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I. SUMMARY

On November 19-21, 1990, National Institute for Occupational Safety and Health (NIOSH) researchers conducted an evaluation of potential musculoskeletal hazards to the upper limbs and back at the U.S. Army Corps of Engineers, North Central Division, Chicago, Illinois. The request was received from the Deputy Commander, Department of the Army, North Central Division, Corps of Engineers, Chicago, Illinois. The objective of this evaluation was to identify job tasks which may cause, aggravate, or precipitate musculoskeletal injuries among Army Corps of Engineer workers. This evaluation focused on workers in the dry dock maintenance area, the lock and dam facilities, and the barge maintenance area in the Rock Island District, Rock Island, Illinois.

The Rock Island District employs 860 workers in the winter season and 900 in the summer. The study included a walk-through survey of the Peoria Maintenance Facility, in Peoria, Illinois, and the Quincy Lock and Dam Facility, in Quincy, Illinois. The walk-through also included a review of OSHA 200 logs, informal interviews with employees, and an ergonomic assessment of three jobs: one at the Peoria Maintenance Facility and two at the Quincy Lock and Dam Facility. Data gathered indicated that potential musculoskeletal disorders could result at the elbow, shoulder, back, and hip during manual material handling in the maintenance shop in Peoria, Illinois, at the Lock and Dam Facility among the lock persons, and during lock maintenance and repair. Job tasks that involve ergonomic risk factors for musculoskeletal injuries include manual handling and transport during roller repair operation, tying off of barge ropes while barges are "locking through," and grinding during repair of lock gates. In addition, hand and wrist disorders may result from exposure to vibration from a hand held power sander used to remove metal debris from the locks during maintenance and repair. Implementation of an ergonomics control program using the recommendations contained in this report will facilitate the development and dissemination of control methods to reduce and prevent musculoskeletal hazards for the facilities evaluated by NIOSH researchers. Because of the uniformity of the lock and dam system the recommendations contained in this report may be extended to all facilities under the control of the Army Corps of Engineers to reduce and prevent musculoskeletal hazards.

On the basis of the information collected during this evaluation, NIOSH researchers determined that musculoskeletal hazards existed for the upper limbs and back. Recommendations for reducing and preventing such hazards at the facilities evaluated by NIOSH researchers are presented in Section VIII of this report. These recommendations may be extended to similar facilities under the control of the Army Corps of Engineers.

Keywords: SIC 4441 (Transportation on Rivers and Canals), 9621 (Regulation and Administration of Transportation Programs), Musculoskeletal Disorders, Manual Materials Handling, Cumulative Trauma Disorders, Maintenance, Locks and Dams, Ergonomics, Workstation Design, Engineering Controls.

II. INTRODUCTION

On September 11, 1990, NIOSH received a request from the Deputy Commander of U.S. Army Corps of Engineers, North Central Division, Chicago, Illinois, to evaluate musculoskeletal hazards to maintenance and construction workers working for the Army Corps of Engineers. The Deputy Commander is responsible for approximately 3,000 construction workers who work in 5 districts covering 12 states. The request was for NIOSH assistance in conducting an ergonomic study to redesign jobs which present back injury problems and to provide recommendations for redesigning these tasks.

Because of the uniformity in the lock and dam system which is under the jurisdiction of the North Central Division, Corps of Engineers, NIOSH researchers focused their evaluation at the Rock Island District, Rock Island, Illinois. The aim of this approach was to provide recommendations not only for workers at the Rock Island District but also to other lock and dam facilities under the control of the Army Corps of Engineers.

On November 19-21, 1990, NIOSH researchers conducted walk-through surveys and performed ergonomic evaluations for two facilities in the Rock Island District.

III. WORK FORCE AND PHYSICAL PLANT DESCRIPTION

The Rock Island District of the U.S. Army Corps of Engineers is responsible for 314 miles of the Mississippi River from Saverton, Missouri, to Guttenberg, Iowa, and also for 269 miles of the Illinois Waterway from La Grange Lock and Dam, Illinois, to Chicago, Illinois. The Rock Island District owns and operates 18 dams and 22 lock chambers. Their primary responsibility is to maintain the locks and dams so that the river is navigable. One of the most important elements in making the river navigable is maintaining a minimum water depth of 9 feet for the transport of river barges. The Rock Island district employs 860 people during the winter season and 900 employees during the summer. These workers include 90 maintenance workers in the winter, 130 in the summer, and 200 lock persons that assist in the operation of the locks year round.

A. Peoria Maintenance Facility

The Peoria Maintenance Facility is located on the Illinois Waterway in Peoria, Illinois. This facility was built in the 1950's and is owned and operated by the U.S. Army Corps of Engineers. It is one of two such maintenance facilities under the responsibility of the Rock Island District of the U.S. Army Corps of Engineers.

This maintenance facility has a machine shop, metal shop, engine repair shop, and a wood shop. This facility also repairs lock gates, which are lifted from the water and transported by barge to the maintenance facility. The gate is then repaired or refurbished by the maintenance staff. The total number of workers at this facility is 46, including 30 maintenance workers.

B. Quincy Lock and Dam

The Quincy Lock and Dam is located in Quincy, Illinois, and is one of 22 lock chambers for which the Rock Island District is responsible. The structure, dedicated in 1936, is owned and operated by the U.S. Army Corps of Engineers.

The lock chamber is 600 feet long by 110 feet wide and has a 5.2 million gallon capacity. There is an average of 15 lockings per day. The dam includes four roller gates in the center, and the rest are "tainer" gates.

During the NIOSH visit, a maintenance crew was working at the Quincy Lock and Dam on a maintenance barge. There were approximately 20 workers in the maintenance crew.

IV. DESIGN AND METHOD

A. Ergonomic Analysis

On November 19, 1990, NIOSH investigators conducted an opening conference at the Rock Island Facility with the Safety Manager for the Rock Island District and the Industrial Hygienist for the North Central Division of the U.S. Army Corps of Engineers. Following this meeting, the NIOSH investigators were transported to the Peoria Maintenance Facility, to conduct a walk-through survey and to determine jobs which may involve ergonomic hazards. Following the walk-through survey, a machinist repairing dry dock rollers was selected for an ergonomic evaluation. This job was considered by the Safety Manager to be representative of other maintenance work at this facility. Following the walk-through survey, NIOSH investigators were transported to Quincy, Illinois.

On November 20, 1990, NIOSH investigators visited the Quincy Lock and Dam Facility to determine which jobs were ergonomic hazards. Following the walk-through survey of this lock and dam facility, two jobs were selected for ergonomic evaluations: lock operators, who handled ropes to secure the barges in the lock, and a maintenance worker, who performed grinding tasks on a lock gate.

B. Work Documentation and Analysis

The ergonomic evaluations for the jobs listed above consisted of: (1) discussions with the workers regarding musculoskeletal hazards associated with their job; (2) videotaping the selected jobs; and (3) biomechanical evaluation of musculoskeletal stress during manual handling.

Videotapes were analyzed at regular speed and slow motion to determine musculoskeletal stresses to the upper limbs during the tasks, and at stop-action to perform biomechanical evaluations of working postures. All video analysis procedures were used to document potential musculoskeletal hazards in performing the job.

The first phase of the job analyses was to review the job for recognized occupational risk factors for Cumulative Trauma Disorders (CTDs). These CTD risk factors can be summarized as repetition, force, posture, contact stress, low temperature, and vibration.[1,2] In addition, biomechanical evaluation of forces, which are exerted on the upper limbs, back, and lower limbs of the worker during performance of a task, can also be conducted. Such evaluations are aided by the use of formulas developed by NIOSH[3] and the University of Michigan Center For Ergonomics (2D Static Strength Software Program, version 4.1E™). This approach to job analysis and quantifying forces that act upon the body during materials handling forms the basis for proposed engineering and administrative control procedures aimed at reducing the risk for musculoskeletal stress and injury.

V. BACKGROUND

A. Cumulative Trauma Disorders of the Upper Limbs

Reports of chronic musculoskeletal disorders have been documented as far back as the year 1717 by the physician, Ramazini, who documented that certain occupations caused certain violent and irregular motions and unnatural postures of the body, which resulted in impairment and disease.[4] Several case reports over the years have cited certain occupational and nonoccupational risk factors which give rise to musculoskeletal injuries.[5,6,7,8] However, only recently have epidemiologic studies attempted to examine the association between job risk factors such as repetition, awkward postures, and force with excess musculoskeletal morbidity. Several cross-sectional and case-control retrospective studies of occupational CTDs have been employed.[9,10,11,12,13,14] The conclusions from these studies have drawn us closer to identifying risk factors with disease outcome.

Work-related cumulative trauma disorders (CTDs) of the upper limbs have been associated with job tasks that include: (1) repetitive movements of the upper limbs; (2) forceful grasping or pinching of tools or other objects by the hands; (3) awkward positions of the hand, wrist, forearm, elbow, upper arm, shoulder, neck and head; (4) direct pressure over the skin and muscle tissue; and (5) use of vibrating hand-held tools. Because repetitive movements are required in many service and industrial occupations, new occupational groups at risk for developing CTDs continue to be identified.

One of the most commonly reported disorders of the upper limb is carpal tunnel syndrome (CTS). CTS, the result of compression or irritation of the median nerve as it passes through the carpal tunnel in the wrist, can be caused, precipitated, or aggravated by repetitive, awkward postures, and forceful motions.[15] Symptoms of CTS include pain, numbness, and weakness of the hand. Without intervention, CTS can lead to severe discomfort, impaired hand function, and disability. Workers who perform repetitive tasks are therefore at risk of CTS include automobile manufacturers and assemblers, electrical assemblers, metal fabricators, garment makers, food processors, grocery checkers, typists, musicians, housekeepers, and carpenters.[15,16]

The diagnosis is confirmed by physical examination and/or electrodiagnostic studies.[18] CTS can be managed with conservative measures, such as wrist immobilization and nonsteroidal anti-inflammatory medications.[17] However, these methods are not recommended as the main course of action because symptoms are likely to recur when the patient resumes the precipitating tasks.[17] Recognition and evaluation of work-related risk factors which may cause CTS should be conducted in order to implement controls to reduce such risk factors. Engineering controls are the preferred method, with administrative controls, such as work enlargement, rotation, etc., as an interim measure. For all patients with symptoms suggestive of CTS, an occupational history should be obtained that includes a description of tasks involving use of the hands. Failure to eliminate contributory job factors can result in recurrence or progression of symptoms, impaired use of the hand, and the need for surgical treatment. Redesign of tools, workstations, and job tasks can prevent occurrence of CTS among co-workers.[17] Surveillance of work-related CTS, including the use of health-care-provider reports, can aid in identifying high-risk workplaces, occupations, industries, and in directing appropriate preventive measure.[17]

B. Back Injuries

Eighty percent of all Americans will suffer low back pain sometime during their lifetime.[18,19,20,21] Over 30 million Americans currently experience low back pain;[22] 13 million of those cases have resulted in reduced ability to function.[23] Ten million cases of back impairment are in the employed U.S. population between the ages of 18 and 64.[25] Lost time from work has increased significantly over the past 30 years, while the incidence of low back pain has stayed the same.[24] Estimated total costs for low back pain are approximately $16 billion annually (compensable and noncompensable) in the United States.[24] The distribution of low back compensation costs is skewed: 25% of low back cases account for 95% of the costs.[25] Current estimates for low back compensation costs are approximately $6,807 as the average or mean costs and $390 for the median.[27] The large difference between the mean and median shows that costs for low back pain are not evenly distributed where a few cases account for most of the costs.[27] The higher cost for the few cases were attributed to more hospitalization, surgery, litigation, psychologic impairment, and extended loss of time from work. Age, gender, and occupation are risk factors for the occurrence and severity of low back injuries. Older workers are more likely than younger workers to have severe back disorders.[26] More women than men are likely to have restricted-activity, bed disability, and work loss days.[27]

Construction, mining, transportation, and manufacturing occupations have been shown to have high rates of low back injuries.[28]

Occupational risk factors for low back injuries include manual handling tasks,[29] lifting,[30] twisting,[32] bending,[32] falling,[31] reaching,[31] excessive weights,[32,33] prolonged sitting,[34] and vibration.[35,36] Some nonoccupational risk factors for low back injury includes obesity,[37] genetic factors,[38] and job satisfaction.[39,40]

Return to work following a back injury is dependent on the extent of injury, as measured by the amount of time away from the job; the longer the worker was away from the job the less likely the worker would be to return to work.[41,42]

Control and prevention of low back pain can be accomplished through the evaluation of jobs and the identification of job risk factors. Bending, twisting, reaching, handling of excessive loads, prolonged sitting, and exposure to whole-body vibration are recognized risk factors for back injuries. Redesign of jobs can lead to the reduction of these risk factors, and good job design initially will prevent back injuries. To reduce bending, twisting, and reaching by the worker, the work should be at the optimum work level - from waist to elbow height to reduce excessive bending and reaching; the workplace should be well laid out so as to reduce twisting; sit/stand workstations should be allowed where possible, with good seat design so as to reduce prolonged sitting and standing; good package design, such as hand holes for better coupling by the worker, package sized so the worker can hold the load close to the body, and package weight limited so as not to exceed human capabilities.[3] Suggested interim changes to reduce back injuries include work enrichment, enlargement, or rotation to reduce cumulative exposure. In addition to educating and training the worker, unions, and management about risk factors which cause back injury and pain, there appears to be no clear, single solution other than good initial job design. Multiple approaches such as job redesign, worker placement, and training may be the best methods for controlling back injuries and pain.[43]

Evaluation Criteria for Risk of Back Injury

The NIOSH Work Practices Guide for Manual Lifting[3] was developed using medical, scientific, and engineering resources to develop quantitative recommendations regarding the safe load weight, size, location, and frequency of a lifting task. The recommendations assume that:

1. the lift is smooth.
2. the lift is two-handed and symmetric in the sagittal plane (directly in front of the body with no twisting during the lift).
3. the load is of moderate width, e.g., 30 inches or less.
4. the lift is unrestricted.
5. the load has good couplings (handles, shoes, floor surface).
6. the ambient environment is favorable.

It is further assumed that other material handling activities such as holding, carrying, pushing, and pulling are minimal; the individual performing the lifting activities is at rest when not lifting; those involved in lifting are physically fit and accustomed to labor.

The formulas for the Action Limit (AL) and the Maximum Permissible Limit (MPL) are as follows:

$$AL(lb) = 90\left(\frac{6}{H}\right)(1 - .01|V - 30|)\left(.7 + \frac{3}{D}\right)\left(1 - \frac{F}{F_{\max}}\right)$$

$$MPL = 3AL$$

Where:

AL(lb) - Action Limit, in pounds
H - horizontal location forward of midpoint between ankles at origin of lift
V - vertical location at origin of lift
D - vertical travel distance between origin and destination of lift
F - average frequency of lift (lifts/minute)
F_{max} - maximum frequency which can be sustained (table of values provided in the Work Practices Guide).

Tasks analyzed in this manner are divided into three categories:

1. Those above the maximum permissible limit (MPL) which are considered unacceptable and which require engineering controls.
2. Those between the AL and MPL which are unacceptable without administrative or engineering controls.

3. Those below the AL, which are believed to represent minimal risk to most industrial work forces.

The Work Practices Guide indicates that corrective action is needed for jobs which exceed the AL. The incidence and severity rates of musculoskeletal injury have been found to increase in populations "exposed to lifting conditions" described by the AL (over 75% of women and over 99% of men could (safely) lift loads described by the AL).[3]

Biomechanical compression forces over 1,430 lb on the L_5/S_1 disc are not tolerable in most workers. This condition would result in conditions over the MPL. A 770 lb compression force on the L_5/S_1 disc can be tolerated by most young, healthy workers. Such forces would be created by conditions described by the AL.

C. Segmental Vibration

For more than 75 years, workers who operated vibrating tools on the job have reported symptoms resembling the signs and symptoms of primary Raynaud's disease.[44] These symptoms included episodic numbness and tingling of the fingers, episodic blanching of the fingers with pain occurring in response to cold exposure and on return of circulation, and reduction in grip strength and finger dexterity. These signs and symptoms increased in number and severity as the exposure to vibration increased.[54]

An estimated 1.45 million workers use vibrating tools in the United States.[45] In worker populations which use vibrating tools the prevalence of hand-arm vibration syndrome (HAVS) ranges from 6% to 100%. Risk factors for HAVS depends on many factors such as: the vibration energy produced by the tool, the length of time the tool is used each day, the cumulative number of hours, months, and years the worker has used the tool, and the ergonomics of tool use.

HAVS may take months or years to develop and can be reversed in the early stages. However, advanced stages of HAVS are not reversible and lead to loss of effective hand function and necrosis of the fingers. Engineering controls, work practices, administrative procedures, medical supervision, worker training, ergonomic design of the tools and the task, and other procedures can be implemented to effectively reduce the risk of developing HAVS. While no specific recommended exposure limits are provided in the NIOSH Criteria Document on Hand-Arm Vibration, it is recommended that engineering controls be the first level of protection through: (1) the elimination or reduction at the source (controlling acceleration of the tool), (2) reduction of transmission (the use of energy-damping materials between the tool and the worker's hands), and (3) process modification (ergonomic analysis and evaluation of work processes to determine vibration exposure sources and their elimination). Good work practices are also recommended, as are worker training and medical monitoring.[54]

VI. RESULTS

Peoria, Illinois - Maintenance: Machinist for Roller Repair

1. Work Content

The job being performed by the machinist on the day NIOSH researchers investigated the Peoria, Illinois facility included the refurbishing of large rollers which are part of the dry dock assembly. The roller consists of a large roller and pin weighing 120 pounds. The roller and pin are fastened to a base which weighs 171 pounds, making a combined weight of 291 pounds. The roller and pin are separated from the base on the floor. A jack-stand hoist is used to lift the base to the work bench which stands 27.5" high. Refurbishing is performed by cleaning the excess debris with a powered hand grinder. When finished, the base is lowered to the floor with the hoist and the roller and pin are lifted to the work bench with the hoist, and the refurbishing process is repeated. The roller and pin assembly is then lowered to the floor with the hoist. The roller and pin is "rolled" on the floor by the machinist's foot to a standing drill machine located approximately 25 feet from the work bench. The 120 pound roller and pin is manually lifted from the floor to the clamp of the standing drill machine. The vertical travel distance that the roller and pin assembly is transported is 38 inches (i.e., from the floor to the clamp of the machine). Holes are drilled in the pin, and the roller and pin are manually lowered back to the floor. The roller and pin are reattached to the base, and the process is repeated for the next assembly. The operator refurbished 12 of 20 of these rollers, pins, and base assemblies on the day of the NIOSH investigation. The machinists' responsibilities vary, from general maintenance work to fabrication of specialized materials for the Army Corps of Engineers.

2. Biomechanical Evaluation

Biomechanical evaluation of musculoskeletal forces on the upper limbs, back, and lower limbs for this job showed that certain elements put this worker at risk for musculoskeletal disorders. The allowable limits were exceeded for certain segments of the worker population. Therefore, it is recommended that administrative or engineering controls be implemented. A comprehensive explanation of how the NIOSH ALs and MPLs were derived is contained in the NIOSH Work Practices Guide for Manual Lifting.[3] Strength predictions for each of the major articulations (joints) are explained in the textbook: Occupational Biomechanics.[46] [Note: When the AL is exceeded for joints other than the back, less than 99% of men and less than 75% of women are capable of performing the task. When the MPL is exceeded, less than 25% of men and less than 1% of women are capable of performing the task.

The biomechanical evaluation showed that there were some tasks that would exceed the biomechanical and static strength capabilities of the worker in relation to the demands of the job. NIOSH researchers focused on the most hazardous biomechanical demands observed for this job. The 2D Static Strength Prediction Program allowed for specific anthropometric data (height and weight) to be entered for this worker, who was in the upper 5 percent (95th percentile) of the American male population for size and weight. Posture and link angles were determined from stop action analysis of videotapes during the job cycle. Since both hands were used to perform this task, this information was entered into the model.

Analysis was performed on the following tasks: (1) the initial lift of the roller and pin from the floor; (2) moving the roller and pin into the clamp of the drill at the worker's waist height; and (3) balancing the roller, pin, and base.

Based on observation of the all the work elements observed, analysis showed that during lifting of the roller and pin (120 lbs) from the floor, the compressive force on the back was 1,416 lbs. Lifting this weight in this posture, the NIOSH AL for back compression for this worker, 770 lbs, was exceeded and that the MPL of 1,430 lbs was nearly reached (see Figure 1 and Table 1). In addition, the strength required to perform this task exceeded the AL for the worker's hip and knee. The 120 pound weight and the initial location of the roller and pin, when it is picked up from the floor, are two important factors contributing to the high compressive forces on the back and the excessive torques or stresses on the hips and knees.

Biomechanical analysis was also performed as the roller and pin assembly was moved horizontally into the drill clamp. During this maneuver, the worker extended his arms to place the roller and pin into the drill clamp. The worker had to extend to reach the drill clamp because the base of the stand extended from underneath the drill. This base formed a barrier which prevented the worker from standing closer. As a result, the MPL was exceeded for the elbow and shoulder (see Figure 2 and Table 2). Also, the action limit was exceeded for the L_5/S_1 of the back, hips, knees, and ankles.

The third task analyzed for this worker was balancing the roller, pin, and base on the floor while maneuvering a mechanical lift into position to lift the 291 lb unit. During the positioning and balancing of this unit, the NIOSH AL was exceeded for back compression (see Figure 3 and Table 3).

Quincy, Illinois - Lock Persons

1. Work Content

The job being performed by the lock persons during the NIOSH investigation at the Quincy, Illinois, facility included the connecting and disconnecting of the ropes, that secure the barges and boats during a lock operation.

The lock person begins this task by tossing a 1/4" rope from the lock wall to the bargeman who connects it to a 2 1/4" rope. The lock person pulls the heavier rope to the lock wall and while holding the rope, walks along the lock wall as the barge is steered into the lock by the ship's captain. The lock person loops the end of the rope around one of the metal posts on the lock wall located at the lock person's feet. The bargeman ties off the other end of the rope with a slip knot around the kevel of the barge while the ship's captain guides the barge into the lock. When the barge is stabilized in its approach into the lock, the bargeman pays out the rope through the kevel. This loosens the rope enough to let the lock person remove the rope from the metal post. The process of attaching and removing the rope from metal posts along the lock wall is repeated until the barge is fully into the lock.

The lock person and bargeman work together to secure the rope to the lock wall and the barge. When the barge is in place, the lock gates are closed and the water is emptied by gravity or added through valves and tunnels from the lock chamber. Finally, the water level reaches the river level to which the barge is moving. As the water is added or drained, the bargeman pays the rope in or out. Once the barge is at the river level, the rope is loosened from the barge kevel and the lock person removes the rope from the metal post on the lock wall. At this point, the lock person gathers the excess rope and pitches it onto the barge. This technique of gathering and pitching the rope reduces the chance of it being thrown or falling into the water.

It is very important that the rope be kept out of the water during the locking process. If the rope goes into the water it becomes much heavier and more difficult to handle, especially during winter when the water can freeze on the rope. Also, the bargeman may fall overboard while fishing the rope out of the water.

This entire procedure is repeated several times per day for each "locking-through" operation. The lock persons at the Quincy, Illinois, lock and dam were observed locking-through three tows (15 barges per tow) on the day NIOSH researchers evaluated this job.

2. Biomechanical Evaluation

The biomechanical evaluation showed that there were tasks that exceeded the biomechanical and static strength capabilities of this worker in relation to the demands of the job. NIOSH researchers focused on the lock person's task of putting the rope on and off the metal posts as the barge advanced through the lock. Four biomechanical analyses of the lock person's task were computed: (1) holding a rope before "pitching" the rope out and back down to the barge as the barge entered the lock; (2) taking a rope off a metal post after the water level was lowered to the lower river ("pool") level; (3) taking in approximately 20 feet of rope; and (4) pitching the rope out and onto the deck of the barge. During the first and fourth tasks, the worker pitched the rope far enough onto the barge in order to keep it from going into the water.

The lock person performing these tasks was estimated to be approximately 6' tall and approximately 200 pounds; therefore the University of Michigan 2D model was adjusted for an American male worker in the 95th percentile. Posture and link angles were determined from stop action analysis of videotapes during the job cycle. The weight of the rope varied according to the amount handled by the lock person. The NIOSH investigators estimated that the maximum weight of a well used 2 1/4" rope would be 2 pounds per foot. The estimated weight of the rope during these tasks would then vary from 50 to 80 pounds, depending on how much rope was held by the lock person.

During the first task, only one hand was used to pitch the rope onto the deck of the barge. The analysis showed that the compressive force on the back was 762 pounds, which is only slightly under the NIOSH AL of 770 pounds. In addition, the strength required to perform this task exceeded the AL for the worker's elbow, hip, knee, and ankle. Additionally, strength requirements for the shoulder exceeded the MPL (see Figure 4 and Table 4).

During the second task, both hands were used to lift up the rope from the bottom of the metal post. The analysis showed that the compressive forces on the back was 1,558 pounds, which exceeded the NIOSH MPL. In addition, the strength required to perform this task exceeded the NIOSH AL for the worker's elbow, shoulder, hip, knee, and ankle (see Figure 5 and Table 5).

During the third task, the worker used one hand at a time to take the rope in. The analysis showed that the compressive force on the back was 393 pounds, which was below the NIOSH AL. The strength required to perform this task exceeded the AL for the worker's shoulder, hip, and knee. It was also noted that the worker used the weight of the rope as a counter balance while taking in the rope. This technique may reduce compressive forces on the back but may pose a slip and fall hazard because of balance problems (see Figure 6 and Table 6).

During the fourth task, only one hand was used to pitch the rope back to the deck of the barge. The analysis showed that the compressive force on the back was 364 pounds, which is below the NIOSH AL. The strength required to perform this task exceeded the AL for the worker's shoulder, hip, knee, and ankle (see Figure 7 and Table 7).

As mentioned previously, when compressive forces exceed the AL, administrative or engineering controls are recommended to decrease such forces and reduce the probability of musculoskeletal injury, especially the back. The weight of the rope and the techniques for taking up the rope and pitching it out are two important factors contributing to the compressive back forces and the excessive torque (strength requirements) on the other joints. Quincy, Illinois - Maintenance: Lock Gate Repair Operations

1. Work Content

The job being performed by the maintenance worker during the NIOSH investigation at Quincy, Illinois, included grinding of metal flashing from a lock gate. This type of maintenance is considered routine, especially during the winter months. Selected gates are pulled from locks and dams and scheduled for maintenance. In this case, these gates were put on a floating barge for maintenance and repair. These gates are approximately 22' tall by 55' long. Refurbishing of these gates can take several months depending on the amount of work to be done. Normally, general maintenance consist of cleaning, sandblasting, cutting, welding, grinding, and painting operations. In the Rock Island District four to six lock gates are refurbished every winter at this and other maintenance facilities.

NIOSH researchers observed the maintenance operator performing his duties by using a two-handed power grinder. The work being performed was to remove excess metal flash from a cut out section at the bottom of the lock gate. This task involved working in awkward postures and using a powered grinding tool weighing approximately 12 pounds. The bottom of the lock gate was supported 3 feet from the deck of the barge by large timbers and cabling. This allowed the maintenance worker to perform grinding operations on the side and underneath the lock gate at the time of this investigation. Grinding operations are a routine operation during lock gate maintenance.

2. Biomechanical Evaluation

The biomechanical evaluation showed that there were some tasks that would exceed the biomechanical and static strength capabilities of this worker in relation to the demands of the job. NIOSH researchers focused on the grinding operations of the lock gates. Two biomechanical analyses of the maintenance worker were performed: (1) grinding to remove metal burrs and to smooth the rough metal edges of the lock gates while the worker was in a standing position; and (2) grinding the rough metal edges on the inside of the same lock gate while in a kneeling position.

This worker was estimated to be over 6' tall and over 200 pounds; therefore, the University of Michigan 2-D model was adjusted for an American male worker in the 95th percentile. Posture and link angles were determined from stop action analysis of videotapes during the job cycle. The weight of the powered hand grinder was estimated to be 12 pounds. However, because of the force required for the maintenance worker to "lean in" while using the grinder, the magnitude of the force was estimated to be approximately 50 pounds.

During the first task, the worker was standing and grinding the side of a lock gate. Biomechanical analysis showed that the compressive forces on the back was 277 pounds, which is below the NIOSH Action Limit. However, the strength required to perform this task exceeded the AL for the worker's shoulder and knee (Figure 8 and Table 8).

During the second task in which the worker was on his knees working underneath the lock gate, the biomechanical analysis showed that the compressive forces on the back was 179 pounds, which is well below the AL. However, the strength required to perform this task exceeded the AL for the worker's shoulders, hips, knees, and ankles (see Figure 9 and Table 9).

3. Hand and Arm Vibration Hazards

Segmental vibration of the hands and arms may also be a risk factor for musculoskeletal stress, notably hand-arm vibration syndrome (HAVS). This syndrome may result from prolonged exposure to a powered hand grinder and grinding operations such as grinding metal debris from the lock gates.

VII. DISCUSSION AND CONCLUSIONS

Based on the NIOSH evaluation, it is probable that many U.S. Army Corps of Engineers jobs involve musculoskeletal hazards. The weight and size of objects handled, the variety of tasks, and the changing weather conditions contribute to a potentially hazardous environment. The three jobs evaluated by NIOSH researchers demonstrated that these workers are exposed to a variety of hazards, including manual materials handling, slips, trips, falls, repetitive motion, stressful postures, high forces, and hand-arm vibration. These jobs represent only a fraction of the jobs performed by these workers to maintain the lock and dam system. As such, a musculoskeletal injury prevention program would be the most effective long-term approach toward anticipating problems, and elimination of serious musculoskeletal injuries.

The justification for such a program is supported by the unique and myriad tasks performed by these workers. For example, the lock persons who work in a variety of weather conditions (rain, snow, ice, wind) and at quickly changing levels of physical exertion (resting condition in a "warming hut" at the end of a lock to *full maximal exertion* during rope "tossing" and "pulling in" for a barge entering a lock). The weather and changing levels of exertion can be hazards which are not quantified by job analysis. It is only after a thorough evaluation of the job and the elements which contribute to injury that such hazards become apparent.

VIII. RECOMMENDATIONS

A. General

1. A Corps-wide ergonomics control program to prevent musculoskeletal injuries should be implemented. The principal elements should include: (1) job analysis in which jobs that have had the highest number of injuries and/or the most costly injuries should be ranked high in priority for analysis. Based on the analysis,

engineering controls should be considered first; (2) education and training of workers, line supervisors, and upper management about musculoskeletal injuries and the factors that contribute to such injuries should be implemented. Orientation should be for all workers with detailed instruction and training to workers who are at high risk; (3) a medical surveillance system which identifies the nature of the injury, type of injury, time and location, and any supporting documentation on how such an injury can be prevented in the future; and (4) development of an ergonomics task force. The task force could be comprised of existing safety committee members who receive specialized training on ergonomics, as well as workers who have knowledge and skills in designing and building equipment. It is especially important to include the worker who is currently doing the job in question in the task force. The U.S. Army Corps of Engineers appears to have the skill and experience to develop strategies for reducing musculoskeletal injuries. A well coordinated program, developed by the Corps headquarters staff, should insure that successful strategies are disseminated and effectively implemented throughout Corps facilities.

B. Specific

Peoria, Illinois - Maintenance: Machinist for Roller Repair

Engineering

1. Obtain or fabricate adjustable height work benches for various sizes or the type of work done (i.e., lower benches for heavy work, higher benches for precision work).

2. Obtain tool balancers to support the weight of the tool during work.

3. Hoists, either fixed or portable, should be used for all heavy lifts. Fixed hoists should be designed to reach all machines in which heavy parts are used or fabricated. The hoists should not be so large that the worker does not want to use them or so small that the weight limit is exceeded. A 1/2 ton portable hydraulic hoist should be used as a "work horse" for small material handling jobs when the larger hoists are too cumbersome. For example, there was no hoist specifically for the drill at the Peoria Maintenance Facility. Therefore, the worker lifted the 120 pound roller and pin assembly to the drill. The lifting device, in order to serve the purposes of lifting and positioning the roller and pin, should have three degrees of motion, vertical lifting, movement forward and back, and side to side.

4. The Maximum Permissible Limit (MPL) for the shoulder and elbows were exceeded when the worker moved the roller and pin horizontally into the drill clamp. One way to minimize these forces is by removing the physical barriers at the worker's feet which prohibit the worker from standing close to the machine.

Administrative

1. Develop a mechanism to get input from the workers doing the job. NIOSH investigators saw some very creative engineering controls which made a worker's job easier. These ideas should be collected from all facilities and the best ideas should be transferred to other maintenance facilities. One idea that worked well at the Peoria Maintenance Facility was a metal scrap cart. The scrap cart is emptied only once a week with a fork lift. Previously, scrap was removed two times per day with a wheel barrow. The new idea is safer because it contains the scrap better during transport and also saves time.

Other Concerns

1. General ventilation is used instead of local exhaust ventilation, which may be a problem during "production" torch cutting of metal. Hazardous vapors from metal cutting should be controlled with the use of a local exhaust hood which vents to the outside.

Quincy, Illinois - Lock Personnel

Engineering

1. Consider moving the height of the metal posts to approximately 32". A biomechanical analysis was performed for the lock person lifting the rope off of a metal post at 32". This improved location of the post significantly reduced the compressive force on the back from 1,558 to 693 pounds (see Figure 10 and Table 10, compare these with original Figure 5 and Table 5). However, this measure will not significantly change the strength requirements for the other joints (i.e., elbow, shoulder, hip, and ankle). If extending the height of the metal posts is not feasible, then consider using a portable lift (like a car jack) to raise the rope to the worker's knuckle height. An in-house ergonomics task force could brainstorm other solutions for this problem.

2. Besides raising the height of the metal posts, reposition the posts in relation to the railings. Awkward postures resulted from handing the rope over railings to connect to the metal post. When the rope is positioned, the rope had to be passed under the railing and connected to the posts. These postures can result in excessive strain on the back.

3. Consider a temporary locking device (such as those used on sail boats) to hold the rope in place when bringing it in from the barge. This will reduce the handling of the rope.

Administrative

1. During locking operations, lock persons and barge hands should train together to keep the rope out of the water so as not to add more weight to the rope. In addition, the lock person and barge hand should be instructed and practiced in not putting too much tension on the rope so that it will cause excess strain to the back of both workers.

Quincy, Illinois - Maintenance: Lock Gate Repair Operations

Engineering

1. Possible controls to reduce the musculoskeletal stresses for this job are: (1) for the shoulder - a smaller hand-held power grinder to reduce the weight of the tool, or if a larger powered tool is required, a portable tool balancer which can be attached if grinding is done in the same area for extended periods; (2) for the upper limbs - coarse grinding pads for the tool in order to reduce the amount of "lean-in" force required by the worker; and (3) for the knees - knee pads to reduce trauma.

Administrative

1. Obtain the vibration frequency spectrum from the manufacture for all hand-held power tools to see if there is a possible vibration hazards associated with their extended use. Refer to the NIOSH Criteria Document: "Criteria for a Recommended Standard - Occupational Exposure to Hand-Arm Vibration," for details on how to measure and control for this hazard.[44]

2. Have a variety of grinding wheels, as well as power grinders, available so that the right grinding wheel and grinder can be selected for each particular job. Let the grinder and grinding wheel do the work so that manual force does not have to be used to do the job.

3. Provide a portable hard hat light so the worker can see what he is doing when working in confined, dark spaces.

Other Concerns

1. During the NIOSH evaluation of these facilities, it was observed that welding and cutting operations were performed in areas without adequate ventilation for the workers. Provide adequate ventilation for welding or cutting metal, preferably local exhaust ventilation. The NIOSH Criteria Document: " Criteria for a Recommended Standard - Welding, Brazing, and Thermal Cutting," is recommended as a guide for protecting workers from hazardous exposure during these operations.[47]

2. Because of the variety of chemicals used by the Corps of Engineers and the potential for worker exposure to these chemicals, a respirator protection program should be in place. The NIOSH report on Respirator Decision Logic[48] is recommended for the proper selection and use of respirators as a first step in developing such a program.

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Figure 2 Lift of Roller and Pin from Floor

TABLE 1
Lift of Roller and Pin from Floor

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	120 lbs	Body Parts	Percent Capable[1]	
Number of Hands	2	Elbow	99%	
Height of Worker	74 in	Shoulder	99%	
Weight of Worker	212 lbs	L5/S1	94%	AL
Gender	Male	Hip	76%	AL
Back Compression[2]		Knee	84%	AL
1413 lb - AL		Ankle	99%	

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.

[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.

Figure 3 Lift of Roller and Pin at Waist

TABLE 2
Lift of Roller and Pin at Waist

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	120 lbs	Body Parts	Percent Capable[1]	
Number of Hands	2	Elbow	7%	MPL
Height of Worker	74 in	Shoulder	1%	MPL
Weight of Worker	212 lbs	L5/S1	57%	AL
Gender	Male	Hip	46%	AL
Back Compression[2]		Knee	93%	AL
1327 lb - AL		Ankle	74%	AL

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.

[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.

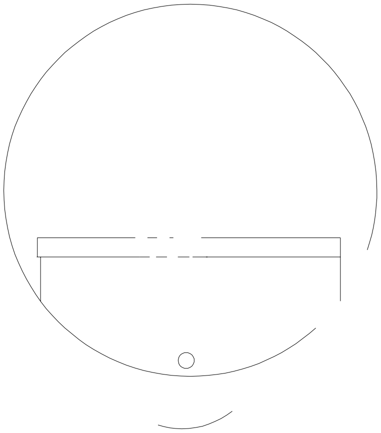

Figure 4 Balance Roller, Pin, and Base

TABLE 3
Balance Roller, Pin, and Base

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	30 lbs	Body Parts	Percent Capable[1]	
Number of Hands	2	Elbow	99%	
Height of Worker	74 in	Shoulder	99%	
Weight of Worker	212 lbs	L5/S1	99%	
Gender	Male	Hip	90%	AL
Back Compression[2]		Knee	99%	
781 lb - AL		Ankle	99%	

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.

[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.

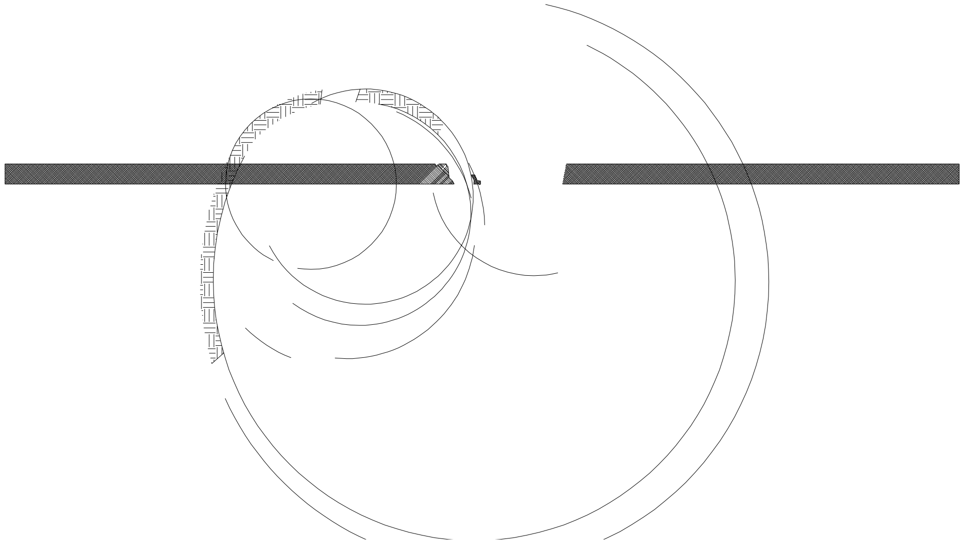

Figure 5 Holding Rope Before Pitching Out

TABLE 4
Holding Rope Before Pitching Out

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	60 lbs	Body Parts	Percent Capable[1]	
Number of Hands	1	Elbow	31%	AL
Height of Worker	74 in	Shoulder	4%	MPL
Weight of Worker	212 lbs	L5/S1	91%	AL
Gender	Male	Hip	77%	AL
Back Compression[2]		Knee	62%	AL
762 lb		Ankle	52%	AL

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.

[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.

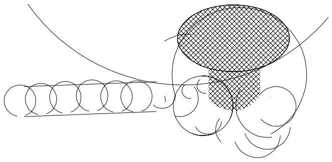

Figure 6 Lifting Rope From Bottom of Metal Post

TABLE 5
Lifting Rope From Bottom of Metal Post

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	80 lbs	Body Parts	Percent Capable[1]	
Number of Hands	2	Elbow	88%	AL
Height of Worker	74 in	Shoulder	91%	AL
Weight of Worker	217 lbs	L5/S1	94%	AL
Gender	Male	Hip	72%	AL
Back Compression[2]		Knee	99%	
1558 lb - MPL		Ankle	85%	AL

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.

[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.

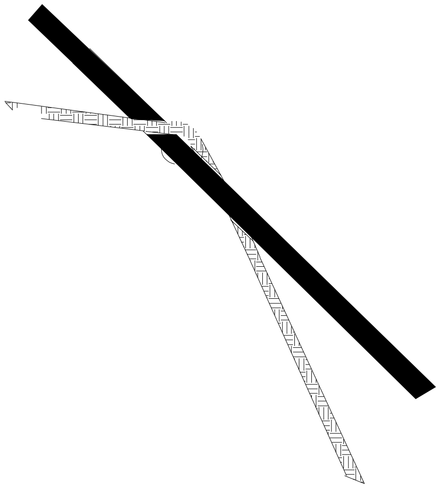

Figure 7 Pulling Rope Up From Barge Before Throw

TABLE 6
Pulling Rope Up From Barge Before Throw

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	80 lbs	Body Parts	Percent Capable[1]	
Number of Hands	1	Elbow	99%	
Height of Worker	74 in	Shoulder	53%	AL
Weight of Worker	217 lbs	L5/S1	99%	
Gender	Male	Hip	95%	AL
Back Compression[2]		Knee	92%	AL
393 lb		Ankle	99%	

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.

[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.

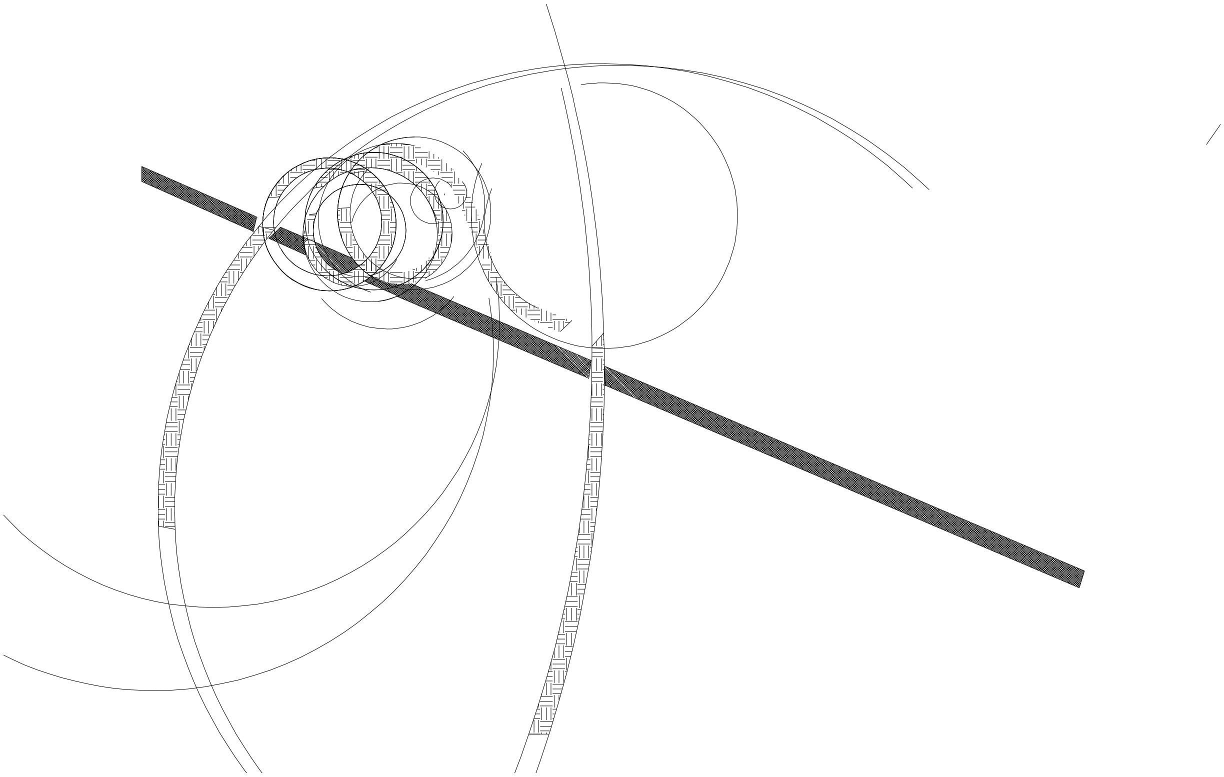

Figure 8 Throwing Rope on to Barge

TABLE 7
Throwing Rope on to Barge

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	50 lbs	Body Parts	Percent Capable[1]	
Number of Hands	1	Elbow	99%	
Height of Worker	74 in	Shoulder	98%	AL
Weight of Worker	217 lbs	L5/S1	98%	AL
Gender	Male	Hip	94%	AL
Back Compression[2]		Knee	88%	AL
364 lb		Ankle	40%	AL

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.

[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.

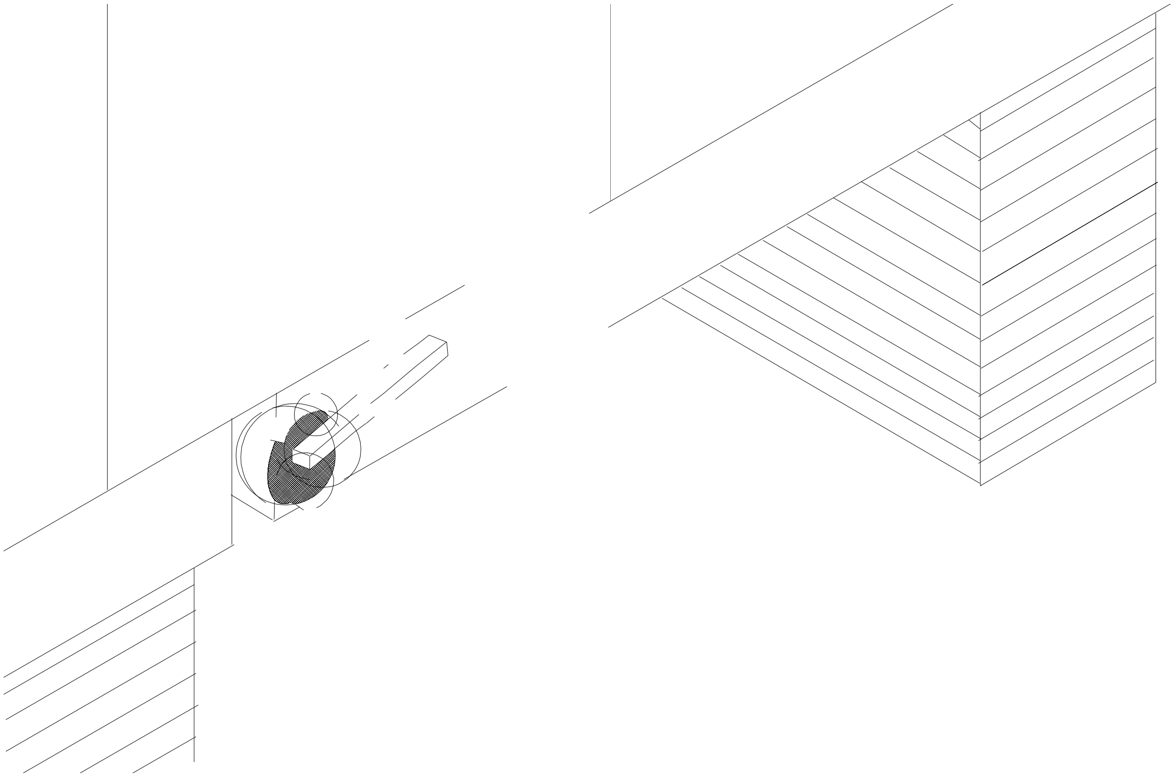

Figure 9 Grinding While Standing

TABLE 8
Grinding While Standing

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	50 lbs	Body Parts	Percent Capable[1]	
Number of Hands	2	Elbow	99%	
Height of Worker	74 in	Shoulder	96%	AL
Weight of Worker	217 lbs	L5/S1	99%	
Gender	Male	Hip	99%	
Back Compression[2]		Knee	59%	AL
277 lb		Ankle	99%	

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.
[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.

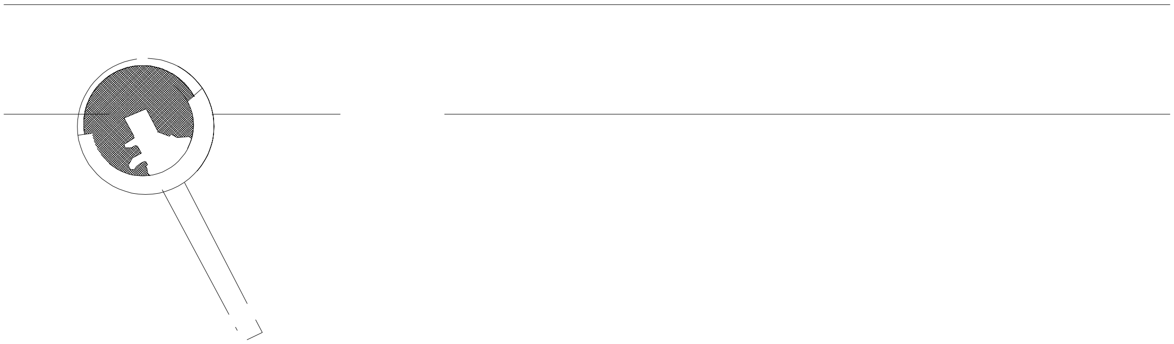

Figure 10 Grinding While Kneeling

TABLE 9
Grinding While Kneeling

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	50 lbs	Body Parts	Percent Capable[1]	
Number of Hands	2	Elbow	99%	
Height of Worker	74 in	Shoulder	98%	AL
Weight of Worker	217 lbs	L5/S1	99%	
Gender	Male	Hip	98%	AL
Back Compression[2]		Knee	59%	AL
179 lb		Ankle	98%	AL

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.

[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.

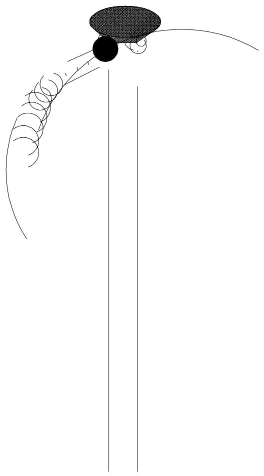

Figure 11 Lifting Rope from Metal Post (If at Waist Height)

TABLE 10
Lifting Rope From Metal Post (If at Waist Height)

Force Parameters and Anthropometric Data		Percent of Population with Corresponding Anthropometric Data Capable of this Task		
Weight of Lift	80 lbs	Body Parts	Percent Capable[1]	
Number of Hands	2	Elbow	93%	AL
Height of Worker	74 in	Shoulder	98%	AL
Weight of Worker	217 lbs	L5/S1	92%	AL
Gender	Male	Hip	87%	AL
Back Compression[2]		Knee	99%	
693 lb		Ankle	75%	AL

[1] AL is indicated when the percent of the population capable of the lift is below 99% for men and 75% for women; MPL is indicated when percent capable is below 25% for men and 1% for women.

[2] The Action Limit and Maximum Permissible Limit for back compression are 770 lb and 1430 lb, respectively. When an AL or MPL is present, the back compression has exceeded that limit.