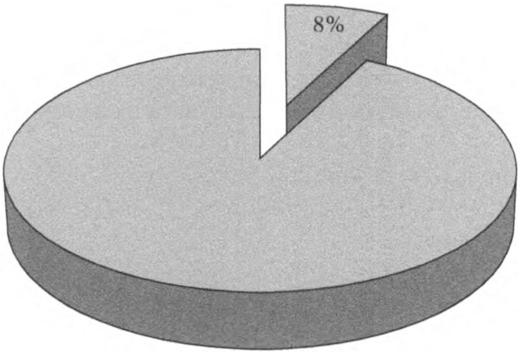
## CHAPTER 14

# Materials Handling and Storage



***Percentage of OSHA General Industry citations addressing this subject***

The usual concept of a factory is a place where things are made or materials are processed, but often the major activity in a factory consists of moving things and materials around. Lifting, a most basic material-handling activity, accounts for most back injuries, one of the largest workplace injury categories of all. A Liberty Mutual Insurance Company study in 2016 found that overexertion involving outside sources was almost 25% of the total national cost of disabling injuries. This category includes injuries related to "lifting, pushing, pulling, holding, carrying or throwing objects" (2016 Liberty Mutual Workplace Safety Index, 2016). Industrial trucks, tractors, cranes, and conveyors all have the simple mission of moving materials, and they all cause injuries and fatalities every year.

The National Safety Council (NSC) charges materials handling with 20 to 25% of all occupational injuries. The size of the problem is emphasized in NSC's *Accident Prevention Manual for Industrial Operations* as follows:

> As an average, industry moves about 50 tons of material for each ton of product produced. Some industries move 180 tons for each ton of product.

In materials handling, masses are usually measured in tons or pallet loads instead of ounces, pounds, or kilograms. The human body is light and frail by comparison, so bulk materials' masses can easily pinch, fracture, sever, or crush its parts. Contributing to the hazards of large masses is the reality that materials handling includes *motion* for these masses.

To illustrate the general *mass/motion* hazards of material-handling equipment, consider the following comparison of processing versus material-handling equipment. To be struck by a moving part of a processing machine may or may not cause injury, depending on the size of the machine, the motion of the moving part, and the shape or surface characteristics of the part. However, being struck by an industrial truck or conveyor is almost certain to cause injury. More indirectly, the mass/motion hazards of materials handling can affect safety by impacting facilities such as gas lines or electric lines or by overloading structural components of buildings.

Another general hazard of materials handling is its automatic or remote-control nature. Materials pumps and conveyors are often started automatically on demand or from a manual switch that is located far away. Conveyor accidents are often caused by this remoteness characteristic. In another example, railroad cars often move about a yard, far from the eye of the engineer, or worse yet, they may roll almost silently, coasting independently into position from the momentum of a locomotive's momentary push with no local control at all.

An indirect general hazard from materials handling is fire. This hazard emphasizes the storage aspect of materials handling. Warehouse fires are costly in terms of property loss, but they can also be dangerous to workers.

## MATERIALS STORAGE

Materials handling standards say that bags, containers, or bundles stored in tiers shall be "stacked, blocked, interlocked, and limited in height so that they are stable and secure against sliding or collapse." For general materials, the standard does not explain what constitutes "blocking" or "interlocking" and does not specify height limits for stacks. Some industry practices, however, seem to defy the standard. Since the standard for materials storage is not specific in its requirements but does address results (e.g., "so that they are stable and secure against sliding or collapse"), the standard should be recognized as a performance standard.

Housekeeping is another consideration for materials in storage. Sloppy warehouse practices can lead to trip hazards or fire. Pest harborage can result from certain accumulations of materials and can constitute a hazard. Outside storage can become grown over in weeds and grass, which can be a fire hazard in dry weather.

The safety and health manager should monitor the ups and downs of the company's sales and production fortunes. If there is a recent buildup in production in anticipation or in response to booming sales, there is likely to be a warehousing problem. Additional warehouse space is likely to be added later, after the upturn appears more permanent. Even after an expansion decision is made, a certain amount of lead time is necessary to plan and build add-on warehouse space. Meanwhile, the existing warehouse space becomes crowded and unsafe. Judgmental limits for material stacking are cast aside as creative ideas are explored to squeeze more material into a small space.

Some of these new ideas will be good ones; it is not basically unsafe to try to conserve space. However, during a period of warehouse crowding, special attention should be given to new hazards that may result from new procedures in the warehouse. Aisle and exit blockage are likely to occur during such periods of warehouse stress, as is the incidence of storage stack collapse. Any accidents that occur during such periods will point to some of the new hazards being generated, and these accidents should be analyzed to eliminate cause.

## INDUSTRIAL TRUCKS

This category of material-handling equipment is exemplified by the forklift truck. There is no question that OSHA considers safety with forklift trucks important. OSHA's own estimate of the number of forklift trucks nationwide is over 1 million (OSHA commits to Reducing Forklift Accidents in the Southeast, 2002). When you consider that each forklift truck may have more than one employee within the plant authorized to drive it, it is easy to see that forklift truck safety is very important to worker safety. Typically, forklifts either are powered by electric motor or have internal combustion engines. Besides forklifts, there are tractors, platform lift trucks, motorized hand trucks, and other specialized industrial trucks. Not included are trucks powered by means other than electric motors or internal combustion engines. Also not included are farm tractors or vehicles primarily for earth moving or over-the-road hauling.

### Truck Selection

"Ignorance is bliss" for most industrial managers who set out to buy a forklift truck. Little known is the fact that there are 11 different design classifications by type of power and by degree of hazard for which approved. These 11 design classifications are distributed over at least 26 different classifications of hazardous locations to which the forklift truck may be exposed.

One can easily wonder why it must be so complicated to select a forklift truck. The basis for this complication is that engines and motors can be dangerous sources of ignition for flammable vapors, dusts, and fibers. To design these engines and motors to effectively prevent ignition hazards is a costly matter, and the marketplace will not support the purchase of an explosion-safe forklift truck for use in an ordinary factory location. Thus, a complicated array of classifications and regulations is set up to permit the specification of the right industrial truck for the right job—no more, no less.

Industry standards for industrial truck classifications and their corresponding hazardous location codes are a maze of abbreviations and definitions. To understand these abbreviations, keep in mind that the objective is safety from *fires and explosions*. Whether the industrial truck is diesel, gasoline, electric, or LP gas powered, the more fire-safe models are designed to prevent ignition of accidental fires, and thus they are more expensive. A simple summary is contained in Table 14.1. More details are contained in the standards, but most safety and health managers will need only the general idea. Another thing to keep in mind is that it is legal to use a safer, higher classified industrial truck than the minimum required, but of course it usually will not be economical to do so. If a firm already has an EE-approved electric forklift, however, it may be

**TABLE 14.1** Summary of Industrial Truck Design Classifications

| Diesel | Electric | Gasoline | LP gas |
|---|---|---|---|
| D | E | G | LP |
| Standard model | Standard model | Standard model | Standard model |
| Cheapest | Cheapest | Cheapest | Cheapest |
| DS | ES | GS | LPS |
| Safer model | Safer model | Safer model | Safer model |
| More expensive | More expensive | More expensive | More expensive |
| Exhaust, fuel, electrical systems safeguards | Spark prevention<br>Surface-temperature limitation | Exhaust, fuel, and electrical systems safeguards | Exhaust, fuel, and electrical systems safeguards |
| DY | EE | | |
| Safest diesel | Safer still | | |
| More expensive diesel | More expensive | | |
| No electrical equipment<br>Temperature limitation feature | All motors and electrical equipment enclosed | | |
| | EX | | |
| | Safest of all<br>Most expensive electrical truck | | |
| | Even electrical *fittings* designed for hazardous atmospheres | | |

*Source*: Summarized from Code of Federal Regulations 29 CFR 1910.178.

**TABLE 14.2** Allowable Categories for Industrial Trucks for Various Hazardous Locations

| Class | Group | Division 1 | Division 2 |
|---|---|---|---|
| I | A | No industrial truck permitted | DY, EE, EX |
| | B | No industrial truck permitted | DY, EE, EX |
| | C | No industrial truck permitted | DY, EE, EX |
| | D | EX | DS, DY, ES, EE, EX, GS, LPS |
| II | E | EX | EX |
| | F | EX | EX |
| | G | EX | DY, EE, EX, DS, ES, GS, LPX |
| III | | DY, EE, EX | DS, DY, E[a], ES, EE, EX, GS, LPS |

[a] Permitted to continue if previously in use.

*Source*: Summarized from Code of Federal Regulations 29 CFR 1910.178.

expedient to go ahead and use it instead of buying a new ES- or E-approved unit that would suffice for the given application.

Summarizing these principles and several pages of applicable regulations, Table 14.2 gives the safety and health manager a perspective into the approval classes of various industrial truck designs. The *classes*, *groups*, and *divisions* represent varieties of hazardous locations in which the definitions correspond *roughly* to those of the

*National Electrical Code* and are covered in more detail in Chapter 17. *Class* and *group* refer to the type of hazardous material present, and *division* refers to the extent or degree to which the hazardous material is likely to be present in dangerous quantities.

There are so many categories of "approvals" for industrial trucks that it is easy to lose sight of the overall objective in the approval process: to prevent fires and explosions from improper use of the wrong truck in a hazardous atmosphere. The authority for approval of industrial trucks is delegated to nationally recognized testing laboratories, such as Underwriters' Laboratories, Inc. and Factory Mutual Engineering Corporation. The prudent safety and health manager will leave the application-for-approval process to the manufacturer of the equipment and simply look for the UL or FM approval classification, such as DY, EX, GS, and so on. For nonhazardous locations, even an *unapproved* truck may be used if the truck *conforms* to the requirements of type D, E, G, or LP.

In these days of high energy costs and the search for alternatives, some company managements may desire to convert an industrial truck from one energy source to another. However, tampering with the design or altering the truck may invalidate the approval. Industrial truck conversions can be made, but the process is a bit tricky. The conversion equipment *itself* must be approved, and there is a right way and many wrong ways to carry out the conversion.

The hazard of fires and explosions may be the most complicated factor in the selection of forklift trucks, but it certainly is not the only factor. Far more important than the fire hazard rating of the design of the truck are the operations, fueling, guarding, training of drivers, and maintenance—subjects discussed in the next section.

## Operations

One of the first items of interest to the safety and health manager should be the refueling or recharging area of forklifts. Smoking is prohibited in these areas, and, historically, this fault has been found more frequently than any other. In the twenty-first century, however, the continuing evolution of the smoke-free workplace has largely eliminated this problem in forklift refueling stations. Another problem is the charging of forklifts in a *nondesignated area*. Hazards in the area include spilled battery acid, fires, lifting of heavy batteries, damage to the equipment by the forklifts, and battery gases or fumes. All of these hazards need to be addressed by the safety and health manager in some way.

Federal standards forbid pouring water into acid when charging batteries. Perhaps a sign in the area would achieve compliance with the rule. A better way to promote safety, though, would be to include in an employee training program an explanation of the violent and exothermic reaction that occurs when water is poured into a concentrated strong acid.

Everyone knows that arcs and sparks frequently fly when battery connections are made. What most do not know is that gases liberated during charging processes can reach ignitable concentrations. Fire is little or no hazard when a battery is simply "jumped" to another. However, a forklift charging area is a different matter: Large volumes of gases are liberated; therefore, adequate ventilation is essential. In addition to ventilation, personal protective equipment and emergency eyewash and shower should be provided in the battery-charging area owing to potential exposure to acid.

With hazards of gases and acids in battery-charging areas, the alternative of the internal combustion engine seems attractive. However, each of the internal combustion engine choices—diesel, gasoline, and LP gas—emit another dangerous gas: carbon monoxide. Since forklifts usually operate indoors, carbon monoxide gas levels can be a problem. The 8-hour time-weighted-average exposure limit for carbon monoxide is 50 ppm.

If the safety and health manager determines that a carbon monoxide problem exists in the plant and that the forklift trucks are the culprits, several alternatives are possible. The obvious one is to switch to electric forklifts. Another solution might be to alter the building or to install adequate ventilation systems. Perhaps the cheapest solution of all would be to review procedures and operations to determine whether sources of emissions can be reduced or perhaps eliminated entirely. The following are key questions:

1. Are operators leaving engines running unnecessarily?
2. Can the layout of warehouses or plant facilities be revised to reduce concentrations?
3. Are faulty or worn-out lift trucks creating more emissions than necessary?

Although there are no universal general minimum lighting requirements for industrial plants, where industrial trucks are operated, safety demands that the trucks themselves have directional lights if the plant area is too dark. Truck lights are required if the general lighting is less than 2 lumens per square foot. This is really a quite low level of light, since an ordinary 100-watt incandescent bulb can produce 1700 lumens. Even in an all-black room with nonreflective walls, a 100-watt bulb could produce more than 2 lumens per square foot in an 8 by 12 by 16 foot room. Wall or other surface reflections help the overall situation, so the requirement for 2 lumens per square foot is not difficult to meet. A lighting consultant can help in this determination.

## Forklift Driver Training

The original National Consensus Standard adopted by OSHA emphasized the proper selection and hazard rating of forklift trucks, as well as the procedures surrounding their operation and maintenance. However, far more important to the safety of operators and other workers around forklift trucks is how they are driven. Ironically, only one small general paragraph in the standards required operator training for forklift trucks. Employers were able to show compliance to this very general requirement by merely exposing new forklift drivers to a videotape. The result was a very haphazard approach to forklift driver training and a continued high incidence of fatalities.

Recognizing the gravity of the problem, OSHA promulgated a major change to the Powered Industrial Truck standard in 1999. To safety and health managers in general industry, the most important part of this standard was the dramatic change it brought to the operator training provision of the standard. Responsibility was placed on the employer to ensure that forklift truck drivers are competent. Content of the training must include formal instruction, which can consist of classroom training or videotape training, but this is only part of the requirement. The training must also include practical training, including driving demonstrations, and, perhaps most important of all, evaluation of the operator's performance in the workplace.

The specific content of the formal instruction is outlined in the standard and relates to both the equipment itself and the special hazards of the given workplace in which the equipment will be used. Therefore, it is not enough just to use a standard training program supplied by the equipment manufacturer. The instructor must also be qualified and capable of training the operators to deal with the specific hazards to which they will actually be exposed—for example, ramps that could cause tipping accidents, pedestrian traffic areas within the plant, or narrow aisles and places in which turning and driving will be restricted. These are items that would not be addressed in a general equipment operations manual.

The standard provides for evaluation of the operator's actual driving experience on the job, and if accidents or dangerous near misses occur, the driver must receive refresher training. Additional training may also be required if driving conditions change within the plant, such as those brought about by a remodeling of the work or traffic areas.

The final, clinching requirement of the forklift truck operator training requirement is certification. The employer or employer representative must certify and document the training, the evaluation, the dates of both the training and evaluation, and the identities of both the drivers and the trainers. The certification requirement traces the responsibility for the training and its effectiveness.

There is no doubt that OSHA has stiffened the requirements for forklift truck driver training and has made these requirements more specific. There is also little doubt that OSHA will continue to give this subject a great deal of attention. The problem is a serious one, and resolution will take years to achieve. In 2002, more than 3 years after the new standard on operator training, OSHA was reacting to new reports of large numbers of fatalities from forklift trucks. In one four-state region, 86 fatalities were reported within a 4-year period from forklift truck accidents alone (OSHA Commits to Reducing Forklift Accidents in the Southeast, 2002).

Just why are forklift trucks so dangerous? Some insight to this hazard may be gained by considering the special hazards associated with the stability of forklift trucks and the lack of knowledge of this characteristic on the part of forklift drivers.

Many workers feel that because they know how to drive an automobile, they also basically know how to operate a lift truck. Unfortunately, many employers are inclined to take their word for it. However, the operation of a lift truck takes a great deal more skill than the operation of an automobile. Compared to an automobile, a lift truck has a much shorter wheelbase, and when the load is lifted, the center of gravity is very high. This creates stability problems to which the operator may be unaccustomed. Compounding the stability problem are the small-diameter wheels found on lift trucks, making chuckholes and obstructions more hazardous. When loaded, the center of gravity of the lift truck and load together can be shifted dangerously forward. Picking up and depositing loads require skill in proper manipulation and safe positioning. An off-center load presents a special hazard in which the load might tip in transit even though the truck itself is in a stable position.

Figure 14.1 diagrams the center of gravity of a forklift truck. The center of gravity shifts forward when the forks are loaded. If the load is too great, the center of gravity will shift forward of line BC and the forklift will tip dangerously forward, possibly dumping the load and overturning. Counterweights are added to the back of the forklift to counteract the forward-tipping forces, but if too much counterweight is attached, the

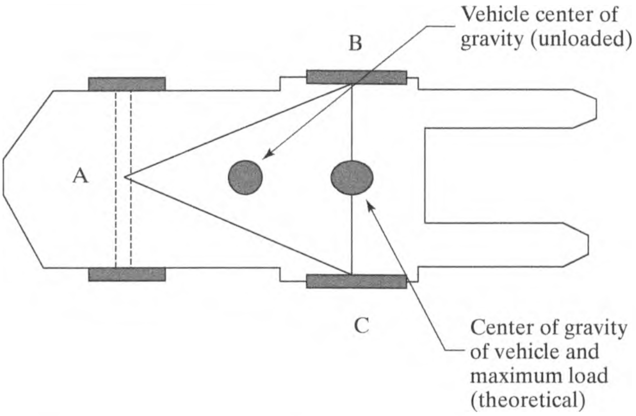


FIGURE 14.1

Top view of forklift truck illustrating the locations of the center of gravity when the forklift is unloaded and when it is loaded to capacity (*Source*: OSHA standard 1910.178, Appendix A).

forklift becomes unstable when it is not loaded. Because of the three-point suspension scheme, the forklift may become laterally unstable when traveling while unloaded and tip sideways, especially when traveling on uneven terrain. Recognition of these physical factors facilitates understanding of the special hazards of driving a forklift truck and the need for the training specified by OSHA.

Besides stability problems, visibility can be a problem with lift trucks. The load itself can block the view and necessitate driving with the load trailing. Driving in worker aisles presents problems of pedestrian traffic, especially at corners where visibility is limited. Although lift trucks are not silent, they may seem so in a noisy factory environment. This increases the hazard to pedestrians and the need for greater visibility for lift truck operators.

One of the greatest hazards with forklifts and other industrial trucks is the transition between dock and cargo vehicle. Figure 14.2 shows precautions to be taken. Although a highway truck is shown in the figure, the hazard also exists for loading railroad cars.

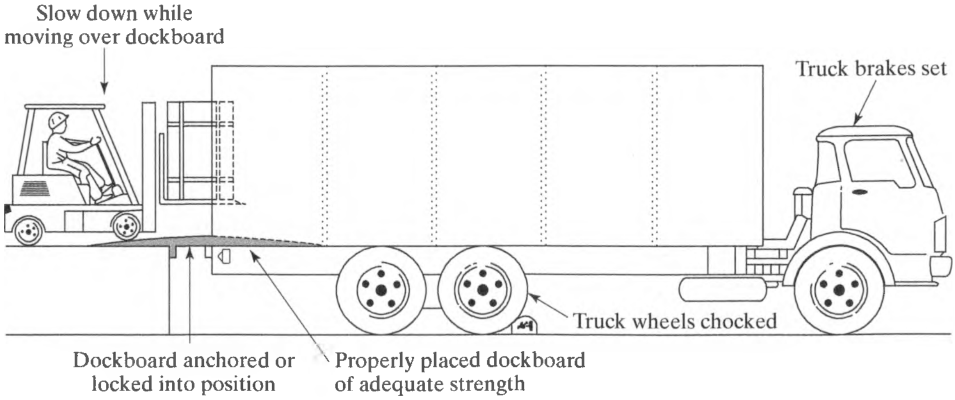


FIGURE 14.2

Preventing forklift hazards: transition from dock to cargo vehicle.

## PASSENGERS

Passengers on a lift truck can be a hazard in more than one way. For one thing, the truck is often equipped to seat only the driver, and there may be no safe place for a passenger to ride. Hitchhikers also can distract the driver, whose attention is even more important on a lift truck than in an automobile. One practice particularly frowned on is riding on the lift *forks*. The temptation is great to use a forklift truck as a personnel elevator. Actually, this practice can be safe *if* all of the following conditions are obtained:

1. A safety platform is firmly secured to the lifting fork.
2. The person on the platform can shut off power to the truck.
3. Protection from falling objects is provided if needed.

An ordinary wood pallet is not generally considered to be a safety platform, although it is often used for lifting personnel.

Some readers may consider the rule that the person on the platform be able to shut off power to the truck to be unreasonable. This rule also stands in the way of use of an ordinary pallet as a lifting platform. Workers, too, may resist this rule, and the safety and health manager needs to be in a position to counter this resistance with training programs that effectively explain the reasons for the rule. As a rationale for the rule, ask workers to consider the hazard caused by unexpected obstructions. A small obstruction could do any or all of the following:

1. Damage the platform
2. Tip the platform, causing the worker to lose balance
3. Injure the worker on the platform
4. Knock the worker off balance

The forklift driver is really in a poor position, owing to distance or angle, to see all obstructions and to judge their distance from the lifted platform. One might argue that the lift may be entirely clear of any obstructions, but such lifts would be unusual. There is usually no reason for employees to be lifted unless the lift is adjacent to equipment, stacks of material, or building structure. Any of these items can present obstruction hazards.

A variation of the *forklift rider* is the *carpet pole rider*. In carpet warehouses, the lift truck is equipped with a single pole, which is guided into the spool of a roll of carpet to lift the roll and transport it around the plant. Workers have been known to ride these poles rodeo style to gain access to the top of a stack of carpet rolls. Normally, there should be no reason for a worker to ride the pole because the pole can be raised and guided into position by the driver without assistance.

When manipulating loads, the forklift is often operating close to observers, supervisors, or assistants giving directions to the operator. A dangerous place to stand is beneath the elevated fork, whether it is loaded or not. Another dangerous position is between an approaching lift truck and a fixed object or bench.

### Parking and Maintenance

One thing to check is parked, unattended forklift trucks. The first thing to do is determine whether the lift truck is really unattended. If the operator cannot see the truck, it should be considered unattended. Even if the operator can see the truck, if the truck is more than 25 feet away, the truck is unattended. If the truck is unattended, the motor should be turned off. Even if the operator *is* close by, if the operator is *dismounted*, the fork must be fully lowered and the controls neutralized. The next thing to check is whether the brake is set, and if the truck is on an incline, whether the wheels are blocked. Finally, the horn should be tested.

Federal standards take very seriously the question of maintenance, inspection, and service for industrial trucks. No latitude is permitted concerning defective industrial trucks, to prevent them from being operated until the next regular overhaul. Any condition in a forklift, such as an inoperative horn, a defective brake, or a broken headlight, is cause to remove it from use until it is repaired.

Most people are amazed to learn that federal standards require industrial trucks in use to be inspected *daily* for safety. Compare this rule with procedures for automobile safety inspections, which most states require *annually*. If the industrial truck is used on a round-the-clock basis, safety inspections are required *after every shift*. It would be wise for the safety and health manager to institute some type of procedure or record to ensure that this job gets done and that proof of performance will be kept on file.

A final note on the subject of industrial trucks is the provision of an overhead guard to protect the operator from objects falling from the elevated load. More and more forklifts are being equipped with such guards for protection against falling objects such as small packages, boxes, and bagged material. They are not designed for protection against the impact of a full capacity load. These overhead guards are not to be confused with the much sturdier rollover protective structures (ROPS) described in Chapter 18, although the same structure can be used for both purposes if it is constructed properly. Some loads are unitized, and objects within the load are secured from falling back on the operator. For such applications, the hazard to the operator from falling objects disappears, and the overhead guard becomes unnecessary.

## CRANES

An industrial truck is convenient for general material handling of palletized loads. However, some material-handling jobs cannot be handled by an industrial truck. Larger, heavier, more awkward loads require the versatility of a crane, especially if the path of travel is complicated.

A crane is a construction industry device that is typically seen lifting heavy steel beams to lofty places. Although this image is accurate, it is incomplete. Cranes are also used extensively in general industry, although they usually take a different form. Cranes in industrial plants are generally limited in travel by a track or overhead runway structure, typified by the *overhead traveling crane* shown in Figure 14.3. Such cranes are popularly called *overhead bridge cranes* or simply *bridge cranes* by the workers who use them. Some models, such as those shown in Figure 14.3, are operated from a cab mounted on the crane itself. Others are operated from the floor by means of a hanging

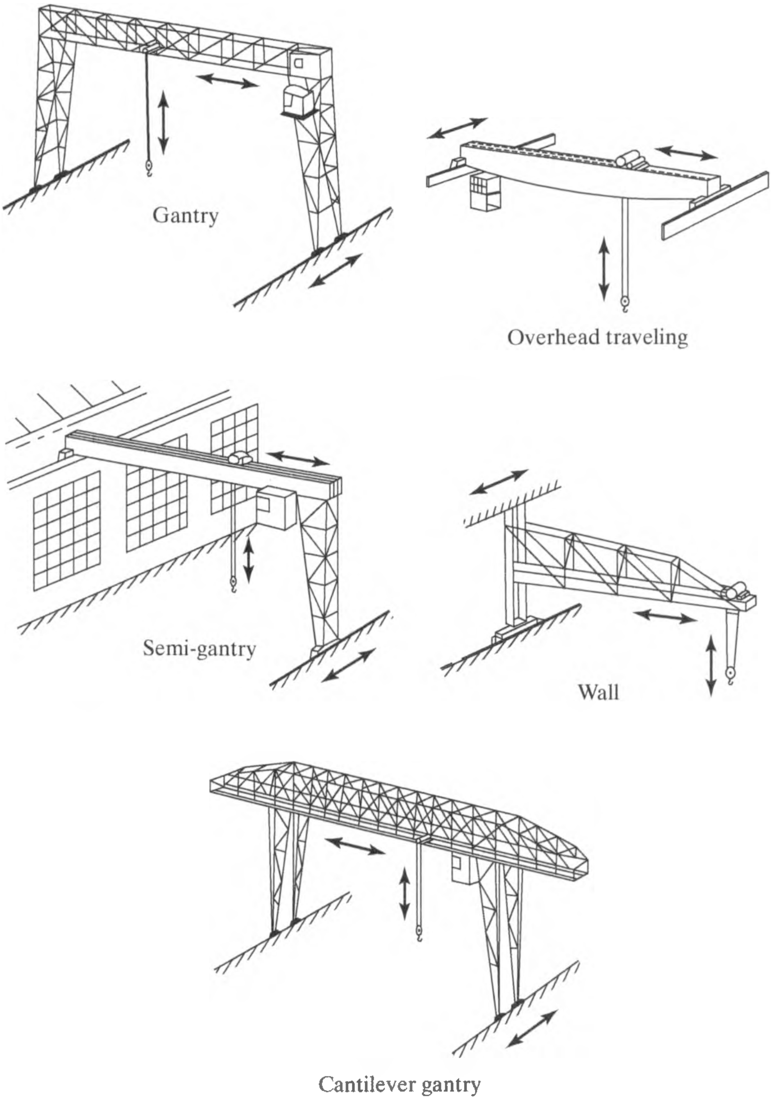


FIGURE 14.3

Various configurations for overhead cranes (*Source*: ANSI Standard B30.2.0-1976, reprinted with permission of ANSI and ASME).

cord control called a *pendant*, or from a fixed remote station called a *pulpit. Gantry* cranes have legs that support the bridge above the railway. *Cantilever* gantry cranes have extensions on one or both ends of the bridge; these extensions extend the reach of the crane outside the area between the rails on which the crane travels. One characteristic common to all overhead and gantry cranes is that the trolley, which carries the hoisting mechanism, rides *on top of* the rail on which it travels. Overhead cranes whose trolleys are not so mounted are called *underhung cranes* or *monorails*, depending on

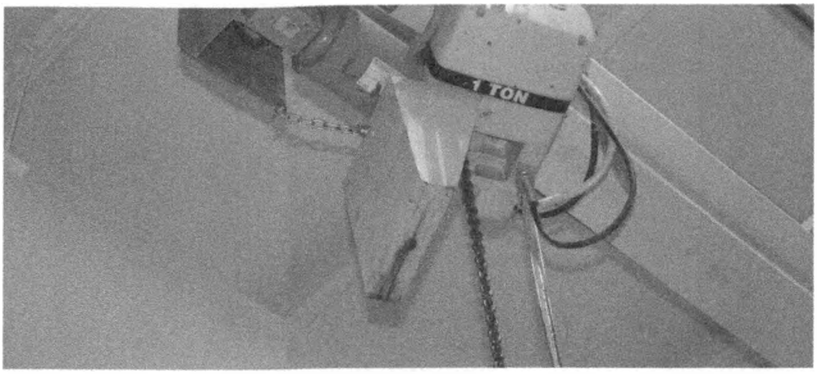


FIGURE 14.4

Load rating label on an overhead crane hoist (*courtesy*: Pratt & Whitney).

the type or application. Safety standards for overhead and gantry cranes are different from standards for monorails.

The safety and health manager's chief concern with regard to overhead cranes should be that workers will overload the crane. The rated load should be plainly marked on each side of the crane, and if the crane has more than one hoisting unit, each hoist must have its rated load clearly marked. In instances where the various components (i.e., wire rope, hoist, and gantry) have different load ratings, the minimum load rating should be posted for the crane. The crane can only lift as much as its lowest rated component. Load rating labels can be seen in Figure 14.4. So easily recognized are crane load markings that their absence is conspicuous.

Even if the rated load marking *is* on the crane, workers will sometimes be tempted to exceed the rated capacity. Everyone knows that engineers provide for a safety factor in their designs, so virtually every crane will support more than its rated load, even without damage to the crane. However, uncertainties in the actual weight of the load, dynamic loads during transport, shock loads during lifting, variations in crane components, and unavoidable design variabilities can combine to result in a very dangerous situation—even when rated load capacities are exceeded "slightly" or only "occasionally." As with running a stop sign, an alert driver can almost always avoid an accident, but once in a great while, another driver will be approaching the intersection at a high rate of speed, the visibility will be obstructed, or the stop sign violator will be complacent or distracted, and a serious accident will occur. It becomes very difficult for the safety and health manager or anyone else in the plant to police the proper use of cranes within their rated load limits at all times. This is where training becomes important so that workers will understand the risks and consequences of their actions. Recalling the principles set forth in Chapters 2 and 3, another way to control this problem is to take the time to make a big example out of any accident or near accident that occurs as a result of overloading a crane, even if no injuries occur.

Many overhead cranes operate outdoors, where wind can be a hazard. Wind alone is usually not dangerous, but a wind load in combination with a working load can result in dangerous structural damage to the crane. Automatic rail clamps are required for outdoor storage bridge cranes. The purpose of these clamps is to lock the bridge to the rail if the wind exceeds a certain velocity. This idea sounds good because it protects against the types of wind hazards just described and also protects the bridge from unintentional and uncontrolled rolling in a high wind or a brake failure. However, like some other devices, the safety device carries with it a hazard of its own. Think about it for a moment: In what mode of crane operation would the tripping device most likely engage the automatic rail clamp? The answer is when the bridge is traveling *at top speed* against the wind. The sudden engagement of the rail clamp when the bridge is traveling at top speed is likely to injure the operator in the cab, dangerously swing the load, damage the crane, or all three. Therefore, the crane needs either a visible or an audible alarm, or both, to warn the bridge operator *before* the rail clamp engages.

If the crane operator rides in a cab mounted on the bridge or the trolley, the operator must somehow have a way to gain access to his or her station. One idea that comes to mind is to use a portable ladder, but this is not such a good idea. Since the bridge travels, the operator, cab, trolley, and bridge may roam far from the point at which the operator mounted. The idle ladder standing far away would be an invitation for someone to remove it for some other use or perhaps just to get it out of the way. A ladder used for crane cab or bridge access should be of the fixed type. Stairs or a platform, or both, can also be used, but must require no step over a gap exceeding 12 inches.

Overhead cranes designed or constructed in-house sometimes do not meet accepted principles for crane design and overlook some of the necessary safety features specified by applicable standards. Besides cab access, there are specifications for footwalks for safe maintenance of the trolley and bridge. These footwalks need standard toeboards and handrails, as described in Chapter 7.

Ideally, footwalks will have at least 78 inches of headroom. Sometimes, however, this is not practical because the crane may be near the ceiling of the building. The standards recognize this difficulty and permit less than 78 inches of headroom. However, a footwalk becomes rather ridiculous if the headroom is less than 48 inches and would more properly be called a *hands-and-knees* walk. In these situations, footwalks should be omitted, and a stationary platform or landing stage for crane maintenance workers should be installed.

A critical hazard to the wire rope of a crane or hoist results from drawing the load hook or hook block up too far—to the point at which the load block makes contact with the boom point of the crane or other mechanical assembly for reeving the wire rope. This event is known as *two-blocking*, the term being derived from the physical contact of two blocks in the reeving system. On the incidence of two-blocking, continued travel of the load block causes a severe tensile stress to be immediately imparted to the wire rope, and this stress usually stretches or breaks the wire rope. The blocks may also be damaged.

Two-blocking is a very serious hazard that has resulted in many fatalities. A sudden break in a load-bearing wire rope constitutes an obvious hazard, especially if personnel are under the load or are themselves being hoisted aloft by the crane. As a matter of ergonomics, it can be shown that it is very difficult for a crane operator to be sufficiently vigilant to prevent an occasional dangerous brush with two-blocking, especially for construction cranes. So many fatalities have resulted from two-blocking that crane construction standards now address this hazard, and devices are on the market for the purpose of preventing two-blocking or the damage that can result from it. These mechanisms, usually electromechanical, are commonly called *anti two-block devices*.

An obviously serious hazard associated with the operation of an overhead bridge crane is overtravel. Devices to control overtravel would include trolley stops, trolley bumpers, and bridge bumpers. Bumpers and stops are somewhat different in that bumpers absorb energy and reduce impact, whereas a stop simply stops travel. The stop is simpler and can consist merely of a rigid device that engages the wheel tread. For safety, such a stop needs to be at least as high as the wheel axle center line. Bumpers soften the shock by absorbing energy, but are not as positive as a true stop. For example, bridge bumpers need only be capable of stopping the bridge if it is traveling at 40% or less of rated load speed. If the crane travels only at slow speeds, shock loads are not significant, and bridge bumpers and trolley bumpers are not necessary. There may be other circumstances of operation, such as restriction of crane travel, that eliminate the need for bridge bumpers or trolley bumpers.

Related to bumpers and stops are rail sweeps. If a tool or some item of equipment happens to obstruct one of the rails on which the bridge travels, a catastrophic accident could occur. Therefore, bridge trucks are equipped with rail sweeps, projecting in front of the wheels, to eliminate this hazard. There is nothing magical about the term *sweep*; even part of the bridge truck frame itself may serve as a sweep.

One obstruction that can be encountered by an overhead crane is another overhead crane that runs adjacent to it with parallel side rails. Proper clearance should be provided between the two adjacent bridge structures. Unfortunately, such clearance may make it impossible for one crane to transfer its load to the domain of the adjacent crane. Some factories resolve this problem using retractable extension arms on the crane. The trouble with these retractable arms is that the operator may inadvertently leave them extended, resulting in a collision between the two adjacent cranes.

Electric shock is a concern with overhead cranes in two principal areas:

- Shock from exposure to current-carrying portions of the crane's power delivery system
- Shock from a shorted connection in a hanging control pendant box (see Figure 14.5).

A third area of concern for electrical shock is the accidental contact of live, high-voltage overhead transmission lines. This is a hazard for mobile cranes with booms (discussed in Chapter 18) because of their wide use in the construction industry. Exposed live parts in the crane's power delivery system are usually protected by their remoteness or "guarded by location." Some older models might present hazards and need modification.

A greater hazard is the possibility of shock from a pendant control. The electrical conductors can be strained if they are the sole means of support for the pendant. The control station must be supported in some satisfactory manner to protect against such strain. If there is a failure, it is likely to occur at a connection within the box. This raises the possibility of a dangerous short to ground through the operator's body. Pendant controls take much abuse and need to be of durable construction.

Noprati somchit/Shutterstock

FIGURE 14.5

Hand-held pendant control for overhead crane.

Not related to electrical shock but on the subject of pendant control boxes is the requirement that boxes be clearly marked for identification of functions. Some older model or homemade cranes might have pendant control boxes without function markings. Without a great deal of trouble or expense, the safety and health manager can check the cranes in-house for compliance and get the control functions marked on the pendant controls.

One hazard to think about with overhead cranes is what would happen if a temporary power failure occurred. Suppose that the crane were in the process of lifting a heavy load by means of its hoist mechanism. Obviously, no one would want the crane to drop its load to the floor upon power failure, but the hazard does not end here. Suppose that the crane bridge is traveling in a horizontal direction, whether loaded or unloaded. Upon power failure, the bridge would stop, which might not be dangerous. However, when power is *restored*, dangerous lurching action might occur. In fact, upon a power failure, the crane operator might even leave the crane cab!

Several design alternatives can protect against these hazards. One solution is to equip the control console with spring-return controllers. Pendant boxes can be constructed with spring push buttons instead of toggle switches. A disconnect device can neutralize all motors and not permit a reconnect until some sort of positive "reset" action is taken. Even if the power remains on, it could be a hazard to inadvertently switch on a lever at the wrong time. Notches, latches, or detents in the "off" position can prevent such inadvertent actions.

Brakes are of obvious importance to the safe operation of a crane, yet a large number of crane operators do not use brakes, but instead rely on a practice the industry calls “plugging.” The operator merely reverses the control and applies power in the opposite direction, thereby stopping the load. Although no OSHA standard prohibits the practice of *plugging*, it should be pointed out that plugging is not as effective as applying a brake under extreme conditions, such as stopping a large, fast-moving load. Under no circumstances should a crane operator depend entirely on plugging owing to the brake being inoperative. In fact, plugging would be completely useless in the event of crane motor failure.

A crane has many moving parts, many of which are located far from the operator’s console in the cab or from a floor operator holding a pendant. Moving machine parts are hazardous, and the remoteness characteristic amplifies the hazard. Moving parts are hazardous not only to personnel; they can be hazardous to the crane itself, which in turn can be indirectly hazardous to personnel. Hoisting ropes, for instance, can possibly run too close to other parts in some crane configurations and in some positions of the bridge and trolley. The result can be chafing or fouling of the hoist rope. If the configuration of the equipment will permit this situation to develop, guards must be installed to prevent chafing or fouling. Such moving parts as gears, setscrews, projecting keys, chains, chain sprockets, and reciprocating components need to be checked to determine whether they present a hazard; if so, they must be guarded.

As with conveyors and other material-handling equipment, overhead cranes are often large and widely distributed items of equipment. Electrical power is distributed over long distances, sometimes by means of open runway conductors. An example of such runways can be seen in Figure 14.6. Portions may be so far away as to be obscured from view from the location of the power supply switch. Picture the insecurity of the maintenance worker who is compelled to repair a crane and is in direct contact with an exposed 600-volt (but deenergized) runway conductor, but the power supply switch is so

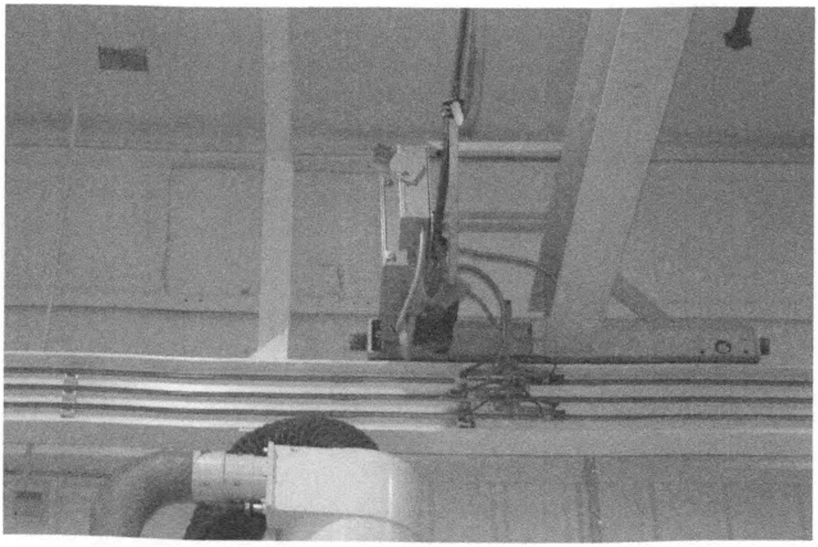


FIGURE 14.6

Open runway conductors on an overhead crane (*courtesy*: Pratt & Whitney).

far away that it is out of sight! Therefore, such switches should be so arranged as to be *locked* in the open or "off" position. This is an example of a *lockout/tagout* requirement that was in place before the general lockout/tagout standard was promulgated by OSHA in 1989. The general lockout/tagout standard will be covered in more detail in Chapter 15.

## Ropes and Sheaves

Safety standards for wire rope strength state that "rated load divided by the number of parts of rope shall not exceed 20% of the nominal breaking strength of the rope." The term *rated* implies that a safety factor has been applied, which is numerically equivalent to 5, as can be derived from the standard as follows:

$$\frac{\text{Rated load (including load block)}}{\text{Number of parts of rope}} \leq 20\% \times (\text{nominal breaking strength}) \tag{14.1}$$

It will later be explained that the "number of parts of rope" is a multiplying factor that enables a multiple-sheaved block-and-tackle assembly to be loaded much higher than the wire rope load. Thus,

$$\text{Wire rope load} = \frac{\text{rated load (including load block)}}{\text{number of parts of rope}} \tag{14.2}$$

From equations (14.1) and (14.2)

$$\text{wire rope load} \leq 20\% \times (\text{nominal breaking strength}) \tag{14.3}$$

Multiplying each side of the inequality by 5, we have

$$5 \times (\text{wire rope load}) \leq 100\% \times (\text{nominal breaking strength}) \tag{14.4}$$

Rearranging to create a ratio yields

$$\frac{\text{Nominal breaking strength}}{\text{Wire rope load}} \geq 5 \tag{14.5}$$

Since the ratio of the strength to the load is at least 5, the *safety factor is 5*.

The term *parts of rope* refers to the mechanical advantage provided by the block-and-tackle assembly. *Parts of rope* is computed by counting the number of lines supporting the load block. Of course, all the lines make up one continuous line that is reeved through several sheaves to achieve mechanical advantage. The concept is best explained by a picture; Figure 14.7 shows five different reeving combinations. Note that the mechanical advantage is numerically equivalent to the number of parts of line.

One additional caution is in order when determining the appropriate maximum load to be applied to a given reeving setup. The weight of the load-carrying sheave must be added to the weight of the load to be picked up to arrive at the total load of the line. The weight of the load block cannot be ignored, as is emphasized by the massive load block displayed in Figure 14.8. Case Study 14.1 will now be used to illustrate calculations used to determine the safety of a wire rope reeving application.

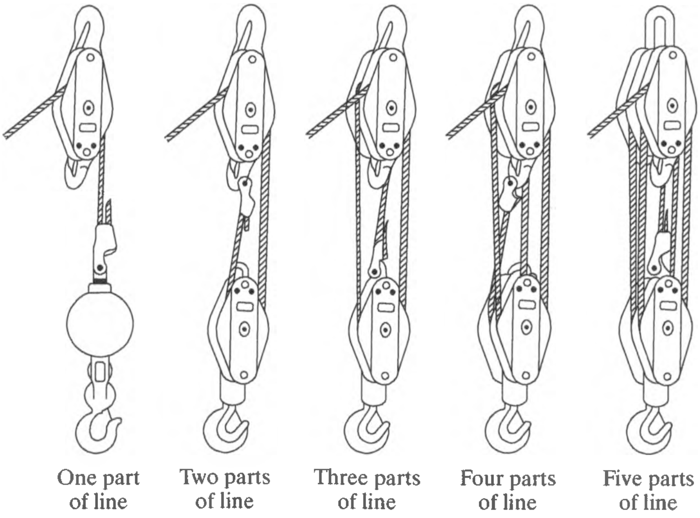


FIGURE 14.7

Five different reeving combinations. The mechanical advantage is equal to the number of "parts of line" supporting the load block.

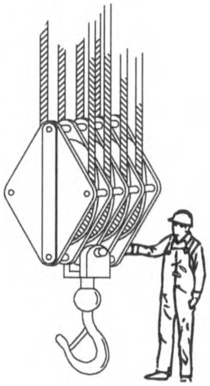


FIGURE 14.8

Massive load block. The load block becomes part of the total load on the line.

## CASE STUDY 14.1

## BLOCK-AND-TACKLE SAFETY FACTOR

The lower block of a block-and-tackle assembly has three sheaves and is thus supported by six parts of line as the wire rope is wrapped around the sheaves, plus a seventh part as the wire rope is tied off on the lower block. The wire rope has a nominal breaking strength of 4000 pounds. The lower block (the load block) itself weighs 80 pounds. Calculate what maximum payload this block-and-tackle assembly can pick up safely.

***Solution:***

$$\frac{\text{Rated load (including load block)}}{\text{Number of parts of rope}} < 20\% \times \text{(nominal breaking strength)}$$

$$\frac{\text{Rated load (including load block)}}{7} < 20\% \times 4000\text{ lb}$$

$$\text{Rated load (including load block)} < 7 \times 20\% \times 4000\text{ lb}$$

$$< 5600\text{ lb}$$

$$\text{Maximum payload} = \text{rated load} - \text{weight of the load block}$$

$$= 5600\text{ lb} - 80\text{ lb} = 5520\text{ lb}$$

One way to prevent overloading the wire rope and the crane itself is to provide a hoist motor that can develop insufficient torque to overload the wire rope. The combination of such a hoist motor and correct reeving for the crane design will result in no overloading. Under this arrangement, the crane simply will be unable to lift any load that would damage the crane or exceed its safety factor. Most overhead cranes today are designed this way. How fortunate it would be if the human back had this design feature.

Any time a rope is wound on a drum, the rope-end anchor clamp bears very little of the load when several wraps are on the drum. The friction of the rope on the drum holds the load. However, if the drum is unwound to less than two wraps, dangerous loading of the anchor clamp may result in failure—the wire rope will break free from the drum. Usually, the overhead crane is set up so that, even if the load block is lying on the floor, several wraps remain on the hoist drum. The floor may not be the extreme low position for the crane, however. The safety and health manager should look around for pits or floor openings into which the overhead crane might operate, resulting in dangerous unwinding of the hoisting drum.

"Don't saddle a dead horse" is a familiar safety slogan that refers to the improper mounting of wire rope clips employing U bolts. Such a clip assembly bears a resemblance to a saddle, and the U bolt represents the cinch strap. The U bolt places more stress on the wire rope and has less holding power than the clip. Therefore, it should not be placed on the live portion of the rope when a loop is formed. The "dead" end of the rope gets the U bolt, and the "live horse" gets the clip. Right and wrong methods are illustrated in Figure 14.9. Unfortunately, some workers in the field, unsure of the correct method, place the clips *both ways* in alternating fashion, thinking they are "playing it safe." Such an arrangement may be even more unsafe than "saddling dead horses" with every clip.

Before leaving the subject of wire rope, the hazard of rope whip action should be emphasized. Wire rope "cable" seems so heavy and inflexible that it seems unnatural that it could crack like a whip or any fiber rope. It is difficult for anyone to visualize the tremendous tension forces on a wire rope during use in material-handling operation, until that wire rope breaks. Most workers have never seen what happens when a wire

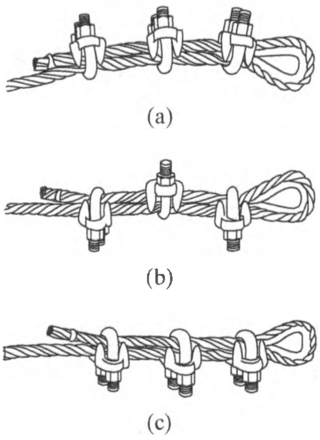


FIGURE 14.9

"Don't saddle a dead horse." Right and wrong ways to secure wire rope loops using U-bolt clips. (a) Incorrect—"saddle" is on dead end of rope; (b) incorrect—clips are staggered both ways; (c) correct—all clips are placed with the saddle assembly on the live portion of the rope and the U bolt on the dead end.

rope breaks; perhaps this explains why so many workers stand too close while the rope is drawn taut by the load. The hazard is very serious, and an injury accident is very likely to be a fatality.

## Crane Inspections

Almost everyone is aware of the long, perhaps tedious checklists for inspection of an aircraft every time it flies. An aircraft must not fail in any catastrophic way during operation, and this makes frequent inspections worthwhile, even if they are repetitious and rarely uncover any defects. In some ways, a crane is like an aircraft; it, too, must not fail.

With regard to crane inspections, the standards use the terms *frequent* or *periodic* to specify when various items on the crane should be checked. Such usage is an attempt to avoid being overly specific in telling the employer *what* to do and *how often* to do it. Some broad guidelines describing the meaning of these terms are illustrated in Figure 14.10. Note that there is some overlap, as monthly inspections can be considered either frequent or periodic.

The crane manufacturer is a good source for detailed guidance in what to look for in the frequent inspections. This type of inspection is performed by the crane operator, just as a pilot inspects his or her aircraft before a flight. This analogy between aircraft

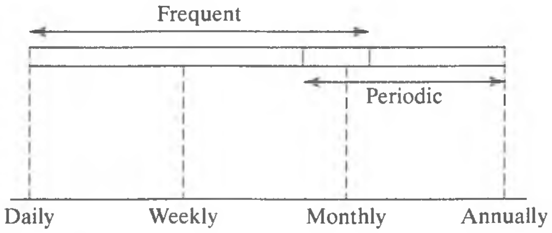


FIGURE 14.10

Inspection intervals for overhead cranes.

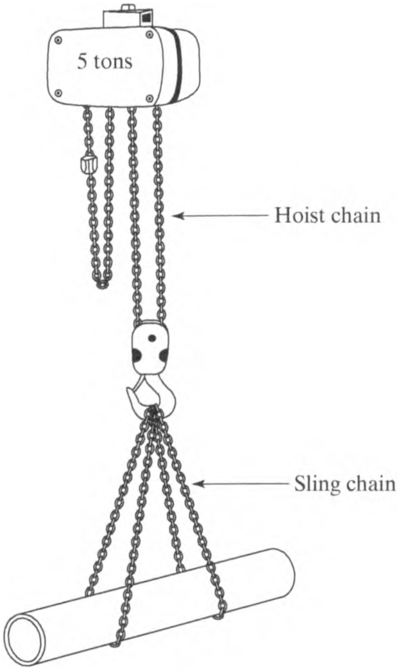


FIGURE 14.11

Hoist with sling. Hoist chain is not to be confused with the sling chain.

and cranes might be a starting point for a safety theme in a training program for crane operators.

The frequent-inspection routine should include a daily visual inspection of hoist chains, plus a monthly inspection with a signed report. In the field, the term *hoist chains* has been widely misinterpreted to include chain *slings* for handling the load. A separate standard exists for slings. Figure 14.11 identifies which chain is hoist and which is sling.

Crane hooks take a great deal of abuse and are critical to the safe operation of the crane. Although they usually contain considerable overdesign, damage or wear can reduce the margin of safety. Telltale signs of an abused and dangerous hook are illustrated in Figure 14.12.

A more thorough inspection of crane components is needed for "periodic" intervals. Whereas daily inspection of crane hooks is merely visual, the periodic inspection calls for a more scientific approach, such as using magnetic-particle techniques for detecting cracks. More extensive checks for wear are appropriate also, such as the use of gauges on wire rope sheaves and chain sprockets.

For most kinds of plant equipment, safety testing is customarily done by an independent testing laboratory such as Underwriters' or Factory Mutual. However, the safety of an overhead crane is in part a function of the installation method and proper adjustments at the site. Therefore, an actual rated-load test is needed prior to initial use to confirm the load rating of the crane. This is a bit tricky, because if the crane is subjected to too heavy a load, the crane may fail; but if it is not tested with a heavy enough load, why conduct the test? Standards specify that the maximum load during the test should go 25% higher than the crane's load rating. This will provide some assurance

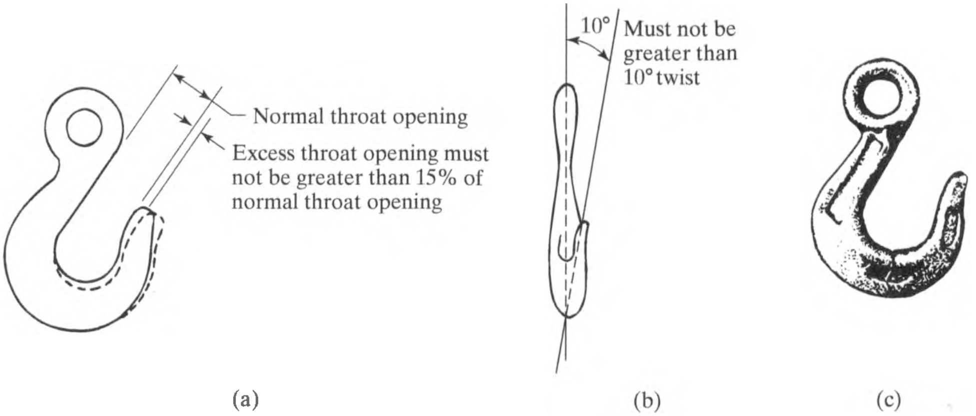


FIGURE 14.12

Defective crane hooks: (a) bent hook; (b) twisted hook; (c) cracked hook.

that the crane will withstand its rated load. During use, however, the crane should not be loaded with more than its rated load. Any extensive repair or alteration of the crane may subject it to a retest.

## Wire Rope Wear

The two principal moving parts of an overhead crane are the wire rope and the drum and sheaves on which they travel. In addition, the wheels for the bridge and trolley move, as do a few other items on the crane. Whenever parts move and contact other parts, they are subjected to wear. Wear on the bridge and trolley wheels may eventually lead to problems, but is not likely to cause crane failure. Wear on the drum and sheaves is more dangerous because of the harm this can bring to the wire rope. However, worn sheaves and drum *alone* are generally not the *direct* cause of crane failure. The wire rope remains as the most critical moving part. With continued use, every wire rope will eventually wear out and fail, a hazard that generally is not tolerable. Some way has to be devised to predict the failure of wire rope and withdraw it from use before a catastrophe.

It is not a simple matter to determine when a wire rope needs replacing. A wire rope has many individual wires, and it is easy to cut or break away any one of these small wires. Almost everyone has seen broken wires in an old wire rope (or “cable,” as laypersons often say), which raises the question, “Is such a wire rope dangerous?” Safety and health managers do not survive long in their companies if they go around ordering wire rope to be replaced every time they find a broken wire. And if they did survive, their companies would not survive. Before delving into this issue, some basics about wire rope need to be examined.

A wire rope should really be considered a machine because the individual wires move on each other while the rope flexes, resulting in friction and wear. Furthermore, unless the individual strands are able to move properly during flexure, tremendous tensile stresses may be placed on some of the wires, causing them to break. Rust, kinks, and other types of abuse can interfere with the movement of the wires and lead to the stresses that cause wire breakage. As some wires break, the tensile stresses on other wires increase, leading to their breakage as well. Eventually, the force of the crane load will be sufficient to overcome the tensile strength of all remaining wires combined, and the wire rope will fail.

Even a well-maintained wire rope will be subject to wear on the individual wires, especially the outside wires. As the wear causes the diameter of the wire to become smaller, the tensile force increases the tensile stress on that single wire owing to its reduced cross-sectional area. Thus, the worn wire, too, may break due to stress concentration, even if there are no kinks or rust, and even if the wires move properly to distribute the load among all wires.

For obvious purposes, a wire rope is overdesigned and will withstand more than its rated load. Equally obvious is that all wire ropes will eventually develop broken wires with continued use. Broken wires are permissible to an extent, but beyond a certain point, the rope becomes dangerous. A means of evaluating the *degree* of wire rope deterioration is awkward and difficult, but nevertheless *necessary*, to prevent catastrophic failure.

The ANSI standard recommends[1] a procedure for counting the broken wires. Figure 14.13 diagrams the components of wire rope, defining the terms *strand* and *lay*. If there are more than 12 randomly distributed broken wires in a single strand in a single lay, there should be cause for questioning the continued use of the rope. A good place to look for broken wires is around end connections. Sometimes an expert can evaluate the remaining strength in a deteriorated rope after inspection. This possibility is acknowledged by the ANSI standard, which advocates the use of good judgment.

Another measure of rope condition is the amount of reduction of rope diameter below nominal. Figure 14.14 shows that when gauging a wire rope, the caliper can be

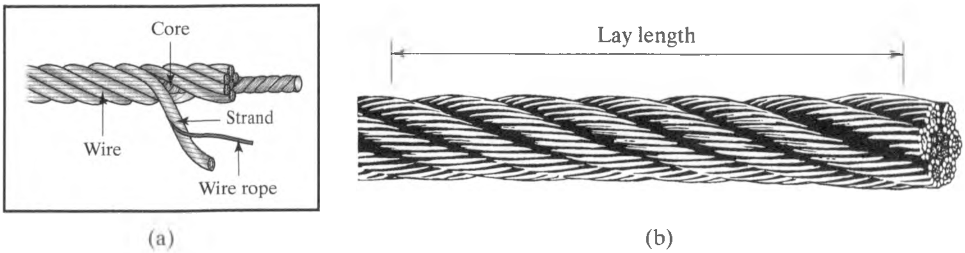


FIGURE 14.13

Wire rope components. (a) This wire rope has six strands plus an inner core. Do not confuse *strands* with *wires*. (b) Wire rope lay. *Lay* is one complete wrap of a single strand around the rope. Since this rope has six strands, lay is the length from the first hump to the seventh hump, as shown in the diagram.

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[1] ANSI B30.2–2.4.2.

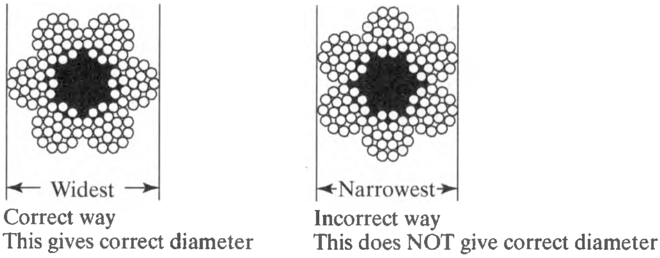


FIGURE 14.14

Gauging wire rope (rotate rope to select the largest diameter)

placed on a small diameter or a larger diameter. The convention for wire rope terminology is to use the larger diameter for designation as the nominal diameter of the rope. Most people pay little attention to wire rope, but wire rope is no small matter considering that a quarter million tons of wire rope is sold annually.

### Operations

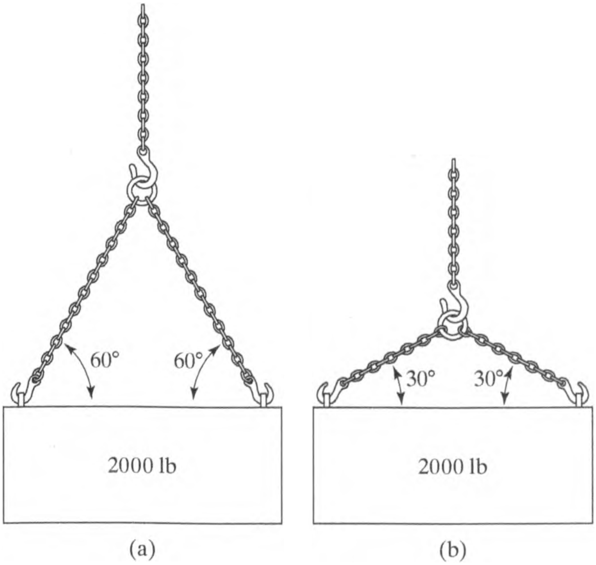
The actual handling and moving of the load by the crane is a function of the skill, knowledge, and performance of the crane operator and the workers who attach and secure the sling or lifting device. As is the case with motor vehicles, the *operator* of the crane is probably the most important factor in preventing accidents.

A good deal of skill is required to attach the load safely, especially if a sling is used. Slings will be discussed in the next section. The hoist rope is not intended for wrapping around the load, as this kind of abuse may damage the rope and at the same time be an inadequate support for the load. Misplacing the attachment off the line of the center of gravity can cause dangerous swings when the load is lifted. After the load is lowered to the ground or floor, the tendency is to be relieved and think that the hazard is now removed. However, disengaging the load attachment can also result in dangerous shifts in material that can injure the inexperienced or unwary worker on the floor.

## SLINGS

Slings are used to attach the load to the crane, helicopter, or other lifting device. Slings come in a great many varieties and are very important in the safety of material-handling operations. Components of the sling assembly are often subjected to much larger forces during lifting than is the hoist rope or other material-handling equipment. Because the skill of the user is so important in the proper application of the sling, slings are often misused, resulting in much more abuse and damage to slings than to the components of the crane.

The most important point to remember for the safe use of all slings is that the stress on a sling is greatly dependent on the way it is attached to the load. Figure 14.15 shows two different ways of applying a sling to pick up identical loads. If the angle of



(a) (b)

FIGURE 14.15

Comparison of sling tensile forces for two different methods of lifting identical loads: (a) tensile force on the sling is approximately 1150 pounds; (b) tensile force on this sling is approximately 2000 pounds.

the supporting legs of a sling is sharp, as in Figure 14.15b, the advantage of multiple legs can be lost. Using too short a sling is the most common cause for this condition. The "rated capacity" of a sling is the working load limit under *ideal* conditions; if the sling is applied at leg angles other than those specified in the rated capacity table, the capacity can be drastically reduced owing to the physics of the applied forces. Therefore, *rated capacity* is an incomplete term without the accompanying leg angle.

Note the following progression in capacities of 1/2-inch alloy steel chain as the number of legs increases:

| | |
|---|---|
| Single (at vertical) | 11,250 pounds |
| Double (at 60° from horizontal) | 19,500 pounds |
| Triple (at 60° from horizontal) | 29,000 pounds |
| Quadruple (at 60° from horizontal) | 29,000 pounds |

It might be assumed that the capacity of the sling increases as the number of legs or supporting members is increased. However, note that no increase in capacity is shown in going from three to four legs. The reason for this is that, as in a four-legged chair, three legs will actually carry the load. At times, the weight distribution might be equal among legs of the sling, but usually the balance is not so perfect. As the load shifts around, it is entirely possible for one of the four legs to become slack and for the other three to bear the entire load.

Alloy steel chain, besides being very strong, is very durable and capable of withstanding the physical abuse that industrial slings routinely receive. The ordinary carbon steel chain commonly found in hardware stores should not be used for slings. Wire rope slings can be just as strong as steel chain slings, but wire rope is more subject to wear. Individual wires in the wire rope are more easily broken, with eventual incapacitation of the sling.

Wire rope slings also have a specification for the permitted number of broken wires; the rule is that there should be no more than 10 randomly distributed broken wires in one rope lay, or five broken wires in one strand in one rope lay. Note from our earlier discussion that this is a bit more strict than the requirement for wire rope for overhead cranes.

Selection of the proper sling for a given application can consider several factors besides rated load. The nature of the item to be lifted, its surface finish, temperature, sling cost, and environmental factors must be considered. The safety and health manager is usually not the person who makes this decision, but there is increasing reason for the safety and health manager to have a voice in what is done in this area. Many factory superintendents, supervisors, and material-handling workers are not aware of the many federal standards confronting the criteria for selection of slings. In fact, many of these personnel do not even have a clear understanding of the inherent hazard mechanisms surrounding industrial slings. Therefore, it is recommended that the safety and health manager provide consultation and advice in the selection and use of industrial slings in the interest of worker safety.

For some criteria, such as load markings, repair procedures, proof testing, and operating temperatures, the requirements for various types of slings are not identical, and even vary in curious ways. Some of these variations are due to the physical differences in sling types, and some due to the various origins and rationales for the requirements for various slings. Table 14.3 is intended to summarize some of the more curious differences between requirements for various types of slings, but it is by no means exhaustive. For instance, nylon web slings are not permitted in the presence of acid or phenolic vapors. In the case of caustic vapors, polyester and polypropylene web slings and web slings with aluminum fittings are not permitted. The safety and health manager can use Table 14.3 as a first check in an in-house inspection or purchase decision; then further details should be checked out in the standards.

It must be reemphasized, however, that the skill and training of the worker who uses the sling to attach the load is more important than all of the detailed specifications and sling standards combined. This is a good place for the reader to reflect on the fatality described in Case Study 14.2.

## CASE STUDY 14.2

Two inexperienced workers had the assignment of hoisting a 40-foot-bundle of channel steel. The question was where to attach the hoist hooks to the load. The solution they selected was based on their experience in lifting loads with which they were familiar—hand-held loads. To these workers, the heavy, steel straps used to secure the bundle seemed to be a natural attachment point. However, these straps were not intended to be used as a substitute for a sling. Their strength was insufficient, and the angle of attachment was severe. The angle of attachment will always be severe when bundle straps are used in this way, because to do their job, the straps must be tight. When the load was lifted one of the straps gave way and one of the workers was killed.

TABLE 14.3 Comparison of Certain Requirements for Slings

| Type of sling | Rated capacity *markings* required? | Repairs permitted? | Employer required to maintain *records* of periodic inspection? | Employer required to maintain a *certificate* of proof test? | Safe operating temperature (°F) | | Proof test of *sling* required? | Repair records required?[a] |
|---|---|---|---|---|---|---|---|---|
| | | | | | Maximum | Minimum | | |
| Alloy steel chain | Yes | Yes | Yes | Yes | 1000[b] | None specified | Yes | No, except for welding or heat treating |
| Wire rope | | | | | | | | |
| With fiber core | No | Yes | No | Yes, for welded end attachments | 200 | None specified | Yes, for welded end attachments | No |
| With nonfiber core | No | Yes | No | | 400[c] | −60[c] | | No |
| Metal mesh | Yes | Yes | No | No | 550[d] | 20[d] | Yes | Yes |
| Natural fiber rope | No | No | No | No | 180 | 20 | No | N/A |
| Nylon fiber rope | No | No | No | No | 180 | 20 | No | N/A |
| Polyester fiber rope | No | No | No | No | 180 | 20 | No | N/A |
| Polypropylene fiber rope | No | No | No | No | 180 | 20 | No | N/A |
| Nylon web | Yes | Yes | No | Yes, for repaired slings | 180 | None specified | Yes, for repaired slings | Yes |
| Polyester web | Yes | Yes | No | Yes, for repaired slings | 180 | None specified | Yes, for repaired slings | Yes |
| Polypropylene web | Yes | Yes | No | Yes, for repaired slings | 200 | None specified | Yes, for repaired slings | Yes |

[a] N/A, not applicable.

[b] If alloy steel chains are working in temperatures exceeding 600°F, load limits are reduced.

[c] Seek manufacturer's recommendations for use outside the temperature range.

[d] Impregnated metal mesh slings have more restricted temperature requirements.

## CONVEYORS

Hazards with conveyors can be quite serious, and workers seem to sense these hazards more than with some other types of machines. It seems that all of us have implanted somewhere in our imaginations the vision of being tied to the conveyor in a sawmill about to be sawed in half. The truth is that sometimes workers *are* caught in industrial conveyors and not only killed, but dismembered or even pulverized beyond recognition. The horror of this truth instills a healthy respect on the part of most workers around industrial conveyors.

By contrast, some of the worst conveyor hazards are very innocent in appearance. In-running nip points that themselves might not even seriously injure a hand or arm can start an irreversible process once the employee is caught, resulting in an employee's entire body being drawn into a machine. Loose clothing in particular can get caught, and the employee, even before being injured in the slightest way, can become doomed.

### Belt Conveyors

On a belt conveyor, in-running nip points are seemingly everywhere. Pulleys are required to drive the belt, change direction of the belt, support the belt, and tighten the belt. One side of every pulley is always an in-running nip point. Defense against this hazard generally consists of one of three means: isolating the nip points, installing guards, and installing emergency tripping devices.

The best method of protection is to isolate the in-running nip point so that an employee would not or could not come into the danger area. If isolation is impractical, a guard can sometimes be installed to keep out the worker's body or extremities. The design of the guard must vary with the application, and sometimes it is difficult to make the guard practical because it may interfere with the operation of the conveyor. Because of body geometry, distance from the danger zone is a design factor in building the guard, a principle that is covered in more detail in Chapter 15.

If both isolation and guarding are impossible or infeasible for the application, the workers can be protected by some type of emergency tripping mechanism. A wire or rope can be run along the length of the conveyor so that a worker falling into the conveyor can grab the trip wire and stop the machine. Unfortunately, this method of protection requires the overt action of an alert worker or coworker.

### Overhead Conveyors

Large appliance parts or vehicle assemblies are often handled by overhead conveyors. Hooks attached to a moving chain support each item as it is moved. This type of conveyor is particularly suited for products that have delicate or finished surfaces because so little of the conveyor actually contacts the product. For the same reason, overhead conveyors are very useful for paint spray or finishing operations.

Overhead conveyors avoid many of the risks of belt conveyors by eliminating many of the in-running nip points and by removing the moving parts from worker access. However, overhead conveyors have hazards of their own, such as dropping conveyored materials to the plant floor or onto workstations. Screens or guards can protect against this hazard, but not entirely, because the moving parts must be accessible to workstations for processing. A good rule is to place screens or shields under the conveyor whenever it passes over an aisle or other area where personnel are likely to gather. Another good place for screens is where the conveyor chain moves up or down an incline. Such movements cause the loads to shift on their hangers and increase the possibility of a falling load.

Figure 14.16 shows three different orientations for the hangers or hooks that support the work held by an overhead conveyor. Note how much safer is the orientation in which the work is held in front of the hook. If the work encounters an obstruction, it is more likely to catch and stop the conveyor if the work is in front of the hook. If the work trails the hook, an obstruction may lift and knock off the load.

### Screw Conveyors

Screw conveyors can be very dangerous. The very principle of their operation is an ingoing nip point at the intake. Complicating the hazard is the fact that in order to operate at full capacity, the intake must be completely submerged in the material to be transported. *Submerged* usually also means hidden, so an unseen serious hazard exists at the intake. Finally, there may be a need for the worker to be fairly close to the screw conveyor for many applications in order to shovel or distribute material into the intake.

A simple and often effective way to protect workers from the hazards of the screw intake is to box the intake area in a small screen enclosure that allows passage of the material, but keeps out fingers, hands, and feet. If even a coarse screen mesh is too fine to permit passage of the material, an enclosure with larger openings may be necessary, perhaps with openings large enough to admit a finger or hand. This type of enclosure can be made safe, too, by making the box large enough that the worker's *reach* will not permit entry of hands or fingers into the danger zone. This follows principles of machine guarding, which are discussed in more detail in Chapter 15.

## LIFTING

Before closing this chapter on materials handling, we return to the subject of lifting. It was stated earlier that back injury, mostly from lifting, is one of the biggest compensable injury categories of all. Lifting injuries are very complex and very difficult to control. Naturally, the amount of weight lifted is important, but many other factors determine whether an injury occurs. Even a lightweight lift of 5 to 10 pounds can cause serious back injuries if conditions are just right (rather, wrong). The physical condition of the person doing the lifting is also important.

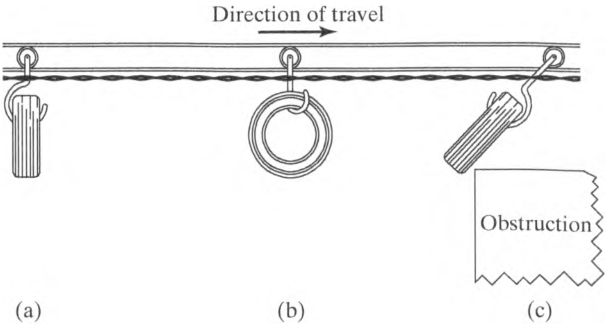


FIGURE 14.16

Three different orientations for conveyor hooks: (a) hook trails the load; (b) side orientation; (c) load trails the hook (dangerous).

Much emphasis has been placed on technique, with the most frequently heard saying being "Lift with your legs, not with your back." Unfortunately, the rule is rather difficult to follow because almost everyone is able to lift a heavier weight with the back than with the legs. Lifting with the legs requires squatting down and then lifting both the load and the lifter's body. This requires a great deal of leg strength for heavy lifts and is especially difficult when the worker is unaccustomed to lifting with the legs. Training and exercise with light loads can help in developing the technique, but there are other disadvantages of lifting with the legs. Chaffin and Park (1974) have shown that if the shape of the load is such that it must be brought out in front of the knees, lifting with the legs *increases* the compression force on the lower back! Also overlooked by the often-quoted rule is the fact that lifting with the legs takes as much as 50% more energy as lifting with the back, especially when the load is light and the frequency of lifting is higher.

The capacity to lift varies greatly with the horizontal position of the load, which is determined largely by the shape of the object being lifted. Various independent studies of this relationship have been analyzed by NIOSH, resulting in a proposed specification for maximum weight lifted versus the horizontal distance of the load from the center of gravity of the body. This specification is summarized in Figure 14.17, but it must be remembered that the graph represents merely a NIOSH recommendation, not an established standard.

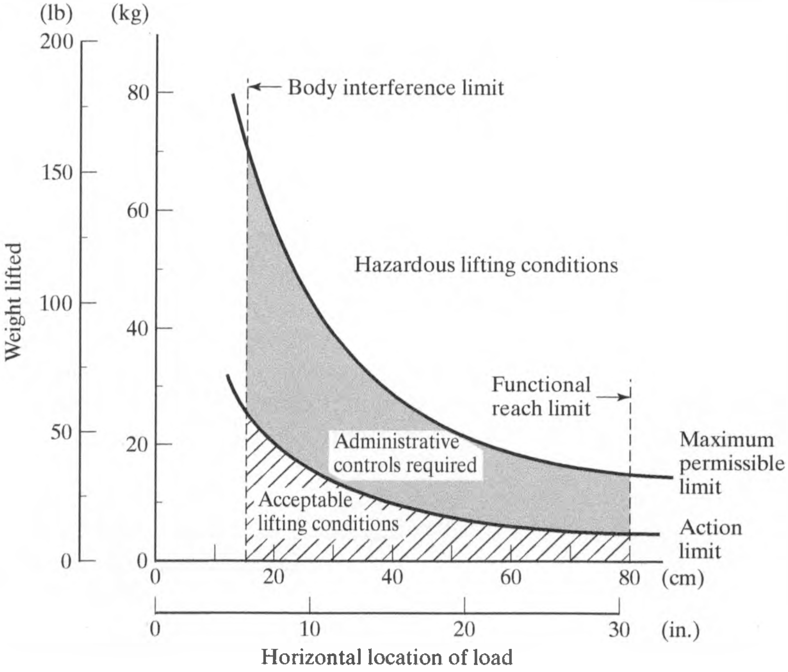


FIGURE 14.17

NIOSH-recommended specification for maximum lift weights at various horizontal distances for infrequent lifts from floor to knuckle height (*Source*: NIOSH-National Institute for Occupational Safety and Health).

## SUMMARY

This chapter has brought recognition to the fact that the handling of material in a manufacturing plant can be as hazardous as the industrial process itself. The basic nature of material-handling hazards were examined; then hazards of specific machines and equipment were discussed.

The safety and health manager needs to be aware not only of the proper safety features to seek in new equipment, but also of the inspection, service, and maintenance of equipment in-house. However, for industrial trucks, cranes, slings, and perhaps *all* material-handling equipment, the operator's skill, attitude, and awareness of hazards are probably more important to the safety of the worker than are the safety features of the equipment itself.

## EXERCISES AND STUDY QUESTIONS

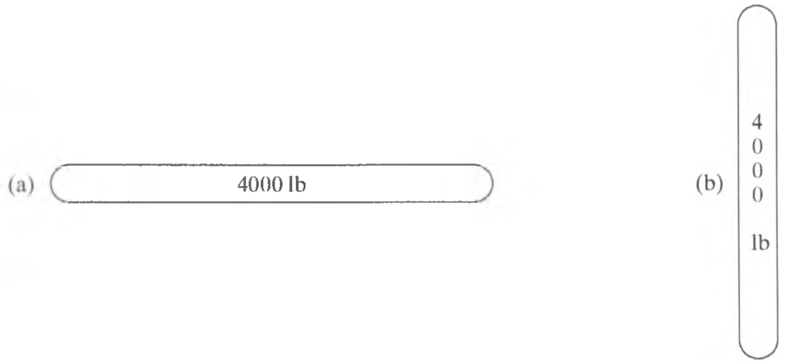
**14.1** Why are four-legged slings rated no higher than three-legged slings?

**14.2** An often-heard safety slogan is "Don't saddle a dead horse!" What does this slogan mean?

**14.3** What *safety* design feature do most modern overhead cranes have that is unfortunately not characteristic of the human back?

**14.4** Name a part of the plant to which the safety and health manager should give special attention when production and sales are booming.

**14.5** In the diagrams, which orientation of the 4000-pound load will place less stress on the sling that handles it? Explain.



**14.6** Suppose that a company was able to save some money by trading in its type LPS forklift truck for a type DY. Would this introduce some safety problems? What if the trade were from DY to LPS?

**14.7** Why might spring push buttons be a better crane control than toggle switches?

**14.8** In Figure 14.18, what is the mechanical advantage? If the nominal breaking strength of the rope is 5000 pounds and the load block weighs 200 pounds, calculate the maximum rated payload of the hoist (not including the load block).

**14.9** What is a rail sweep, and why is it needed?

**14.10** Name in order of preference three methods of protection for in-running nip-point hazards on conveyor belts.

**14.11** Why are overhead crane access ladders specified to be of the fixed type?

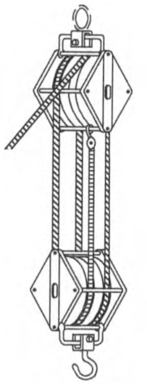


FIGURE 14.18

Blocks and pulleys for Exercise 14.8.

**14.12** Because of rising gasoline costs, a company desires to convert existing gasoline-powered forklifts to LPG powered. What implications would such a decision have?

**14.13** Identify a performance standard in the standards for materials handling. Explain why it is a performance-type standard.

**14.14** Explain the following terms as applied to industrial cranes: *bridge, trolley, pendant, pulpit, gantry*, and *cantilever gantry*.

**14.15** Name at least four characteristics of forklift trucks that require more skill for safe operation than is required for operation of an automobile.

**14.16** At least four general characteristics of materials handling contribute to its intrinsic hazard potential. Name and explain four such characteristics.

**14.17** A 2000-pound payload is supported by the crane block-and-tackle assembly shown in Figure 14.19. In addition to the payload, the load-carrying sheave weighs 100 pounds. Calculate the approximate load on the wire rope. How many parts of rope are used in the reeving, as shown in Figure 14.19?

**14.18** What minimum nominal breaking strength is specified by safety standards to be suitable for the application described in Exercise 14.17?

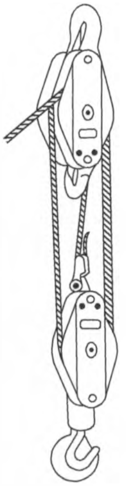


FIGURE 14.19

Blocks and pulleys for Exercise 14.17.

**14.19** Suppose the wire rope in use in the reeving shown in Figure 14.18 is rated at 2000 pounds and the load-carrying block weighs 150 pounds. The objective is to lift a load weighing 3000 pounds. Does the assembly as described meet safety standards?

**14.20** What maximum payload rating would you assign to the block-and-tackle assembly described in Exercise 14.19? What is the nominal breaking strength of the wire rope?

**14.21** A sling with three legs is used to pick up a 1000-pound load. The load is distributed equally among the three legs. When the load is picked up, each leg forms an angle of 30° with the horizontal. Calculate the tensile force on each leg.

**14.22** A three-legged sling distributes its load equally among its three legs. When the load is picked up, each leg forms an angle of 60° with the horizontal. The rated load of the chain used in the sling is 6 tons. Calculate the maximum total load this sling is rated to pick up.

**14.23** From a safety standards aspect, what is the significance of whether a crane trolley rides on top of the rail or hangs from the lower flange?

**14.24** Explain the term *plugging* as it applies to the operation of an overhead bridge crane. Do the OSHA standards prohibit plugging?

**14.25** Explain the difference between a sling and a hoist.

**14.26** Explain the relationship of leg angle to the stress that is placed on a sling.

**14.27** What is the principal hazard of using a sling that is too short?

**14.28** Explain why it is often hazardous to pick up a load by its binding straps.

**14.29** Explain two complicating factors that heighten the hazard of the in-running nip point at a screw conveyor intake.

**14.30** Explain how to design out the risk created by the hazards of the in-running nip point at a screw conveyor intake.

**14.31** Explain why there is a concern for pits in the floor of a factory served by an overhead crane.

**14.32** Compare the rules for judging when to replace wire rope. Are the rules for slings different from the rules for crane rope? If so, for which is the rule more strict? Explain the rationale behind the differences in rules, if any.

**14.33** Rated load is the most obvious, but not the only factor in selection of a sling for a particular lifting task. Identify at least four other factors of importance.

**14.34** Refer to the table in this chapter that compares requirements for various types of slings. The right-hand column of this table refers to requirements to keep records of repairs. For four of the sling types, the column shows "n/a." Why are repair records "not applicable" for these particular types of slings?

**14.35** In the design of belt conveyors, identify the three basic approaches to protecting the worker from in-running nip points. Which of the three is best? Why? Which is the least preferred? Why?

**14.36** What characteristic of overhead conveyors makes them an attractive choice for spray painting operations?

**14.37** Why do overhead conveyors have screens or guards to catch falling loads along some sections of travel, but not others? What sections along the route of travel especially need such protection? Why? Why not simply place guards along the entire route of travel of the conveyor?

**14.38** A particular overhead conveyor employs hooks for suspending the overhead load. Workers hang items on the hook as it passes by overhead. Is it better for the hook to point in the direction of travel or point backward? Why?

**14.39** What type of conveyor has a built-in in-running nip point at the intake?

**14.40** A commonly heard safety slogan is "Lift with your legs, not with your back." Why is this rule often violated?

**14.41** Explain the term "wire rope lay." How does it pertain to safety?

**14.42** Wire rope is not perfectly round; the "diameter" depends on the placement of the caliper used to measure it. Is the correctly gauged diameter the larger or smaller diameter?

**14.43** When calculating the load on a multiple-sheaved wire rope hoist, what additional load must be considered besides the payload?

**14.44** What type of conveyor has a hidden intake?

**14.45** What is an alternate remedy when it is impractical to guard an in-running nip point on a conveyor?

**14.46** What method of protection for a conveyor has the disadvantage of requiring an overt action by the worker?

**14.47** In the application of crane inspections, what intervals are considered "frequent" and which are considered "periodic?"

**14.48** To what hazard is an unsuspecting worker exposed when working near a wire rope lifting device?

**14.49** Why is it not a good idea to use the full length of a lifting rope attached to a rotating drum?

**14.50** On a wire rope conveyor, what can be the advantage of replacing a powerful hoist motor with a smaller one?

**14.51** In a wire-rope hoist,why might a 5000-pound load cause an overload in a rope that is rated to withstand a 5000-pound load?

**14.52** **Design Case Study.** The objective is to design a trolley hoist for an overhead bridge crane that will meet OSHA standards. The hoist must be rated at 10 tons. The hoist will be reeved with wire rope that has a nominal breaking strength of 30,000 pounds. Specify the reeving arrangement, including the number of sheaves on the load block and on the upper block. Include a reasonable estimate of the weight of the load block. Sketch the reeving arrangement showing the relationship between the blocks and the number of parts of rope.

**14.53** **Design Case Study.** You are on the design team for building an overhead bridge crane for use in-house within the company. The design team is considering a proposal to place a switch box on the wall with toggle on/off switches for control of the bridge, trolley, and hoist, respectively. What would be your design input to this committee? Explain the rationale behind your recommendations.

## RESEARCH EXERCISE

**14.54** Research suppliers of overhead conveyors on the Internet.

**14.55** Search for currently available simulation tools to enable a designer to use virtual reality to test various workplace designs to determine whether the human operator at a proposed workstation will exceed NIOSH-recommended lifting limits.