eight bags from the hand truck and place the bag on the rim of the hopper to open it and let the contents spill into the hopper. During the lift, the worker twists from the hand truck position to the hopper position. The task occurs roughly 10 times per 8-hour shift. Because the main lifting problem is the bottom bag, it will be analyzed. Compute the RWL and LI for the task and recommend any revisions to the lifting task.

In analyzing the lifting task, the following are established:

The hands are at a vertical location of 15 in for the origin and 36 in at the destination.

The hands are at a horizontal location of 18 in at the origin and 10 in at the destination.

The asymmetric angle is 45° to the left from the origin to the destination.

The frequency is fewer than 0.2 lifts/min for less than 1 hour.

The worker can flex the fingers approximately 90° and the bags are fairly rigid (do not sag in the middle).

Each bag weighs 40 lb.

The following multipliers are determined:

$LC = 51$

$HM = 10/H = 0.56$

$VM = 1 - (0.0075|V - 30|) = 1 - (0.0075|15 - 30|) = 1 - 0.11 = 0.89$

$DM = 0.82 + (1.8/D) = 0.82 + 1.8/21 = 0.91$

$AM = 1 - (0.0032A) = 1 - (0.0032[45]) = 1 - 0.14 = 0.86$

FM = 1.0 from Table 15-3

CM = 0.95 (from Table 15-5), because the coupling classification is "fair" (Table 15-4) and $V < 30$ in.

Then, RWL = 18.9 lb and LI = 40/18.9 = 2.1.

Possibilities for improving the tasks are bringing the load closer to increase HM, reducing the asymmetry to increase AM by repositioning the hand truck relative to the hopper, and raising the height of the bags at the origin to increase VM. For example, by decreasing H to 10 in, RWL would increase to nearly 34 lb and LI would decrease to approximately 1.2.

15-3 JACKS

There are many kinds of jacks, including hydraulic, mechanical, and pneumatic ones. There are bumper jacks for cars, scissors jacks, jacks with ratchet mechanisms, and jack screws. Each jack has a maximum design load. Although jacks are very common, users should understand how to use them safely and what their load limits are before using them.

Hazards

Major hazards with jacks are overloading their capacity and that of related elements involved in the lift, improper placement and their inherent instability, and having a load slip from them.

A jack may have enough capacity to support a load, but the surface or structure that it sets on or bears against may not have enough capacity. For example, a jack placed on the ground may sink when fully loaded. An object being lifted may not withstand the load and may fail by bending, breaking, or puncture.

Because they only support a single point, jacks are rather unstable, and the instability may increase because of a small bearing support for the jack. Because of their instability, loaded jacks may tip easily. If not properly positioned, they may slip at the top or the base. The object being lifted may shift and make the jack unstable.

Jacks are most often made of steel and are very often used to lift steel objects. The coefficient of friction for steel against steel is very low, and a small lateral load may cause a load to slip.

Controls

A jack should have enough capacity for the load to be lifted and should have a solid bearing support so that it will not sink or slip. Jacks that are used to lift things should be plumb throughout their use. Sometimes jacks or jack-type devices are used to pry things apart. In such cases, they should be positioned so that the ends are well anchored and will not slip. The load being lifted should be stabilized at locations away from the jack. Blocking or anchoring the load may be needed. Avoid metal on metal when using a jack. A wood block placed between the jack and the load can reduce the chances of slipping because it will deform at compression points and help keep the jack and load aligned. People should stand clear of the load being raised. A jack should never be used to support a load. Some other suitable blocking device or support should be used.

15-4 HAND-OPERATED MATERIALS HANDLING VEHICLES

There are many kinds of hand-operated materials handling vehicles. Hand trucks, dollies, carts, and wheelbarrows are hand powered. There are also hand-operated vehicles that use batteries or other power sources.

Hazards

Like all other load-carrying devices, one hazard is a load shifting or tipping and falling. When maneuvering hand-powered vehicles in tight spaces, an operator may strike the handles against a wall or objects and injure the hands. A hand-operated vehicle loaded too high will obscure the visibility of an operator and may cause accidents.

A variety of traffic problems can occur when vehicles are in motion. Examples are blind corners and passage of vehicles moving in different directions. When pulling a load, the operator may slip. The momentum of the vehicle and load may cause the load to run over the operator. An example is a hospital crash cart loaded with oxygen tanks, medicines, and other emergency supplies. The array of materials, often weighing 200 to 300 lb, is rushed to a patient room to treat life-threatening conditions. Because of the weight and the difficulty of maneuvering the cart around turns in a corridor, two people often rush it to an emergency. In one case, such a cart ran over the heel of the person pulling on it and severed an Achilles tendon.

Controls

Loads should be stable and well secured, should be limited in height and provide good visibility for an operator, and should not exceed weights that operators can handle or the capacity of the vehicle. Most loads should be pushed rather than pulled. If a load on a powered, hand-operated vehicle can be raised overhead, the vehicle should have overhead protection for the operator and possibly outrigger devices for stability.

If a vehicle is designed to be pulled, the tongue and handle should extend far enough from the vehicle so the operator's feet are not run over. Hand-powered vehicles should be operated at speeds that allow an operator to easily maneuver and stop the vehicle. Design features, like large diameter wheels or pneumatic tires, can make maneuvering and operation easier on rough surfaces and over bumps. Handles should be designed with a recessed location for hands so that the handle structure will strike a wall or object, not the hands. Knuckle guards are available for some handles to provide this protection. Incorporating soft rubber bumpers on the handles or other protruding elements of a cart can reduce injury and damage if the cart runs into something.

There are special hand operated vehicles for particular handling tasks. For example, there are hand trucks designed for handling gas cylinders. They have restraints that fit around a cylinder and are part of the design. There are special carts for handling carboys of acids or cryogenic liquids. Operators should learn to operate hand-powered vehicles safely.

15-5 POWERED VEHICLES

Equipment

There are many different powered vehicles for materials handling. Many are included in the term *industrial trucks*. The most common industrial truck is a forklift truck, fitted with two forks or tines. Other devices may be installed on an industrial truck for special lifting tasks. A single, long fork is used for lifting carpet rolls and similar rolled material. A clamp device is used to pick up rolls of paper.

Some industrial vehicles pull carts or push objects. At an airline terminal, one can see some of these vehicles in use. There are backhoes, end loaders, scrapers, bulldozers and earthmovers, and other powered vehicles for handling earth and bulk materials.

Hazards

Powered materials-handling vehicles have some hazards in common. Other hazards are unique to particular vehicles and their use. There are also hazards related to the kind of power.

All powered materials-handling vehicles may have visibility problems for an operator, although the problems may differ in type and degree. The vehicles can drive or back over someone or something. The operator may not be able to see the load or how well it is positioned. All have hazards related to traffic and the movement of several vehicles in the same area, all have minimum space requirements for safe operation, and all have hazards related to proper design and functioning of controls, lifting devices, brakes, and steering. A failure of these components could lead to accidents. All vehicles have load limits. Exceeding safe load limits can lead to structural failure and accidents. All have hazards related to proper loading and load stability. A falling load could injure the operator or someone nearby or could damage the vehicle, materials, or other nearby objects.

All have hazards associated with improper operation and use. For example, driving with a load in an elevated position may result in striking an overhead, protruding object or door header.

There are hazards associated with the source of power. Most battery-powered vehicles use lead-acid batteries. There are dangers related to electricity and to battery charging. Gasoline and propane fuels, used to power some vehicles, are flammable. Engines and exhaust are hot. In poorly ventilated or confined spaces, the exhaust could create hazardous conditions from carbon monoxide and other products of combustion.

Many powered materials-handling vehicles have a high center of gravity. When operated too fast in a turn, they can roll over. The problem is even greater when a load is elevated during a turn. Because the loads on forklifts and similar vehicles are cantilevered from the vehicle, counterweights help ensure that tipping over from loads is minimized. The potential for rollover in a turn can be analyzed by evaluating moments about the lateral boundary of support formed by the tires. The centrifugal force is compared with the pull of gravity about the lateral support line. From this analysis, the maximum forward or rearward velocity, $V_{\max}$, a vehicle can handle in a turn without tipping over is

$$V_{\max} = \left[gr\left(\frac{d_{cg}}{2h_{ce}}\right)\right]^{1/2}, \tag{15-3}$$

where

$V_{\max}$ is in feet per second,

g is the gravitational constant (32.2 ft/s^2),

r is the turn radius (feet),

d is the distance from the composite center of gravity for the vehicle and load to the lateral support line (feet), and

h is the height of the composite center of gravity from the ground (feet).

Example 15-2 (a) A loaded, four-wheeled cart weighs 500 lb. The wheels on each axle are 24 in apart and the axles are 48 in apart. Its center of gravity is located at the center of the cart in plan view and 30 in from the floor. The cart is pulled around a corner. The turning radius is 6 ft. What is the maximum velocity for the cart that will not cause it to tip over? Applying Equation 15-3,

$$V_{\max} = \left[32.2 \left(6 \left\{ \frac{\frac{12}{12}}{2\frac{30}{12}} \right\} \right) \right]^{1/2} = 6.22\,\mathrm{ft/s} = 4.24\,\mathrm{mi/hr}.$$

(b) If the center of gravity were raised to 36 in and the turning radius was extended to 10 ft, what is the maximum velocity without tipping over?

$$V_{\max} = 7.33 \text{ ft/s} = 4.99 \text{ mi/hr}.$$

A vehicle may skid in a turn. This potential can be determined by comparing forces acting horizontally on the vehicle, that of the centrifugal force from the turn at $V_{\max}$ and frictional force on the tires. If the centrifugal force at $V_{\max}$ is more than the resistance force of friction, the vehicle will skid before it will tip.

Example 15-3 Consider the vehicle in Example 15-2(a). Assume the coefficient of friction, μ, between wheels and the floor is 0.65. Will the vehicle skid before it will tip?

Assuming all wheels are in contact with the supporting surface, the frictional force acting at the wheels is $F_f = \mu N$. The centrifugal force $F_c = mV^2/r$. The centrifugal force is $F_c = (500/32.2)(4.9)^2/6 = 62.13$ lb. The frictional force is $F_f = 0.65(500) = 325$ lb. Because $F_f > F_c$, the cart will not skid, but may tip.

Operating materials-handling vehicles on rough, irregular, and sloping surfaces can add to instability. The momentum of a jostled and tilted vehicle and load could cause the load to fall or the vehicle to tip. A load or vehicle may tip, even on a smooth, sloped surface. If the sum of forces acting through the center of gravity falls outside the support zone created by the tires, the vehicle will tip over. An analysis of static conditions will reveal when forward, rearward, or lateral tilt will cause tipping for various load elevations. Dynamic conditions are more difficult to analyze.

Some vehicles, like forklifts, can raise a load overhead. A load or parts of it that fall from an elevated level can injure the operator or anyone nearby.

Another hazard for some vehicles is catching on protruding objects during operation. For example, forklifts often carry loads into or out of truck trailers. Some rollup doors on truck trailers have short, flat straps for pulling the door down. If a rope is used instead of the flat strap or a knot is placed in the rope or strap, the knot may catch on the structure of the forklift and pull the door down on the operator. Obstructions, like items protruding from storage racks, door frames, and suspended light fixtures, can extend into the potential operating zone of a materials-handling vehicle and create catch points or introduce other hazards.

Controls

To protect operators from vehicle rollover injuries, some vehicles have a rollover protection system (ROPS). The concept is the same as that for motor vehicles. It consists of a structure surrounding the operator and forming an operator compartment. During an accident, it is essential to retain the integrity of the operator compartment. ROPS may be formed by a rollover bar on some vehicles, like tractors. Other elements of the vehicle structure help establish the envelope for the compartment. For other vehicles, four columns and connecting crossbars or a cab that meets ROPS standards create the safety envelope for the operator. Seat belts prevent the operator from being thrown from the compartment or crushed by ROPS or the vehicle itself during a rollover. One study estimated that 80% of operators of farm tractors who were killed in rollover accidents had vehicles without ROPS. With ROPS, the fatality rate was very low.

To protect operators from falling objects, overhead protection is needed. Materials-handling vehicles that have this hazard need a falling object protection system (FOPS). The size of opening should be small enough to prevent objects in a load from penetrating into the operator compartment. The operator also must be able to see the load through or around the FOPS. If there is a hazard from materials falling on an operator when a vehicle backs into something, FOPS should extend to the rear of the operator. Often ROPS and FOPS are incorporated into the same protective system.

The Society of Automotive Engineers (SAE) has several ROPS and FOPS standards. OSHA incorporates many of these standards into its regulations.

The integrity of the operator compartment provides protection from other hazards as well. For example, the operator stands in some industrial trucks. If feet or other parts of the body extend outside the vehicle, they can be crushed if the vehicle runs into something or passes close to an object, wall, or column. Protective enclosures or doors can reduce this hazard.

Vehicles and their components must be properly maintained to ensure their safe use. Operators must be trained in safe use of the vehicle. In most cases, operators have primary responsibility for safe materials-handling operations for their vehicles. Where exhaust may create a hazard, there should be adequate ventilation. Electric vehicles may be safer in enclosed areas.

Other controls include keeping areas clear of obstructions where materials-handling vehicles are operated, having horizontal and vertical pathways large enough for safe maneuver of the vehicle and the load, and providing protective barriers for racks and other objects, which could pose dangers when struck by powered vehicles that operate nearby. Trailers being loaded by materials-handling vehicles should have wheel chocks, devices to lock trailers to loading docks or other means to lock them in place.

Where visibility is a problem, visual assistance, which may be as simple as a mirror, must be provided for the operator. A classic products liability case involved the lack of a rearview mirror on a materials-handling vehicle. Assistance may be in the form of an assistant who gives standard hand signals or in the form of audio and visual warning devices on the vehicle to indicate when the vehicle is moving backward or in a direction where the operators visibility is inhibited.

15-6 HOISTING APPARATUS

Equipment

There are many kinds of equipment for hoisting and positioning materials. Not all can be discussed here. Most involve vertical movement of materials. Some include lateral movement or a combination of motions. There are hoists, which may be hand operated or powered, blocks and tackle, derricks and winches of various types, fixed and mobile cranes, tower cranes, gantry cranes, overhead cranes and boom cranes, aerial baskets (for positioning people), and elevated baskets (for positioning supplies; not to be used by people). These devices may be independent or may be installed in buildings, on trucks, or on railroad cars, or may be incorporated into the design of other items. Most involve rigging of some kind. Each may have special features and fixtures for handling particular kinds of materials or objects.

Hazards

Hoisting devices have some of the same hazards as other materials-handling equipment. Elevated materials can fall on people or items below. Structural failure can occur when load limits are exceeded. There are also load limits for stability. When they are exceeded, a hoisting apparatus will tip over and operators or assistants may become caught in the machine.

Visibility may be limited during operation. Supporting surfaces for wheels, outriggers, or other supports may not be able to carry the load, and the equipment may then tip over. Operation near power lines can result in electrocution. Operations in windy conditions may cause overloads and structural failure.

There are also hazards associated with the kind of power, the type of operation, the materials being handled, and the condition of the vehicle and its components.

Controls

One control for hoisting apparatus is proper setup and planning. This can include placement on a level site, staying away from power lines, and proper assembly of tower, boom, jib, and other elements. Chains and ropes should be free of kinks and twists, and the hoisting equipment should be inspected regularly, preferably before use. Many hoisting devices must be certified regularly for safe use. Soil conditions and other factors in the work area should be checked. For some crane operations, a lift diagram or plan is written and approved by all participating parties. A crane and its load must have stability. Stability may be achieved in various ways, from outriggers for boom cranes to anchoring cables for tower cranes.

Another control is a safe load. A hoisting apparatus should have load limits clearly marked. The ratings assume a static load. Loads that are jerked or dropped some distance and place inertial loads on the rigging can overload the apparatus or its rigging. Cranes, for example, should have a load chart affixed to the operator's cab and should have an operator's manual in the cab. The weight of the load to be picked up must be known, and the capacity of the equipment should not be exceeded.

There must be a trained operator. Some hoisting equipment has simple controls, whereas other types have complex controls. The operator must know more than how to make the crane and its movements work. The operator must know what can go wrong and how to deal with such situations; must understand the changing conditions during an operation; must evaluate the site for other workers, potentially changing site conditions and other factors that could affect safe operation; must know if the load is properly rigged; and must be able to read a load chart, if one is applicable.

Operating hoisting equipment safely can be a very complex process. For example, to make a safe lift with a mobile crane, at least seven items of information are needed:

1. Is the vehicle level?
2. Are all outriggers extended or retracted?
3. Are extended outriggers supported by stable ground?
4. Are tires fully inflated?
5. What is the angle of the boom?
6. What are the boom and jib lengths?
7. What positions will the boom be in during the lift?
8. How much does the load weigh?

If these things are known, the operator can make readings on the load chart (see Figure 15-2) and determine if the operation will be within all structural and stability limits. The limits assume a level machine, and they are different when tires are not fully inflated and when the outriggers are not in place. The limits change suddenly when a load is moved from the front to the side and to the rear of the vehicle because of the changing distance of frontal, lateral, and rearward supports from the pivot point. The boom angle and length also are needed to determine the safe loads. Precise measurements may be needed when operations take place in tight spaces. The use of the crane can begin after evaluating the site and the environment around the crane and after comparing conditions with the load chart and deciding that a load can be lifted safely. Figure 15-2 illustrates how complex the use of a load chart can become while it helps ensure that lifts are completed safely.

With the wide variety of configurations of a mobile crane, using a load chart to determine a safe lift can be quite complicated. Today, some manufacturers build computers into the cab, require the operator to input a sequence of data in response to prompts, and combine the data with sensory data from crane components to handle the information sequence in deciding if a lift can be accomplished safely.

Excessive wind, potential contact with electrical lines and equipment, job site congestion, or poor soil and bearing under outriggers may require scrapping an operation. The load must be properly rigged, and all participants must understand the lifting plan. It is then lifted and moved, most likely with the assistance of others observing the load and the site, to make sure that no one is under the load or that other dangerous conditions develop. An assistant may use standard hand signals to guide the operator, who cannot see

GROVE®

LOAD CHARTS
RT530E

85% STABILITY
ON OUTRIGGERS
75% STABILITY
ON RUBBER

Figure 15-3. Representative load chart for a mobile crane (Grove Mobile Hydraulic Crane, Model RT530E). Data show lifting capabilities for various crane operations. Capacities below bold lines are based on failure by tipping; capacities above bold lines are based on structural strength. Notes and diagrams identify many additional factors and assumptions that must be considered in deciding if a load can be lifted safely. (Reprinted with the permission of Grove U.S., LLC.)

NOTES FOR LIFTING CAPACITIES

GENERAL:

1. Rated loads as shown on lift chart pertain to this machine as originally manufactured and equipped. Modifications to the machine or use of optional equipment other than that specified can result in a reduction of capacity.
2. Construction equipment can be hazardous if improperly operated or maintained. Operation and maintenance of this machine shall be in compliance with the information in the Operator's and Safety Handbook, Service Manual and Parts Manual supplied with this machine. If these manuals are missing, order replacements from the manufacturer through the distributor.
3. The operator and other personnel associated with machine shall fully acquaint themselves with the latest American National Safety Standards (ASME/ANSI) for cranes.

SETUP:

1. The machine shall be level and on a firm supporting surface. Depending on the nature of the supporting surface, it may be necessary to have structural supports under the outrigger floats or tires to spread the load to a larger bearing surface.
2. For outrigger operation, all outriggers shall be properly extended with tires raised free of crane weight before operating the boom or lifting loads.
3. When machine is equipped with center front stabilizer, the front stabilizer shall be set in accordance with instructions in Operator's and Safety Handbook.
4. When equipped with removable and/or extendible counterweight, the proper counterweight shall be installed and fully extended before and during operation.
5. Tires shall be inflated to the recommended pressure before lifting on rubber.
6. With certain boom and hoist tackle combinations, maximum capacities may not be obtainable with standard cable lengths.
7. Unless approved by the crane manufacturer, do not travel with boom extension or jib erected unless otherwise noted. Refer to Operator's and Safety Handbook for job-site travel information.

OPERATION:

1. Rated loads at rated radius shall not be exceeded. Do not attempt to tip the machine to determine allowable loads. For clamshell or concrete bucket operation, weight of bucket and load must not exceed 80% of rated lifting capacities.
2. All rated loads have been tested to and meet the requirements of SAE J1063 - Cantilevered Boom Crane Structures - Method of Test, and do not exceed 85% of the tipping load on outriggers fully extended and SAE J1289 - Mobile Crane Stability Ratings [$1.25P < (T-0.1A)$] on outriggers 50% and 0% extended (fully retracted) as determined by SAE J765 - Crane Stability Test Code.
3. Rated loads include the weight of hookblock, slings and auxiliary lifting devices and their weights shall be subtracted from the listed rating to obtain the net load to be lifted. When more than the minimum required parts of line needed to pick the load are used, the additional rope weight as measured from the lower sheaves of the the main boom nose shall be considered part of the load to be lifted. When both the hook block and headache ball are reeved, the lifting device that is NOT in use, including the line as measured from the lower sheave(s) of the nose supporting the unused device shall be considered part of the load.
4. Load ratings are based on freely suspended loads. No attempt shall be made to move a load horizontally on the ground in any direction.
5. The maximum in-service wind speed is 20 m.p.h. It is recommended when wind velocity is above 20 m.p.h., rated loads and boom lengths shall be appropriately reduced. For machines not in-service, the main boom should be retracted and lowered with the swing brake set in wind velocities over 30 m.p.h.
6. Rated loads are for lift crane service only.
7. **Do not** operate at a radius or boom length where capacities are not listed. At these positions, the machine may overturn without any load on the hook.
8. The maximum load which can be telescoped is not definable because of variations in loadings and crane maintenance, but it is safe to attempt retraction and extension of the boom within the limits of the capacity chart.
9. When the boom length or lift radius or both are between values listed, the smallest load shown at either the next larger radius or next longer or shorter boom length shall be used.
10. For safe operation, the user shall make due allowances for his particular job conditions, such as: soft or uneven ground, out of level conditions, high winds, side loads, pendulum action, jerking or sudden stopping of loads, experience of personnel, two machine (tandem) lifts, traveling with loads, electric wires, obstacles, hazardous conditions, etc. Side pull on boom or jib is extremely dangerous.
11. If machine is equipped with individually controlled powered boom sections, the boom sections must be extended equally at all times.
12. Never handle personnel with this machine unless the requirements of the applicable national, state, and local regulations and safety codes are met.
13. Keep load handling devices a minimum of 42 inches below boom head at all times.
14. The boom angle before loading should be greater than the loaded boom angle to account for deflection.
15. Capacities appearing above the bold line are based on structural strength and tipping should not be relied upon as a capacity limitation.
16. Capacities for the 29 ft. boom length shall be lifted with boom fully retracted. If boom is not fully retracted, capacities shall not exceed those shown for the 40 ft. boom length.
17. When operating the machine in the "On Outriggers 50% Extended (14' spread)" mode, the outrigger beam pins must be engaged. When operating in the "On Outriggers 0% Extended (7' 10" spread)" mode, the outrigger beams must be fully retracted. Failure to follow these precautions could result in structural damage or loss of stability of the machine.
18. Regardless of counterweight and outrigger spread configuration, no deduct is required from the main boom charts for a stowed boom extension.
19. **Do not** lift loads when boom is fully lowered. The Load Moment Indicator (LMI) senses pressure and will not provide warnings or lockout. The crane can become overloaded if lift cylinder(s) is fully retracted.
20. The maximum outrigger pad load is 48,900 lb.

DEFINITIONS:

1. Operating Radius: Horizontal distance from a projection of the axis of rotation to the supporting surface before loading to the center of the vertical hoist line or tackle with load applied.
2. Loaded Boom Angle (Shown in Parenthesis on Main Boom Capacity Chart): is the angle between the boom base section and the horizontal, after lifting the rated load at the rated radius with the rated boom length.
3. Working Area: Areas measured in a circular arc about the center line of rotation as shown on the working area diagram.
4. Freely Suspended Load: Load hanging free with no direct external force applied except by the lift cable.
5. Side Load: Horizontal force applied to the lifted load either on the ground or in the air.

RT530E - S/N

Figure 15-3. *continued*

WEIGHT REDUCTIONS FOR LOAD HANDLING DEVICES

26 FT. OFFSETTABLE BOOM EXTENSION	
*Erected -	2,960 lbs.
26 FT. - 45 FT. TELE. BOOM EXTENSION	
*Erected (Retracted) -	4,220 lbs.
*Erected (Extended) -	5,780 lbs.

*Reduction of main boom capacities

AUXILIARY BOOM NOSE	142 lbs.
HOOKBLOCKS and HEADACHE BALLS:	
30 Ton, 3 Sheave	580 lbs.+
15 Ton, 2 Sheave	425 lbs.+
7.5 Ton Overhaul Ball (top swivel)	354 lbs.+
7.5 Ton Headache Ball	338 lbs.+

+Refer to rating plate for actual weight.

When lifting over swingaway and/or jib combinations, deduct total weight of all load handling devices reeved over main boom nose directly from swingaway or jib capacity.

NOTE: All load handling devices and boom attachments are considered part of the load and suitable allowances MUST BE MADE for their combined weights. Weights are for Grove furnished equipment.

LINE PULLS AND REEVING INFORMATION

HOISTS	CABLE SPECS.	PERMISSIBLE LINE PULLS	NOMINAL CABLE LENGTH
Main	5/8" (16 mm) 6x37 Class, EIPS, IWRC Special Flexible Min. Breaking Strength 41,200 lb.	11,640 lb.	450 ft.
Main & Aux.	5/8" (16 mm) Flex-X 35 Rotation Resistant (Non-rotating) Min. Breaking Strength 61,200 lb.	11,640 lb.	450 ft.

The approximate weight of 5/8" wire rope is 1.0 lb./ft.

HOIST PERFORMANCE

Wire Rope Layer	Hoist Line Pulls	Drum Rope Capacity (ft.)	
	Available lb.*	Layer	Total
1	11,640	77	77
2	10,480	85	162
3	9,530	94	256
4	8,730	102	358
5	8,060	111	469
6	7,490	119	588

*Max. lifting capacity: 6x37 class = 11,640 lb.
35x7 class = 11,640 lb.

Figure 15-3. *continued*

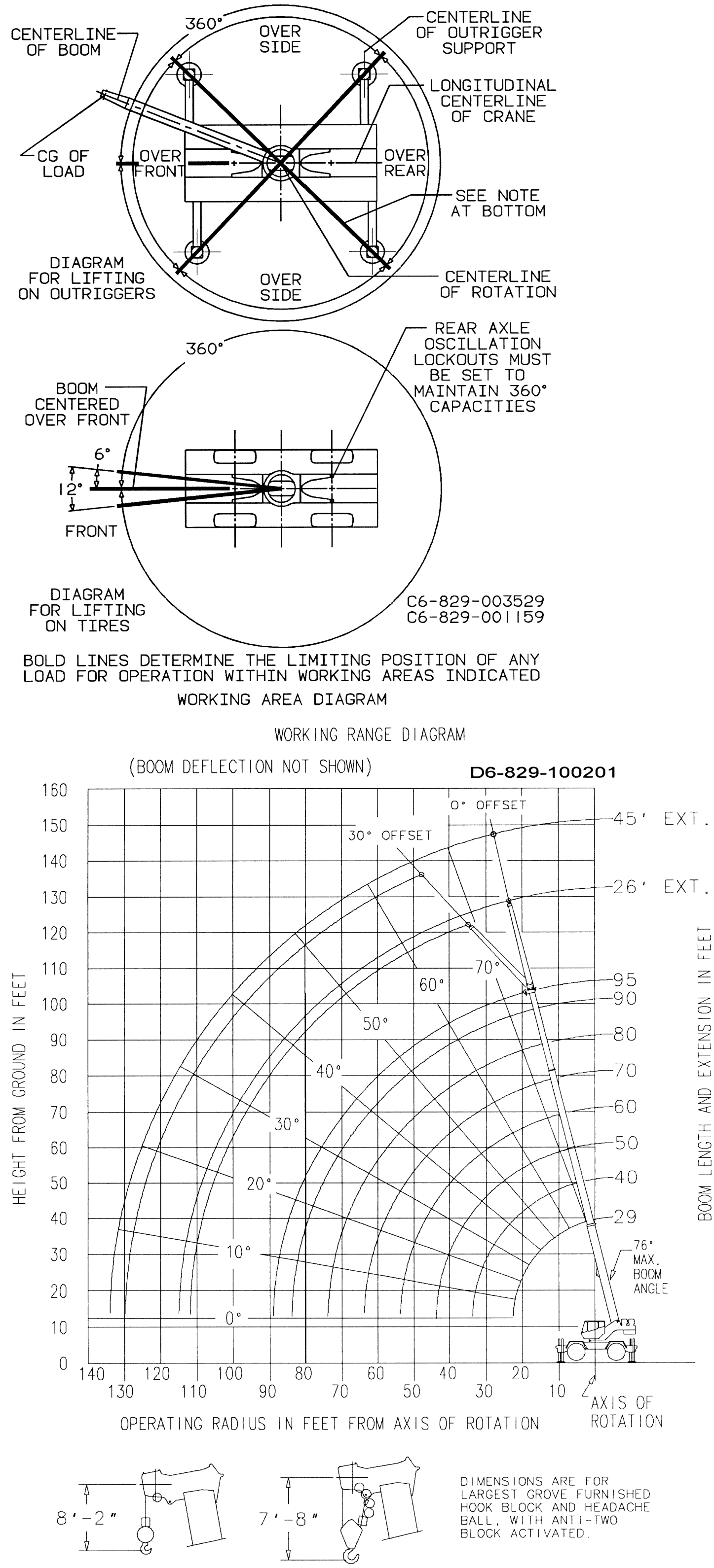

Figure 15-3. *continued*

RATED LIFTING CAPACITIES IN POUNDS
29 FT. - 95 FT. BOOM
ON OUTRIGGERS FULLY EXTENDED - 360°

Radius in Feet	#0001							
	Main Boom Length in Feet							
	29	40	50	60	70	80	90	95
10	60,000 (60.5)	50,100 (69.5)	46,950 (74.5)					
12	54,650 (56)	50,100 (66.5)	44,950 (72)	*38,850 (76)				
15	42,850 (47.5)	43,800 (61.5)	41,050 (68)	36,000 (72)	*29,450 (76)	*22,450 (76)		
20	30,700 (30)	31,650 (53)	32,100 (61.5)	29,500 (67)	27,400 (71)	22,450 (73.5)	*18,550 (76)	*15,500 (76)
25		24,050 (42.5)	24,500 (54.5)	24,800 (61.5)	23,100 (66.5)	19,250 (70)	16,500 (72.5)	15,300 (74)
30		18,800 (29)	19,250 (47)	19,550 (56)	19,600 (61.5)	16,850 (66)	14,400 (69)	13,200 (70.5)
35			15,550 (38)	15,850 (49.5)	16,000 (56.5)	14,850 (61.5)	12,700 (65.5)	11,500 (67.5)
40			12,800 (26)	12,950 (42.5)	13,000 (51.5)	13,050 (57.5)	11,000 (62)	10,000 (64)
45	See Note 16			10,450 (34.5)	10,500 (46)	10,550 (53)	9,630 (58.5)	9,060 (60.5)
50				8,610 (23.5)	8,630 (39.5)	8,670 (48)	8,720 (54.5)	7,990 (57)
55					7,170 (32)	7,200 (43)	7,250 (50)	7,100 (53)
60					6,000 (22)	6,030 (37)	6,100 (45.5)	6,110 (49)
65						5,080 (30)	5,120 (40.5)	5,150 (44.5)
70						4,270 (20.5)	4,330 (35)	4,350 (40)
75							3,650 (28.5)	3,700 (34.5)
80							3,100 (20)	3,100 (28)
85								2,600 (20)
Minimum boom angle (°) for indicated length (no load)								0
Maximum boom length (ft.) at 0° boom angle (no load)								95

NOTE: ( ) Boom angles are in degrees.
#LMI operating code. Refer to LMI manual for operating instructions.
*This capacity is based on maximum boom angle.

Lifting Capacities at Zero Degree Boom Angle On Outriggers Fully Extended - 360°								
Boom Angle	Main Boom Length in Feet							
	29	40	50	60	70	80	90	95.2
0 deg.	26,100 (22.8)	15,800 (33.8)	11,000 (43.8)	7,430 (53.8)	5,220 (63.8)	3,730 (73.8)	2,660 (83.8)	2,220 (89)

NOTE: ( ) Reference radii in feet. A6-829-101755

Figure 15-3. *continued*

26 FT. - 45 FT. TELE OFFSETTABLE BOOM EXTENSION ON OUTRIGGERS FULLY EXTENDED - 360°

Radius in Feet	**26 ft. LENGTH		45 ft. LENGTH	
	#0021	#0023	#0041	#0043
	0° OFFSET	30° OFFSET	0° OFFSET	30° OFFSET
30	*8,200 (76)			
35	8,200 (73.5)		*5,250 (76)	
40	8,200 (71)	*5,780 (76)	5,250 (75)	
45	8,120 (68.5)	5,780 (73.5)	4,940 (73)	
50	7,350 (66)	5,360 (71)	4,540 (71)	
55	6,370 (63)	4,750 (68)	4,150 (68.5)	*2,730 (76)
60	5,670 (60.5)	4,290 (65)	3,890 (66)	2,730 (74.5)
65	4,820 (57.5)	3,870 (62)	3,740 (64)	2,730 (72)
70	4,200 (54.5)	3,530 (59)	3,600 (61.5)	2,580 (69.5)
75	3,680 (51.5)	3,230 (56)	3,470 (59)	2,520 (67)
80	3,080 (48.5)	3,000 (52.5)	3,240 (56.5)	2,460 (64)
85	2,520 (45)	2,780 (49)	3,050 (54)	2,420 (61.5)
90	2,050 (41)	2,410 (45)	2,820 (51)	2,390 (58.5)
95	1,670 (37)	1,970 (40.5)	2,480 (48.5)	2,370 (55.5)
100	1,370 (32.5)	1,580 (35.5)	2,090 (45.5)	2,310 (52)
105	1,020 (27.5)		1,740 (42)	2,000 (49)
110			1,430 (38.5)	1,580 (45)
115			1,150 (35)	1,260 (40.5)
120			900 (30.5)	
Min. boom angle for indicated length (no load)	24°	30°	30°	30°
Max. boom length at 0° boom angle (no load)	80 ft.		80 ft.	

NOTE: ( ) Boom angles are in degrees. A6-829-100272A
#LMI operating code. Refer to LMI manual for instructions.
*This capacity based on maximum boom angle.
**26 ft. capacities are also applicable to fixed offsettable ext. However, the LMI codes will change to #0051 and #0053 for 0° and 30° offset, respectively.

BOOM EXTENSION CAPACITY NOTES:

1. All capacities above the bold line are based on structural strength of boom extension.
2. 26 ft. and 45 ft. boom extension lengths may be used for single line lifting service.
3. Radii listed are for a fully extended boom with the boom extension erected. For main boom lengths less than fully extended, the rated loads are determined by boom angle. Use only the column which corresponds to the boom extension length and offset for which the machine is configured. For boom angles not shown, use the rating of the next lower boom angle.

   WARNING: Operation of this machine with heavier loads than the capacities listed is strictly prohibited. Machine tipping with boom extension occurs rapidly and without advance warning.
4. Boom angle is the angle above or below horizontal of the longitudinal axis of the boom base section after lifting rated load.
5. Capacities listed are with outriggers fully extended and vertical jacks set only.

Figure 15-3. *continued*

ON RUBBER CAPACITIES

STATIONARY CAPACITIES 360°

Radius in Feet	#9005 Main Boom Length in Feet 29	40	50	60
10	25,550 (60.5)	25,550 (70)	*16,450 (76)	
12	20,600 (56)	20,600 (66.5)	16,450 (72)	
15	14,350 (47.5)	14,350 (62)	14,350 (68)	14,350 (72.5)
20	8,280 (30)	8,280 (53)	8,280 (61.5)	8,280 (67)
25		5,330 (42.5)	5,330 (54.5)	5,330 (61.5)
30		3,630 (29)	3,630 (47)	3,630 (56)
35			2,500 (38)	2,500 (49.5)
40			1,690 (26)	1,690 (42.5)
45				1,090 (34.5)
Min. boom angle for indicated length (no load)				34°
Max. boom length at 0° boom angle (no load)				50 ft.

NOTE: ( ) Boom angles are in degrees.
#LMI operating code. Refer to LMI manual for instructions.
*This capacity is based upon maximum boom angle.

Lifting Capacity at Zero Degree On Rubber - 360°

Boom Angle	Main Boom Length in Feet 29	40	50	
0°	6,110 (22.8)	2,730 (33.8)	1,210 (43.8)	

NOTE: Reference radii in feet A6-829-100274C

STATIONARY CAPACITIES DEFINED ARC OVER FRONT (See Note 3)

Radius in Feet	#9005 Main Boom Length in Feet 29	40	50	60
10	30,100 (60.5)	26,550 (70)	16,450 (74.5)	
12	26,550 (56)	22,100 (66.5)	16,450 (72)	
15	22,100 (47.5)	22,100 (62)	16,450 (68)	16,450 (72.5)
20	16,050 (30)	16,050 (53)	16,050 (61.5)	16,050 (67)
25		11,005 (42.5)	11,005 (54.5)	11,005 (61.5)
30		8,060 (29)	8,060 (47)	8,060 (56)
35			6,110 (38)	6,110 (49.5)
40			4,720 (26)	4,720 (42.5)
45				3,680 (34.5)
50				2,870 (23.5)
Min. boom angle for indicated length (no load)				0°
Max. boom length at 0° boom angle (no load)				60 ft.

NOTE: ( ) Boom angles are in degrees.
#LMI operating code. Refer to LMI manual for instructions.

Lifting Capacity at Zero Degree On Rubber Stationary- Defined Arc Boom Centered Over Front

Boom Angle	Main Boom Length in Feet 29	40	50	60
0°	12,700 (22.8)	6,500 (33.8)	3,890 (43.8)	2,360 (53.8)

NOTE: Reference radii in feet. A6-829-100275B

Figure 15-3. *continued*

ON RUBBER CAPACITIES (cont'd.)

PICK & CARRY CAPACITIES (UP TO 2.5 MPH) - BOOM CENTERED OVER FRONT (See note 7)

Radius in Feet	#9006			
	Main Boom Length in Feet			
	29	40	50	60
10	25,900 (60.5)	25,900 (70)	18,250 (74.5)	
12	22,350 (56)	22,350 (66.5)	18,250 (72)	
15	18,250 (47.5)	18,250 (62)	18,250 (68)	13,350 (72.5)
20	13,350 (30)	13,350 (53)	13,350 (61.5)	13,350 (67)
25		10,350 (42.5)	10,350 (54.5)	10,350 (61.5)
30		8,060 (29)	8,060 (47)	8,060 (56)
35			4,810 (38)	4,810 (49.5)
40			3,770 (26)	3,770 (42.5)
45				2,930 (34.5)
50				2,240 (23.5)
Min. boom angle for indicated length (no load)				0°
Max. boom length at 0° boom angle (no load)				60 ft.

NOTE: ( ) Boom angles are in degrees.
#LMI operating code. Refer to LMI manual for instructions.

Lifting Capacity at Zero Degree On Rubber Pick & Carry - Boom Centered Over Front				
Boom Angle	Main Boom Length in Feet			
	29	40	50	60
0°	11,400 (22.8)	5,090 (33.8)	3,110 (43.8)	1,800 (53.8)

NOTE: Reference radii in feet A6-829-100276B

NOTES TO ALL RUBBER CAPACITY CHARTS:

1. Capacities are in pounds and do not exceed 75% of tipping loads as determined by test in accordance with SAE J765.
2. Capacities are applicable to machines equipped with 20.5x25 (24 ply) tires at 75 psi cold inflation pressure, and 16.00x25 (28 ply) tires at 100 psi cold inflation pressure.
3. Defined Arc - Over front includes 6° on either side of longitudinal centerline of machine (ref. drawing C6-829-003529).
4. Capacities appearing above the bold line are based on structural strength and tipping should not be relied upon as a capacity limitation.
5. Capacities are applicable only with machine on firm level surface.
6. On rubber lifting with boom extensions not permitted.
7. For pick and carry operation, boom must be centered over front of machine, mechanical swing lock engaged and load restrained from swinging. When handling loads in the structural range with capacities close to maximum ratings, travel should be reduced to creep speeds.
8. Axle lockouts must be functioning when lifting on rubber.
9. All lifting depends on proper tire inflation, capacity and condition. Capacities must be reduced for lower tire inflation pressures. See lifting capacity chart for tire used. Damaged tires are hazardous to safe operation of crane.
10. Creep - not over 200 ft. of movement in any 30 minute period and not exceeding 1 mph.

Figure 15-3. *continued*

RATED LIFTING CAPACITIES IN POUNDS
29 FT. - 95 FT. BOOM
ON OUTRIGGERS 50% EXTENDED (14.0 FT. SPREAD) - 360°

Radius in Feet	#4001							
	Main Boom Length in Feet							
	29	40	50	60	70	80	90	95
10	60,000 (60.5)	48,000 (69.5)	45,000 (74.5)					
12	53,300 (56)	48,000 (66.5)	44,950 (72)	*37,000 (76)				
15	42,100 (47.5)	40,500 (61.5)	38,350 (68)	36,000 (72)	*27,400 (76)	*21,000 (76)		
20	23,950 (30)	23,850 (53)	23,900 (61.5)	24,050 (67)	23,200 (71)	21,000 (73.5)	*17,000 (76)	*15,500 (76)
25		15,850 (42.5)	15,950 (54.5)	16,150 (61.5)	16,350 (66.5)	16,400 (70)	15,950 (72.5)	15,300 (74)
30		11,350 (29)	11,500 (47)	11,650 (56)	11,800 (61.5)	12,000 (66)	12,150 (69)	12,100 (70.5)
35	See Note 16		8,620 (38)	8,820 (49.5)	8,930 (56.5)	9,050 (61.5)	9,190 (65.5)	9,260 (67.5)
40			6,610 (26)	6,820 (42.5)	6,900 (51.5)	6,990 (57.5)	7,100 (62)	7,150 (64)
45				5,350 (34.5)	5,400 (46)	5,470 (53)	5,550 (58.5)	5,600 (60.5)
50				4,220 (23.5)	4,260 (39.5)	4,310 (48)	4,370 (54.5)	4,410 (57)
55					3,350 (32)	3,390 (43)	3,430 (50)	3,460 (53)
60					2,600 (22)	2,640 (37)	2,670 (45.5)	2,700 (49)
65						2,020 (30)	2,050 (40.5)	2,060 (44.5)
70						1,490 (20.5)	1,520 (35)	1,530 (40)
75							1,070 (28.5)	1,080 (34.5)
0.1A (lb.)	660	610	580	560	550	540	540	530
Minimum boom angle (°) for indicated length (no load)							15	20
Maximum boom length (ft.) at 0° boom angle (no load)							80	

NOTE: ( ) Boom angles are in degrees.
#LMI operating code. Refer to LMI manual for operating instructions.
*This capacity is based on maximum boom angle.

Lifting Capacities at Zero Degree Boom Angle On Outriggers 50% Extended - 360°								
Boom Angle	Main Boom Length in Feet							
	29	40	50	60	70	80		
0 deg.	18,800 (22.8)	9,000 (33.8)	5,400 (43.8)	3,480 (53.8)	2,100 (63.8)	1,130 (73.8)		

NOTE: ( ) Reference radii in feet. A6-829-100270A

Figure 15-3. *continued*

26 FT. - 45 FT. TELE BOOM EXTENSION

ON OUTRIGGERS 50% EXTENDED (14.0 FT. SPREAD) - 360°

Radius in Feet	**26 ft. LENGTH		45 ft. LENGTH	
	#4021	#4023	#4041	#4043
	0° OFFSET	30° OFFSET	0° OFFSET	30° OFFSET
30	*8,200 (76)			
35	8,200 (73.5)		*5,250 (76)	
40	6,940 (71)	*5,780 (76)	5,250 (75)	
45	5,580 (68.5)	5,780 (73.5)	4,940 (73)	
50	4,490 (66)	5,360 (71)	4,540 (71)	
55	3,600 (63)	4,350 (68)	4,150 (68.5)	*2,730 (76)
60	2,860 (60.5)	3,430 (65)	3,490 (66)	2,730 (74.5)
65	2,190 (57.5)	2,670 (62)	2,870 (64)	2,730 (72)
70	1,610 (54.5)	2,030 (59)	2,340 (61.5)	2,580 (69.5)
75	1,120 (51.5)	1,490 (56)	1,840 (59)	2,520 (67)
80		1,020 (52.5)	1,400 (56.5)	2,260 (64)
85			1,020 (54)	1,760 (61.5)
90				1,310 (58.5)
0.1A (lb.)	570	540	500	460
Min. boom angle for indicated length (no load)	44°	46°	48°	49°
Max. boom length at 0° boom angle (no load)	60 ft.		60 ft.	

NOTE: ( ) Boom angles are in degrees. A6-829-100273B
#LMI operating code. Refer to LMI manual for instructions.
*This capacity based on maximum boom angle.
26 ft. capacities are also applicable to fixed offsettable ext. However, the LMI codes will change to **#4051 and **#4053** for 0° and 30° offset, respectively.

BOOM EXTENSION CAPACITY NOTES:

1. All capacities above the bold line are based on structural strength of boom extension.
2. 26 ft. and 45 ft. boom extension lengths may be used for single line lifting service.
3. Radii listed are for a fully extended boom with the boom extension erected. For main boom lengths less than fully extended, the rated loads are determined by boom angle. Use only the column which corresponds to the boom extension length and offset for which the machine is configured. For boom angles not shown, use the rating of the next lower boom angle.

   WARNING: Operation of this machine with heavier loads than the capacities listed is strictly prohibited. Machine tipping with boom extension occurs rapidly and without advance warning.
4. Boom angle is the angle above or below horizontal of the longitudinal axis of the boom base section after lifting rated load.
5. Capacities listed are with outriggers properly extended and vertical jacks set only.

Figure 15-3. *continued*

RATED LIFTING CAPACITIES IN POUNDS
29 FT. - 95 FT. BOOM

ON OUTRIGGERS 0% EXTENDED (7 FT. 10 IN. SPREAD) - 360°

Radius in Feet	#8001							
	Main Boom Length in Feet							
	29	40	50	60	70	80	90	95
10	34,700 (60.5)	32,400 (69.5)	30,400 (74.5)					
12	26,200 (56)	25,400 (66.5)	24,100 (72)	*22,900 (76)				
15	17,750 (47.5)	17,550 (61.5)	17,550 (68)	17,250 (72)	*16,550 (76)	*10,900 (76)		
20	10,650 (30)	10,600 (53)	10,650 (61.5)	10,750 (67)	11,000 (71)	10,900 (73.5)	*10,500 (76)	*10,350 (76)
25		6,930 (42.5)	7,020 (54.5)	7,170 (61.5)	7,350 (66.5)	7,560 (70)	7,610 (72.5)	7,490 (74)
30		4,670 (29)	4,780 (47)	4,950 (56)	5,080 (61.5)	5,240 (66)	5,390 (69)	5,480 (70.5)
35			3,270 (38)	3,450 (49.5)	3,550 (56.5)	3,660 (61.5)	3,780 (65.5)	3,850 (67.5)
40			2,170 (26)	2,370 (42.5)	2,440 (51.5)	2,520 (57.5)	2,620 (62)	2,670 (64)
45				1,550 (34.5)	1,600 (46)	1,660 (53)	1,740 (58.5)	1,780 (60.5)
50							1,050 (54.5)	1,080 (57)
0.1A (lb)	660	610	580	560	550	540	540	530
Minimum boom angle (°) for indicated length (no load)				33	43	51	53	55
Maximum boom length (ft.) at 0° boom angle (no load)				50				

NOTE: ( ) Boom angles are in degrees.
#LMI operating code. Refer to LMI manual for operating instructions.
*This capacity is based on maximum boom angle.

Lifting Capacities at Zero Degree Boom Angle On Outriggers 0% Extended - 360°								
Boom Angle	Main Boom Length in Feet							
	29	40	50					
0 deg.	8,310 (22.8)	3,390 (33.8)	1,480 (43.8)					

NOTE: ( ) Reference radii in feet. A6-829-100271A

TIRE INFLATION - PSI (BAR)				
SIZE (FRONT & REAR)	LOAD RANGE	TRA CODE	LIFTING SERVICE AND GENERAL TRAVEL STATIC, CREEP & 2.5 MPH (4.0 km/h)	EXTENDED TRAVEL
20.5x25	24 PR	E-3	75 (5.2)	70 (4.8)
16.00x25	28 PR	E-3	100 (6.9)	95 (6.6)

Figure 15-3. *continued*

the load during parts of the operation. There may also be someone who is clear of the load, but guides it with a tag line.

There are many design features that can reduce risks in the use of hoisting apparatus. Not all safety features in cranes are fail-safe devices; each has its limitations. Not all can be discussed here. A few examples will suffice. An overhead crane often is built into a building's structure. Overhead cranes operate on rails attached to building columns. This allows the crane bridge to move through a building elevated well above the floor. A trolley attached to the bridge of the crane provides movement perpendicular to the movement of the bridge. The rails should be equipped with limit switches and bumpers to prevent the crane from running off the end of the rails or into the building structure.

Cranes may have built-in safety devices or warning devices. One type of device, load indicating devices, measure the load and provide the operator with a reading of load or an overload warning signal. There are limit switches to prevent "double blocking," which refers to the load block or hook reaching the top of its travel. Often the cable to which the block is attached runs into or tries to pass over another sheave. When double blocking occurs, the hoisting mechanism is likely to become overloaded and fail.

Boom cranes have special safety devices for their unique hazards. One device is a boom angle indicator or boom radius indicator. A reading from this device provides the operator with information to help determine if a load is within safe limits. There are also devices, called load-moment indicators, that combine boom angle and load. If the moment necessary to overturn a crane is approached or exceeded, an alarm sounds for the operator.

When crane booms operate near overhead power lines, there is a danger of contacting them and possibly electrocuting the operator or someone in contact with the crane. There are power line proximity warning devices that notify the operator if the boom becomes too close to an energized powerline. Regulations require that booms be kept certain distances from such energized power lines, and the distance is related to the voltage of the power line. There are devices for insulating cranes and booms from electrical power if contact is made with an overhead line. It is also important to ground cranes and other materials handling equipment that could come into contact with electrical power sources.

There are limit switches for hoists and cranes. On a crane, for example, the limit switch prevents the load block or hook from overrunning the sheave at the end of a boom. If the hook begins to pass over the sheave, the mouth of the hook may reach a position where the end loops of a sling fall out of the mouth. If this occurs, a load will fall from the hook.

15-7 ROPES, CHAINS, AND SLINGS

Equipment

Ropes, chains, and slings are the rigging used to lift loads. They form the interface between the hoisting equipment and the load. There are many kinds of rigging materials.

Ropes normally are twisted strands of material. They may be made from natural fibers like manila, from synthetic fibers like nylon and polypropylene, or from metal, usually steel. The nomenclature for wire rope usually includes an outer diameter. Wire rope also has a numbering system that indicates the numbers of wire bundles in the rope surrounding the core and the number of continuous wires in a bundle. For example, in a 6×19 wire rope, there are six bundles composed of 19 wires each for a total of 114 wires.

A common rigging component is a hook on the end of a hoist or crane rope. Like other elements of rigging, the hook has a load limit.

There are many kinds of slings. Slings normally have a fixed length and they may be made from various materials and have the form of rope, belts, mesh, or fabric. To prevent damage to an object being lifted, a sling may be a wide band of fabric or a belt to distribute the load. This prevents the sling from cutting into or scratching the object. Some slings have a loop on each end. One or both ends may be placed into the mouth of a hook. Slings are suspended from a hook in different ways. Figure 15-4 illustrates three common methods: vertical, choker, and basket hitch. Some slings have more than two legs; three- and four-legged slings are quite common. Some slings have a hook on the end of each leg instead of a loop. In some rigging arrangements, a spreader is placed between legs of a sling above the load to help the sling legs stay vertical rather than compress around the sides of the load. A four-legged sling and the use of a spreader are illustrated in Figure 15-5.

Hazards

The main hazards of rigging are failures resulting from overloading, deterioration or wear, exposures, and improper rigging or abuse.

Each type of rigging can carry some load. A rope of a certain diameter has a rated capacity, based on ultimate strength and a factor of safety. (A factor of safety for materials was discussed in Chapter 10.) Fittings on the rope, the way it is used, and its physical condition will only reduce its capacity. The amount of reduction can vary considerably. A rope, chain, or sling is no stronger than its weakest element. A rigging with full capacity is rated as 100% efficient. Fittings, splices, bends around sheaves or objects, and damaged segments or links all can reduce the load capacity to some efficiency level less than 100%. Tables and charts in several references give efficiencies for fittings and splices.

One factor that affects the load that can be lifted with a sling is related to the type of hitch applied in the rigging. The type of hitch determines the number of active legs. For a choker hitch, one live element or leg of the sling ends up carrying the entire load (see Figure 15-4). In a vertical hitch, the entire load is carried by one live leg. In a basket hitch, there are two live legs, each carrying half the load.

Another factor that determines the load that a sling can carry is the angle formed by the legs. Refer to Figure 15-6 for a two-legged sling. The greater the angle from vertical that a leg has, the greater the load on the leg.

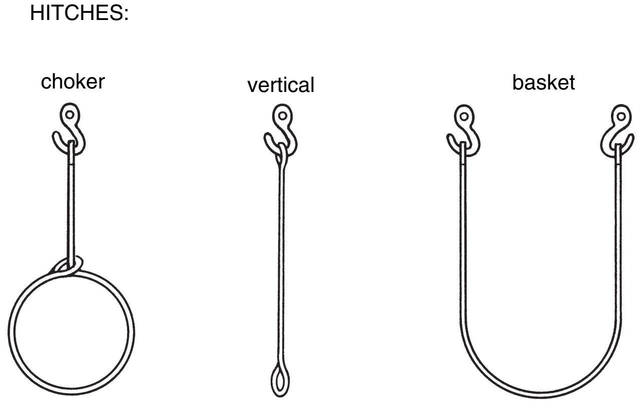

Figure 15-4. Kinds of slings.

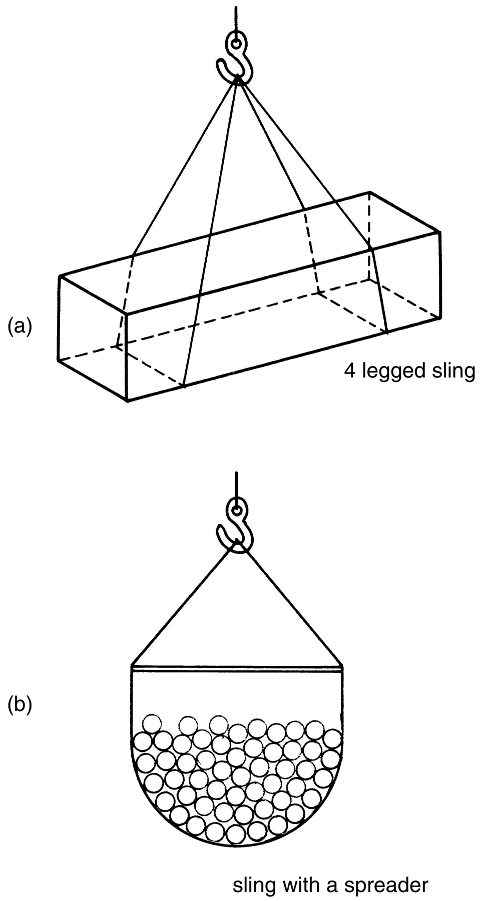

Figure 15-5. (a) A four-legged sling and (b) a sling with a spreader.

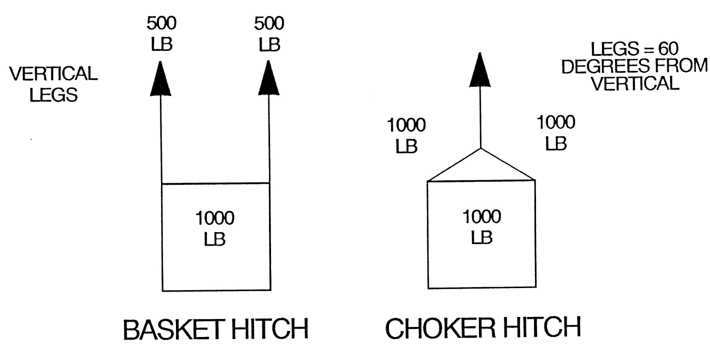

Figure 15-6. Comparison of basket hitch and choker hitch load capacities.

A load may slip from rigging if the arrangement for the rigging is not properly attached. For example, it is not uncommon for a load to slip from a two-legged sling.

Hooks are usually made from ductile steel because if they were brittle, they would not be as durable under repeated loading. One hazard occurs when rigging becomes disengaged from the mouth of a hook, causing the load to fall. Another hazard is the widening of the mouth opening of a hook resulting from repeated loading. This can increase the chances of rigging slipping from the hook.

Improper storage and exposure to weather, sunlight, high temperatures, chemicals, moisture, or other elements can reduce the capacity of rigging. Sunlight affects the strength of certain synthetic materials. Moisture can induce rotting in natural materials and corrosion in metals. Physical damage occurs when rigging is run over, loads are dropped on rigging components, or when rigging is dragged around. When ropes bend around small radius corners or sheaves, the outer fibers are overstressed and may fail. As a result, some of the load capacity is lost. Some wires or fibers are made smaller simply by wear, thereby reducing the capacity.

Another hazard of rigging is injury to users or others nearby. If the rigging fails, the load can fall and possibly injure someone nearby or below it. Loaded rigging stretches and stores some energy, much like a rubber band (some rigging materials stretch more than others), and if there is a failure, the line can snap back in each direction from the break. The line, a clevis used for a connection or other component, may fly rapidly and strike someone. Even a rope used in a tug-of-war has been known to rip participants' hands apart when it breaks. The greater the load elongation and energy stored, the greater the danger of injury after a failure.

Controls

Important controls to minimize rigging hazards are proper selection of rigging materials, proper use, not overloading the rigging, regular inspection and testing of rigging components, training of riggers, and effective presentation of reference materials.

The *Handbook of Rigging* is one of the most complete references on proper selection, use, inspection, and testing of rigging. A number of standards define the frequency and method for testing of certain rigging components.

The *Handbook* also illustrates what to look for during inspections. For example, there are approximately 25 kinds of failures in rope that may be discerned. Some failures, like broken outer wires or fibers, may be easy to detect. Others are more difficult to find visually. Hooks must be inspected for cracks and the amount of growth in the jaw opening; when the angle of the jaw increases by 15°, the hook is removed from service. One reason is that as the jaw of a hook grows, the chances of rigging slipping from it increase. When chain is overloaded, the links will grow, causing the inside radius of one loop to wrap around the next loop. An inspector often can tell quite easily if a chain has been overloaded by observing how easily the links articulate. Any stiffness between links suggests that wrapping has taken place and capacity is reduced.

Hooks should be fitted with a retainer device that prevents rigging from slipping out of the jaw. There are a number of patented designs to accomplish this. The retainer allows rigging to slip into the jaw easily, but prevents it from slipping off the jaw. The retainer devices are not designed to carry a load, merely to keep rigging in the jaw.

There are load capacity charts for materials handling equipment and rigging. When these charts are for field use, they should avoid the need for computations before reading them. The need to make a computation creates a potential source of error. The charts or tables should include accepted safety factors and should indicate clearly what safety factors and other considerations are included in each table. Engineers may find tables with basic properties more valuable because they want to use them in many applications that require special computations. Tables 15-6 through 15-11 are examples of field tables.

Some examples of rigging consideration illustrate some important rigging principles.

Example 15-4 The angle formed by the legs of a sling affect the actual load carried by them. Figure 15-6 illustrates this. A basket hitch sling supports a 1,000-lb load; each vertical leg carries 500 lb. A choker hitch sling carries the same load, but the 1,000-lb load is carried by the single vertical element. The load in each of the legs that forms an angle of 60° from vertical between the choker and the object itself is quite different. The load in each leg, F_1, is solved by summing forces in the vertical direction: $F_y = 0 = 1{,}000\ 2F_1 \cos 60$; $F_y = 1{,}000$ lb.

Example 15-5 A hoist with a 10,000-lb capacity will be used to lift a load of 7,500 lb. A wire rope sling will be used to lift the load. If a vertical hitch is used, what size rope is needed to lift the load safely, if the rope is

(a) 6 × 19 FC (fiber core) wire rope with a mechanical splice?

(b) nylon rope?

(c) polypropylene rope?

What factor of safety is included in each of these ropes?

From Tables 15-7, 15-9, and 15-11, respectively, the sizes are

(a) 3/4 in diameter

(b) 1 3/4 in diameter

(c) 2 in diameter

TABLE 15-6 Rated Capacity (Working Load Limit; Pounds) for Alloy Steel Chain Slings[a]

Chain Size (in)	Single Branch Sling 90° Loading	Double Sling (Angle from Vertical)			Triple and Quadruple Sling (Angle from Vertical)		
		30°	45°	60°	30°	45°	60°
1/4	3,250	5,560	4,550	3,250	8,400	6,800	4,900
3/8	6,600	11,400	9,300	6,600	17,000	14,000	9,900
1/2	11,250	19,500	15,900	11,250	29,000	24,000	17,000
5/8	16,500	28,500	23,300	16,500	43,000	35,000	24,500
3/4	23,000	39,800	32,500	23,000	59,500	48,500	34,500
7/8	28,750	49,800	40,600	28,750	74,500	61,000	43,000
1	38,750	67,100	54,800	38,750	101,000	82,000	58,000
1 1/8	44,500	77,000	63,000	44,500	115,500	94,500	66,500
1 1/4	57,500	99,500	81,000	57,500	149,000	121,500	96,000
1 3/8	67,000	116,000	94,000	67,000	174,000	141,000	100,500
1 1/2	80,000	138,000	112,500	80,000	207,000	169,000	119,500
1 3/4	100,000	172,000	140,000	100,000	258,000	210,000	150,000

[a] From 29 CFR 1926.251, Table H-1. Other grades of proof tested steel chain include proof coil, BBB coil, and hi-test chain. These grades are not recommended for overhead lifting and therefore are not covered by this table. Worn links may require removal of the assembly from service. See 29 CFR 1926.251, Table H-2.

TABLE 15-7 Rated Capacities for Single Leg Slings (6 × 19 and 6 × 37) Classification Improved Plow Steel Grade Wire Rope with Fiber Core[a]

Rope Diameter (in)	Construction	Rated Capacities (tons, 2,000 lb)								
		Vertical[b]			Choker[b]			Vertical Basket[b,c]		
		HT	MS	S	HT	MS	S	HT	MS	S
1/4	6 × 19	0.49	0.51	0.55	0.37	0.38	0.41	0.99	1.0	1.1
5/16	6 × 19	0.76	0.79	0.85	0.57	0.59	0.64	1.5	1.6	1.7
3/8	6 × 19	1.1	1.1	1.2	0.80	0.85	0.91	2.1	2.2	2.4
7/16	6 × 19	1.4	1.5	1.6	1.1	1.1	1.2	2.9	3.0	3.3
1/2	6 × 19	1.8	2.0	2.1	1.4	1.5	1.6	3.7	3.9	4.3
9/16	6 × 19	2.3	2.5	2.7	1.7	1.9	2.0	4.6	5.0	5.4
5/8	6 × 19	2.8	3.1	3.3	2.1	2.3	2.5	5.6	6.2	6.7
3/4	6 × 19	3.9	4.4	4.8	2.9	3.3	3.6	7.8	8.8	9.5
7/8	6 × 19	5.1	5.9	6.4	3.9	4.5	4.8	10.0	12.0	13.0
1	6 × 19	6.7	7.7	8.4	5.0	5.8	6.3	13.0	15.0	17.0
1 1/8	6 × 19	8.4	9.5	10.0	6.3	7.1	7.9	17.0	19.0	21.0
1 1/4	6 × 37	9.8	11.0	12.0	7.4	8.3	9.2	20.0	22.0	25.0
1 3/8	6 × 37	12.0	13.0	15.0	8.9	10.0	11.0	24.0	27.0	30.0
1 1/2	6 × 37	14.0	16.0	17.0	10.0	12.0	13.0	28.0	32.0	35.0
1 5/8	6 × 37	16.0	18.0	21.0	12.0	14.0	15.0	33.0	37.0	41.0
1 3/4	6 × 37	19.0	20.0	24.0	14.0	16.0	18.0	38.0	43.0	48.0
2	6 × 37	25.0	28.0	31.0	18.0	21.0	23.0	49.0	55.0	62.0

[a] From 29 CFR 1926.251, Table H-3. See 29 CFR 1926.251 for additional regulations for wire rope.
[b] HT = hand tucked splice and hidden tuck splice. For hidden tuck splice, IWRC (Independent Wire Rope Core) use values in HT columns. MS = mechanical splice. S = swaged or zinc socket.
[c] Where values only apply when the D/d ratio for HT slings is 10 or more, and for MS and S slings is 20 or more, where *D* is the diameter of curvature around which the body of the sling is bent and *d* is the diameter of rope.

Because the tables are designed for field use, a factor of safety is already incorporated in each table value. Table 15-8 shows a factor of safety of 5, and the factors of safety are 9 for the nylon rope and 6 for the polypropylene rope, shown at the top of the tables.

Example 15-6 A sling will be used to lift a load. The sling is made from 1/2-in 6 × 19 FC wire rope. If a vertical basket hitch is used, how large of a load can be lifted if the sling has a mechanical splice? What can be lifted if the splice is a hand-tucked splice?

The capacity of a sling is determined from its weakest component, and the efficiency of a sling is affected by the kind of splice used to form the loops on the ends. From Table 15-7, the maximum load for the mechanical splice is 3.9 tons. For the hand-tucked splice, the maximum load is 3.7 tons.

15-8 CONVEYORS

Equipment

There are many kinds of conveyors used to move materials. There are roller, belt, screw, bucket, chain, and overhead conveyors; gravity chutes; wheeled carts and hoppers; and others. Some are powered, whereas others depend on people or gravity to move items along them.

TABLE 15-8 Manila Rope Slings[a]

		Rated Capacity (lb; Safety Factor = 5)											
		Eye and Eye Sling						Endless Sling					
				Basket Hitch (Angle from Vertical)						Basket Hitch (Angle from Vertical)			
Rope Diameter (in)	Maximum Breaking Strength (lb)	Vertical Hitch	Choker Hitch	0°	30°	45°	60°	Vertical Hitch	Choker Hitch	0°	30°	45°	60°
$^1/_2$	2,650	550	250	1,100	900	750	550	950	500	1,900	1,700	1,400	950
$^9/_{16}$	3,450	700	350	1,400	1,200	1,000	700	1,200	600	2,500	2,200	1,800	1,200
$^5/_8$	4,400	900	450	1,800	1,500	1,200	900	1,600	800	3,200	2,700	2,200	1,600
$^3/_4$	5,400	1,100	550	2,200	1,900	1,500	1,100	2,000	950	3,900	3,400	2,800	2,000
$^{13}/_{16}$	6,500	1,300	650	2,600	2,300	1,800	1,300	2,300	1,200	4,700	4,100	3,300	2,300
$^7/_8$	7,700	1,500	750	3,100	2,700	2,200	1,500	2,800	1,400	5,600	4,800	3,900	2,800
1	9,000	1,800	900	3,600	3,100	2,600	1,800	3,200	1,600	6,500	5,600	4,600	3,200
$1^1/_{16}$	10,500	2,100	1,100	4,200	3,600	3,000	2,100	3,800	1,900	7,600	6,600	5,400	3,800
$1^1/_8$	12,000	2,400	1,200	4,800	4,200	3,400	2,400	4,300	2,200	8,600	7,500	6,100	4,300
$1^1/_4$	13,500	2,700	1,400	5,400	4,700	3,800	2,700	4,900	2,400	9,700	8,400	6,900	4,900
$1^5/_{16}$	15,000	3,000	1,500	6,000	5,200	4,300	3,000	5,400	2,700	11,000	9,400	7,700	5,400
$1^1/_2$	18,500	3,700	1,850	7,400	6,400	5,200	3,700	6,700	3,300	13,500	11,500	9,400	6,700
$1^5/_8$	22,500	4,500	2,300	9,000	7,800	6,400	4,500	8,100	4,100	16,000	14,000	11,500	8,000
$1^3/_4$	26,500	5,300	2,700	10,500	9,200	7,500	5,300	9,500	4,800	19,000	16,500	13,500	9,500
2	31,000	6,200	3,100	12,500	10,500	8,800	6,200	11,000	5,600	22,500	19,000	16,000	11,000
$2^1/_8$	36,000	7,200	3,600	14,500	12,500	10,000	7,200	13,000	6,500	26,000	22,500	18,500	13,000
$2^1/_4$	41,000	8,200	4,100	16,500	14,000	11,500	8,200	15,000	7,400	29,500	25,500	21,000	15,000
$2^1/_2$	46,500	9,300	4,700	18,500	16,000	13,000	9,300	16,500	8,400	33,500	29,000	23,000	16,500
$2^5/_8$	52,000	10,500	5,200	21,000	18,000	14,000	10,500	18,500	9,000	37,500	32,500	26,500	18,500

[a] From 29 CFR 1926.251, Table H-15.

TABLE 15-9 Nylon Rope Slings[a]

Rope Diameter (in)	Maximum Breaking Strength (lb)	Rated Capacity (lb; Safety Factor = 9)											
		Eye and Eye Sling						Endless Sling					
				Basket Hitch (Angle from Vertical)						Basket Hitch (Angle from Vertical)			
		Vertical Hitch	Choker Hitch	0°	30°	45°	60°	Vertical Hitch	Choker Hitch	0°	30°	45°	60°
1/2	6,080	700	350	1,400	1,200	950	700	1,200	600	2,400	2,100	1,700	1,200
9/16	7,600	850	400	1,700	1,500	1,200	850	1,500	750	3,000	2,600	2,200	1,500
5/8	9,880	1,100	550	2,200	1,900	1,600	1,100	2,000	1,000	4,000	3,400	2,800	2,000
3/4	13,490	1,500	750	3,000	2,600	2,100	1,500	2,700	1,400	5,400	4,700	3,800	2,700
13/16	16,150	1,800	900	3,600	3,100	2,600	1,800	3,200	1,600	6,400	5,600	4,600	3,200
7/8	19,000	2,100	1,100	4,200	3,700	3,000	2,100	3,800	1,900	7,600	6,600	5,400	3,800
1	23,750	2,600	1,300	5,300	4,600	3,700	2,600	4,800	2,400	9,500	8,200	6,700	4,800
1 1/16	27,360	3,000	1,500	6,100	5,300	4,300	3,600	5,500	2,700	11,000	9,500	7,700	5,500
1 1/8	31,350	3,500	1,700	7,000	6,000	5,000	3,500	6,300	3,100	12,500	11,000	8,000	6,300
1 1/4	35,625	4,000	2,000	7,900	6,900	5,600	4,000	7,100	3,600	14,500	12,500	10,000	7,100
1 5/16	40,850	4,500	2,300	9,100	7,900	6,400	4,500	8,200	4,100	16,500	14,000	12,000	8,200
1 1/2	50,350	5,600	2,800	11,000	9,700	7,900	5,600	10,000	5,000	20,000	17,500	14,000	10,000
1 5/8	61,750	6,900	3,400	13,500	12,000	9,700	6,900	12,500	6,200	24,500	21,500	17,500	12,500
1 3/4	74,100	8,200	4,100	16,500	14,600	11,500	8,200	15,000	7,400	29,500	27,500	21,000	15,000
2	87,400	9,700	4,900	19,500	17,000	13,500	9,700	17,000	8,700	35,000	30,000	24,500	17,500
2 1/8	100,700	11,000	5,600	22,500	19,500	16,000	11,000	20,000	10,000	40,500	36,000	28,500	20,000
2 1/4	118,750	13,000	6,600	26,500	23,000	18,500	13,000	24,000	12,000	47,500	41,000	33,500	24,000
2 1/2	133,000	15,000	7,400	29,500	25,500	21,000	15,000	26,500	13,500	53,000	46,000	37,500	26,500
2 5/8	153,900	17,100	8,600	34,000	29,500	24,000	17,000	31,000	15,500	61,500	53,500	43,500	31,000

[a] From 29 CFR 1926.251, Table H-16.

TABLE 15-10 Polyester Rope Slings[a]

Rope Diameter (in)	Maximum Breaking Strength (lb)	Rated Capacity (lb; Safety Factor = 9)											
		Eye and Eye Sling						Endless Sling					
				Basket Hitch (Angle from Vertical)						Basket Hitch (Angle from Vertical)			
		Vertical Hitch	Choker Hitch	0°	30°	45°	60°	Vertical Hitch	Choker Hitch	0°	30°	45°	60°
1/2	6,080	700	350	1,400	1,200	950	700	1,200	600	2,400	2,100	1,700	1,200
9/16	7,600	850	400	1,700	1,500	1,200	850	1,500	750	3,000	2,600	2,200	1,500
5/8	9,500	1,100	550	2,100	1,800	1,500	1,100	1,900	950	3,800	3,300	2,700	1,900
3/4	11,875	1,300	650	2,600	2,300	1,900	1,300	2,400	1,200	4,800	4,100	3,400	2,400
13/16	14,725	1,600	800	3,300	2,800	2,300	1,600	2,900	1,500	5,900	5,100	4,200	2,900
7/8	17,100	1,900	950	3,900	3,300	2,700	1,900	3,400	1,700	6,800	5,900	4,800	3,400
1	20,900	2,300	1,200	4,600	4,000	3,300	2,300	4,200	2,100	8,400	7,200	5,900	4,200
1 1/16	24,225	2,700	1,300	5,400	4,700	3,800	2,700	4,800	2,400	9,700	8,400	6,900	4,800
1 1/8	28,025	3,100	1,600	6,200	5,400	4,400	3,100	5,600	2,800	11,000	9,700	7,900	5,600
1 1/4	31,540	3,500	1,800	7,000	6,100	5,000	3,500	6,300	3,200	12,500	11,000	8,900	6,300
1 5/16	35,600	4,000	2,000	7,900	6,900	5,600	4,000	7,100	3,600	14,500	12,500	10,000	7,100
1 1/2	44,460	4,900	2,500	9,900	8,600	7,000	4,900	8,900	4,400	18,000	15,500	12,500	8,900
1 5/8	54,150	6,000	3,000	12,000	10,400	8,500	6,000	11,000	5,400	21,500	19,000	15,500	11,000
1 3/4	64,410	7,200	3,600	14,500	12,500	10,000	7,200	13,000	6,400	26,000	22,500	18,000	13,000
2	76,000	8,400	4,200	17,000	14,500	12,000	8,400	15,000	7,600	30,500	26,500	21,500	15,000
2 1/8	87,400	9,700	4,900	19,500	17,000	13,500	9,700	17,500	8,700	35,000	30,500	24,500	17,500
2 1/4	101,650	11,500	5,700	22,500	19,500	16,000	11,500	20,500	10,000	40,500	35,000	29,000	20,000
2 1/2	115,900	13,000	6,400	26,000	22,500	18,000	13,000	23,000	11,500	46,500	40,000	33,000	23,000
2 5/8	130,150	14,500	7,200	29,000	25,000	20,500	14,500	26,000	13,000	52,000	45,000	37,000	26,000

[a] From 29 CFR 1926.251, Table H-17.

TABLE 15-11 Polypropylene Rope Slings[a]

Rope Diameter (in)	Maximum Breaking Strength (lb)	Rated Capacity (lb; Safety Factor = 6)											
		Eye and Eye Sling						Endless Sling					
				Basket Hitch (Angle from Vertical)						Basket Hitch (Angle from Vertical)			
		Vertical Hitch	Choker Hitch	0°	30°	45°	60°	Vertical Hitch	Choker Hitch	0°	30°	45°	60°
1/2	3,990	650	350	1,300	1,200	950	650	650	600	2,400	2,100	1,700	1,200
9/16	4,845	800	400	1,600	1,400	1,100	800	800	750	2,900	2,500	2,100	1,500
5/8	5,890	1,000	500	2,000	1,700	1,400	1,000	1,000	900	3,500	3,100	2,500	1,800
3/4	8,075	1,300	700	2,700	2,300	1,900	1,300	1,300	1,200	4,900	4,200	3,400	2,400
13/16	9,405	1,000	800	3,100	2,700	2,200	1,600	1,600	1,400	5,600	4,900	4,000	2,800
7/8	10,925	1,800	900	3,600	3,200	2,600	1,800	1,800	1,600	6,600	5,700	4,600	3,300
1	13,300	2,200	1,100	4,400	3,800	3,100	2,200	2,200	2,000	8,000	6,900	5,600	4,000
1 1/16	15,200	2,500	1,300	5,100	4,400	3,600	2,500	2,500	2,300	9,100	7,900	6,500	4,600
1 1/8	17,385	2,900	1,500	5,800	5,000	4,100	2,900	2,900	2,600	10,500	9,000	7,400	5,200
1 1/4	19,950	3,300	1,700	6,700	5,800	4,700	3,300	3,300	3,000	12,000	10,500	8,500	6,000
1 5/16	22,325	3,700	1,900	7,400	6,400	5,300	3,700	3,700	3,400	13,500	11,500	9,500	6,700
1 1/2	28,215	4,700	2,400	9,400	8,100	6,700	4,700	4,700	4,200	17,000	14,500	12,000	8,500
1 5/8	34,200	5,700	2,900	11,500	9,900	8,100	5,700	5,700	5,100	20,500	18,000	14,500	10,500
1 3/4	40,850	6,800	3,400	13,500	12,000	9,600	6,800	6,800	6,100	24,500	21,000	17,500	12,500
2	49,400	8,200	4,100	16,500	14,500	11,500	8,200	8,200	7,400	29,500	25,000	21,000	15,000
2 1/8	57,950	9,700	4,800	19,500	16,500	13,500	9,700	9,000	8,700	35,500	30,100	24,500	17,500
2 1/4	65,550	11,000	5,500	22,000	19,000	15,500	11,000	11,000	9,900	39,000	34,000	28,000	19,500
2 1/2	76,000	12,500	6,300	25,500	22,000	18,000	12,500	12,500	11,500	45,500	39,500	32,500	23,000
2 5/8	85,500	14,500	7,100	28,500	14,500	20,000	14,500	14,500	13,000	51,500	44,500	36,500	25,500

[a] From 29 CFR 1926.251, Table H-18.

Hazards

Some conveyors present hazards of material falling from them onto people or items below. Conveyors and the structures that support them may fail. For powered conveyors, there is the danger of people becoming caught in moving parts, such as belts and chains. Some conveyors present pinch points and places where workers hands and arms may become caught between materials and fixed parts of the conveyor or other fixed objects. Some conveyors, like belt conveyors, can extend for miles on elevated structures. To lubricate and maintain them, workers must have a walkway with a guardrail and access points to the conveyor components. The guardrail reduces the danger of falling.

Controls

Conveyors that pass overhead should have overhead protection or some enclosure to prevent materials from falling on people below. From time to time, someone must remove fallen materials and parts from the overhead structure. If workers are to remove the material, the overhead netting, screen, or other structure must be substantial enough to carry the load of materials and people. In the classic case that tested the imminent danger rule of OSHA, the Supreme Court ruled in 1980 that, after one worker who was cleaning fallen appliance parts from a wire mesh overhead protection system fell to his death when the screen failed, a second worker could not be suspended from work for refusing to perform the same task without reasonable safeguards.

The moving parts of conveyors, particularly powered conveyors, that pose machine dangers and that are within reach of people must be guarded. Pinch points created by belts and rollers, screw conveyors, chains and sprockets, and other components must meet the machine guarding principles discussed in Chapter 13. Included are emergency shutoff controls and warnings along the conveyor. In some cases, the edges of belts need to be guarded so fingers, hands, and other objects cannot become caught under them. Protection should include emergency shutoff switches at convenient locations, interlock switches, and low speed or jog controls for servicing and maintenance when appropriate.

Where objects suddenly come into view along a conveyor, their arrival may not be anticipated easily by workers nearby. If the objects pose pinch point dangers, audio and visual warning devices can alert people to the pending danger. This problem sometimes occurs on enclosed chute and roller conveyors.

Where access to conveyors requires elevated walking and working surfaces, there must be guardrails. Where conveyors have floor and wall openings through which people and material could fall, the openings must have guardrails with toeboards.

If workers must unjam materials from chutes or other conveyors, they should have tools, such as long poles, for chute conveyors. If a person must enter a chute or similar conveyor opening, power must be locked and tagged out. A lifeline may be necessary for the worker, and an observer/assistant should be available for securing emergency help or rescue.

15-9 ELEVATORS, ESCALATORS, AND MANLIFTS

Equipment

A number of devices move people and goods vertically. Elevators are the most common. An elevator has a car, moved by cables or a hydraulic system. There are also elevators for materials only. One type of elevator that moves goods only is a dumbwaiter. People enter an elevator, or goods are placed on them, through an opening or door. Escalators are moving belts with components that form steps.

Manlifts are belts that move vertically. Along the length of its belt are small platforms that one person can stand on. Handholds are also attached at appropriate heights above each platform. The belts move continuously at a fairly slow speed between two or more vertical locations. One can quickly step on a platform, grab the handhold, and move to the other level and step off.

Hazards

Major hazards for elevators include becoming caught in the opening to a car when the car moves, becoming caught in the doors, a runaway car, falling into the elevator shaft, and being trapped in a stalled car. Others include tripping or falling on entry or egress if the car does not line up with the floor opening and being crushed at the top or bottom of the shaft during service work.

For escalators, there is the danger of becoming caught in the steps as they fold into a fixed end or between the edges of the steps and the side walls. An example is a draw string on the collar or hood of a child's clothes. A free end can get caught in the folds of an escalator step, tighten around the child's neck, and strangle the child.

Hazards for manlifts include becoming caught as one moves through a floor opening or falling from the platform.

Controls

Standards for elevators have existed for a long time. Today, elevators are governed by many laws and codes at national, state, and local levels. Standards apply to design, construction, maintenance, and inspection.

Elevators, escalators, and manlifts must be maintained regularly and must be inspected by trained people. Many states and municipalities require elevator inspectors to be licensed. At regular intervals, inspectors check cables, sheaves, brakes, and other mechanical components. Inspectors sign forms that attest to the fact that all components meet standards.

Design standards incorporate safety features like brake systems, automatic braking if a cable fails, double doors for the car and openings, interlocks on all doors to stop the car if any doors are open, and interlocks on landing doors to keep them closed until the car arrives. Access doors have detector switches to prevent their closing on someone. Each size of car has a load capacity that affects the design and selection of various components. Elevators must contain emergency alarms and means of egress.

Escalators have emergency shutoff switches at each end. They have microswitches located at various points along and behind the side wall panels to stop the escalator if something becomes caught between the steps and the sidewalls.

Because elevators, escalators, and manlifts create vertical openings in buildings, they provide paths for heat and smoke to pass from floor to floor. There are many fire regulations governing elevators, escalators, and manlifts and the openings for them.

The importance of safeguards for elevators is illustrated by an accident involving a dumbwaiter in a restaurant. The dumbwaiter was used to move food and dishes from the kitchen to the dining room above. Employees locked out the interlock switches for the access doors. The doors were left open. One employee stuck his head in the opening to see if the dumbwaiter was coming and was fatally injured when his head was crushed between the door opening and the moving car. There have been many similar accidents involving elevators.

15-10 BULK MATERIALS, EXCAVATION, AND TRENCHING

Properties of Bulk Materials

Bulk materials, like grains, granular materials, sand, and soil, will form a slope, called an angle of repose, along their sides when they are piled up. Under certain conditions, bulk materials may hold together for a time, but when free to form their own shape, the angle of repose will form for loose, dry, bulk materials. Moisture, vibration, particle size, and other factors affect when the angle of repose will form and what the angle will be. Chapter 10 discussed angle of repose.

Bulk materials have some adhesion properties that allow them to support some load. However, the adhesion properties may not be uniform throughout a given pile of materials. Moisture, temperature, pressure, frost, vibration, and other factors can affect the adhesion and load-bearing capabilities of a material.

Hazards

When bulk materials are stored, the components may adhere to each other. However, when material is removed from a pile, the disturbed edge of a pile may not take on the natural angle of repose immediately, and the wall of material could collapse suddenly and bury anyone working below the top level of the pile and near the unrestrained edge.

A person may walk on a pile of some material and be supported by it and then may encounter a location that does not have the same load-bearing capacity and sink into the material. Someone may also fall into a pile of bulk material and sink into it because it cannot support the load presented by a person. Attempts to work free may simply sink the person deeper into the material, because the material acts more like a fluid for larger or moving loads than it does when only the particles of the material are involved. Not only is there a danger of suffocation if breathing air is sealed off from the face, but the bulk material can compress around the chest and severely limit chest movement necessary for inhalation, causing suffocation.

Controls

To prevent bulk materials from caving in on someone, the materials either must be restrained by shoring, must be sloped back to an angle more shallow than the natural angle of repose, or must be restrained by other suitable means. According to some standards, this protection is required when depths are more than 4 ft; others have these requirements for depths of 5 ft or more. Shoring or other restraints must meet accepted engineering standards.

Workers who must work above bulk materials that cannot support the weight of a person should be protected by guardrails and lifelines. Two people should work together so that one can perform emergency rescue tasks if the other falls into the material below. The second person should have a backup if there is a need to approach the entrapped person. Emergency rescue equipment should be nearby.

For work involving bulk materials in enclosed or confined spaces, there may be additional dangers related to breathable atmospheres and requiring necessary supplies of breathable air.

Excavation and Trenching

When there are excavation and trenching operations, there are many other considerations. Adequate drainage will prevent accumulation of water that may reduce the strength of shoring or restraints. Barriers must be installed to prevent people from falling into an excavation. There should be daily inspections of excavations and restraining systems, and emergency means for egress must be in place. Where the quality of the breathing air could be inadequate, tests will ensure that workers will not be overcome by lack of oxygen or by hazardous gases, fumes, or dusts. If people must cross over an excavation, walkways or bridges with standard guardrails are needed. Excavation and trenching were discussed in Chapter 10 in greater detail.

15-11 STORAGE OF MATERIALS

Hazards

Some of the main hazards of stored materials are items falling on someone below them, tripping or running into items protruding into traffic ways or aisles, piled materials tipping over, and physical damage to storage racks or piled materials by materials handling equipment. Not only is there a potential for injury and damage from poorly stored materials, but without good storage organization and practices, the cost of locating and keeping track of materials on hand is expensive.

Improper segregation of materials may create additional hazards from fire, explosion, and corrosion. Refer to Chapter 16.

Controls

The adage "a place for everything and everything in its place" is important for controlling hazards of materials storage. Well-planned, organized, and maintained materials storage areas are essential. There is a wealth of specialized equipment for solving materials storage problems.

Proper stacking is another control. Many kinds of materials are packaged. The packaging or the material inside can hold only so much weight before it crushes. When items are stored on damaged or crushed containers, there is a greater chance of tipping over. The higher materials are stacked, the higher the center of gravity and the less force required to tip the stack over.

Another control for some stored items is cross ties. Items such as lumber and bagged materials are made more stable by placing elements in different directions at different levels of a pile so that materials are interlocked.

Another control is stepping back materials. When materials are stacked several rows deep and several rows high, the front tier has a tendency to tip over. Cross ties may help, and stepping back the rows may help more. Using this method, the front row is not stacked as high as the row behind it, and the second row is not stacked as high as the third row.

Retaining walls can help keep bulk materials from spreading out or collapsing on someone or onto people or equipment. The retaining walls function like shoring and they must have adequate strength and bracing.

Racks keep many materials from falling. There are special racks for bar stock, piping, drums, rolls, and palletized materials. The racks must be sufficiently strong to support the loads placed on them. The Rack Manufacturers Institute[4] has structural standards and test procedures for racks.

It is not uncommon that industrial trucks run into racks. Protective barriers installed along the floor near rack columns can reduce the likelihood of physical damage to the racks. Stiffeners can be added to rack columns that are subject to physical damage by materials handling vehicles. Racks must be designed to remain standing, even when there is some physical damage to structural elements.

There must be enough aisle space between racks and items stored openly. The aisles should allow vehicles to place materials on racks or to remove them safely. Because aisle width is an important economic consideration in storage facilities, special vehicles can minimize aisle width requirements.

Aisles for walking and for materials handling vehicles should be clearly marked. Usually, they are separate aisles. Stored materials must not protrude into the marked aisle space. Some materials that are stored in elevated positions near aisles and may be unstable should be restrained by netting or other means. This is an important concern in some retail facilities where public customers are present.

Fire protection for stored materials will vary with the type and amount of materials, building design, and other factors. Chapter 16 discusses fire protection.

EXERCISES

1. A box is 8 ft high, 4 ft deep, and 6 ft wide and weighs 270 lb. A worker pushes on the box at a location midpoint along the width and 5 ft above the floor. The coefficient of friction between the box and floor is 0.53. Determine what value of the pushing force, *P*, will cause
   (a) tipping (rotation about the edge along the floor opposite the worker)
   (b) sliding
2. A worker picks up boxes from the floor and places them on a conveyor. This activity will occur every 30 s. The boxes, weighing 23 lb each, are located 20 in forward of the worker's ankle midpoint at the point of grasping them. The conveyor is 38 in high. There is no twisting during the lift. Determine the recommended weight limit (RWL) and the lifting index (LI) for this activity.
3. For the activity in Exercise 2, is the activity acceptable or are controls needed to prevent lifting injuries? If controls are needed, what kind would you recommend?
4. A 12,000-lb load is to be lifted with a sling. For the conditions in each of the following cases, determine what size chain or rope is needed.
   (a) Alloy steel chain, double sling, 45′ angle with vertical.
   (b) Single-legged 6×19 improved plow steel grade rope with fiber core, choker, mechanical splice.
   (c) Two-legged bridle sling, 6×19 improved plow steel grade rope with fiber core, 60° angle with vertical, hand-tucked splice.
   (d) Nylon rope, endless sling, basket hitch, 0° angle from horizontal.
   (e) Polypropylene rope, vertical hitch.
5. A sling is used to lift a 1,000-lb load. If the sling is rigged as a choker and the legs below the choke point form an angle of 60° with the vertical, what load is carried by
   (a) each leg?
   (b) the vertical portion?

6. A stationary Grove Model RT530E mobile crane (refer to Figure 15-3) will be used to lift material. The tires are fully inflated. The ground is level and firm. Determine what load can be safely lifted for each of the following conditions and identify the basis for the load limit (structural failure or tip over):
   (a) Boom length: 40 ft
   Radius of load: 20 ft (boom angle is 30°)
   Boom position: centered over front
   On fully extended outriggers
   (b) Same conditions as (a) except the boom is over the side.
   (c) Same conditions as (a) except the crane is on rubber (outriggers not used).
   (d) Boom length: 50 ft
   Radius of load: 12 ft (boom angle is 56°)
   Boom position: centered over front
   On fully extended outriggers
   (e) Same conditions as (d), except the boom is over the side.
   (f) Same conditions as (d), except the crane is on rubber (outriggers not used).

REVIEW QUESTIONS

1. Name one materials handling hazard associated with each of the following and give a control for that hazard:
   (a) environments where materials handling tasks are performed
   (b) maintenance of materials handling equipment
   (c) loading of materials handling equipment
   (d) securing loads
   (e) movement of material and materials handling equipment
2. Explain the biomechanics of lifting and the load effect of
   (a) stooping
   (b) rapidly picking up a load
   (c) distance of a load center of gravity from the body
3. How can the following contribute to injury associated with manual lifting?
   (a) size of load
   (b) raising a load overhead
   (c) frequency of lifting
   (d) asymmetrical loads
4. Explain how the recommended weight limit and lifting index are used to decide what kinds of controls are needed to minimize injury from manual lifting.
5. Describe two hazards and applicable controls related to use of
   (a) jacks
   (b) hand-operated materials handling vehicles
   (c) powered materials handling vehicles

   (d) hoisting apparatus
   (e) conveyors
   (f) elevators
   (g) escalators
   (h) manlifts

6. Define ROPS and FOPS and describe what protection each provides for powered materials handling vehicles.
7. Identify at least one hazard and associated control for the following rigging components:
   (a) ropes
   (b) hooks.
8. Can steel wire ropes store dangerous amounts of energy due to elasticity during loading?
9. What is a primary source publication containing information on proper rigging of loads?
10. Describe two main hazards associated with bulk materials and applicable controls for these hazards.
11. Define angle of repose and its significance for safety of bulk materials and excavations.
12. Explain how a person can suffocate in bulk materials even though the person's head remains above the materials.
13. Name five controls to prevent accidents related to storage of materials.

NOTES

1 *Work Practices Guide for Manual Lifting,* Publication No. 81-122, National Institute for Occupational Safety and Health, Cincinnati, OH, March 1981.

2 *Scientific Support Documentation for the Revised 1991 Lifting Equation*, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Technical Contract Report, May 8, 1991, National Technical Information Service (NTIS), Springfield, VA, NTIS Document Number PB 91-226274.

3 Waters, Rhomas R., Putz-Anderson, Vern, and Gard, Arun, *Application Manual for the Revised NIOSH Lifting Equation*, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, January, 1994.

4 ANSI MH 16.2, *Safety Practices for the Use of Industrial and Commercial Steel Storage Racks* (sponsored by Rack Manufacturers Institute).

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B56.8 Safety Standard for Personnel and Burden Carriers
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PASSENGER CARS, TRUCKS, BUSES, AND MOTORCYCLES
Vehicle Identification Numbers
Passenger Cars, Trucks, Buses, and Motorcycles
Transmissions
Seals
Tires
Wheels
Bumpers
Seat Belts and Restraint Systems
Passenger Car Components and Systems
Trailers
Truck and Bus
Motorcycles

OFF-HIGHWAY MACHINES AND VEHICLES
Snowmobiles
Agricultural Tractors
Construction and Industrial Equipment

MARINE EQUIPMENT
Marine Equipment
Maintenance and Repair

Specifications for the Design, Testing and Utilization of Industrial Steel Storage Racks,

Scientific Support Documentation for the Revised 1991 Lifting Equation, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Technical Contract Report, May 8, 1991, National Technical Information Service (NTIS) Springfield, VA, NTIS Document Number PB 91–226274.

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