CHAPTER 15

MATERIALS HANDLING

15-1 INTRODUCTION

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

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

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

Hazards

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

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

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

Safety and Health for Engineers, Second Edition, by Roger L. Brauer

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

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

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

Controls

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

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

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

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

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

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

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

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

15-2 MANUAL MATERIALS HANDLING

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

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

Hazards

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

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

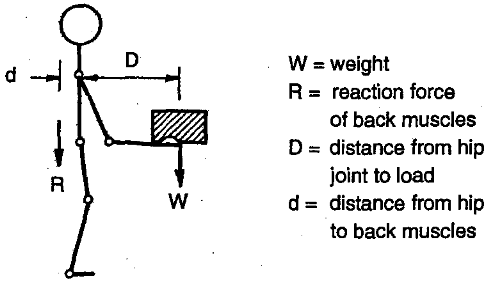

Figure 15-1. Biomechanics of manual lifting. The moment ($W \times D$) created by the load being lifted must be counteracted by the muscles of the back ($R \times d$).

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

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

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

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

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

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

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

Controls

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

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

The Revised National Institute for Occupational Safety and Health Lifting Equations

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

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

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

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

- with one hand;
- for more than 8 hours;

TABLE 15-1 Frequently Recommended Lifting Procedures

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

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

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

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

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

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

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

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

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

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

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

TABLE 15-2 The Seven Lifting Task Multipliers

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

TABLE 15-3 Frequency Multiplier

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

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

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

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

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

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

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

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