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# Chapter 11

# Physical Factors Case Study: Reducing Hazards During Highway Tunnel Construction

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## Learning Objectives

On completion of this chapter, the reader should be able to

- Perform a simple job analysis to identify and control exposures that are potential hazards for developing musculoskeletal disorders.

## Key Words

Ergonomic job analysis
Construction
Musculoskeletal disorders
Intervention

## Abstract

During many manual construction activities, workers are exposed to designs that are not ergonomically configured; that is, the designs do not fit the characteristics and capabilities of the workers. Thus, hazardous exposures exist that increase workers' risk for developing work-related musculoskeletal disorders. An evaluation of the job tasks involved in the ceiling-panel assembly operation in the third harbor tunnel of the Central Artery/Tunnel (CA/T) construction project in Boston was carried out to identify and reduce the hazards of the tasks involved. Each assembly operation employed 10 iron workers, each of whom performed one of four job tasks. The researchers divided each job task into activities and evaluated each activity for hazards using a systematic ergonomic job analysis. This analysis was used to identify the potentially hazardous activities and to list the work-related causes of the hazards (equipment or tool design, work organization). In the analysis, hazards were identified for the trunk, legs, shoulders, hands, wrists, and neck. These hazards included repetitive motions of the wrist and arms, forceful whole-body and hand exertions, awkward body postures, and localized contact stresses. The most frequently observed hazards were static, non-neutral body postures induced by low work heights, heavy pushing of ceiling panels on the assembly line, and forceful, repetitive hand movements with contact stresses during bolting activities.

Recommendations for the redesign of the assembly line to reduce the hazards were suggested. An operation was subsequently developed at a different location in the tunnel that was identical to the first, with the exception of having several of the recommended design changes. A follow-up evaluation on the redesigned operation found that approximately 43% of the previously identified hazards had been eliminated or reduced. This study demonstrates how hazards can be systematically evaluated and reduced with relatively simple and inexpensive interventions for the prevention of musculoskeletal injuries.

## Introduction

Construction workers show elevated risks of developing work-related musculoskeletal disorders

(WRMDs) of the back and of the upper and lower extremities (Damlund et al., 1982; Burkhart et al., 1993; Holstrom et al., 1993). Although WRMDs are quite common in construction work, little has been done in the United States to systematically characterize the hazards for specific construction trades and operations (Schneider & Susi, 1994). Even less effort has been devoted to reducing these exposures.

The CA/T construction project in Boston is currently the largest public works project in the United States. The two main components of the project are (1) the building of a new underground highway, which runs beneath the city and connects freeways from the north and south, and (2) the construction of a third tunnel beneath Boston Harbor linking Logan Airport to downtown Boston.

The Construction Occupational Health Project (COHP) at the Department of Work Environment at the University of Massachusetts, Lowell, is funded by the National Institute for Occupational Safety and Health (NIOSH) through the Center to Protect Workers' Rights as part of a nationwide research effort to reduce WRMDs in the construction industry. The CA/T construction project has served as the site of the COHP's efforts to evaluate the hazards involved in large-scale highway construction projects. As part of this effort, the COHP has evaluated various finishing operations in the recently completed Ted Williams Tunnel, including wall plastering, wall tiling, ventilation duct panel installation, handrail installation, ceiling module assembly, and ceiling module installation. These operations are performed by a variety of union trades such as plasterers, tile mechanics and finishers, iron workers, and laborers.

The contractor responsible for the finishing operations in the tunnel recorded eight injuries on the Occupational Safety and Health Administration logs (OSHA-200 logs), over a 6-week period. Although this contractor employed many construction trades on this site, only iron workers had been injured during this period. Of the eight injuries, six were related to overexertion of the musculoskeletal system: two back strains, two shoulder strains, and two knee or ankle injuries. The contractor's site safety officer requested the COHP perform an analysis of the ceiling module assembly operation, which he considered to be hazardous. During this operation, iron workers assembled individual ceiling panels into 10-panel modules, which were later hung from the tunnel's ceiling.

Researchers conducted the evaluation to summarize some of the hazards found in the ceiling module assembly operation, and to provide recommendations for reducing the hazards and thus minimize the risk of future WRMDs. First, one assembly operation was evaluated and the resulting design recommendations to reduce hazards were given to the contractor. Later, the contractor developed a similar operation that included many of the design recommendations, and the hazards for the job tasks were re-evaluated with a similar analysis to determine which of the hazards had been eliminated or reduced.

## Analysis

### *General Ergonomic Analysis Methods*

The goal of an ergonomic job analysis is to identify the design aspects of a job that increase a worker's exposure to risk factors for WRMDs, in order to reduce these exposures. The commonly cited risk factors for WRMDs are

- Repetitive motions or prolonged activities
- Forceful exertions
- Awkward postures
- Localized contact stresses
- Temperature extremes
- Vibration

The analysis attempts to characterize the magnitude and duration of these exposures. An understanding of the entire work process is also important, so that interventions may be effectively targeted. Therefore, a systematic ergonomic job analysis similar to that described by Keyserling et al. (1991) is used in an ergonomic evaluation to identify the hazardous activities and list the work-related causes of these hazards (equipment or tool design, work organization). The steps involved in the ergonomic evaluation used in this study are listed in Table 11-1.

The initial steps in the ergonomic evaluation are used to describe the various levels of the overall work process. A taxonomy, or classification system, has been developed to aid in the description of the heavy highway construction process (Buchholz et al., 1996). The contents of this taxonomy are based on the "Standard Specifications for Highways and Bridges" used by the Massachusetts Highway

**Table 11-1.** Ergonomic Job Analysis Items

1. Describe the general process and construction stage.
   a. Identify the contractor for the construction site.
   b. Identify the operations being performed.
2. Describe the operation (number of workers, trades involved, locals, machinery, location on site).
   a. Provide a list of the workers (name, description, trade, level, years in trade, injury, symptoms, etc.).
   b. Describe work schedule (shift duration and scheduled breaks).
   c. Describe work pace for each job task (use interviews and observations).
   d. Describe job rotation (if any).
   e. Sketch layout of work area.
3. Describe each job task, break it into activities and identify ergonomic exposures.
   a. Identify ergonomic risk factors for each body region (back, arms, legs, and neck).
   b. Provide a list of tools and equipment, identifying factors influencing exposure level.
   c. Identify tasks/activities that need further evaluation.
4. Design and implement ergonomic interventions.
   a. List possible interventions for reducing hazards.
   b. Prioritize interventions based on anticipated effectiveness and feasibility.
   c. Implement appropriate interventions.
5. Re-evaluate the job tasks after interventions are made.
   a. Identify ergonomic risk factors for each activity of each job task.
   b. Identify tasks/activities that need further evaluation.
   c. List possible ideas for reducing hazards.

Department (1988). The taxonomy is organized hierarchically, with construction projects broken into a series of *stages* and, on a large construction project, different stages can be under way simultaneously along the length of the site. The primary stages in heavy highway construction are earthworks, drainage, paving, curbs and edging, fences and walls, and structures. Each stage may be composed of several *operations*, which are overseen by a foreman and other on-site supervisors and are completed by at least one crew of workers. Each operation consists of *job tasks* that are performed by an individual worker from a specific trade, which is usually defined jurisdictionally (i.e., construction trades negotiate for the right to perform specific job tasks). *Activities* are the fundamental acts required to complete a job task and are based on *work elements* (e.g., lift, carry, reach, grasp, and move) taken from the time-study methodology traditionally used by industrial engineers (Barnes, 1980). Because the taxonomy allows an analysis to be stratified by construction stage, operation, and task, as well as by the trades involved in each operation, it provides the means for achieving a task-based analysis. A comparable taxonomy could be developed for other industries to facilitate a similar task-based analysis.

The first step in the evaluation methodology then is to determine the stages and operations that are under way at the site. Workplace organization can have an important impact on the hazards, and therefore information about the operation's shift schedule, production demands, the physical layout, and material flow is obtained. This information is important for understanding the purpose of the operation of interest, how it is impacted by other operations and how it impacts other operations.

The operation to be studied is described in the second step using observationally collected information. To aid in this description, a narrative of the operation is obtained from engineers, supervisors, and workers on site. The gathered information includes a description of crew size and structure, a description of the work schedule and pace, and a sketch of the layout of the work area. The operation is then divided into job tasks performed by individual workers. Written documentation of the work (such as contract, engineering specifications or production schedules) may provide additional useful information.

In the third step, each job task is described and further divided into activities, listing the tools, equipment, and materials used. If possible, the work cycle is defined (i.e., a repeated set of activities are described in the order that they occur). This is usually difficult in the construction industry, because much of the work is noncyclical or the work cycles

**Table 11-2.** Important Ergonomic Risk Factors and the Guidelines Used to Identify Them

1. Repetitive motions
   a. Hand/wrist motions repeated once per second[1,2]
   b. Sustained static exertions[3]
2. Forceful exertions
   a. Whole body exertions >50 lb required to lift, push, or pull[4]
   b. Grip forces >10 lb[1]
3. Awkward (non-neutral) postures
   a. Trunk flexion >45 degrees[5]
   b. Trunk lateral bending or twist >20 degrees[5]
   c. Neck flexion or twist >30 degrees[6]
   d. Shoulder flexion or abduction >60 degrees[7]
   e. Wrist flexion/extension >45 degrees[2,8]
   f. Wrist radial/ulnar deviation >20 degrees[2,8]
   g. Pinch postures[2,8]
   h. Sustained kneeling or squatting[9,10]
4. Localized contract stresses[8]
5. Temperature extremes
   a. Heat[11]
   b. Cold[8]
6. Vibration
   a. Whole-body[12,13]
   b. Segmental (hand-arm)[14]

[1]Silverstein et al., 1986
[2]Armstrong et al., 1982
[3]Rohmert, 1973
[4]Waters et al., 1993
[5]Punnett et al., 1991
[6]Kilbom & Persson, 1987
[7]Bjelle et al., 1979[1]
[8]Armstrong, 1986
[9]Thun et al., 1987
[10]Felson et al., 1991
[11]Snook & Ciriello, 1974
[12]Wikstrom et al., 1994
[13]Seidel & Heide, 1986
[14]NIOSH, 1989

are long and irregular. However, in large heavy highway construction projects, workers usually perform the same daily job tasks for an operation, which takes weeks or months to complete, and some operations are even performed on temporary assembly lines.

Each job task is then analyzed for exposure to the risk factors for WRMDs. A checklist is usually used for this purpose. The advantages of a checklist are that it is fast, simple, and inexpensive to use. The primary disadvantage is that it gives no detail on the magnitude or duration of the exposure. Direct measurements using a force gauge, stop watch, tape measure, or goniometer can be used to add detail to the analysis. A systematic ergonomic job analysis similar to that described by Keyserling et al. (1991) is then used to identify the potentially hazardous activities and list the work-related causes of the hazards (such as equipment or tool design, work organization). Hazards are identified for the trunk, neck, shoulders, hands, wrists, and legs. Some of the important ergonomic risk factors found in the literature and the guidelines used to identify them are shown in Table 11-2.

A number of methods are available, if a more detailed analysis is desired. More detail can improve intervention targeting and provide a better measure for evaluation. For example, estimates of the percent of time workers spend in awkward postures or the frequency of wrist posture deviations for activities and tasks can be estimated. Methods for detailed evaluation of posture and motion range from direct observations (Buchholz et al., 1996; Karhu et al., 1977) to methods using videotape (Armstrong et al., 1982; Keyserling, 1986) and to electrogoniometers, which are instruments for detailed posture and motion measurement (Marras et al., 1993). The level of detail in an ergonomic analysis is usually determined by logistical considerations, such as time and resources.

The fourth step in this process is to design and implement interventions to control the workers exposure to the identified risk factors. Ideally, this should be a collaborative effort between the ergonomist, workers, management, and other stakeholders. The final step of the ergonomic method is to re-evaluate each of the job tasks for hazards using the same analysis that was used in the original evaluation, so that comparisons can be made between the pre- and post-intervention operations.

### *Specific Methods*

In this study, three researchers observed the operation for approximately 4 hours on each of 4 days over a 2-week period. Each job task was carefully observed for five to ten work cycles. The cycle of activities was recorded and the time needed to complete a cycle (cycle time) was determined to provide estimates of the frequency of activities performed throughout the shift. The hazards for each activity were identified using a checklist-like approach. In some cases the hazards were quantified using direct measurements (frequency of repetitive hand motions, load weights or forces, exposure duration), but in most cases the hazards were only identified. Equipment or work area design problems thought to be the cause of the hazards were also noted. Still photographs were taken to document the hazards for each job task. Temperature extremes and vibration were not considered a problem because of the relatively mild climate inside the tunnel and only nonvibrating hand tools were used.

Recommendations to improve the design of the operation were given to the Site Safety Officer. Some of these recommendations were incorporated in another assembly line that was later constructed for this operation. One researcher observed the operation on the new assembly line for 2 hours on three occasions. Again, information about the work area layout and equipment used was collected. The operation was divided into job tasks and each job task was divided into activities. The hazards associated with each of the activities were then identified. The hazards were then compared to those of the original operation.

### *Results of the Initial Ergonomic Evaluation*

#### *Stage and Operation*

The ceiling module assembly operation that was evaluated was part of the tunnel finishing stage of highway construction. Other operations in this stage include wall plastering, wall tiling, paving, guard rail installation, and ceiling module installation. Because attaching individual panels to the tunnel's ceiling would be difficult and time consuming, the contractor decided that it would be more efficient to first assemble groups of 10 panels together before installing them. Therefore, an assembly line that could accommodate a 10-panel module was constructed. An overhead monorail system was installed so that panels could be moved along the line. Pallets of panels and steel were delivered to the assembly line, and a large truck having a hydraulic flat bed was used to take the completed modules from the line and position the modules close to the ceiling for installation. The assembly line was located in one of the widest sections of the tunnel to minimize disruption of the other construction operations. When the assembly line was set up, little consideration was given to how well the characteristics of the line were suited for the workers assembling the ceiling modules.

The layout of the assembly line is shown in Figure 11-1. The work area was approximately 250 feet long and the assembly line was located 20 in. above floor level. Individual ceiling panels were 4 × 11.5 feet and weighed approximately 700 lb. The panels and steel connector beams were moved and lifted onto an assembly line with powered lifts. The lifts were activated with a four-button control and virtually eliminated manual lifting of the panels and connecting steel. However, panels and steel were manually adjusted (pushed or pulled across the rollers) after being placed on the assembly line. A crew of 10 iron workers (one woman and nine men) participated in the operation. The crew worked a standard 8-hour shift (7 AM to 3 PM). Job tasks were performed at a moderate, steady pace. The crew did not rotate among the various job tasks.

#### *Job Tasks and Hazards*

The operation was divided into four job tasks:

1. *Panel sorting.* Ceiling panels and beams required for assembly were sorted with one of the monorail's powered lifts.
2. *Panel preparation.* Rubber gaskets were glued onto the ceiling panels and the panels were delivered to the submodule assembly using the powered lift.
3. *Submodule assembly.* Sets of three to four panels were aligned and connected with steel I-beams and H-beams.
4. *Module assembly.* Submodules were bolted together into one 10-panel module.

Each assembled module was then connected to another of the monorail's lifts and loaded onto a truck having a hydraulic flat bed. In a separate operation, the module was later delivered to the installation location.

The cycle or sequence of activities for each job task was identified (Table 11-3). Cycle times for job tasks was variable, but the order in which workers performed the activities during a job task was relatively consistent. Each of the job tasks and the activities for which hazards were found are

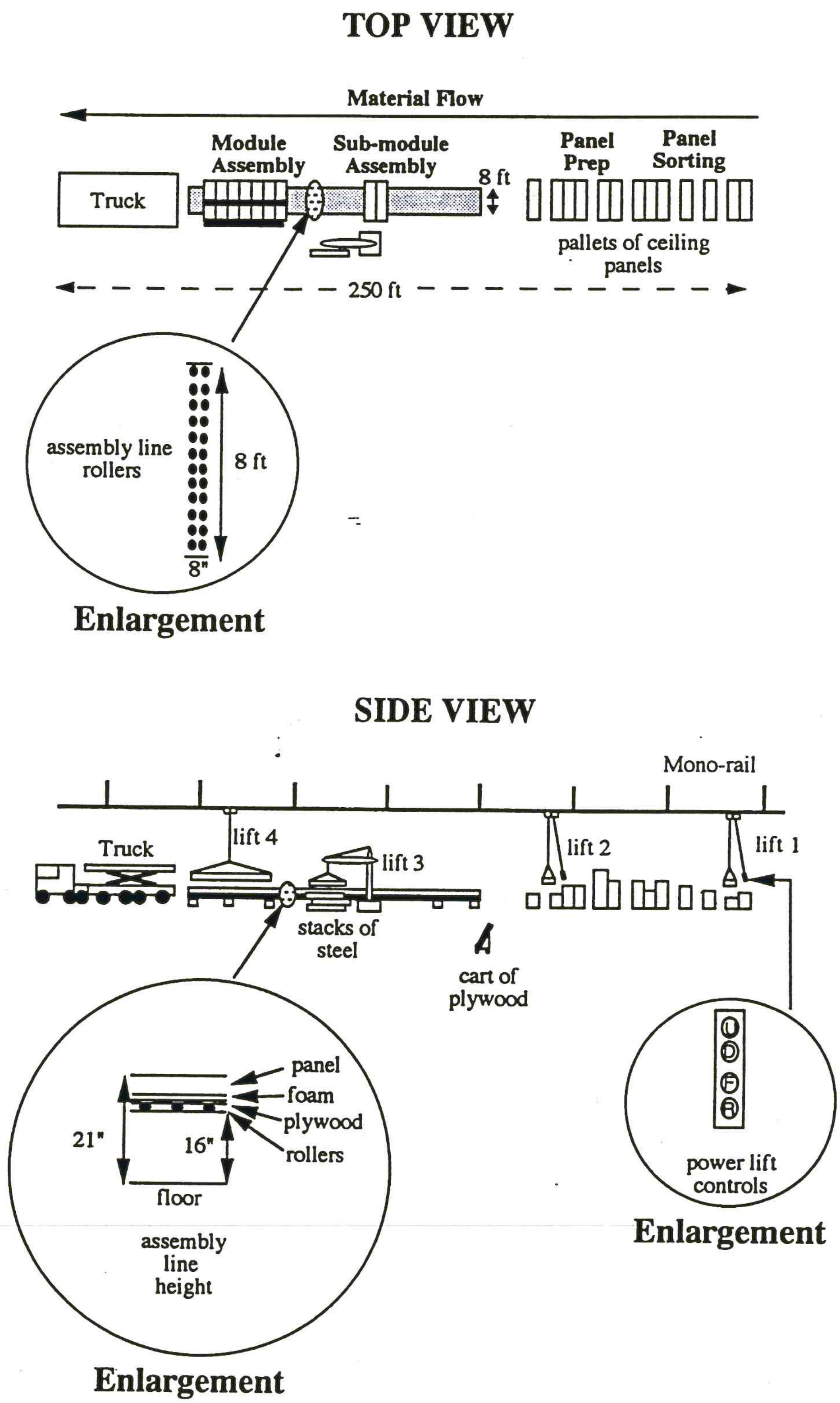


**Figure 11-1.** Ceiling module assembly operation.

**Table 11-3.** Job Tasks and Cycles of Activities During Ceiling Module Assembly

| Number of Workers | Major Activities |
|---|---|
| **Panel sorting and stacking** (cycles ranged between 1 and 10 minutes) | |
| 2 | Wrap strap around ends of pallet and connect strap to lifting cable |
| 1 | Operate powered lifter |
| 1 | Guide load |
| 2 | Disconnect strap from cable and unwrap strap from ends of pallet |
| **Panel preparation** (cycles ranged between 6 and 25 minutes) | |
| 1 | Use powered air-hose to blow screw holes clean of debris |
| 1 | Screw hooks into four corner screw holes |
| 1 | Wipe edges of panel with rag |
| 1 | Retrieve bolts, gaskets, and glue bottles |
| 2 | Align gaskets along edges of panel |
| 2 | Brush glue along panel edges |
| 2 | Brush glue on gasket |
| 2 | Glue gaskets onto panels* |
| 2 | Cut excess gasket with scissors* |
| 2 | Operate powered lift, guide load, place panel onto rollers |
| 2 | Push panel down assembly line* |
| 2 | Take out corner hooks |
| 1 | Operate powered lift to pick up new ceiling panel |
| 1 | Perform miscellaneous clean-up (align boards, etc.) |
| 1 | Screw hooks into new panel |
| **Submodule assembly** (cycles ranged between 20 and 70 minutes) | |
| 2 | Align three or four panels on rollers* |
| 2 | Retrieve clamps |
| 2 | Clamp together submodule |
| 2 | Retrieve rubber gaskets and glue bottles |
| 2 | Align gaskets |
| 1 | Retrieve cart of wood, place wood in cart |
| 2 | Brush glue along submodule |
| 1 | Position washers, nuts, bolts near holes |
| 1 | Glue gasket onto submodule* |
| 2 | Hook lift to I-beam |
| 2 | Operate lift/guide load |
| 1 | Press gasket onto submodule |
| 2 | Push submodule under I-beam |
| 2 | Align I-beam with pins* |
| 2 | Bolt I-beam to panels* |
| 1 | Hook lift to H-beam, operate powered lift |
| 1 | Continue ratchet work |
| 1 | Align H-beam on pins* |
| 1 | Bolt H-beam to submodule* |
| 1 | Tighten bolts with 45 ft-lb ratchet* |
| 2 | Unhook clamps |
| **Module assembly** (cycles ranged between 60 and 200 minutes) | |
| 1 | Push submodule 1 down the assembly line* |
| 1 | Align submodule 1 |
| 1 | Push submodule 2 down the assembly line* |
| 1 | Align submodule 2 |
| 3 | Get ratchets, wrenches, and bolts |
| 2 | Put brackets and hardware on I-beams and H-beams |

**Table 11-3.** *Continued*

| Number of Workers | Major Activities |
|---|---|
| 1 | Push submodule 3 down the assembly line* |
| 1 | Align submodule 3 |
| 2 | Bolt brackets to submodules 24 times* |
| 2 | Tighten down brackets with a 350 ft-lb calibrated torque wrench 8 times |
| 1 | Hook winch to assembled module |
| 1 | Operate powered winch to move module* |

*Potential hazards.

described below. The hazards for each of the listed activities and related work area design problems are summarized in Table 11-4.

**Panel Sorting.** Two iron workers sorted the ceiling panels and connecting steel with one of the monorail's lifts (one worker operated the lift, the other guided the panel). The panels were sorted in the order in which they were to be assembled. Each ceiling panel had been tagged with an alphanumeric identification code. The activities in this job task were not considered particularly hazardous.

**Panel Preparation.** Two iron workers retrieved individual ceiling panels with another of the monorail's lifts, and stacked them near the assembly line. The iron workers glued rubber gaskets onto the ceiling panels and then delivered the panels to the assembly line using the powered lift. The panels were lowered onto plywood sheets, which protected the panels from being damaged by the rollers and were pushed manually on the rollers to the submodule assembly. Potential hazards were identified for three activities:

1. *Gluing the gasket onto the panel.* The gaskets were carefully aligned and pressed against the glued submodules. The work height was at or below waist level (depending on where the panel was located during the sorting job task) for more than half of the work cycles observed. When the work height was low the workers flexed their trunk more than 45 degrees (usually close to 90 degrees) or squatted when pressing the gasket onto the panel in order to view the gaskets. The workers assumed these postures for approximately 2–5 minutes each time they glued the gasket onto a panel that was at or below waist height.

2. *Cutting the excess gasket with scissors (Figure 11-2).* Cutting the excess gasket was also an activity requiring a high degree of precision and therefore the worker again kept the gasket near the eyes. The worker flexed the trunk or squatted while cutting the gasket, although such postures were usually maintained less than 1 minute.

3. *Pushing the panel down the assembly line.* This was the most physical activity during panel preparation. After each panel was placed on the assembly line of rollers it was manually pushed 10–30 feet down the assembly line. Because the height of the panel when on the assembly line was approximately 21 in., the workers were required to flex or twist their trunk over 45 degrees while pushing. Workers also mentioned that it was sometimes difficult to push the panels because the plywood not roll easily on the rollers.

**Submodule Assembly.** Sets of three or four panels were aligned by one or two iron workers. Steel beams were aligned with a powered crane lift (not on the monorail) and bolted to the ceiling panels to form a submodule by two iron workers. Potential hazards were identified for five activities:

1. *Aligning the panels on rollers (Figure 11-3).* The workers were required to flex or twist their trunks over 45 degrees and usually twist their necks while aligning the panels. The weight of the panels placed high forces on the workers' backs and shoulders while pushing the panels.

2. *Gluing the gasket onto the submodule (Figure 11-4).* The workers were required to flex their trunks more than 45 degrees or squat when pressing the gasket onto the submodule. The workers assumed these postures for approximately 2–5 minutes for each gasket.

3. *Aligning the steel with the pins (Figure 11-5).* The steel I- and H-beams each weighed more than 200 lb and the workers were required to push or pull the

Table 11-4. Summary of the Potential Hazards Identified for Each Job Task

| Activity | Body Area | Highly Repetitive Motions | High Forces | Static Non-Neutral Postures | Contact Stresses | Work Area Design Problems |
|---|---|---|---|---|---|---|
| **Panel preparation** | | | | | | |
| Gluing gasket onto panel | Trunk | | | √ | | Low work surface |
| | Legs | | | √ | | |
| Cutting excess gasket with scissors | Trunk | | | √ | | |
| | Legs | | | √ | | Low work surface |
| Pushing panel down assembly line | Trunk | | √ | √ | | Winch not accessible or fast enough |
| **Submodule assembly** | | | | | | |
| Aligning the panels on rollers | Trunk | | √ | √ | | Manual alignment required |
| | Neck | | √ | √ | | and work surface is low |
| | Shoulder | | | | | |
| Gluing the gaskets onto the submodule | Trunk | | | √ | | |
| | Neck | | | √ | | Low work surface |
| Aligning the steel with the pin | Trunk | | √ | √ | | |
| | Neck | | | √ | √ | Low work surface |
| | Legs | | | | | |
| Bolting the steel to the panels | Trunk | | √ | √ | | Low work surface and |
| | Shoulder | √ | √ | | √ | tighten bolts manually |
| | Hand/Wrist | | | √ | √ | |
| | Legs | | | | | |
| Tightening the bolts with the 45 ft-lb ratchet | Trunk | | √ | √ | | Low work surface and |
| | Shoulder | √ | √ | | √ | tighten bolts manually |
| | Hand/Wrist | | √ | √ | √ | |
| | Legs | | | | | |
| **Module assembly** | | | | | | |
| Pushing submodule down assembly line | Trunk | | √ | √ | | Winch not accessible or |
| | Shoulder | | √ | | | fast enough |
| Tightening bolts | Trunk | | | √ | | Low work surface and |
| | Neck | | √ | √ | | tighten bolts manually |
| | Shoulder | √ | √ | | √ | |
| | Hand/Wrist | | | √ | √ | |
| | Legs | | | | | |
| Operating powered winch | Trunk | | | √ | | Winch low |
| | Legs | | | √ | | |

beams manually to align them. While doing this, the workers had to flex their trunks over 45 degrees and assume squatting or kneeling postures and remain in these postures for as much as 3 or 4 minutes.

4. *Bolting the steel to the panels.* Two beams were each attached to a submodule with approximately 10 bolts. For each bolt, the workers usually had to flex their trunks greater than 45 degrees or squat or kneel for up to 1 minute. During this time, the workers flexed or extended their wrist at least 45 degrees approximately 60 times. Therefore, workers assembling submodules deviated their wrists approximately 300 times per submodule (two workers connected the 10 bolts).

5. *Tightening bolts with the 45 ft-lb ratchet.* One worker finished tightening each of the bolts with a ratchet calibrated to 45 ft-lb. This activity required the worker to jerk the ratchet toward his body during each turn of the bolt. This was done until the bolt was tightened the desired 45 ft-lb, at which time the ratchet released its resistance (slipped). The worker usually assumed a three-point crawling (knees and one hand on panel) or kneeling posture while using the ratchet.

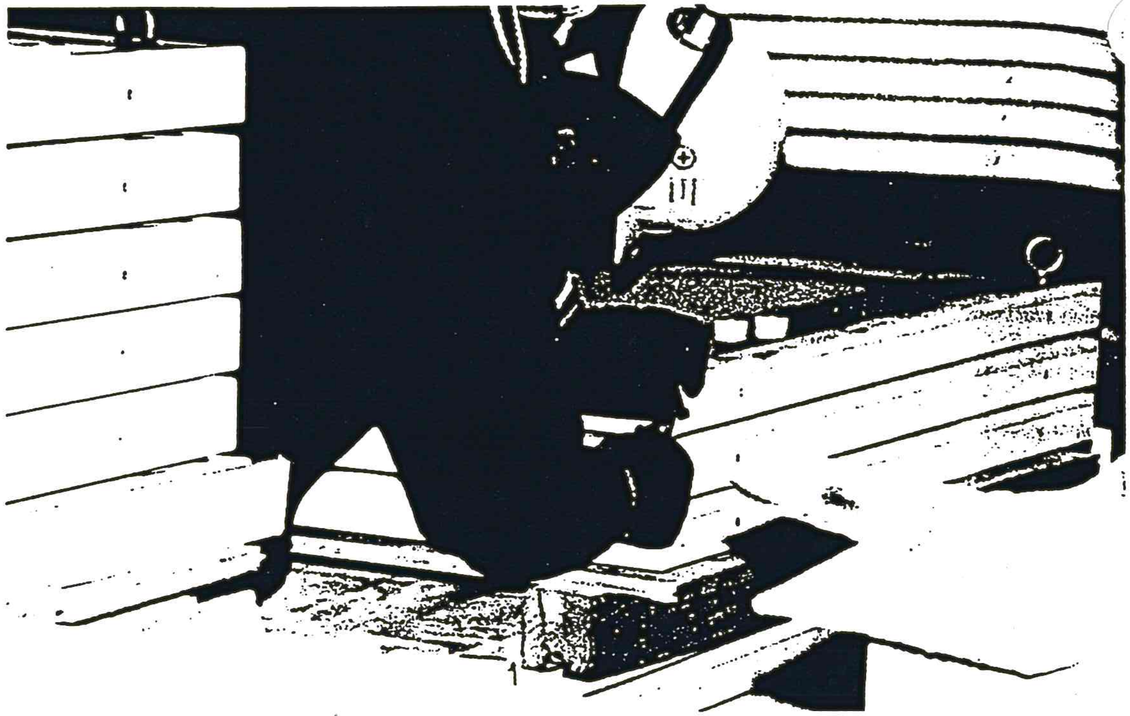

**Figure 11-2.** A low work height forced the worker to flex his trunk when cutting the excess gasket during panel preparation.

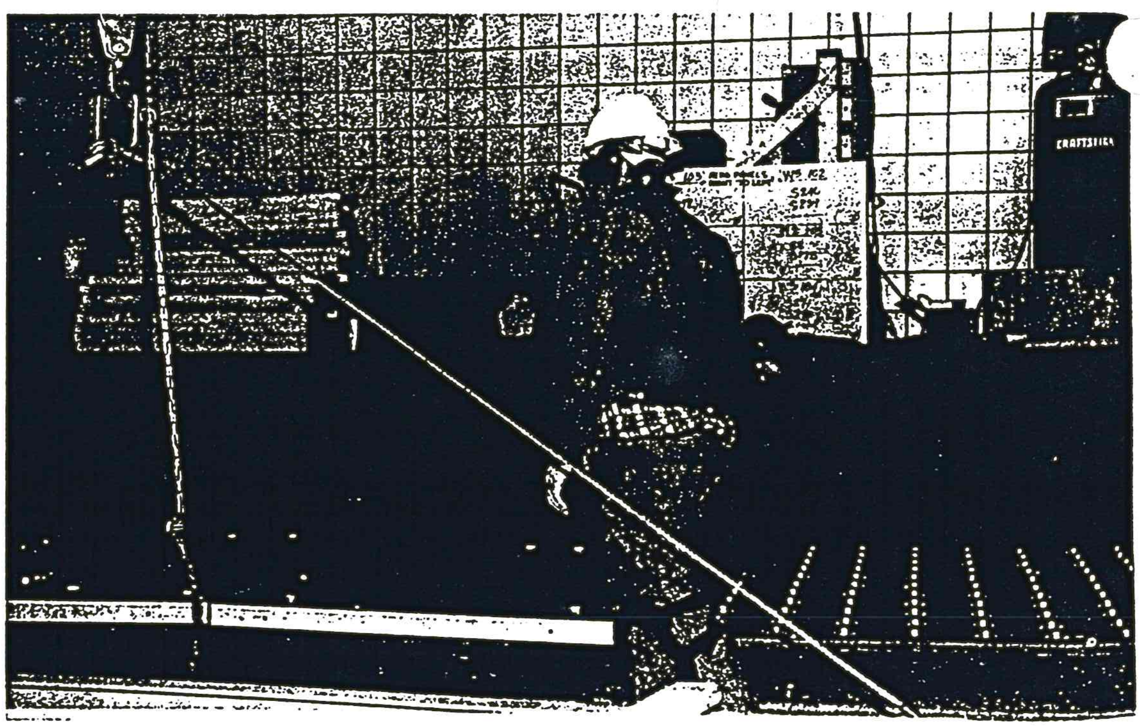

**Figure 11-3.** Workers aligned the panel on the rollers for the submodule assembly. The weight of the panel (approximately 700 lb) and the low height of the assembly line resulted in non-neutral postures of the trunk and neck and high forces on the shoulders and back.

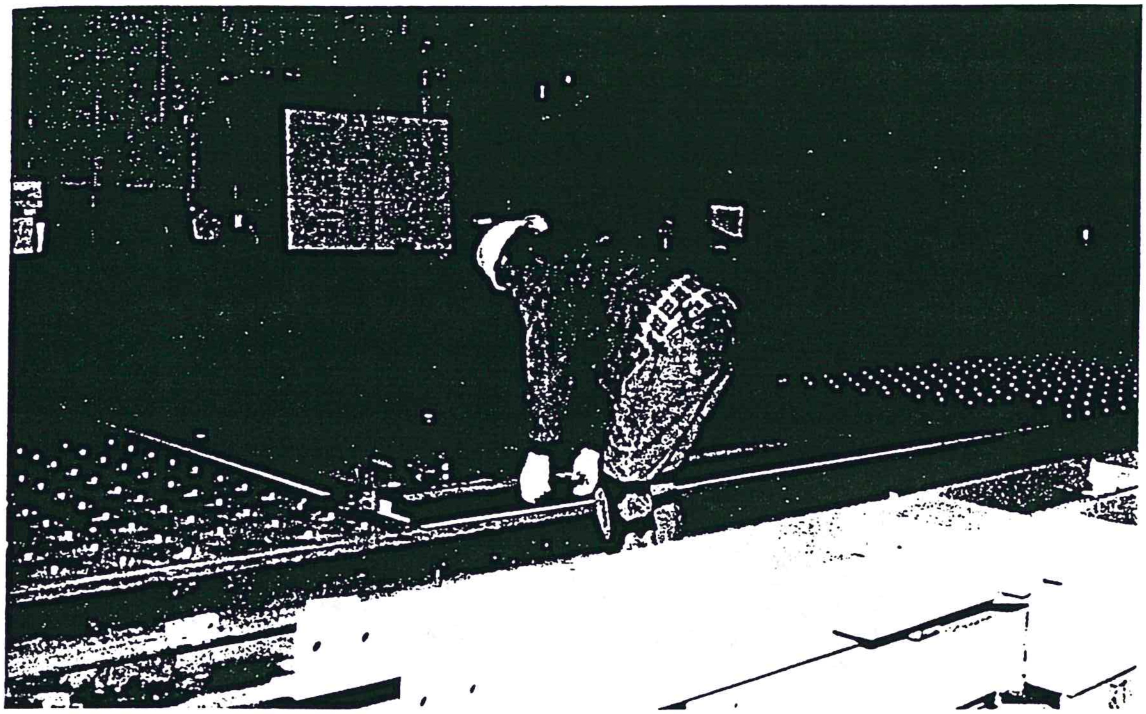

**Figure 11-4.** The worker flexed his trunk while gluing the gasket during submodule assembly because the assembly line height was below his knees.

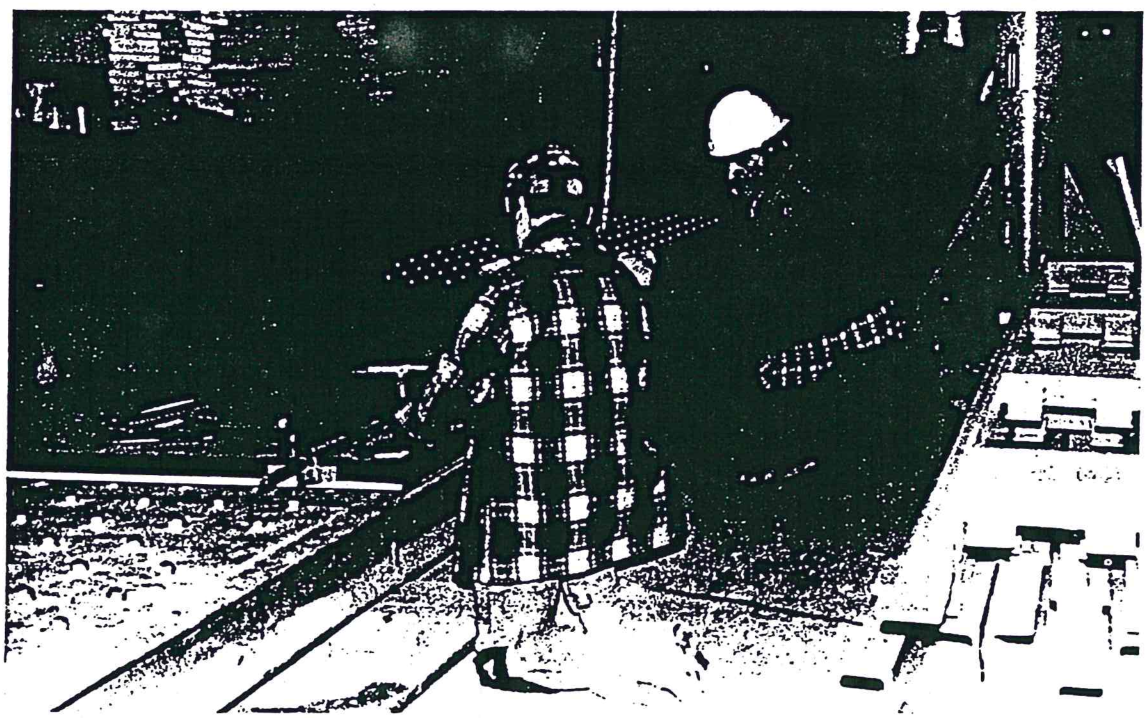

**Figure 11-5.** When aligning the steel with the pins during submodule assembly, the workers experienced static non-neutral postures of the legs and trunk and high forces on the back. The workers wore knee pads to reduce the contact stress placed on their knees.

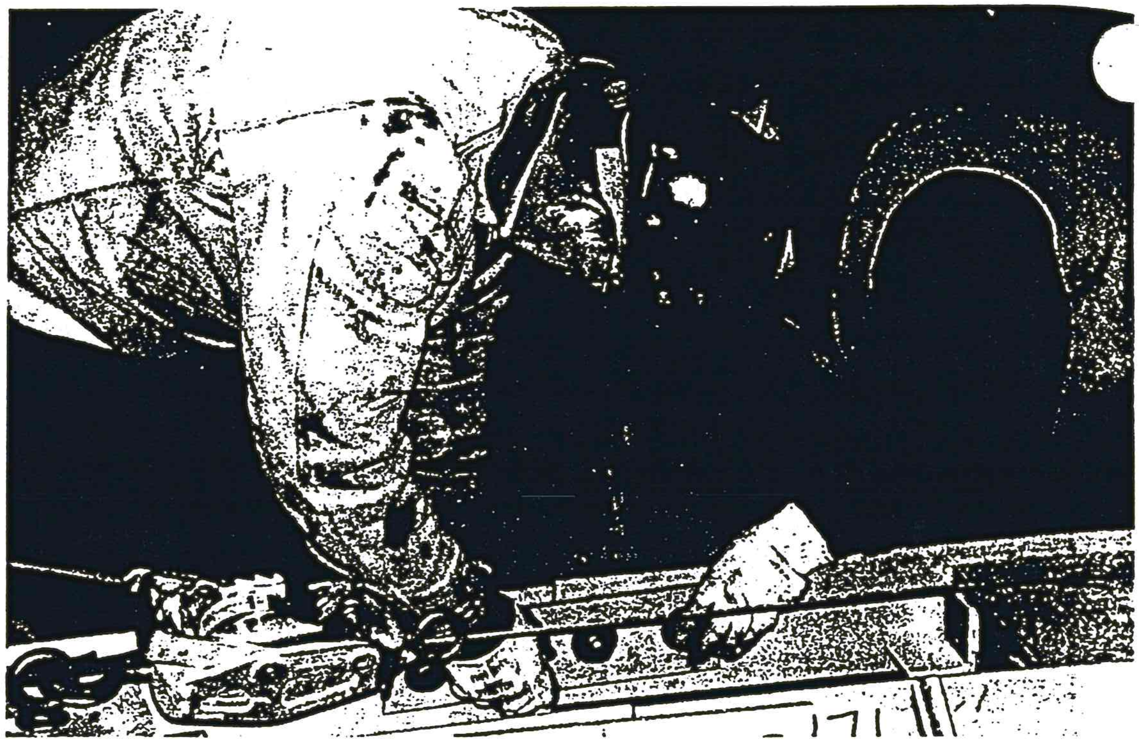

**Figure 11-6.** The low height of the assembly line required workers to flex their trunk while tightening the bolts that splice the submodules together into one module.

**Module Assembly.** Three to four iron workers manually pushed the submodules 20–60 ft. Two to four iron workers bolted groups of three submodules together into one assembled module. The iron worker foreman inspected the modules. The assembled panels were then connected to another of the monorail's lifts and positioned on the truck. Hazards were found for three activities:

1. *Pushing the submodule down the assembly line.* The three or four workers who manually pushed the submodule, weighing 2,500–3,200 lb, down the assembly line had to flex or twist their trunk greater than 45 degrees. This activity was considered to be the one that required the greatest overall exertion by the workers. This was done once every 20–70 minutes.
2. *Tightening bolts (Figure 11-6).* The workers were required to bend their trunk greater than 45 degrees while bolting the submodules together. Workers were observed with their neck flexed greater than 30 degrees during this activity. Twelve bolts were used to connect two submodules. While bolting, the workers flexed or extended their wrist at least 45 degrees approximately 60 times. Each bolt took up to 1 minute to tighten.
3. *Operating the powered winch.* The powered winch, used to move the assembled module beneath the monorail's third lift, was located below knee height. Therefore, the worker was required to assume awkward trunk and leg postures. This activity took approximately 1 minute to complete.

*Summary of Potential Hazards*

Some of the most stressful hazards included

1. Non-neutral trunk, neck, and leg postures caused by the low work-surface heights
2. Heavy loading and static non-neutral trunk

postures during the manual pushing of ceiling panels and submodules

3. Repetitive/forceful wrist deviations during bolting activities

## Design Intervention

The researchers made several recommendations to improve the design of the assembly operation and increase worker awareness of the hazards. These recommendations were first communicated to the site safety representative verbally, and later were included in a brief report to the contractor. In the report, it was recommended that the workers be consulted before any of the interventions were implemented. It was thought that the workers should have control over which of the suggested interventions to accept, and that the workers would have the best understanding as to whether or not the recommendations would disrupt the operation. Most of the recommendations called for changes in the design of the workplace because engineering controls have been shown to be more effective than administrative controls or personal protective equipment for reducing hazards.

### *Recommendations for Ceiling Module Assembly*

1. *Raise the height of the working surface for panel preparation.* Providing a work surface height of at least 40 in. (approximately waist height) for the panel gluing activity during panel preparation would reduce the frequency and duration of awkward trunk and leg postures during the panel preparation job task.

2. *Increase the height of the rollers and add stairs.* Increasing the height of the assembly line rollers to approximately 36 in. (slightly below waist height) would reduce the frequency and duration of non-neutral trunk and leg postures during the submodule and module assembly job tasks. Stairs would then need to be installed to allow workers to easily get on and off of the assembly line.

3. *Possible use of powered ratchets.* Using powered ratchets, calibrated to the 45 ft-lb of torque that is required in the bolting activities would reduce the frequency of wrist motions during the submodule and module assembly job tasks and reduce the duration in which workers are in non-neutral trunk postures.

4. *Improve the design of the powered winch.* The powered winch was not always used to move submodules for submodule assembly because the winch frequently malfunctioned, was not easy to use, or was not fast enough. The winch should be raised to approximately 36 in. from the floor. If feasible, the speed at which the winch pulls the submodules should be increased. A back-up winch should be purchased to replace the winch when it is not functioning properly.

5. *Provide ergonomics training.* Providing the workers with basic ergonomics training that explains the importance of maintaining neutral postures and minimizing heavy manual material handling should increase each worker's ability to recognize hazards and may help reduce the risk to musculoskeletal injury caused by hazardous work procedures.

### *New Design*

A similar ceiling module assembly work area was later developed at a different location in the tunnel. Several improvements were made to this work area that reduced some of the hazards mentioned above. The improvements included

1. *Increased panel preparation work height (Figure 11-7).* Panels were raised with the powered lift to over 40 in. from the floor during panel preparation.

2. *Increased assembly line height (Figure 11-8).* The height of the assembly line was increased and slightly tilted downward from beginning to end so that gravity would assist the workers when pushing panels and submodules. The assembly line heights ranged from approximately 36 in. at the beginning to 18 in. at the end. This was done simply by installing sheets of wood of different heights beneath the assembly line. Stairs were installed so that workers could get on and off of the assembly line easily.

3. *Fork truck replaced powered winch.* A fork truck replaced the powered winch eliminating the awkward static trunk and leg postures when the winch was operated.

4. *Ergonomics training.* The workers in this operation received a basic 20-minute training session about body mechanics and lifting techniques for reducing stress on the lower back during manual material handling.

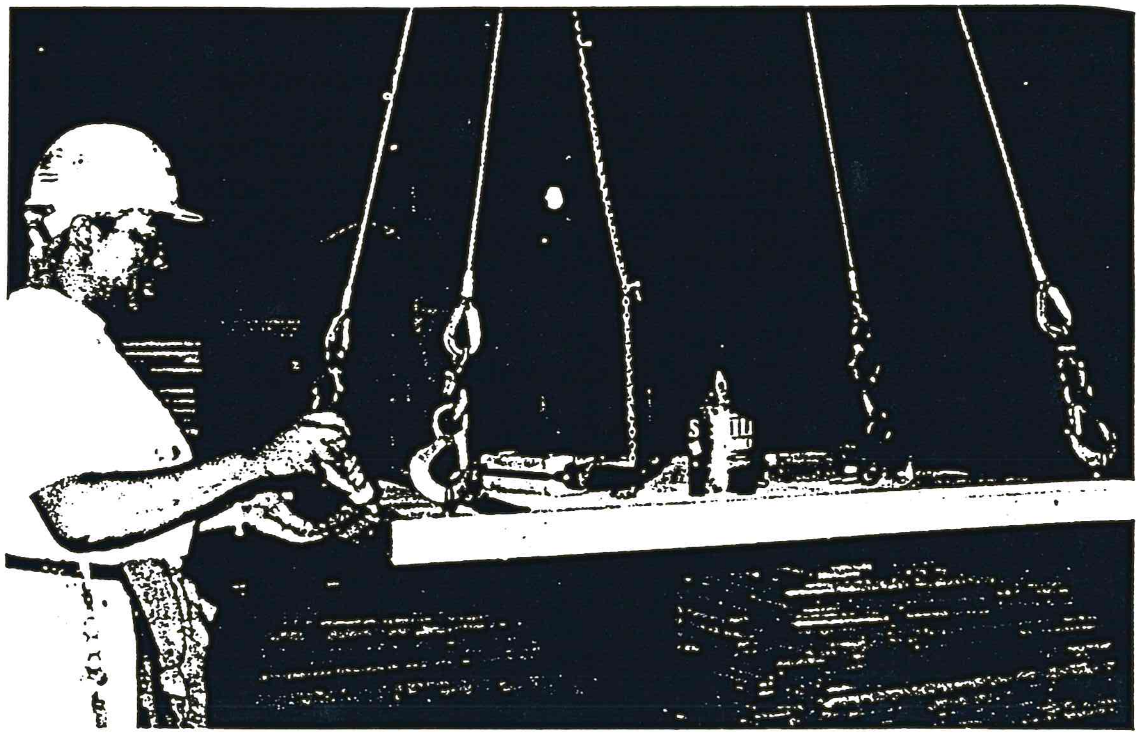

**Figure 11-7.** The panels were raised to a more suitable working height to reduce static non-neutral trunk and leg postures during panel preparation.

## Test and Evaluation

The effectiveness of an ergonomic intervention may be evaluated by measuring the change in morbidity data (such as musculoskeletal injuries rates, absenteeism due to musculoskeletal injuries, prevalence of musculoskeletal symptoms) or the change in hazards that follows the intervention. Sometimes, morbidity or exposure data can be compared to that of a similar group of workers that are not introduced to the intervention (a control group).

It is important to understand some of the logistical difficulties that arise when evaluating an intervention. There are a variety of factors that may confound the effect of an intervention. For example, changes in production demands and economic considerations may affect absenteeism, willingness to report symptoms, and job turnover. Additionally, when only a small group of workers are affected by an intervention, it may be difficult to show a positive change in morbidity or exposure with conventional scientific methods due to a lack of statistical power. Finally, reductions in injuries or symptoms may not immediately follow an intervention. It is therefore important to select a time interval for the intervention that is short enough to minimize the potential possibility for external changes in the workplace and long enough for the true benefit of the intervention to be observed (such as reduction in morbidity or exposure).

In this study, injury data specific to the assembly operations could not be obtained from the contractor (only trade-specific information was available). Therefore, a reassessment of the exposure to poor ergonomic design (i.e., hazards) for each of the tasks was chosen to evaluate the new assembly line. Because of the small number of workers and generally crude measures of exposure, no formal statistical tests were performed. Two important assumptions for this type of analysis are that change in exposure can be identified reliably and that the exposure is a true predictor of the musculoskeletal health outcome of concern.

The work area layout, job tasks, and number of workers performing each job task on the new assembly line were almost identical to those of the original

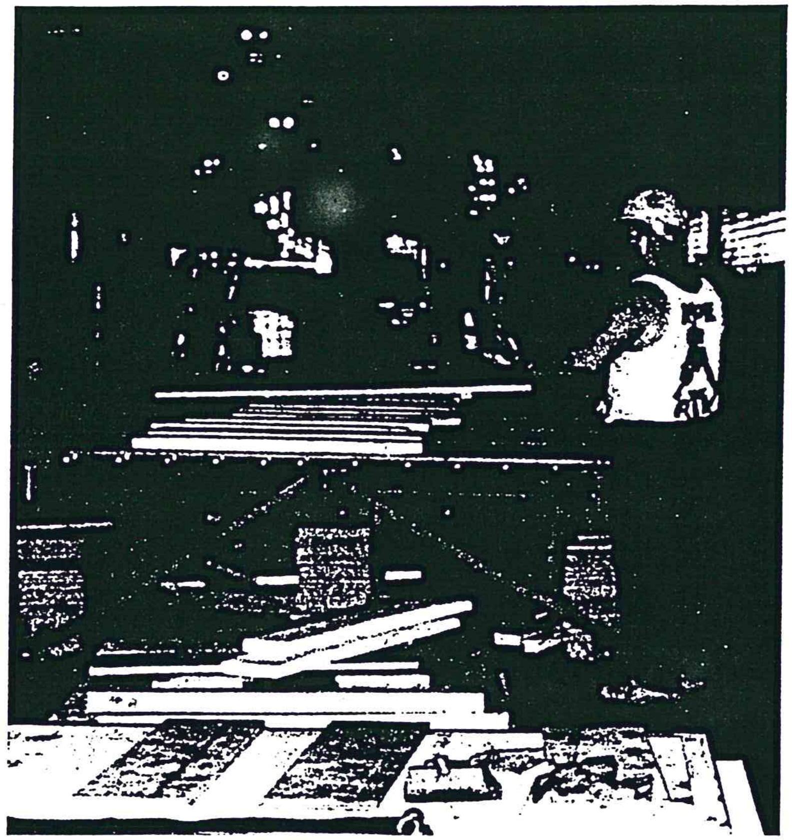

Figure 11-8. Wood was inserted beneath the rollers to increase the height of the assembly line. This helped reduce static non-neutral trunk and neck postures during the submodule assembly.

assembly line with the exception of the improvements mentioned above. The sequence of activities within each cycle as well as cycle times was also similar to the initial operation. The cost of the improvements was limited to the cost of labor and materials (wood) used to raise the height of the line. The training was provided by the researchers as a free service. (The only cost to the contractor was wages for 20 minutes for the 10 iron workers.) Slightly more than 43% of the hazards identified during the earlier operation were eliminated or reduced (Table 11-5). Static non-neutral trunk and leg postures during panel preparation were eliminated with the increased work height. The higher assembly line reduced static non-neutral trunk and leg postures during the manual handling of panels. The tilted assembly line helped reduce forces on the trunk and shoulders during manual pushing of the panels.

Non-neutral static trunk and leg postures for several activities during submodule assembly were affected very little, because workers had to work on top of the panels when aligning and bolting steel. The forceful and repetitive hand motions also remained unchanged during bolting activities. Workers had explained that powered ratchets could not be used because construction design specifications required manual bolting to obtain the desired torque.

## Conclusion

Although not all hazards were eliminated with the new ceiling module assembly operation, this case study demonstrates how hazards can be systematically evaluated and how relatively simple interventions can be used to reduce hazards and help prevent musculoskeletal injuries from occurring in the future. Interventions such as assembly work heights at or above waist height, locating controls

**Table 11-5.** Summary of the Potential Hazards for Each Job Task with the Improved Design

| Activity | Body Area | Highly Repetitive Motions | High Forces | Static Non-Neutral Postures | Contact Stresses | Work Area Design Improvements |
|---|---|---|---|---|---|---|
| **Panel preparation** | | | | | | |
| Gluing gasket onto panel | Trunk | | | E/R | | Height of work surface |
| | Legs | | | E/R | | increased |
| Cutting excess gasket | Trunk | | | | | |
| with scissors | Legs | | | E/R | | Height of work surface |
| | | | | E/R | | increased |
| Pushing panel down | Trunk | | E/R | E/R | | Assembly line height |
| assembly line | | | | | | increased and tilted |
| **Submodule assembly** | | | | | | |
| Aligning the panels on | Trunk | | E/R | E/R | | Assembly line height |
| rollers | Neck | | E/R | E/R | | increased |
| | Shoulder | | | | | |
| Gluing the gaskets onto | Trunk | | | E/R | | Assembly line height |
| the submodule | Neck | | | E/R | | increased |
| Aligning the steel with | Trunk | | √ | √ | | |
| the pin | Neck | | | √ | √ | |
| | Legs | | | | | |
| Bolting the steel to the | Trunk | | √ | √ | | |
| panels | Shoulder | √ | √ | | √ | |
| | Hand/wrist | | | √ | √ | |
| | Legs | | | | | |
| Tightening the bolts with | Trunk | | √ | √ | | |
| the 45 ft-lb ratchet | Shoulder | √ | √ | | √ | |
| | Hand/wrist | | √ | √ | √ | |
| | Legs | | | | | |
| **Module assembly** | | | | | | |
| Pushing submodule down | Trunk | | E/R | E/R | | Assembly line height |
| assembly line | Shoulder | | E/R | | | increased and tilted |
| Tightening bolts | Trunk | | | E/R | | Assembly line height |
| | Neck | | √ | E/R | | increased and tilted |
| | Shoulder | √ | √ | | √ | |
| | Hand/wrist | | | √ | √ | |
| | Legs | | | | | |
| Operating powered winch | Trunk | | | E/R | | Winch not used |
| | Legs | | | E/R | | |

E/R denotes a hazard that was eliminated or reduced in the improved design.

at or above waist height, and ergonomics training may be applicable to a variety of assembly operations, including those not on construction sites.

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