CHAPTER **11**

WALKING AND WORKING SURFACES

The surfaces and devices on which people stand, walk, work, and climb contribute to many accidents, injuries, and deaths. Falls result in 20% of all accidental deaths. Slips and falls are the leading cause of accidents and deaths in the home. A study of California workers' compensation claims found that work surfaces are the most common agent for job-related injuries (21%). Falling objects also cause many on-the-job injuries.[1]

11-1 TRIPPING AND SLIPPING

Tripping

Most everyone has caught the toe of their shoe on a protruding or irregular surface of a floor, carpet, or sidewalk. In tripping, the motion of the foot is interrupted during a step. If the interruption of motion is sufficient, a fall will result.

Hazards Conditions that lead to tripping are irregular surfaces, objects protruding from the floor or walking surface, objects left lying where someone walks, and objects extending into a walking zone from the side and near the floor. Warped floor boards, missing floor tile, uneven tile or brick, carpet edges, loose carpet or rugs, protruding nails and screws, and chipped and cracked concrete are all examples of irregular surfaces or protruding objects. Other common tripping hazards are electrical cords, pipes, boards, and toys.

People do not always monitor the detailed condition of the floor or surface they are walking on. The normal line of sight is approximately 10° to 15° below horizontal relative to the eyes. Most of the time, people do not walk around looking down at their feet. As a result, even small changes in surface elevation are not always seen. Also, if someone is looking down at the surface, irregularities may not be perceived. Studies have shown that color, texture, low light levels, and glare may obscure changes in walking surfaces.

Not all tripping incidents result in falls, and not all falls lead to serious injury. Surrounding conditions contribute to the severity of tripping incidents. On an elevated surface, tripping may lead to a long fall. Even on a flat surface, the fall may be against a protruding object, or one may land in a manner that causes serious injury.

Controls Tripping hazards can be controlled; most often, good housekeeping is all that is needed. Tools, scrap, and waste should be picked up and objects like pipes, lumber, pallets, and file drawers that protrude into the walking zone should be moved out of the

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way. One or two step changes in elevation should be avoided, and the intersection of different floor finishes should be at the same level.

Inspection and maintenance can help remove tripping hazards. Protruding nails and screws should be removed or set even with the floor surface. Damaged tile, floor boards, or carpet should be repaired. Curled or wrinkled mats or flooring should be removed and electrical cords or similar objects that extend across walking zones should be recessed. (When there are temporary runs of electrical or communication cables across a walking zone, the cords should be taped down to minimize tripping hazards or should be routed overhead.)

Changes in elevation often are hard to see, but they can be made more visible by making different levels different colors. Avoid textured patterns that tend to hide changes in elevation. Changing levels should be well lit and warning signs should be posted at locations where there are tripping hazards. Direct or reflected glare that can interfere with the ability to see changes should be avoided.

Slipping

A slip is the sliding of one or both feet on a surface, and if it is unexpected, it can lead to a fall. Even without a fall, a slip can cause strains to muscles and joints. In a fall resulting from a slip, the feet slide out from under the body, producing an unstable condition. People expect to encounter a certain resistance between the floor and their shoes or feet and if that resistance is not there or it changes suddenly, a slip will probably result. A slip occurs when the lateral force applied at the foot–surface interface is greater than the frictional resistance available. Although this principle seems simple, it is complicated by continually changing forces during walking. To a great extent, the possible resistance is a function of the combination of shoe and flooring materials at their interface. Activity and gait or walking style affect the force created by the body. The resistance may be altered by wet, dry, or oily surface conditions, the presence of foreign material, and the roughness or polish of interface materials. Differences between static and dynamic friction coefficients further complicate the resistance possible.

It is difficult to predict when a slip will occur. However, activities like pushing, pulling, accelerating, turning corners, and throwing will produce higher horizontal forces at the foot–surface interface than normal walking. Horizontal forces increase as the angle formed by the leg with vertical increases. When people know that a surface is slippery, they will walk with a short stride to prevent slipping. Sloped surfaces add to horizontal forces and may increase the likelihood of slipping.

Measurement of Floor and Shoe Slipperiness There are a number of methods for measuring floor slipperiness. Typically, each produces a reading on a scale from 0 to 1.

Different devices produce different resulting values. One type, a slip meter, is a small instrument that is pulled along the floor. A dial gives a reading of force created by the device on the string used to pull it. There are several patented slip meters, such as the horizontal pull slipmeter (HPS).[2]

Another type of slipperiness testing device is a swinging pendulum. It gives a reading of drag as a shoe at the end of the swinging pendulum slides for a short time across a surface. The British pendulum tester uses the pendulum principle.[3]

A third type of slipperiness measuring device is an articulating arm device. It is usually a bench-top instrument that places a load on prepared samples of shoe material and floor material. A static load starts directly over the sample. A hinged bar holds the load above the material sample at the other end. The machine moves the load slowly to one side of vertical. The bar begins to form an angle from vertical. The angle of offset is increased until the shoe sample pad slides against the floor sample. Two machines of this type are the James machine[4] and the NBS-Brungraber slip-resistance tester.[5] There is a portable version of the NBS-Brungraber slip-resistance tester.

A more recent device is the English XL Variable Incidence Tribometer (VIT).[6] It is designed to provide reliable testing for wet surfaces.

Some measurement standards suggest that a criterion of 0.5 defines whether a shoe and flooring combination is safe. Higher values are defined as slip resistant; lower values are slippery. However, it is difficult to relate a reading from one of these instruments to a qualitative description of slippery or safe. It is also difficult to relate test values to actual conditions or to predict when someone will slip. For example, a real floor may have wax buildup, small amounts of sand, mud, water, oil, or other material present or may be highly polished. Such conditions are difficult to incorporate into test procedures, and specially prepared test specimens may not replicate actual shoe–floor conditions. Test data provide valuable information for design and for material and finish selection but may not determine why a slip occurred or predict accurately when a slip will occur.

Hazards One hazard related to slips is having a combination of shoe and floor materials and finishes that may cause slipping. Polished shoe and floor materials are more likely to be slippery than rough ones. Repeated mopping of some floor materials may increase slipperiness. The pores of the flooring material that originally were slip-resistant become filled with oily material after the substances dissolved by detergent water dry.

Another hazard is a sudden change in floor conditions. For example, when one moves from a dry surface to one that is wet, muddy, icy or oily there is an increased chance for slipping unless one adjusts the style of walking and movement. A sloped surface can add to a slip hazard.

A rapid change from a low slip resistance surface (slippery) to a high one (not slippery) can be hazardous. In this situation, people may stumble, rather than slip. In a stumbling fall, the body moves faster than the feet to an unstable condition. Some standards require surfaces to have consistent slip resistance.

An additional hazard is the risk associated with a fall resulting from a slip. For example, surfaces with a potential for a fall from an elevated surface to one below may require a higher degree of slip resistance than for those potentially having a fall to the same surface.

Controls One control for preventing slips is housekeeping. As much as possible, walking and working surfaces must be kept free of foreign materials that can result in slipping. Water, mud, snow, ice, oil, grease, loose materials, scrap, and waste must be wiped up or picked up. In some cases, oversprays and foreign material can be prevented from getting on surfaces where people will walk and stand.

In areas where wet processes are expected, surfaces should be well drained to minimize standing liquid. In certain situations, raised floor surfaces may be an option so that workers do not have to stand in accumulated wet, oily, or scrap material. As a temporary solution, absorbent materials may be used to clean up spilled oils.

Where a change in surface conditions occurs, warnings should be provided. For example during mopping activities, workers should mark areas being mopped with warning signs. Procedures like mopping half the width of a hall at a time may help so that people do not have to walk through a wet area. At locations where ice, snow, or water are tracked in, warnings can help. Mats and rugs also can help reduce hazards for such conditions by providing a transition zone and by reducing tracking of foreign materials.

However, protective runners that become slippery when they are wet should be avoided. If there is heavy tracking, cleanup is essential.

Another control is selection of shoe and surface materials and floor finishes. Employers should help employees select appropriate footwear for their jobs. Purchasers should avoid shoe materials that are slippery when dry or wet. There is a wide range of flooring materials that designers can select from. Many manufacturers have slip test data for their flooring and surface products and technical references contain representative data on slipperiness properties of various materials. Designers should avoid sudden changes in slip-resistance properties in flooring, stairs, and other walking and working surfaces.

Selection, application, and maintenance of surface treatments and finishes also are important. Many manufacturers and suppliers have test data on floor finish products, and independent testing and evaluation of samples may be worthwhile before final selection. To lessen slipperiness, abrasive strips can be placed in strategic places, such as on stair nosing or wet areas, or fine silica sand can be mixed with flooring paints. Waxes and other finish materials must be applied and maintained properly because they have slip properties that can be affected by maintenance procedures. For example, excessive buildup of finish material or excessive buffing can alter slip properties from those obtained in test conditions. Locations where slip hazards are high may need different materials and finishes than other locations.

11-2 FALLS

Falls often cause injury. They may result from slipping, tripping, or stumbling and they include falling from one surface to another or on the same surface where standing or walking occurs. Falling objects that may strike people or things below are also included in this category.

Physics

In a moment of humor people say, "Its not the fall that is so bad, it's the sudden stop when you hit the ground." One must understand the physics of falls to understand the potential severity of a potential fall and associated impact and the hazard reduction resulting from controls. Three important aspects of falls are (1) the displacement and motion of a body, (2) the impact, and (3) the ability to withstand impact.

Displacement and Motion One characteristic of a fall is how far a body moves vertically during the fall. Knowing the distance that an object falls, s, allows computation of the velocity, v, at any point in the fall:

$$v = (v_o^2 + 2gs)^{1/2}, \tag{11-1}$$

where

v_o is the initial velocity and

g is the acceleration of gravity.

If the weight of a body, W, is known, one can compute the kinetic energy at the point where the body reaches a velocity, v:

$$KE = \frac{mv^2}{2} = \frac{Wv^2}{2g} \tag{11-2}$$

One can estimate the KE at any point in a fall by combining Equations 11-1 and 11-2.

Impact When one body strikes another, the two bodies absorb much or all of the stored energy. Much of the energy is absorbed by the deformation of the two bodies. The energy in deformation may not be distributed equally between the two bodies. The energy not absorbed by deformation is transferred into motion of the bodies. Very often a falling object strikes the earth, a floor, or other structure that does not deform or deforms very little.

The injuries that result from a fall of a person onto a surface are, in part, a function of the rate of deceleration. From an estimate of the stopping distance (the distance the center of mass moves after initial impact), one can determine the rate of deceleration, a:

$$a = V^2/2s, \tag{11-3}$$

where

V is the velocity at the point of impact and

s is the stopping distance.

Some surfaces are hard or massive and deflect very little.

Often the rate of deceleration is compared with the acceleration of gravity, G. The number of Gs is determined from

$$G = \frac{V^2}{2gs} = \frac{a}{g} \tag{11-4}$$

Another important factor affecting the severity of injury is A, the contact area between two impacting bodies. If the force of a falling object striking a body is distributed over a large area, the severity of injury will be less than if the same force were applied to a small area. For example, a pointed object or sharp edge is more likely to cause injury than a flat object or rounded edge. In general, a similar relationship exists for a person landing following a fall. The force of impact F_i is

$$F_i = \frac{Wa}{g}. \tag{11-5}$$

This force must be resisted by the material, which may be human tissue, to which the force applies. The ability of the material to withstand the impact force can be determined from

$$F = sA, \tag{11-6}$$

where

s is the stress in the material and

A is the area over which the force is applied.

One must compare the induced stress with the tensile, compression, shear, or bending stress the material can withstand.

Injury to tissues other than those receiving the initial impact occur because the force of impact is transferred to other elements of the body, such as muscles, ligaments, bones, and joints.

Impact Limits of the Human Body

Data about the strength properties of human tissue and structure, often from cadaver or animal studies, can be used to estimate the likelihood of injury or severe injury in some situations. The data may be helpful in reconstructing certain accidents. However, because the body and actual conditions of an accident are complex, it is difficult to describe analytically what happened and what caused the resulting injuries. Figure 11-1 provides some data about human tolerance to impacts.

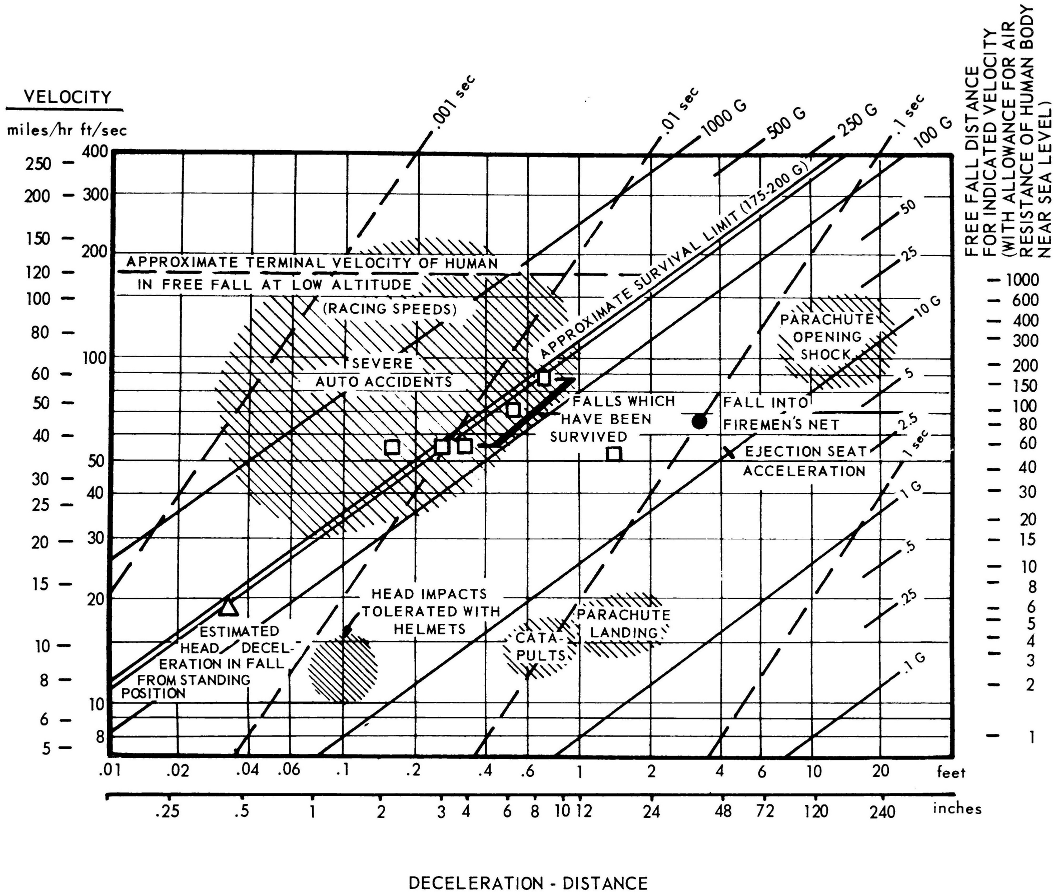

Figure 11-1. The effects of human impacts from falls. (From Webb, P., *Bioastronautics Data Book*, NASA SP3006, Washington, DC, 1964.)

11-3 PREVENTING FALLS AND INJURIES

There are four objectives in fall protection: (1) prevent people from falling, (2) prevent objects from falling, (3) reduce energy levels if falls do occur, and (4) reduce injury at impact. The latter two are not needed if the first two are met. In the following, these objectives are discussed, and they are summarized in Table 11-1.

Preventing People from Falling

Remove Slipping and Tripping Hazards Controls for slipping and tripping hazards were discussed in the preceding text and apply to any surface where people may be present.

Warnings and Barriers Particularly where there are changes in level between surfaces, warnings and barriers are needed. A barrier is a restraint that prevents a fall from an upper to a lower level. It must withstand the force of people running into it, leaning on it, or sometimes standing on it. Common barriers are guardrails, covers over openings, and cages on fixed ladders. OSHA requires that these devices withstand a load of 200 lb at any

TABLE 11-1 Summary of Fall Protection Methods

Objective	Method
A. Prevent falls of people	1. Remove tripping and slipping hazards
	2. Protect edges and openings
	a. Provide barriers (guardrails, covers, cage, etc.)
	b. Proved visual and auditory warnings
	3. Provide grab bars, handrails, and handholds
	4. Provide fall-limiting equipment
B. Prevent objects from falling on people	1. Housekeeping (remove objects that could fall)
	2. Barrier (toe boards, guardrail, infill, covers, etc.)
	3. Proper stacking and placement
	4. Fall zone
	5. Overhead protection
C. Reduce energy levels	1. Reduce fall distances
	2. Reduce weight of falling objects
	3. Control fall deceleration
D. Reduce injuries from falls and impact	1. Increase area of impact force
	2. Increase energy absorption distance

point, but because the weight of many people exceeds this, higher design loads may apply. Designs for covers should not introduce tripping hazards.

Covers over openings should be attached rather than be unsecured or, if they are temporary, should have warnings on them to indicate their purpose. It is not uncommon to have a sheet of plywood covering an opening in a roof or floor during construction. It is also not unusual to have two people pick up the plywood sheet to remove it and have the person carrying the rear of the sheet fall through the opening.

Most warning devices do not fully restrain someone. A barricade placed around a temporary excavation and a rope placed around the perimeter of elevated floors during building construction are warning devices. Flags and bright colors make warnings easier to see, and visual and auditory signals, such as flashing lights and beepers, help people recognize warning devices.

The Standard Guardrail A commonly specified barrier is the standard guardrail, illustrated in Figure 11-2. It is comprised of vertical supports, which are typically 10 ft or less apart, and three horizontal components: the top rail, middle rail, and toe board. Infill between these components is important, too.

The function of the top rail is to prevent someone from falling. The height of a top rail is related to its effectiveness. It should be at least 42 in from a floor; a shorter dimension will protect fewer people. OSHA requires a 42-in height.[7]

Consider the mechanics of someone falling or leaning against a horizontal rail. We know that the center of gravity for a human body is approximately 3 in above the midpoint of one's height. If the center of gravity acts above the rail, a person falling against the rail would rotate over the top of the rail; if it acts below the rail, a body would rotate under the rail. For a person 6 ft tall, the center of gravity acts at a height of approximately 39 in. Therefore, if 99% of the population is less than 6 ft 6 in tall, a 42-in high top rail will prevent rotation over the rail for all but very few people.

The middle rail will keep someone from falling when their body rotates under the top rail. As a precaution for children, infill may be needed.

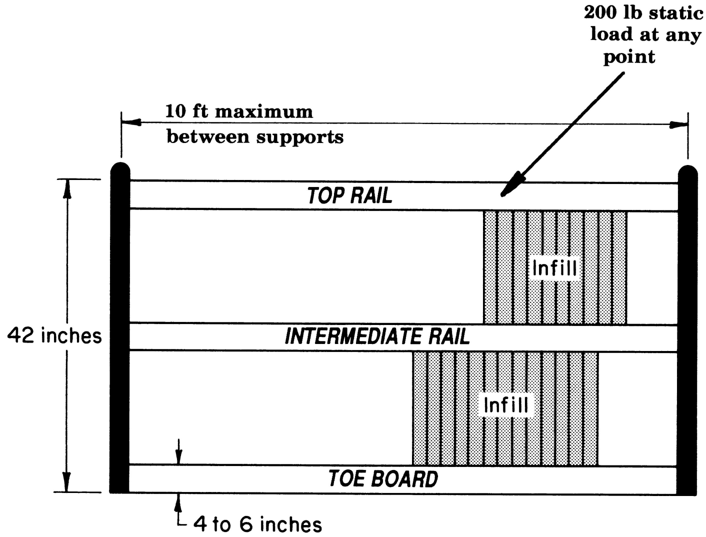

Figure 11-2. Features of the standard guardrail.

A toe board is normally a 4- to 6-in high barrier along the walking surface. Its has two purposes: to prevent someone from placing their foot over the edge of an elevated surface and to prevent objects from sliding or rolling over the edge onto someone below.

Infill also prevents objects from falling from an elevated surface. The size of objects that could fall between the rails and toe board determines the size of the opening in infill material. For architectural handrails, the space between balusters should be small enough to prevent children from falling through the openings or getting their heads caught.

Handholds When people move up or down between two different levels, it is important to provide a capability for three-point support, which means having two hands and one foot or two feet and one hand supported. Steps or ladder rungs provide support points for the feet and grab bars; handrails and handholds provide support for the hands. There are times during climbing activity when a foot or hand must be repositioned to a new support. Should the foot in contact slip, the only way to prevent a fall is with a firm grip with the hands. Handholds must be available at all points of climbing until a person is standing firmly with both feet on the new upper or lower level. There should be enough space in handholds or behind handrails and grab bars for fingers, even when wearing gloves. The cross-sectional shape should permit near maximum grip strength, which occurs when the fingers are well curled, and the grab bars should be able to carry a person's weight. The Department of Transportation has specifications for access to the rear of trucks and truck trailers.[8] Several OSHA regulations address grab bars and handholds.[9]

An important design consideration for handholds, particularly those that extend along lengths of ladders or stairs, is a touch indicator at the end. For people hanging on, but focusing their attention on something other than where they place their hand, some cue, such as change in texture or shape, would warn them that they are at the end of the handhold.

Other Barriers Designs should include barriers where falls may occur. For example, in multistory buildings, people sometimes fall out of windows. Architectural components, like windows and skylights, can be dangerous openings or adequate barriers. The size of the opening, its placement, and the strength of its frame and infill all determine whether such elements are adequate barriers against falls. Openings in doors and walls should be placed properly to prevent falls through them or should be protected with adequate guard rails, covers, or screens. A retaining wall that holds back soil in a landscaped setting should be away from walkways and stairs to discourage people from getting near the edge. Railings and shrubs are also effective. Even Moses recognized the need for barriers: "When you build a new house, you shall make a parapet for your roof, that you may not bring the guilt of blood upon your house, if anyone fall from it."[10]

Fall-Limiting Devices If a fall does occur, intercepting it can prevent injuries. There are several kinds of patented fall-limiting devices, some of which attach to fixed ladders or to other climbing and elevated work equipment. A person using a fall-limiting device wears a harness that attaches to the device with a connection, normally a short, fixed-length rope, called a lanyard. The lanyard connects to the harness through a D-ring. The short length minimizes fall distance and deceleration forces that result from stopping the fall. The longer the fall, the greater the chances of injury when the rope becomes fully extended and the body stops quickly. A supporting rope, called a lifeline, must attach with a minimum of slack to an independent support, not to scaffolding or other equipment. Some patented devices are available that connect a lanyard to the life-line and will control the rate of deceleration in a fall so that injury is less likely. A user must position some devices along the life-line, whereas others move freely, but lock automatically during a fall.

The goal in fall arresting equipment is to minimize the force imposed on a falling person when the fall limit is reached. OSHA requires all safety belt and lanyard hardware to withstand a tensile load of 4,000 lb and requires the anchor and lifeline to withstand 5,400 lb. Body belts are seldom used for fall protection because they can cause injury when the fall is arrested and someone can slip out of them, particularly if the body belt does not fit well. A full harness is highly preferred, because it distributes the arresting load and is not likely to separate from the user if properly attached. Requirements for full harnesses and other components of fall arresting systems appear in ANSI Z359.1.

An empirical formula for estimating the maximum arrest force,[11] *MAF*, is

$$MAF = \frac{\left(W + 1.45(kfW)^{1/2}\right)abs}{c}, \tag{11-7}$$

where

W is the weight of the falling person,

f is a fall factor ($0.1 \le f \le 2.0$) = h/L (h is the fall distance in feet permitted by the lanyard, L = total lanyard length in feet),

k is the rope modulus (pound-force; see Figure 11-3),

a is the factor from Table 11-2,

b is the factor from Table 11-3,

s is the factor from Table 11-4, and

c is the conversion factor (see Figure 11-4).

Equation 11-7, which assumes a rigid anchorage point, was tested for accuracy by the developer and shown to produce results within ±5% of actual test values. This formula permits one to analyze work situations by showing that arresting forces are significantly reduced by the use of shock-absorbing mechanisms. In actuality, however, reduction varies with the kind of shock-absorbing device used and the arresting force is lower than that calculated when the anchor point is not rigid, but has some deflection. Also, the fall

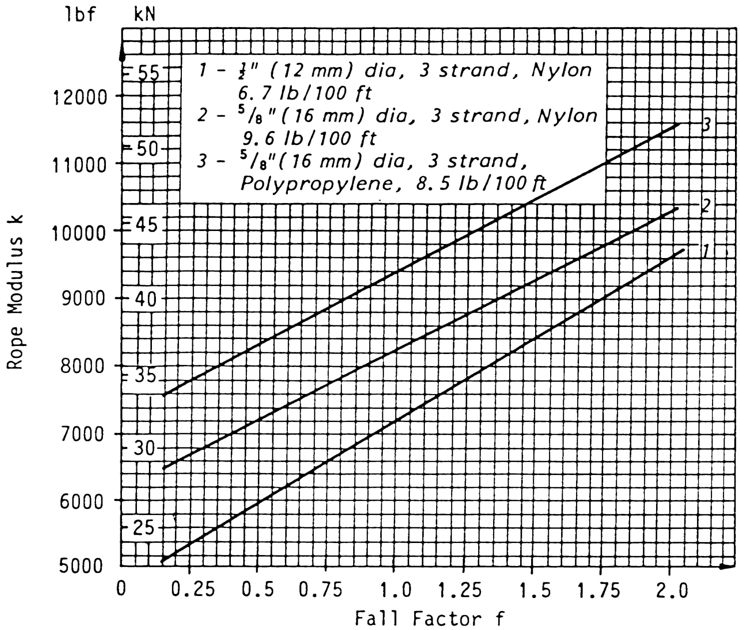

Figure 11-3. Rope modulus (k) versus fall factor (f). (Reprinted with permission from the April 1981 issue of the *National Safety News*, a publication of the National Safety Council. Note: Although the information and recommendations contained in this publication have been compiled from sources believed to be reliable, the National Safety Council makes no guarantee as to and assumes no responsibility for the correctness, sufficiency, or completeness of such information or recommendations. Other or additional safety measures may be required under particular circumstances.)

TABLE 11-2 Fall Arrester Reduction Factor

Type of Fall Arrester	*a* Range	*a* Recommended[a]	Comments
Inertia type, wire rope	0.5–0.7	0.7	for $0 < f < 2$
Inertia type, synthetic	0.75–0.9	0.9	for $0 < f < 2$
Friction type	0.5–0.75	0.7	for $0 < f < 2$
Mechanical lever	0.9–1.0	1.0	for $0 < f < 2$
No fall arrester used in fall arrest system	N/A	1.0	

[a] Recommended when exact value of fall arrester reduction factor, *a*, is not available.

TABLE 11-3 Body Gripping Device Reduction Factor

Belt or Harness	*b* Range	*b* Recommended[a]	Comments
Belt (nylon, 2 in wide)	0.8–0.9	0.9	for $0 < f < 2$
Harness (full body, parachute style)	0.5–0.8	0.8	for $0 < f < 2$
No belt or harness	N/A	1.0	

[a] Recommended when exact value of fall arrester reduction factor, *a*, is not available.

TABLE 11-4 Shock Absorber Factor

	s		
Type of Shock Absorber	Range	Recommended[a]	Comments
Tear-the-stitches (TS)	0.2–0.6	0.6	for $0.1 < f < 2$
Tear-the-fabric (TF)	0.3–0.7	0.7	for $0.5 < f < 2$ (synthetic lifeline)
Tear-the-fabric (TF)	0.2–0.6	0.6	for $0.2 < f < 2$ (5/16-in diameter wire rope)
No shock absorber used N/A		1.0	

[a] Recommended when exact value of fall arrester reduction factor, *a*, is not available.

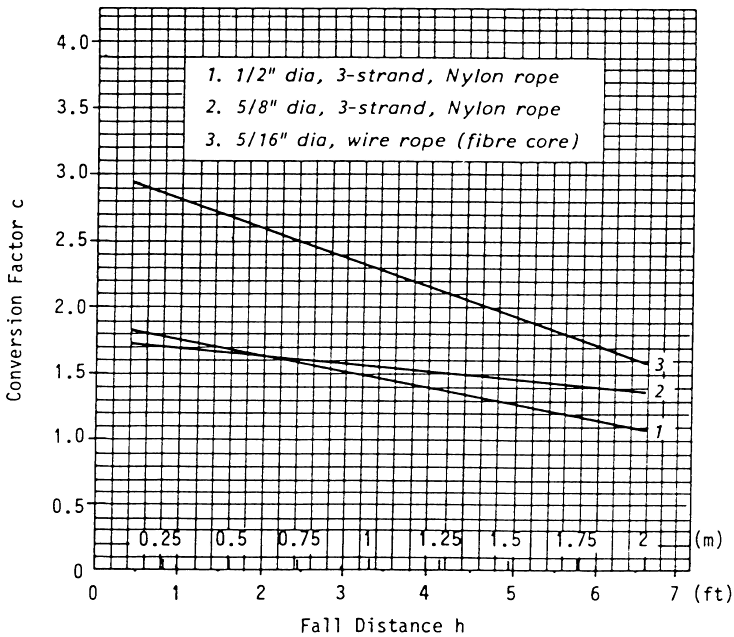

Figure 11-4. Conversion factor (*c*) versus fall distance (*h*). (Reprinted with permission from the April 1981 issue of the *National Safety News*, a publication of the National Safety Council. Note: Although the information and recommendations contained in this publication have been compiled from sources believed to be reliable, the National Safety Council makes no guarantee as to and assumes no responsibility for the correctness, sufficiency, or completeness of such information or recommendations. Other or additional safety measures may be required under particular circumstances.)

distance does not include any clearance required for elongation of the fall arrest system (see Table 11-5) or the extension of the arms or legs of a supported person.

Safety Nets Where other fall protection is impractical, such as construction of bridges, towers, and other structures, safety nets can stop a worker's fall. The nets and anchorages must meet standards and pass tests. OSHA requires a minimum breaking strength of 5,000 lb. Nets are placed to minimize the fall distance. Again, the longer the fall, the greater the likelihood of injury. A net intended for stopping a falling person is a personnel net and one intended for stopping falling materials is a debris net. Debris nets must be strong enough to stop the size and weight of objects that could fall. Their mesh may be as small

TABLE 11-5 Approximate Additional Elongation of Fall Arrest System Resulting from Shock Absorber (ft)

Type of Shock Absorber	Starting Force (lb)	Additional Elongation (ft)
Tear-the-stitches	550	3.6
Tear-the-fabric	1,000	2.9

as $^{1}/_{4}$ in, whereas the maximum mesh for a personnel net is 6 in. A safety net may serve both purposes. Clearing debris regularly from the net will prevent it from injuring a falling worker.

Catch Platforms Catch platforms, which are normally 2 ft wide, are placed at the edge of a sloped roof to prevent someone who slides down the roof from falling to the ground. They may not be necessary if workers use lifelines.

Preventing Objects from Falling

Housekeeping If objects such as tools, waste, and other items are left lying around on an elevated surface, there is a chance that they will fall onto the surface below. Overflowing trash containers create the same hazard.

Standard Guardrail As previously explained, the standard guardrail has a toe board and sometimes infill to prevent objects from falling to lower levels.

Fall Zone A fall zone is a fenced or guarded area where people at lower levels cannot enter so that falling debris will not strike them. The guarding consists of overhead and side protection of the occupied area. The protecting material must have enough strength to provide protection for the size and weight of objects that could fall. Side protection protects occupants from splattering or scattering material.

Overhead Protection In some operations, materials travel above areas where people are. Elevated conveyors and parts lines in assembly operations are common examples. Overhead protection can prevent materials from falling on those below. From time to time, fallen materials must be removed from the overhead screen or barrier, so the barrier must be strong enough to support workers during the removal activities.

Covers Pipes, ducts, conveyors, and other equipment pass through holes in floors and walls. The holes may be oversized for installation and maintenance activities. Openings should be covered to prevent someone from falling through them or items from falling on anyone below. When covers are not in place, other forms of protection may be needed.

Stacking and Storage Proper stacking and storage of materials can prevent objects from falling. Keeping stored items away from openings and not stacking them above barriers will help. Adequate work space and traffic aisles are needed to minimize the danger of running into stacked items. Impact barriers for material handling equipment can reduce the danger of knocking stacked materials over and damaging storage racks. For many kinds of stacked materials, stepping the materials back with each higher tear increases stability of the stacked materials. Cross ties also may be necessary to improve stability. Other storage requirements for fire protection purposes are discussed in Chapter 16.

Reducing Energy Levels

In some cases, one can control energy in a falling body or a body that could fall. One method is minimizing the vertical distance. The other is minimizing the weight of elevated objects.

Reducing Injuries

Cushion the Impact Preventing falls is always the primary objective. However, a variety of things can be done to prevent injury when people do fall. One is increasing the stopping distance. Padding can help. In sports facilities, pads are applied to walls, poles, and other vertical surfaces. In some sports, like gymnastics, floors surfaces are padded. In motor vehicles, the dash, visors, and other interior surfaces are padded with energy-absorbing materials. For building fires, one type of rescue device is a large inflated cube that people can leap to. Fall-arresting devices cushion the impact and extend the distance over which deceleration occurs.

Distribute the Forces If forces of impact are distributed over a larger area, the likelihood of injury is reduced. Pads and cushions not only extend the stopping distance, but distribute the forces over a larger area. The function of a suspension system inside a hard hat or helmet is to distribute the impact force over a larger area. Knee pads for flooring installers serve this same function. Knobs and controls that one can strike can be flat or recessed to enlarge the impact area. Protruding elements on toys made from deformable materials help distribute loads if a child falls on them. A safety harness usually will distribute the force of a fall over a larger area than a life belt.

11-4 APPLICATIONS

There are many kinds of walking and working surfaces and equipment involved with them. The principles discussed in the preceding text apply to them. This section looks at a number of them in more detail.

Stairs

Stairs are the most common device for helping people move from one elevation to another. Normally built on structural supports called stringers, the main components of stairs are the treads (the surfaces stepped on) and the risers (the vertical faces between the treads). Most treads extend beyond the face of the risers; this leading edge is called the nosing. As early as the ancient Egyptians,[12] some stair standards existed. Currently, there are a number of standards for stair design that can be found in OSHA regulations, building codes, life safety codes, books on carpentry, and other sources.

There are a number of factors that affect stair safety. They include uniformity of dimensions, slip-resistant treads, overall slope, visibility, structural strength, width, tread depth, placement, and other features.

Uniformity Stairs should have uniform dimensions for all steps in a flight. A person walking up or down a set of stairs intuitively establishes a measure of what the stair dimensions are and expects the dimensions found in the first step to occur for the others. A sudden change in dimension can cause stumbling similar to when a person misjudges the number of steps.

Slip Resistance Stair treads must have the same slip-resistance characteristics that floors do. When people walk on stairs, they expect the resistance to be the same or very similar to adjacent surfaces. Sudden changes may cause slipping or stumbling.

Slope The slope of a stairs is the ratio of riser height to tread depth. The preferred slope for stairs is approximately 30° to 35° from horizontal, although standards differ on actual values, and slopes may fall between 20° and 50°. Tread and riser dimensions should be easy to establish with a tape or rule. Otherwise, it is difficult to lay them out or buy them. Table 11-6 lists some combinations of tread and riser dimensions that result in slopes between 30° and 40°. The Life Safety Code (NFPA 101) limits riser heights to 7 in, minimum height to 4 in, and minimum tread depth to 11 in.

Visibility Visibility on stairs is very important. It includes having enough light to see steps easily and avoiding glare that obscures the ability to see steps. For example, a window or door placed at the base of a stairs can create glare that makes it difficult to see steps. When one enters a building from bright outdoor conditions, minimum lighting levels for stairs (often 1 to 5 footcandles) are inadequate because the eyes do not have time to adjust to low light levels. Visibility also includes clear definition of tread nosing and avoidance of surface finishes and textures that make one step blend in with another.

Structure Stairs must be able to carry an anticipated load. Standards for stairs include minimum load capacity. OSHA requires a stairs to carry five times the normal live load and not less than a moving concentrated load of 1,000 lbs. In fire exiting, one often plans exit stairs to carry the maximum concentration of people for which there is space.

TABLE 11-6 Some Acceptable Combinations of Stair Riser and Tread Dimension[a]

Angle to Horizontal	Riser (in)	Tread Depth (in)
30°35′	6 1/2	11
32°08′	6 3/4	10 3/4
33°41′	7	10 1/2
35°16′	7 1/4	10 1/4
36°52′	7 1/2	10
38°29′	7 3/4	9 3/4
40°08′	8	9 1/2
41°44′	8 1/4	9 1/4
43°22′	8 1/2	9
45°00′	8 3/4	8 3/4
46°38′	9	8 1/2
48°16′	9 1/4	8 1/4
49°54′	9 1/2	8

[a] 29 CFR 1910.24 (e).

Width Life safety codes define stair widths for exiting during fires. NFPA 101 generally requires stairs to be at least 44 in wide, unless there are fewer than 50 occupants at all stories served by the stairs, which can then be at least 36 in wide. Chapter 16 gives more information on life safety for exits, including stairs, doorways, and corridors.

Distractions One study[13] filmed people walking down stairs. The study found that the people who stumbled or fell usually did so at the same location on the stairs, even though there were no changes in the physical characteristics of the stairs. The conclusion was that as their heads moved below the floor opening, the people were distracted by the sudden view of the large room. Many retailers have experienced similar effects when displays or pictures are placed on landings or in view of people using stairs. Enclosing a stairs or otherwise preventing such a visual distraction can help minimize this problem.

Other Features The number of steps included in a staircase can create hazards. A one- or two-step change often is not seen and causes people to fall. Consequently, for small changes in elevation, ramps are better than steps. Because climbing stairs is hard work and too many steps can be tiring, multistoried buildings and long flights of stairs should have landings to give people a chance to recover.

The base of a stairway should be free of hazards. For example, if someone fell down a stairs into a glass wall or door, a severe injury could result. The base of a stairway also should be free of objects that could cause injury. An example of this is people who use stairs for storage because they do not want to carry items all the way up or down. Stairs should be free of waste, like paper or other objects, that can create tripping or slipping hazards.

Stairs must have handrails that will support a person's weight. Handrails provide at least two-point support during ascending or descending activities. Handrail cross sections should be easy to grasp and should be placed according to life safety codes and other standard specifications. In addition to handrails along the sides of stairs, wide stairs should have one or more handrails located at intermediate locations across the width of the stairs.

Ramps

Ramps have a hazard related to their slope because a force component runs parallel to their surface and could contribute to slipping. To minimize slipping, ramps must have a limited slope and a slip-resistant finish. The preferred angle for a ramp is 15° or less; the maximum for access by the handicapped is 11°. The Life Safety Code (NFPA 101) limits ramps to a 1 in 12 slope. For slopes of more than 15°, cleats are needed to help provide traction. Ramps may have one or both sides open to the lower level. Unless protected by guardrails, someone could fall from such ramps. Handrails are needed to assist those negotiating them. Long ramps need landings similar to long stair runs.

Dock Plates and Gangplanks

Dock plates and gangplanks bridge gaps between a platform or surface and a vehicle or ship. They often serve both pedestrian traffic and material-handling vehicles. Major hazards for dock plates and gangplanks are structural failure, sliding out of position, falling off supporting edges, and difficulty in placing them into position. Slipping and tripping hazards and controls previously discussed also apply.

To reduce the possibility of structural failure, dock plates and gangplanks must carry anticipated loads, and they should be labeled to show load capacity. They should be inspected regularly for defects or failures and they should be repaired or replaced when defective or damaged.

To help prevent vehicles from running off their edge, dock plates should have a curb or lip along their sides. Dock plates often are made from lightweight materials, like aluminum or magnesium, to make them easier to handle; some even have handholds. Some have features that facilitate material-handling equipment or forklift trucks. Some dock plates are integral parts of loading platforms and are equipped with powered devices to adjust them to different positions without manual lifting.

Dock plates will slide if they are not locked into position. Some of the devices for locking them into position are stop pins, cleats, or built-in flanges and blocks. Anchoring methods should not create tripping hazards.

Ladders

Types There are many types of ladders. They are classified by material of construction (wood, metal), load capacity, function, and design. Some ladders are classified as type I, II, or III, depending on the standard loads (200, 225, and 250 lb) used for certain tests. Most ladders are manufactured and sold for use. However, ladders called job-made ladders are made on job sites. Ladders can be portable or fixed in place. Common types of portable ladders are step, platform, straight, and extension ladders. Some ladders, such as those on truck trailers, have custom designs to fit around other design elements. There are many standards for ladder construction.

Hazards and Controls Ladder rungs or steps must have slip resistance to prevent slips and falls. Especially for ladders used around wet, oily, and muddy conditions, rungs or steps must have side protection, so a foot cannot slip sideways and off them. There must be enough space between a rung and a wall behind it so the arch of the foot, not just the toes, can fit on the rung. Flat rungs or steps should be very near horizontal when the ladder is in position for use. If not, they create sliding forces parallel to the surfaces.

Ladders must withstand reasonable forces applied to them without collapsing or having other structural failures. Inspections will help locate defects and ensure integrity. Defective ladders should be repaired or thrown away. Misuse and improper use can create structural failure. For example, an extension ladder must have a minimum amount of overlap between sections. If not, the bending load at the connection will cause failure. The exact amount depends on the ladder length.

Ladders can tip over sideways, tip over backwards, or slip out at the bottom, depending on ladder type. If the user of a straight or extension ladder leans out to reach something and the resultant force for the ladder and occupant falls outside the support area, the ladder will tip over. An outrigger attachment at the top will reduce this hazard. Anchoring or tying a ladder to a support structure will also prevent sliding. All ladders should rest on a solid base because on soft soil the feet may sink in, causing tipping.

Step or platform ladders may collapse or tip if the spreaders are not fully opened and locked. A load on the ladder may cause it to "walk," twist, and close up when spreaders are not fully extended and locked.

As one climbs up a ladder, the center of mass goes higher. The higher the center of mass, the easier it is to tip a ladder over. Generally, users should never stand on upper rungs or steps, although the type and length of ladder determines which rungs should not be used.

Proper positioning will prevent straight or extension ladders from tipping over backward. The preferred angle is 75° from horizontal. A rule of thumb is to place the feet of these ladders so that the horizontal distance from the support point at the top to the ladder feet is one quarter of the working length of the ladder. If the angle formed by the base with vertical is too large, these ladders will slide out at the bottom. To prevent sliding, the top should be tied off and the bottom restrained. Special feet are available on some ladders to reduce the chances of sliding.

When a straight or extension ladder provides a route to a higher work surface, the top of the ladder should extend 3 ft above the upper surface. This provides a handhold when getting on or off the ladder.

Metal ladders can conduct electricity. Therefore, they should not be used around electrical conductors or equipment.

Inspect ladders regularly and before use for cracks, wear, sway, breaks, bends, and other kinds of damage. Examine extension locks, bolts, fasteners, and feet for defects or looseness. Remove defective ladders from service until they are properly repaired. Unrepairable ladders should be destroyed and replaced.

People must learn how to use ladders correctly. They need to know how to select them for the job, place them, carry them, and store them. Ladders are not intended for transporting materials. If someone carries an object and cannot grasp onto the ladder, the three-point support principle is violated. A slip is very likely to lead to a fall. Users should clean their shoes and ladder steps or rungs to reduce the chances of slipping.

Scaffolds

Types There are many kinds of scaffolds: wood, metal, fixed, moveable. Many scaffolds have patented designs and features. There are tubular, suspended, and special classes of scaffolds. There are standards for most of these. Large scaffold systems require structural design and analysis by people trained and qualified for such work.

Tubular Scaffolds There are two main types of tubular scaffolds: frame and tube. Both are modular and are erected from components to fit particular job requirements. Frame types have fewer individual parts and connections and have standard frame components used to assemble and lock parts together.

Suspended Scaffolds Hanging scaffolds are classified by number of suspension points, type of anchoring, and suspension system. Single-point suspension scaffolds include a boatswain's chair and a single person work cage. Suspended scaffolds usually hang by ropes from cornice hooks, outrigger beams, or other anchors. Work platforms assembled at a job site include the platform, guardrails, and suspension. Manufactured stages have preassembled components. Powered or manually operated pulleys, winches or other devices move platforms up and down. Proper rigging is very important.

Special Scaffolds There are many kinds of specialty scaffolds. Ladder jacks attach to straight or extension ladders. Two ladders with ladder jacks will support planks between them. Roofing brackets, anchored to a roof with steep slopes, support planks between them. The brackets are nailed to a roof or are suspended with ropes and are removed after shingles are in placed. Some masonry scaffold systems allow for incrementally jacking the working surface upward as the courses of masonry are completed.

Another special type of scaffolding, called slip form scaffolding, combines concrete forms with scaffolding. The scaffolding is raised as the concrete cures. In some cases, these systems allow for continuous pouring of concrete.

Planking Planking for scaffold work surfaces may be wood or metal. Wood planking is a special grade of lumber free of knots and other defects that would reduce load capacity. Cleats may lock planks in place. Many scaffolding accidents are the result of unsecured and loose planks.

Loads A major hazard for scaffolding is overloading and structural failure. Often scaffolding is load tested before use. Scaffolding is rated light, medium, and heavy duty, depending on designed working loads of 25, 50, and 75 lb/ft^2, respectively. All load-carrying components must meet design standards. Scaffolds should be inspected before use. Complete assembly of all fastening bolts, connectors, and bracing is important. Ropes, suspension fittings, wear on ropes, counterweight adequacy, outrigger beams, and clamp tightness should all be checked.

Tipping For ground-supported scaffolds, a hazard is tipping over. Placing each leg on a solid base will prevent tipping. Tying a scaffold to an adjacent building or structure also will prevent tipping.

Falls Falls of people and objects from scaffolds is another hazard. Controls previously discussed are appropriate.

Use Users of scaffolds must learn proper assembly, testing, inspection, and use. A qualified scaffold designer should oversee many scaffold applications, particularly large and complex scaffolding systems.

Elevated Work Platforms

Some work sites where assembly of scaffolding would be expensive require a temporary work platform at some height. A number of mobile devices provide vertically adjustable work platforms; some are self-propelled. One type of mobile device is an aerial basket, or "cherry picker," which can move vertically and horizontally. Other types may telescope vertically. Platforms used around electrical equipment must be insulated from electrical hazards. Properly positioned outriggers on some work platform devices provide stability and ensure that the telescoping section is plumb. The use site may need preparation to be sure that it is level. The surface also should be solid to prevent sinking of supports and tipping of equipment.

Some powered platforms have controls at the platform or basket. A second set of operator controls are located at ground level for general and emergency use. The platform should lock at the level desired and should not be subject to free fall if there is a power failure. Users must learn how to set up and operate elevated work platforms. Lifelines are worn and connected to the platform to prevent workers from falling. Controls should be fail safe and have features to prevent inadvertent actuation. Some controls are interlocked to level indicator switches to prevent tipping the equipment over.

EXERCISES

1. A fixed stairs is to be constructed between two floors of a building. The distance between floors (surface to surface), is 140 in. Using OSHA stairs criteria, determine

(a) how many steps are needed

(b) the depth of each tread and the height of each riser

(c) the stairs slope for your solution

2. A straight ladder that has a length, *L*, of 35 ft is placed against a building that is 50 ft tall. The ladder forms the desired angle with the wall, the base being *L*/4 ft from the wall. Assume the ladder weighs 90 lb and the person climbing on it weighs 200 lb. Assume that the person's center of gravity acts 3 ft vertically from the point of contact on the ladder rungs. The coefficient of friction between the ladder feet and surface it rests on is 0.5.

   (a) How far up the ladder can the worker go before it slides out at the bottom?

   (b) If the worker stands 3 ft from the top of the ladder, how much force is required to tip the ladder away from the wall, assuming the force is acting horizontally against the top of the ladder? Neglect vertical forces at the wall.

3. A worker is struck by a 30-in long piece of pipe weighing 1.92 lb/ft. The pipe fell out of an overflowing trash can from a platform at a level 70 ft above the worker's head.

   (a) What was the velocity of the pipe when it struck the worker?

   (b) What is the kinetic energy of the pipe at the point of impact?

4. While walking on a level surface, a person exerts a force, *F*, of 100 lb from the hip joint to the shoe of the forward foot just at the time the forward foot is planted fully. Assume the leg forms an angle of 15° with the vertical. What coefficient of friction is required to prevent the shoe from slipping on the floor?

5. A hemispherical plastic skylight is located on a roof directly adjacent to a work surface for air conditioning equipment. The skylight is not designed to carry the weight of a person. The work surface is about 44 in above the skylight and there are no access steps to it. What forms of protection would protect a worker who might

   (a) fall from the platform onto the skylight?

   (b) step on the skylight as a means to get onto the platform?

   What standards should one apply to this situation?

REVIEW QUESTIONS

1. Define tripping.
2. Identify at least three tripping hazards.
3. What factors contribute to lack of visibility of tripping hazards?
4. What controls will help remove tripping hazards?
5. Define slipping.
6. Identify at least three hazards that may cause slipping.
7. What activities and environmental conditions contribute to slipping?
8. Name three types of instruments for measuring slipperiness.
9. Name five controls to prevent slipping.
10. What factors contribute to injury from falls?

11. What are four objectives of fall protection?

12. What kinds of controls prevent people from falling?

13. Identify the elements of the standard guardrail and the function of each.

14. Explain why guardrails should be at least 42 in high.

15. Explain the components of fall-limiting devices and the function of each.

16. Name seven controls for preventing objects from falling.

17. What are two ways to reduce injuries from falls?

18. Identify hazards and hazard controls for each of the following:

(a) stairs

(b) ramps

(c) gangplanks

(d) dock plates

(e) ladders

(f) scaffolds

(g) elevated work platforms

NOTES

1 Szymusiak, S. M., and Ryan, J. P., "Prevention of Slip and Fall Injuries," Part 1, *Professional Safety*, June: 11–15; Part 2, July: 30–35 (1982).

2 Refer to ASTM F 609, Standard Test Method for Using a Horizontal Pull Slipmeter (HPS).

3 See ASTM E 303, Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester.

4 See ASTM F 489, Standard Test Method for Using a James Machine; D 2047, Standard Test Method for Static Coefficient of Friction of Polish-Coated Floor Surfaces as Measured by the James Machine and D 6205, Standard Practice for Calibration of the James Static Coefficient of Friction Machine.

5 See ASTM F 1677, Standard Test Method for Using a Portable Inclineable Articulated Strut Slip Tester (PIAST) and ASTM F 1678, Standard Test Method for Using a Portable Articulated Strut Slip Tester (PAST).

6 See ASTM F1679, Standard Test Method for Using a Variable Incidence Tribometer (VIT) and ASTM D 5859, Standard Test Method for Determining the Traction of Footwear on Painted Surfaces Using the Variable Incidence Tester.

7 29 CFR 1910.23(e) and 29 CFR 1926.500(f).

8 49 CFR 399 subpart L.

9 29 CFR 1910 and 1926.

10 Deuteronomy 22:8, *Revised Standard Version Bible,* Thomas Nelson and Sons, New York, 1952.

11 Sulowski, A. C., "Assessment of Maximum Arrest Force," *National safety News*, April: 50–53 (1981).

12 Szyumusiak, S. M., and Ryan, J. P., "Prevention of Slip and Fall Injuries," Part 2, *Professional Safety*, July: 30–35 (1982).

13 Archea, J., Collins, B. L., and Stahl, F., *Guidelines for Stair Safety*, Building Sciences Series 120, National Bureau of Standards, Washington, DC, May 1979.

BIBLIOGRAPHY

American National Standards Institute, New York:

A10.4 Safety Requirements for Personnel Hoists and Employee Elevators.

A10.8 Safety Requirements for Scaffolding.

A10.11 Safety Requirements for Safety Nets.

A10.18 Construction Safety Requirements for Temporary Floor and Wall Openings, FlatRoofs, Stairs, Railings, and Toeboards.`

A10.28 Safety Requirements for Work Platforms Suspended from Cranes or Derricks.
A10.32 Personal Fall Protection Safety Requirements for Construction Demolition Operations.
A14.1 Safety Requirements for Portable Wood Ladders.
A14.2 Safety Requirements for Portable Metal Ladders.
A14.3 Safety Requirements for Fixed Ladders.
A14.4 Safety Requirements for Job-Made Wooden Ladders.
A14.5 Safety Requirements for Portable Reinforced Plastic Ladders.
A14.7 Safety Requirements for Mobile Ladder Stands and Mobile Work Platforms.
A14.9 Safety Requirements for Ceiling Mounted Disappearing Climbing Systems.
A14.10 Special Duty Ladders.
A90.1 Safety Standard for Belt Manlifts.
A92.2 Vehicle-Mounted Elevating and Rotating Aerial Devices.
A1264.1 Safety Requirements for Workplace Floor and Wall Openings, Stairs, and Railing Systems.
A1264.2 Provision of Slip Resistance on Walking/Working Surfaces.
Z359.1 Requirements for Personal Fall Arrest Systems, Subsystems, and Components.
ANSI/ALI ALCTV, Safety Requirements for Construction, Testing and Validation of Automotive Lifts.
ANSI/ALI ALIS, Safety Requirements for Installation and Service of Automotive Lifts.
ANSI/ALI ALOIM, Safety Requirements for Operation, Inspection and Maintenance of Automotive Lifts.

American Society of Mechanical Engineers, New York:
A17.1 Safety Code for Elevators and Escalators.
A17.2 Guide for Inspection of Elevators, Escalators, and Moving Walks.
A17.3 Safety Code for Existing Elevators and Escalators.
A17.4 Guide for Emergency Evacuation of Passengers from Elevators.
A17.5 Elevator and Escalator Electrical Equipment.
A18.1 Safety Standard for Platform Lifts and Stairway Chairlifts.
A120.1 Safety Requirements for Powered Platforms for Building Maintenance.
B56.10 Safety Standard for Manually Propelled High Lift Industrial Trucks.

American Society for Testing and Materials, West Conshohocken, PA:
C1028, Standard Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method.
D5859 Standard Test Method for Determining the Traction of Footwear on Painted Surfaces Using the Variable Incidence Tribometer.
D6205 Standard Practice for Calibration of the James Static Coefficient of Friction Machine.
F462 Consumer Safety Specification for Slip-Resistant Bathing.
F469 Standard Test Method for Using a James Machine.
F609 Test Methods for Using a Horizontal Pull Slipmeter (HPS).
F802 Guide for the Selection of Certain Walkway Surfaces when Considering Footwear Traction.
F1240 Guide for Categorizing Results of Footwear Slip Resistance Measurements on Walkway Surfaces with an Interface of Various Foreign Substances.
F1637 Practice for Safe Walking Surfaces.
F1646 Standard Terminology Relating to Safety and Traction for Footwear.
F1677 Standard Test Method for Using a Portable Inclineable Articulated Strut Slip Tester (PIAST).
F1678 Standard Test Method for Using a Portable Articulated Strut Slip Tester (PAST).
F1679 Standard Test Method for Using a Variable Incidence Tribometer (VIT).
F1694 Standard Guide for Composing Walkway Surface Evaluation and Incident Report Forms for Slips, Stumbles, Trips and Falls.
F2047 Standard Test Method for Static Coefficient of Friction of Polich-Coated Floor Surfaces as Measured by the James Machine.
F2048 Standard Practice for Reporting Slip Resistance Test Results.
G115 Standard Guide for Measuring and Reporting Friction Coefficients.

Institute of Electrical and Electronic Engineers, New York:
IEEE 1307 Standard for Fall Protection for Utility Work.

Archea, J., Collins, B. L., and Stahl, F. I., *Guidelines for Stair Safety*, Building Sciences Series 120, National Bureau of Standards, Washington, DC, May 1979.

Brungraber, R. J., *An Overview of Floor Slip-Resistance Research*, Technical Note 895, National Bureau of Standards, January 1976.

Burkhart, Mathew J., McCann, Michael, and Paine, Daniel M., *Elevated Work Platforms and Scaffolding*, McGraw-Hill, New York, 2000.

Carson, D. H., Archea, J. C., Margulis, S. T., and Carson, F. E., *Safety on Stairs*, Building Sciences Series 108, National Bureau of Standards, Washington, DC, November 1978.

Chang, Wen-Ruey, Courtney, Theodore K., Grongvist, Raoul, and Rdfern, Mark, eds., *Measuring Slipperiness: Human Locomotion and Surface Factors*, CRC Press, Boca Raton, FL, 2003.

Cohen, H. H., and Compton. D. M. J., "Fall Accident Patterns," *Professional Safety*, June: 16–22 (1982).

Di Pilla, Steven, *Slip and Fall Prevention: A Practical Handbook*, CRC Press, Boca Raton, Fl, 2003.

Ellis, J. Nigel, *Introduction to Fall Protection*, 3rd ed., American Society of Safety Engineers, Des Plaines, IL, 2001.

English, William, *Slips, Trips and Falls: Safety Egnineering Guidelines for the Prevention of Falling Accidents*, Hanrow Press, Rancho Santa Fee, CA, 1989.

Injuries Resulting From Falls on Stairs, Bulletin 2214, Bureau of Labor Statistics, U.S. Department of Labor, Washington, DC, August 1984.

IRVINE, C. H., “Measurement of Pedestrian Slip Resistance,” *Professional Safety*, December: 30–33 (1984).

KING, R., and HUDSON, R., *Construction Hazard and Safety Handbook*, Butterworths, London, 1985.

NFPA 101 Life Safety Codes, National Fire Protection Association, Boston, MA.

ROSEN, S. I., *The Slip and Fall Handbook*, Hanrow Press, Rancho Santa Fee, CA 1983.

SZYMUSIAK, S. M., and RYAN, J. P., “Prevention of Slip and Fall Injuries,” Part 1, *Professional Safety*, June: 11–15; Part 2, July: 30–35 (1982).