Ergonomic Analysis of Construction Tasks for Risk Factors for Overexertion Injuries

Final Report
NIOSH Grant #5 R03 OH03154-02
Technical Report UMCEE 96-27
May 6, 1997

by John G. Everett, Ph.D., P.E.

Center for Construction Engineering and Management
Department of Civil and Environmental Engineering
2352 G. G. Brown Lab
University of Michigan
Ann Arbor, MI 48109-2125

Table of Contents

List of Tables

Significant Findings

Each of sixty-five common construction activities was broken into several constituent tasks and evaluated for seven generic risk factors for overexertion injuries: repetitive exertions, static exertions, forceful exertions, localized mechanical stresses, posture stresses, low temperature, and vibration. For each risk factor, each step is rated on a scale of 1 to 3, corresponding to an ordinal scoring system where: 1 = Insignificant: The job is free of potentially harmful ergonomic stresses in the risk factor of interest. No corrective actions are necessary; 2 = Moderate: The job has stresses in the risk factor of interest that could be problematic (i.e. cause fatigue and/or injury) for some workers. Additional analyses using more precise methods should be used to determine the necessity for intervention; and 3 = High: The job has significant stresses in the risk factor of interest that are likely to cause fatigue and/or injury in some workers. Additional analyses and interventions should be taken at a high priority.

According to the scoring system, any task and its associated activity with a score of 3 should be considered a high priority for additional analysis and intervention, but virtually every activity has at least one risk factor with a score of 3. Of the sixty-five activities, fifty-three had at least one constituent task with at least two risk factors with scores of 3. Thirty-seven activities had at least one constituent task with at least three risk factors with scores of 3. Clearly there are serious ergonomic hazards throughout all construction trades.

Two detailed studies have been conducted to attempt to improve the tools and methods used by craft workers. One study involves a series of experiments to analyze vibration in hammer handles. One hammer model with a steel handle transmits significantly less ($p<0.05$) vibration to the user than a wood handled hammer. This research not only quantifies the vibration levels in a variety of hammers, but contradicts the myth that wood handled hammers offer superior vibration characteristics than steel handled hammers.

A second study evaluates the effect of drywall panel and joint orientation on productivity and postural stresses for drywall finishers. Depending on the wall geometry, the choice between

vertical and horizontal joint orientation can make a large difference in the time required to finish the joints. Horizontal joints are preferred by craft workers because they do not require the constant bending down and reaching overhead associated with vertical joints.

Usefulness of Findings

The findings of the research have widespread application in the construction industry. Most earlier research in this area has looked at construction activities for potential ergonomic hazards. This research breaks each activity into several tasks and evaluates the tasks individually. With this approach, specific problems are identified. In many cases, only one or two specific attributes of an activity need to be improved, there is no need to completely redesign the entire activity. This focused approach is more likely to be embraced by an industry that is reluctant to make any changes at all.

Other researchers may use the results to identify specific tasks for further investigation. From the beginning, it was expected that the scoring system would be used to identify problems, not to solve them. The results show that ergonomic hazards are rampant and that further investigation and intervention is warranted in most types of construction work.

The two detailed studies evaluating hammer vibration and drywall panel and joint orientation have immediate usefulness to the construction industry by themselves. On a more general level, these two examples demonstrate that significant improvements can be made in construction work by simply making better informed choices from among existing alternative tools and methods. Frequently, craft workers and construction managers base their choice of tools and methods on tradition, myth, and productivity concerns, when there may or may not be any sound basis for the choice.

Ergonomic Analysis of Construction Tasks for Risk Factors for Overexertion Injuries

by John G. Everett, Ph.D., P.E.

Abstract

Overexertion injuries are the single largest classification of injury in construction, accounting for about 24% of all injuries. Overexertion injuries generally occur as a result of performing a given task as planned. While overexertion injuries are not intentional, the underlying causes of the injuries are built into the prescribed tools and work methods. If the causes can be identified, it should be possible to engineer them out of the work. The objectives of this project are to develop a catalog of construction tasks and to analyze each task as a whole and each step of each task for the presence of seven generic risk factors for overexertion injuries: repetitive exertions, static exertions, forceful exertions, localized mechanical stresses, posture stresses, low temperature, and vibration. Ratings for each risk factor have been made on a three point scale: 1 = insignificant, 2 = moderate, and 3 = high.

Virtually every activity has at least one risk factor with a score of 3. Of the sixty-five activities, fifty-three had at least one constituent task with at least two risk factors with scores of 3. Thirty-seven activities had at least one constituent task with at least three risk factors with scores of 3. Clearly there are serious ergonomic hazards throughout all construction trades.

As an example of evaluating alternative tools that are used in many different activities, experiments were conducted to measure the vibration transmitted to craftworkers' hands and wrists by eight (8) widely used types of claw hammers. The experimental results show a statistically significant difference ($p < 0.05$) in vibration transmission (weighted rms acceleration) between two of the hammers. A steel handled hammer with a wood plug in the head transmits 31% less vibration than another wood handled hammer. These results are in contrast with the widely held

belief among craft workers that wood handled hammers transmit the least vibration and steel handled hammers transmit the most vibration.

A second study evaluates the effect of drywall panel and joint orientation on productivity and postural stresses for drywall finishers. Depending on the wall geometry, the choice between vertical and horizontal joint orientation can make a large difference in the time required to finish the joints. Horizontal joints are preferred by craft workers because they do not require the constant bending down and reaching overhead associated with vertical joints.

Introduction

Construction has one of the worst safety records of any industry. The construction industry employs about 5% of the work force, but accounts for 11% of occupational injuries and 18% of all occupational fatalities (*Accident* 1996). Overexertion injuries resulting from work activities (e.g. low back pain, cervicobrachial disorders, and upper extremity cumulative trauma injuries) are the single largest classification of injury in construction, accounting for about 24 percent of all construction injuries (*Construction* 1992). The Bureau of Labor Statistics and OSHA define overexertion injuries as "nonimpact cases in which the injury resulted from excessive physical effort, as in lifting, pulling, pushing wielding, or throwing the source of injury. Includes conditions resulting from repetitive motion in the use of hand tools" (*Method* 1962).

Increased recognition by the medical community, insurance carriers, and by the workers themselves has contributed to this dramatic increase in reporting of these injuries. For example, in 1981, the number of new reports of disorders associated with cumulative trauma was about 20,000, representing 18% of all illnesses for all industries. By 1992, 292,000 new cases were reported, representing 62% of all new cases (*Occupational* 1995).

Because cumulative trauma disorders and other overexertion injuries tend to be "unreported or misdiagnosed, statistics on the extent of the problem in construction are elusive. Nonetheless, 'All the crafts have it,' claims Jim E. Lapping, director of the AFL-CIO Building and Construction Trades Dept." ("Repeat" 1989).

As bad as the construction industry's safety record is, it is likely to get worse if current practices continue. Demographic projections show that the age of the civilian work force is increasing, from a median 34.3 years in 1980 to a predicted 40.6 years in 2005 (*Projections* 1988). While older construction craft workers generally experience lower injury rates than younger workers (*Construction* 1992), probably due to their increased awareness of the hazards of the work (Oglesby et al. 1989), the consequences of injuries (e.g. days of lost or restricted work) are more serious for older workers (Abraham et al. 1996). The Bureau of Labor Statistics projects that

there will be about one million additional workers age 45 and above each year for the next 20 years (*Projections* 1988). The trend is largely due to the aging of the baby-boom generation. By 2005, 15 percent of the workforce is projected to be 55 years or older.

Workers of either gender gradually lose strength as they age. The strength of an average 65 year old person is only 75-80 percent of the peak strength that occurs about age 20 (Astrand and Rodahl 1986). Older workers also have reduced postural flexibility making them more susceptible to back injuries (Helander 1981).

Demographic projections also show that the percentage of women in the workforce in increasing (Johnston and Packer 1987). Today, only about 2-3% of the construction workforce is female ("Encouraging" 1993, "Women" 1993). Compared to males, females are shorter, lighter, have lower strength, and lower anaerobic power, forcing females to work at a higher percentage (compared to males at similar production rates) of their maximum capacities and making them more vulnerable to overexertion injuries (Helander 1981, Astrand and Rodahl 1986).

The construction work force has traditionally been composed primarily of young males. With increasing numbers of women and older workers in construction, it is increasingly imperative to reduce the risk exposure to overexertion injuries.

Once afflicted with an overexertion injury, many construction craft workers can be excessively challenged by the physical demands of their jobs. If alternative less physically demanding work cannot be found, the injured worker faces the dilemma of continuing at a job that causes excess fatigue or discomfort, or perhaps dropping out of the workforce.

Skilled labor shortages

Despite advances in technology, construction remains a physically strenuous occupation. In the *Jobs Rated Almanac* ranking of 250 jobs for physical demands, construction trades account for 20 of the worst 60 jobs (Krantz 1995).

Except for earthmoving equipment and cranes, highly capital intensive automation and robotic equipment that has become widespread in many manufacturing industries has not gained

acceptance in construction. The culture of the construction industry has evolved such that contractors rely heavily on hand labor with small, relatively inexpensive, multipurpose tools.

Compared to many blue collar industries, construction craft workers are highly skilled, highly trained individuals. A major problem facing the construction industry is the shortage of skilled labor (Business Roundtable 1991). High accident and injury rates are often cited as reasons why young people entering the workforce shy away from construction (Korman et al. 1992).

By the time many young construction workers have completed four year union apprenticeship training programs, they are unable to work in the trade for which they are trained due to overexertion and other injuries. This results in waste of all the time and money invested in training the individual and exacerbates existing skill labor shortages.

Overexertion Injuries are Built into the Work

Overexertion injuries generally occur as a result of performing a given task as planned. While overexertion injuries are not intentional, the underlying causes of the injuries are built into the prescribed tools and work methods. If the causes can be identified, it may be possible to engineer them out of the work, or select alternative means and methods of performing the work.

This is in contrast to other types of injuries (e.g. struck by, fall from elevation, struck against, fall same level, etc.) which occur due to an error or unplanned event. These so-called traumatic accidents are not intentionally built into the task. Reducing traumatic injury rates requires a totally different type of workplace intervention compared to overexertion injuries.

Objective

The objective of this research is to identify construction activities and tasks which place craft workers at risk for overexertion injuries. High risk activities and tasks can then be identified so that ergonomic principles can be applied to modify the work or work environment to accommodate human capabilities and limitations or to select appropriate tools or means and methods from among existing alternative technologies. If it is possible to identify the underlying

causes of overexertion injuries for specific construction activities and tasks, then it may be technically and economically feasible to reduce the level of physical demands placed on craft workers.

This project has completed the specific aims of the original proposal as follows:

1. Develop a catalog of construction activities broken down step-by-step at the Basic Task level according to the hierarchical taxonomy of construction field operations developed by Everett (1991).

2. Analyze, using a three point rating scale, each constituent task for the presence of seven generic risk factors for overexertion injuries: repetitive exertions, static exertions, forceful exertions, localized mechanical stresses, posture stresses, low temperature, and vibration.

3. Use the above methods to identify activities and tasks which expose craft workers to high risks for overexertion injuries and evaluate interventions or alternative tools and means and methods to reduce ergonomic stresses for those activities and tasks.

4. The final specific aim, to quantify or measure the reduction of risk resulting from the interventions or selection of alternate tools and means and methods in #3 above as prototypes for widespread application of the knowledge gained in #1 and #2 above, has not been fully completed. An explanation appears below under the section: *Objective 4*.

Research design, methods, and results

Construction injuries and illnesses have been categorized in many ways, including by trade (e.g. carpenters, electricians, laborers, etc.) but few attempts have been made to identify causal relationships between specific activities and tasks within a trade and the associated overexertion injuries. For example, carpenters account for 17% of all injuries and illnesses (*Construction* 1992), but carpenters perform many fundamentally different activities such as erecting concrete

formwork, installing suspended ceilings, hanging drywall, etc. Ed Nyhus, Business Manager of the Carpenters Union Local 512 (southeast Michigan) (personal communication) reports that carpenters who install formwork for concrete experience high rates of tendinitis in their elbows from banging the forms and connectors with hammers; carpenters who install suspended ceiling systems experience neck and shoulder problems from constantly looking and reaching up; and carpenters who hang drywall often suffer nerve damage in their hands from the vibration of the screwguns used to fasten the drywall to the framing system. All of these injuries fall into the general classification of overexertion injuries to carpenters, but the underlying causes are quite different and they call for fundamentally different types of workplace intervention.

Schneider and Susi (1994) performed a qualitative evaluation of the presence or absence of ergonomic hazards for several trades and tasks in new construction. Holmström et al. (1995) cite a number of studies documenting a variety of knee problems among carpet and floor layers, plumbers, and roofers. A study recently published by the Injury Prevention Research Center at the University of Iowa, in conjunction with the Center to Protect Workers' Rights (the research arm of the Building and Construction Trades Department of the AFL-CIO), confirms this situation. Every trade in the survey listed the lower back as most associated with pain, physician visits, and missed work. When identifying other areas of the body causing pain, the responses varied by trade. For example, ironworkers reported shoulder problems, cement masons reported hand and wrist pain, and roofers and cement masons reported knee problems (Cook et al. 1996).

Objective 1: Develop catalog of construction activities

A cursory inspection of any large construction site reveals that there are many craft workers doing many different things at the same time. Compared to many industrial settings, construction sites may appear chaotic. To bring some order to what may appear to be chaos to some observers, the first objective of this research is to develop a catalog of construction activities broken down step-by-step at the Basic Task Level according to the hierarchical taxonomy of construction field operations developed by Everett (1991).

Taxonomy of construction field operations

Construction field operations can be classified into a hierarchical taxonomy as shown in Table 1. Starting from the most general perspective, the construction project is divided into seven levels, each more detailed or refined than its predecessor.

Level (1)	Examples (2)	Unique/Repetitive (3)
1. Project	Petrochemical plant, office building	Unique
2. Division	Concrete, masonry, mechanical	Unique
3. Activity	Drywall partition, concrete wall	Semi-unique
4. Basic Task	Connect, Cut, Measure, Position	Semi-repetitive
5. Elemental Motion	Reach, grasp, eye travel	Repetitive
6. Orthopedics	Muscle, bone, joint	Repetitive
7. Cell	Muscle fiber, nerve	Repetitive

Table 1. Taxonomy of construction field operations (Everett 1991).

Construction differs from most other industries because of its *Project* (Level 1) orientation. "Projects are distinguished by their relatively short time frame; definite starting and stopping points; non-routine, often unique, interrelated activities; and a limited time, budget, and resource allocation for the projects performed" (Frankel 1990). Typical projects include petrochemical plants, office buildings, single family homes, and highways.

Level 2 represents a breakdown of on-site construction work into the major *Divisions* of work or trades. The most commonly used classifications in the U.S. are the sixteen Construction Specifications Institute (CSI) divisions, such as concrete, masonry, mechanical, and electrical work (*MASTERFORMAT* 1988).

Level 3 breaks Divisions into specific units of work, or *Activities*. Using the CSI format, an Activity corresponds to a specification subsection. An Activity represents all the field work

which results in a recognizable, completed unit of work with spatial limits and/or dimensions. Examples include build the eight inch concrete block south foundation wall or erect structural steel at the third floor.

At Level 4, *Basic Tasks* are the fundamental building blocks of construction field work, each representing one in a series of steps which comprise an Activity. Any productive work performed in the field can be categorized into one or more Basic Tasks. Table 2 presents a set of twelve Basic Tasks with definitions and examples. The twelve Basic Tasks are: Connect, Cover, Cut, Dig, Finish, Inspect, Measure, Place, Plan, Position, Spray, and Spread (Everett 1991). Some of these Basic Tasks are adapted from Warszawski and Sangrey (1985). All Basic Tasks can be performed by human craftspeople; some can be performed by machines. Other investigators have described some components of construction work at a level analogous to Basic Tasks (Halpin and Woodhead 1976, Warszawski 1990, and Tucker et al. 1990).

Level 5 examines *Elemental Motions*. Industrial engineers have been studying manufacturing work at the Elemental Motion level for nearly a century. In 1903, Frederick W. Taylor divided shoveling work into several simple motions in a series of time studies (Taylor 1947). In the 1920's, Gilbreth and Gilbreth developed time and motion studies by dividing human movements into seventeen components called *therbligs* such as reach, grasp, and eye travel (Gilbreth and Gilbreth 1924). Another example of the Elemental Motion level is Methods-Time Measurement (MTM) (Maynard et al. 1948). MTM classifies human movements into a set of motions similar to therbligs but also applies standard units of time to each motion to arrive at the total theoretical time required to perform a given task using a prescribed method. Both therbligs and MTM are still widely used in manufacturing.

At the *Orthopedics* level (Level 6), physicians and physiologists analyze human motions by studying muscles, bones, joints, and the nervous system. Researchers in the fields of ergonomics and occupational biomechanics examine work at this level to optimize safety and efficiency of the human machine (e.g. Chaffin and Andersson 1991).

Basic Task (1)	Definition (2)	Examples (3)
Connect	Join or attach components together	Screw, nail, bolt, staple, weld
Cover	Spread or overlay sheet material over surface	Unroll carpet or single ply roofing
Cut	Penetrate or separate with sharp edge	Saw wood, cut drywall, drill hole
Dig	Loosen, remove, or move soil	Excavate trench, backfill
Finish	Apply continuous mechanical treatment	Grind, bushhammer, sand, rub
Inspect	Examine critically to identify flaws or verify correctness	Read level, verify alignment of machinery
Measure	Determine or layout dimensions	Mark drywall, layout track
Place	Move small object to specified location and orientation	Set tile, lay brick, align conduit
Plan	Gather information, think about upcoming work	Read blueprints, formulate work sequence
Position	Move large object to specified location and orientation	Erect steel beam, lift drywall
Spray	Direct jet of liquid or particles, no contact with surface	Spray paint, sandblast
Spread	Distribute liquid or paste material	Paint with brush, cast concrete

Table 2. Basic Tasks (Everett 1991)

At the *Cell* level (Level 7), investigators examine individual muscle fibers, nerves, and cellular metabolic activity to understand how the human machine functions and how certain occupational injuries and illnesses are caused.

Any problem in construction requires analysis at the appropriate level of detail. For example, if the federal government decided to formulate a national industrial policy, it might compare the construction industry to the manufacturing industry, to the aerospace industry, or

possibly to the construction industries of other countries. This analysis would be performed at the most general level. A scientist developing hearing protection devices for jackhammer operators might study cells of the inner ear. This investigation would be at a microscopic level. National industrial policies and hearing loss are both significant issues in construction, but they obviously require different levels of attention.

Analysis of construction field operations for risk factors for overexertion injuries also requires the appropriate level of detail. Column 3 of Table 1 shows how constructions become progressively more repetitive as the level of detail increases. At the Project or Division level, each operation is unique and it would be impossible to analyze each possible case. At the Elemental Motion, Orthopedics, and Cell levels, analysis of each operation is highly repetitive, but construction work varies enough that too much detail misses the overall picture.

This research focuses on the Activity and Basic Task levels because it is here that the essence of construction field operations is captured. The work is similar, yet not identical, from day-to-day, from worker-to-worker, from project-to-project, and from employer-to-employer. The nature of construction work is that the worksite is constantly changing, so the analysis and any interventions must be in the work, not the worksite. Throughout this report, the terms *activity* and *task* refer to the corresponding levels in the taxonomy just described.

Union craft jurisdictions

The nature of construction work requires craft workers to be able to perform many different activities. However, on all but the smallest projects, craft workers tend to become specialized and spend a large fraction of their time performing essentially the same few activities over and over for weeks, months, or years.

In union construction, the assignment of specific activities to members of specific trade unions is very well defined in local practice and in collective bargaining agreements. In fact, this characteristic of union construction is such an important issue that jurisdictional disputes often arise when members of one union perform or attempt to perform work claimed by another union. For

the purposes of this project, it is convenient to catalog different construction activities according to the trade union that normally performs that activity. This breakdown by trade union corresponds to the Division level in Table 1.

In open shop construction, there is generally less concern with which worker performs which particular activity, but someone has to perform each activity. In any case, this research examines the work, not the workers or their organizational affiliations, so the results can be applied to any construction work.

There are fifteen building trade unions affiliated with the Building and Construction Trades Department (BCTD) of the AFL-CIO, representing more than 3.5 million members. The official names of these BCTD unions are:

1. International Association of Heat and Frost Insulators and Asbestos Workers
2. International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers and Helpers
3. International Union of Bricklayers and Allied Craftsmen
4. United Brotherhood of Carpenters and Joiners of America
5. International Brotherhood of Electrical Workers
6. International Union of Elevator Constructors
7. International Association of Bridge, Structural and Ornamental Iron Workers
8. Laborers' International Union of North America
9. International Union of Operating Engineers
10. Operative Plasterers' and Cement Masons' International Association of the Unites States and Canada
11. International Brotherhood of Painters and Allied Trades
12. United Union of Roofers, Waterproofers and Allied Workers
13. Sheet Metal Workers International Union
14. International Brotherhood of Teamsters

15. United Association of Journeymen and Apprentices of the Plumbing and Pipe Fitting Industry of the United States and Canada

At the local level, the organization of the unions is considerably more complex. There may be several specialized trade unions in the same geographical area affiliated with a single BCTD union. For example, in southeastern Michigan there are separate locals for commercial carpenters, residential carpenters, and resilient floor setters all affiliated with the United Brotherhood of Carpenters and Joiners of America.

Methods and results

Members of the research team contacted representatives of the building trade unions' locals in southeastern Michigan to identify all the activities performed by that union. In some cases, the union representatives provided a document such as a collective bargaining agreement listing the activities. In other cases, the union representatives prepared lists specifically for this research.

Each union performs many different activities, but most of the man-hours are devoted to a relatively small number of activities. It was decided to focus the research efforts on all activities that union representatives estimated to consume ten percent or more of all the man-hours logged by members of that union.

The results of Objective 1 are found in Appendix A which is organized in the order that the BCTD Unions are listed above. Under each BCTD union is a table for each major activity performed by that union.

In some cases, the research team split up activities into two or more crews, because the crews, while working together, performed fundamentally different types of work and had different exposure to risk factors for overexertion injuries. For example, structural steel erection is divided into an erection crew, a ground crew, and a detailing crew.

Many construction activities are performed by composite crews, where members of more than one trade union work together. In those cases, the activity is listed only once under the trade union that is responsible for the highest percentage of man-hours for that activity. For example

precast concrete erection is sometimes performed with a composite crew of carpenters and ironworkers, and sometimes with only ironworkers. It is listed under ironworkers in this report.

Some work may be performed by several different unions. For example, scaffolding is erected by the crew that will use the scaffolding, so bricklayers erect their own scaffolding, roofers erect their own scaffolding, etc. However, on many projects, one set of scaffolding is erected for the use of all trades. In this case, carpenters erect the scaffolding. Therefore, in this report, scaffolding is listed under carpenters.

Some work is claimed by more than one union and must be assigned by the employer on a project-by-project basis. For example, installation of brick pavers are claimed by laborers (under a landscaping agreement) and bricklayers, and, if the pavers are thin enough, by tile setters, a separate part of the bricklayers union. In this report, the work is listed under bricklayers.

Local practice varies from one place to another, and specifically from one local union jurisdiction to another. In this report, activities are listed under the trade union that performs the work in southeastern Michigan. This organization will not be completely correct in some other locations. Again, it does not really matter to which union, if any, the craft worker belongs, it is the work that is under scrutiny.

Many construction activities follow the same general pattern: formulate work sequence; measure or layout the work; cut, finish, or otherwise process a component to be assembled; place or position the component to its final location; connect the component to other components already constructed; and finally inspect the work.

Many other construction activities consist of just one Basic Task after a brief period of preparation. For example, once a painter gets set up to paint with a brush or roller, he/she can paint or Spread for hours. Drywall finishers spend virtually all of their time either applying (Basic Task = Spread) joint compound or sanding (Basic Task = Finish) joints (Appendix A - Table 11c). In many cases, there is a primary cycle that is repeated over and over, with an occasional interruption to measure, relocate tools and materials, etc.

There are also some activities that do not lend themselves well to this type of analysis. Elevator constructors, for example spend a great deal of their time installing rails (Appendix A - Table 6a) and assembling the elevator cab (Appendix A - Table 6b), but after that they do lots of little things that are difficult to characterize using the methods of this research.

Plumbers install many different kinds and sizes of pipes, with many different types of fittings, valves, types of connections, etc. Appendix A - Table 15b applies to a few cases, but the numbers vary depending on the size and type of material installed. Similarly, much of the work of electricians involves installing conduit (Appendix A - Table 5a) and wiring (Appendix A - Table 5b). The risk factors will vary depending on the size and type of material installed.

The work of boilermakers is even more difficult to capture with this type of analysis. The installation of pipes, valves, fittings, etc. has the same variety as similar related work performed by plumbers, but the installation of the large boilers (Appendix A - Table 2a) is not adequately captured by a simple cycle of positioning materials and connecting them to each other.

Every attempt was made to find and analyze craft workers performing "typical" work. However, each worker and employer has his/her own style, and there is often more than one way to perform an activity. Different tools can be used, some more automated than others. The availability of lifting devices varies. Elevated work can be performed from different types of ladders, scaffolding, cherry pickers, etc. The level of prefabrication of materials varies. These and other factors make it difficult to cover every possible situation.

Most activities require the craft worker to move about as the work progresses. This in itself can be physically demanding. Climbing up and down ladders and stairs contributes to the overall demands of the work. Sitting or standing all day is a well establish postural stress. Only when the moving about itself is particularly stressful is a separate line on a table entered. For example, iron workers installing rebar in a high wall or column (Appendix A - Table 7b) often must climb up the rebar and hook themselves to the formwork or previously installed rebar as part of their work.

Nevertheless, most construction work is repetitive and is well suited for this type of analysis. The results of the first objective are tabulated in Appendix A. At the top of each page is the name of the BCTD union. Each of sixty five activities is listed in a separate table. Each table is identified by a numeral indicating the BCTD union (1-15, in the order listed above) and a letter (a - z) within that trade. For example, Table 1a on page A-1 is for "Install duct insulation," performed by the International Association of Heat and Frost Insulators and Asbestos Workers. The first two columns give a description of each step in the primary activity cycle and the corresponding Basic Task. On some tables there is a second section for occasional steps that may be performed depending on the particular project.

The sixty five activities are:

International Association of Heat and Frost Insulators and Asbestos Workers
- Table 1a - Install duct insulation
- Table 1b - Install Pipe Insulation Covers

International Brotherhood of Boiler Makers, Iron Ship Builders, Blacksmiths, Forgers and Helpers
- Table 2a - Install boiler

International Union of Bricklayers and Allied Craftsmen
- Table 3a - Lay Brick (wall)
- Table 3b - Lay Block
- Table 3c - Wash down brickwork/ blockwork
- Table 3d - Install Stone Panels
- Table 3e - Tile Setting (floor)
- Table 3f - Tile (hard) Setting (wall)
- Table 3g - Grout tile (wall and floor)
- Table 3h - Install brick pavers

United Brotherhood of Carpenters and Joiners of America
- Table 4a - Light gauge steel partition framing
- Table 4b - Install drywall
- Table 4c - Install suspended and acoustic ceiling grid
- Table 4d - Install suspended and acoustic ceiling tiles
- Table 4e - Build modular concrete forms
- Table 4f - Install millwork
- Table 4g - Residential framing
- Table 4h - Interior trim
- Table 4i - Erect Scaffolding
- Table 4j - Pile driving
- Table 4k - Resilient Tile Setting
- Table 4l- Install carpet
- Table 4m - Install wood flooring

International Brotherhood of Electrical Workers
- Table 5a - Install conduit
- Table 5b - Install wiring
- Table 5c - Install lighting systems and fixtures

International Union of Elevator Constructors
- Table 6a - Install rails
- Table 6b - Install cab/equipment

International Association of Bridge, Structural and Ornamental Iron Workers
- Table 7a - Install rebar for slab or footing
- Table 7b - Install wall or column rebar in place
- Table 7c - Build rebar cages/ mats at work station
- Table 7d - Structural steel erection (ground crew)
- Table 7e - Structural steel erection (erection crew)
- Table 7f - Structural steel erection (detailing crew)
- Table 7g - Metal Deck Installation
- Table 7h - Precast Concrete Erection (ground crew)
- Table 7i - Precast concrete erection (erection crew)

Laborer's International Union of North America
- Table 8a - Place Concrete - slabs
- Table 8b - Place Concrete - walls, columns, beams
- Table 8c - Supply masons with brick/ block
- Table 8d - Mix/ transport mortar for masons

International Union of Operating Engineers
- Table 9a - Operate cranes, dozers, scrapers, loaders, trucks, rollers. etc.
- Table 9b - Operation of elevators

Operative Plasterers and Cement Masons International Association of the United States and Canada

Table 10a - Manual Concrete Screeding
Table 10b - Mechanical Concrete Screeding
Table 10c - Cement Finishing
Table 10d - Sawcut concrete

International Brotherhood of Painters and Allied Trades
Table 11a - Spray Painting
Table 11b - Brush and Roller Painting
Table 11c - Drywall taping and finishing
Table 11d - Paper/ wall cover hanging
Table 11e - Abrasive blasting

United Union of Roofers, Waterproofers and Allied Workers
Table 12a - Install rigid insulation
Table 12b - Install single ply roof membrane
Table 12c - Install asphalt shingle roof
Table 12d - Tear off built up roofing
Table 12e - Install built - up roof

Sheet metal workers International Association
Table 13a - Install duct hangers
Table 13b - Install ductwork
Table 13c - Install equipment

International Brotherhood of Teamsters
Table 14a - Operate trucks

United Association of Journeymen and Apprentices of the Plumbing and Pipe Fitting Industry of the United States and Canada
Table 15a - Install pipe hangers
Table 15b - Install domestic water pipes, sanitary sewers, gas pipes, etc.
Table 15c - Install fixtures

Objective 2: Analyze tasks for risk factors for overexertion injuries

The second objective of the research is to analyze each step of each activity for the presence of risk factors for overexertion injuries.

Generic risk factors for overexertion injuries

There are seven generic risk factors for overexertion injuries: repetitive exertions, static exertions, forceful exertions, localized mechanical stresses, posture stresses, low temperature, and vibration. These risk factors for overexertion injuries have been well documented by many researchers. Armstrong (1993) defines the risk factors in Table 3. [Note: Other researchers package the risk factors in slightly different format. For example, Schneider and Susi (1994) evaluate awkward posture, force, weight, repetition, hand tools, static position, and vibration.]

Risk Factor (1)	Definition (2)
Repetitive exertions	Performing the same acts or motions over and over again
Static exertions	Maintenance of the same position of the body or some part of the body throughout each work cycle or for prolonged periods
Forceful exertions	An exertion performed to overcome weight, resistance, or inertia of the body or a work object
Localized mechanical stresses	Mechanical tissue stresses in the area of contact with external objects
Posture stresses	Positions of the body that require more effort than others or result in compression or stretching of tissues in or around the joints, e.g. nerves or tendons
Low temperature	Contact of the hand with air or work objects below 20°C or exposure of the worker to low ambient temperatures that result in reduced peripheral circulation
Vibration	Contact of the hands with vibrating objects

Table 3. Generic risk factors for overexertion injuries.

Scoring system

Each construction activity was broken into its constituent steps as described above. For each risk factor, each step is rated on a scale of 1 to 3, corresponding to an ordinal scoring system (Keyserling and Wittig 1988) where:

1 = Insignificant: The job is free of potentially harmful ergonomic stresses in the risk factor of interest. No corrective actions are necessary.

2 = Moderate: The job has stresses in the risk factor of interest that could be problematic (i.e. cause fatigue and/or injury) for some workers. Additional analyses using more precise methods should be used to determine the necessity for intervention.

3 = High: The job has significant stresses in the risk factor of interest that are likely to cause fatigue and/or injury in some workers. Additional analyses and interventions should be taken at a high priority.

It is important to note that the procedure described above is not diagnostic, i.e., it will not provide any insight to specific causes of excess physical stress nor will it offer any suggestions as to appropriate interventions to reduce physical stress. The purpose here is to help identify problem areas for further investigation.

There are many systems available for ergonomic analysis of manual work activities. Analysis tools range from simple checklists to highly sophisticated automated computer-based data collection and analysis systems. In determining what type of system to use, one should consider the level of user expertise and the intended use of the collected data.

Perhaps the most basic analysis is one such as that performed by Schneider and Susi (1994). They used a two point scale in their evaluation of construction activities: either a hazard was present or it was not. More complex analysis tools require considerable user expertise. The Revised NIOSH Lifting Equation (Waters et al. 1993) provides a quantitative analysis of manual lifting tasks. The Ovako Working Posture Analysis System (OWAS) (Karhu et al. 1981) focuses on postural analysis.

Checklists give structure to the job analysis process and serve as reminders of what questions need to be answered. The purpose of the job analysis in this research is to perform rapid screening of many tasks to determine if they warrant more detailed investigation. It is hoped that construction industry practitioners will apply the results of this research or use the methods to perform their own investigations. For these reasons the 3 point scale described above is most appropriate.

Three point scales have been used extensively in other industries. Examples include: 1, 2, 3; red, yellow, green; zero, check, star; and never, sometimes, greater than one-third scales. Checklist findings from novice users are generally in agreement with expert ergonomists' findings. If anything, the checklists tend to overestimate the seriousness of certain exposures (Keyserling et al. 1992) so the approach taken here is conservative.

There will always be some disagreement, even among experts, about the extent of ergonomic stressors, even in highly repetitive tasks (Keyserling and Wittig 1988). Because of the great variations in the way construction work is performed from project to project, from day to day on a single project, from worker to worker, and even from minute to minute for a single craft worker, it would be unproductive to attempt to perform any statistical analysis of the results shown below. The continually changing nature of the work itself would make detailed analysis of differences in the scoring meaningless. Again, the purpose is to perform a first pass, rapid screening of common construction activities to identify potential problems. If, upon further investigation, it is determined that a 3 should have been a 2, no harm has been done.

Results

The results of the analysis are shown in Appendix A. On the right side of each table are columns corresponding to the seven risk factors. Each task has a score of 1 to 3 for each risk factor. Every effort was made to find craft workers performing "typical" work sequences. Most of the activities were videotaped and reviewed by at least three independent observers. However,

each project is different, and each observer had to use some judgment in arriving at the scores, so there were occasional differences of opinion and the values shown are consensus values.

It should be noted that all scores for low temperature have been set equal to 1. It was decided to score all tasks this way because this risk factor is almost entirely weather dependent and not specifically related to the work except in a few unusual circumstances (e.g., exposure to cold exhaust air from pneumatic tools). In fact, many of the observations were made in the middle of the winter in Michigan and it was indeed very cold. However, the same work can also performed in the middle of the summer when low temperatures would not be a problem.

Objective 3a. Identify high risk tasks and activities

A quick glance through the tables reveals many 2s and 3s, particularly in the repetitive exertions, forceful exertions, and posture stresses columns. This should not come as any surprise to veterans of construction. Any task and its associated activity with a score of 3 should be considered a high priority for additional analysis and intervention, but virtually every activity has at least one score of 3. To narrow the focus somewhat, the individual tasks with at least two risk factors scoring 3 were counted. Of the sixty-five activities, fifty-three had at least one constituent task with at least two risk factors with scores of 3. Thirty-seven activities had at least one task with at least three risk factors with scores scores of 3. These are shown in Table 4.

The results of the preceding job analysis can be used in two ways. The first is to identify specific activities or tasks within an activity to target for intervention or evaluation of existing alternative tools and methods. Any of the activities or tasks in Table 4 would be obvious candidates for this type of further investigation.

A second possibility is to search for similar individual tasks that are part of different activities. A successful intervention that improves one task within one activity may have applications for similar tasks in several dissimilar activities. For example, of the tasks listed in Table 4, three common tasks appear among several activities. Cutting (with a utility knife) appears in: 1a - install duct insulation, 4b - install drywall, 4l - install carpet, and 12c - install shingle roof,

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
1a - Install duct insulation								
Cut	Cut insulation	3	1	2	3	3	1	1
3b - Lay Block								
Position	Lay block	2	2	3	3	3	1	1
3e - Tile Setting (floor)								
Place	Place tile	3	2	3	3	3	1	1
3g - Grout tile (wall and floor)								
Spread	Spread grout on tile surface	3	3	3	3	3	1	1
Spread	Wipe grout off	3	3	3	3	3	1	1
3h - Install brick pavers								
Place	Place paver	3	2	3	3	3	1	1
4a - Light gauge steel partition framing								
Connect	Connect track to slab, deck	3	2	2	2	3	1	3
Connect	Connect studs to track	3	2	2	2	3	1	3
4b - Install drywall								
Position	Carry materials to work location	1	2	3	3	3	1	1
Cut	Cut drywall	3	1	3	3	3	1	1
Position	Carry and position panel	2	3	3	3	3	1	1
Connect	Screw/nail panel to studs	3	2	2	2	3	1	3
4c - Install suspended and acoustic ceiling grid								
Place	Move T's to correct location	2	3	2	1	3	1	1
Connect	Snap T's together	2	3	3	2	3	1	1
4e - Build modular concrete forms								
Position	Carry materials to work location	3	2	3	3	3	1	1
Position	Move panels to correct location	2	2	3	3	3	1	1
Connect	Connect panels, ties	3	2	3	2	3	1	3
4g - Residential framing								
Position	Carry materials to work location	3	2	3	3	3	1	1
Position	Position members	2	3	3	2	3	1	1
Connect	Nail members together	3	2	2	2	2	1	3
4i - Erect Scaffolding								
Position	Position scaffolding sections	2	2	3	3	3	1	1
4k - Resilient Tile Setting								
Place	Place tile	3	2	3	3	3	1	1
4l- Install carpet								
Cut	Cut pad to required dimensions	1	2	3	3	3	1	1
Cut	Cut carpet to required dimensions	1	2	3	3	3	1	1
Spread	Spread adhesive	2	2	3	3	3	1	1
Position	Stretch carpet with knee kicker	3	2	3	3	3	1	2
4m - Install wood flooring								
Connect	Nail wood strips to sub floor	3	2	3	2	3	1	3
5b - Install wiring								
Position	Pull wires	3	2	3	3	3	1	1

Table 4. Tasks with at least three risk factors scoring 3. Number/letter designation refers to Appendix A Table number.

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
6a - Install rails								
Position	Carry materials to work location	2	2	3	3	3	1	1
Connect	Attach to wall and other sections	3	3	2	3	3	1	1
7a - Install rebar for slab or footing								
Cut	Cut tie wire	2	1	3	3	3	1	1
Connect	Tie rebar	3	1	2	3	3	1	1
7e - Structural steel erection (erection crew)								
Position	Position and align members	1	2	3	3	3	1	1
Position	Worker move to next position	2	2	3	3	3	1	1
7f - Structural steel erection (detailing crew)								
Connect	Bolt with spud wrench	3	1	3	3	3	1	1
Connect	Bolt with impact wrench	2	2	3	1	3	1	3
Position	Align members	2	2	3	3	3	1	1
7g - Metal Deck Installation								
Position	Carry/position deck	2	3	3	2	3	1	1
Connect	Screw deck	3	2	2	2	3	1	3
7i - Precast concrete erection (erection crew)								
Position	Position and align precast members	1	2	3	3	3	1	1
8a - Place Concrete - slabs								
Spread	Spread concrete	3	1	3	3	3	1	1
8b - Place Concrete - walls, columns, beams								
Spread	Spread concrete	3	1	3	3	3	1	1
8c - Supply masons with brick/ block								
Position	Move brick/ block to scaffolding	3	2	3	2	3	1	2
8d - Mix/ transport mortar for masons								
Position	Mix mortar	3	2	3	2	3	1	1
Position	Transport mortar w/ motorized buggy	3	2	3	2	3	1	3
9a - Operate cranes, dozers, scrapers, loaders, trucks, rollers, etc.								
Position	Operate machinery	3	2	1	2	3	1	3
10a - Manual Concrete Screeding								
Finish	Screed concrete	3	2	3	3	3	1	1
10c - Cement Finishing								
Finish	Trowel by hand	3	3	3	3	3	1	2
11a - Spray Painting								
Finish	Sand/ scrape/ clean surface	3	2	2	3	3	1	2
Spray	Spray paint	2	2	2	3	3	1	3
11b - Brush and Roller Painting								
Finish	Sand/ scrape/ clean surface	3	2	2	3	3	1	2
Spread	Paint with brush	3	3	2	3	3	1	1
Spread	Paint with roller	3	3	2	2	3	1	1
11c - Drywall taping and finishing								
Spread	Apply joint compound	3	2	2	3	3	1	1
12a - Install rigid insulation								
Connect	Attach to roof deck	3	2	2	2	3	1	3

Table 4. Tasks with at least three risk factors scoring 3. Number/letter designation refers to Appendix A Table number.

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
12b - Install single ply roof membrane								
Ballast installation								
Position	Transport ballast with wheel barrel	2	2	3	3	3	1	1
Position	Rake out ballast	3	2	3	3	3	1	1
12c - Install shingle roof								
Position	Carry materials to work location	2	2	3	3	3	1	1
Connect	Nail felt to roof deck	3	2	2	3	3	1	3
Cut	Cut shingle	1	2	3	3	3	1	1
Place	Place shingle	3	2	1	3	3	1	1
Connect	Nail shingle to deck	3	2	2	3	3	1	3
12d - Tear off built up roofing								
Position	Carry materials to work location	2	2	3	3	3	1	1
Position	Carry roofing to stockpile	3	1	3	3	1	1	1
12e - Install built - up roof								
Position	Carry materials to work location	2	2	3	3	3	1	1
Connect	Nail felt to deck (wood deck only)	3	1	2	2	3	1	3
Ballast installation								
Position	Transport ballast with wheel barrel	2	2	3	3	3	1	1
Position	Rake out ballast	3	2	3	3	3	1	1
14a - Operate trucks								
Position	Drive truck	3	2	2	2	3	1	3

Table 4. Tasks with at least three risk factors scoring 3. Number/letter designation refers to Appendix A Table number.

and other activities and tasks that did not qualify for Table 4. The use of hammers appears in: 4b - install drywall, 4e - build modular concrete forms, 4g - residential framing, 4I - erect scaffolding, 4m - install wood flooring, 12c - install shingle roof, and 12e - install built-up roof, and other activities and tasks that did not qualify for Table 4. There are also many activities and tasks that involve lifting, carrying, pushing, and pulling of large or heavy objects. These are all Positioning tasks, any would certainly benefit from improved material handling devices, but their similarities are not quite as clear as for the Cutting (knife) and Connecting (hammer) tasks.

Objective 3b. Evaluate interventions and alternative technologies

Clearly there are many opportunities for reduction in the risk factors for overexertion injuries in the construction activities and tasks analyzed above. Developing new workplace interventions for construction is a daunting undertaking. Countless attempts have been made to change the work or to introduce new means and methods. Schneider and Susi (1994) have conducted an extensive review of "solutions to ergonomic problems in new construction." Often the solution is simply selecting a better alternative from among several existing technologies.

In most previous research, identifying the problem and assessing the proposed solution have been approached qualitatively. Getting the industry and the craft workers to adopt the proposed solution is a different matter. Schneider et al. (1995) describe a number of organizational and psychosocial factors that hinder implementation of proposed solutions.

In the original proposal for this research, it was stated that prioritizing physically strenuous tasks for ergonomic improvements would consider a number of factors, including:

1. The number of craft workers assigned to the task and the number who might benefit directly from ergonomic improvements.

2. The time required to develop and implement change. Initially, jobs where changes can be implemented quickly will have high priority.

3. The cost of the change. In general, changes that have low costs will be of higher priority than high-cost changes. However, this rule will not be absolute.

4. The technical feasibility of the change. Changes that require major technological interventions would have lower priority than changes that can utilize "off-the-shelf" technology.

This philosophy has been adopted to avoid spending a great deal of time, effort, and resources developing one more in a long list of good ideas that suffer from lack of adoption.

With this in mind, two specific interventions have been evaluated as part of this project. The first is an evaluation of the vibration characteristics of hammers. As described above, hammers are used by many trades for many tasks and activities. A better hammer can reduce the vibration exposure to a great number of craft workers and possibly reduce injuries. Evaluating commercially available hammers makes the time, cost, and technical feasibility of implementing the findings very favorable.

Details of the hammer vibration analysis are attached as a separate paper in Appendix B. The abstract of the paper follows:

MEASUREMENT OF VIBRATION IN CLAW HAMMER HANDLES

by John G. Everett and Bernard J. Martin

Abstract

Vibration of hand tools is associated with hand, wrist, and upper limb disorders including carpal tunnel syndrome, white finger disease, and Raynaud's syndrome. The most basic of hand tools, the hammer, imparts vibration to the user's hand with very high acceleration (>>1000m/s^2) but with a duration of only a few milliseconds each time the hammer strikes a nail. Steel handled hammers are more durable than wood handled hammers, but it is widely believed among construction craft workers that wood handled hammers transmit less vibration to the

user than do steel handled hammers. Fiberglass, and more recently graphite, handles have been introduced as a compromise between the durability of steel and the feel and natural vibration damping characteristics of wood.

This paper describes an experiment to measure and compare the vibration levels of eight different claw hammers, all with 0.45 kg (16 ounce nominal) heads. Five professional carpenters drove 16 d (penny) (8.9 cm) nails into plywood and 2x4 wood framing studs. Handle vibration was measured by means of a small piezoelectric shock accelerometer placed on the hammer handle, adjacent to the user's hand. Vibration was measured perpendicular to the axis of the handle, parallel to the driving direction. Signals were fed into a charge amplifier, displayed on an oscilloscope, and captured by computer. Sampling frequency was 10,000 Hz. Weighted and unweighted one-third octave band frequency spectra were obtained with a signal analyzer.

A statistically significant difference was found for only one pair of hammers, but the finding is in direct contrast to the widely held notion that wood handles vibrate less than steel handles. The Craftsman steel hammer with a wood core in the head had an average weighted rms acceleration of 0.86 m/s^2, while the Stanley wood handled hammer had 1.13 m/s^2.

A second evaluation conducted in conjunction with this project is analysis of drywall panel and joint orientation and its effect on finishing operations. The task of spreading joint compound is specific to only one activity, 11c - drywall taping and finishing, but this is a very common activity with very high risks for injury, and two clear alternative methods of performing the work, one of which is an ergonomic disaster (vertical joints) and the other being relatively benign (horizontal joints).

Following is the abstract of a paper describing research to evaluate productivity and ergonomic of drywall joint finishing. The full paper has been attached as Appendix C.

DRYWALL JOINT FINISHING: PRODUCTIVITY AND ERGONOMICS

by John G. Everett and Dennis L. Kelly

Abstract

Gypsum drywall panels are used extensively for wall cladding and structural fireproofing. Most interior building walls are of sufficient length and width to require at least two panels of drywall for complete coverage. Generally speaking, in residential construction, boards are placed horizontally (perpendicular to framing) and in commercial construction, boards are placed vertically (parallel to framing). This paper analyzes the effect of drywall panel and joint orientation on joint finishing operations. Productivity comparisons are made by investigating the total quantity of joint produced, production rates for various types of horizontal and vertical joints, and total time required to finish the joints. For typical residential applications, horizontal joints require less time to finish. For many commercial applications, vertical joints require less time to finish. However, there are many exceptions. Contractors and designers can save time and money by selecting the proper orientation.

The locations of the joints on the wall also affects the motions and positions the craft worker must endure to complete the work. Professional finishers prefer horizontal joints because they greatly reduce the ergonomic stresses associated with bending down and reaching overhead. Over the course of an 8 hour day, the typical finisher bent down 746 times and reached up 835 times. While standing on the floor, the finisher bends down relatively more often; while working on stilts, the finisher reaches up more often.

Objective 4. Quantify or measure reduction of risk.

The hammer vibration experiments and drywall finishing evaluations described above have quantitatively evaluated some of the physical characteristics of construction work. In the hammer experiments, it has been shown that some types of hammers transmit less vibration to the user than

others. In the drywall finishing evaluation, horizontal joints are clearly preferable to vertical joints from an ergonomic point of view under certain conditions.

However, it has not been possible in this research to measure the reduction of risk directly. In the case of the hammers, it is possible that the score of 3 could be reduced to 2 for the vibration risk factor. Unfortunately, there are no widely accepted exposure guidelines or dose-response relationships for the type of vibration generated by impact tools such as hammers, so it is difficult to say whether the differences among hammers would really reduce the risk of injuries.

In the case of drywall finishing, the score for postural stresses would be 1 or 2 for horizontal joints and 3 for vertical joints. The number of times the finisher bends down and reaches overhead to finish mid-wall joints can be reduced from many hundreds to zero under the right circumstances. Clearly this is desirable, but it is difficult to translate this directly into a reduction in the risk of injuries.

Conclusion

Numerous qualitative studies have looked at ergonomic problems and some of the risk factors for overexertion injuries in construction. The research reported here is an important step in starting to identify and quantify specific problems.

This research has developed a catalog of sixty-five common construction activities, each broken down into several tasks. Each task has then been scored on a three point scale for each of seven generic risk factors for overexertion injuries. Of the sixty-five activities, fifty-three had at least one constituent task with at least two risk factors that could cause injuries in some workers. Thirty-seven activities had at least one constituent task with at least three risk factors that could cause injuries in some workers. Clearly ergonomic hazards are a major problem in construction work.

Two detailed studies have been conducted to attempt to improve the tools and methods used by craft workers. One study involves a series of experiments to analyze vibration in hammer handles. One hammer model with a steel handle transmits significantly less ($p < 0.05$) vibration to

the user than a wood handled hammer. This research not only quantifies the vibration levels in a variety of hammers, but contradicts the myth that wood handled hammers offer superior vibration characteristics than steel handled hammers.

A second study evaluates the effect of drywall panel and joint orientation on productivity and postural stresses for drywall finishers. Depending on the wall geometry, the choice between vertical and horizontal joint orientation can make a large difference in the time required to finish the joints. Horizontal joints are preferred by craft workers because they do not require the constant bending down and reaching overhead associated with vertical joints.

Knowledge gained in this project has improved curricular content on occupational health and safety in construction at the University of Michigan's Construction Engineering and Management Program and will spread throughout the academic and business communities.

Acknowledgments

This research was sponsored by NIOSH (National Institute for Occupational Safety and Health) Grant #5 R03 OH03154-02. The author is grateful for the cooperation and support of the building trade unions in southeastern Michigan. Four graduate students in Construction Engineering and Management at the University of Michigan assisted in the data collection and analysis: Dennis L. Kelly, Satyaraghu Seelamsetty, Olga Agalakova, and Taivo Tammaru. Several other students observed and analyzed activities as part of a course project: Jihad Bou Nader, Shang-Kai Chang, Michael Devine, Daniel Liera Fucuy, Kosuke Hirase, Khalil Kanaan, Veerasak Likhitruangsilp, Young Sub Lim, Kevin Matzke, Maria Melzian, Bonnie Newkirk, Hee-Sung Park, Paul Stoddard, Craig Synnestvedt, Ruei-Hong Tseng, Richard Uren, and I-Tung Yang.

References

Abraham, K. G., Weber, W. L., and Personick, M. E. (1996). "Improvements in the BLS safety and health statistical system." *Monthly Labor Review*, 119(4), 3-12.

Accident Facts. (1996). 1996 edition. National Safety Council. Itasca, IL.

Armstrong, T.A. (1993). *Analysis and Design of Jobs for Control of Upper Limb Musculoskeletal Disorders.* University of Michigan, Ann Arbor, MI.

Astrand, P.O. and Rodahl, K. (1986). *Textbook of Work Physiology.* McGraw-Hill, New York.

Chaffin, D. B. and Andersson, G. B. J. (1991). *Occupational biomechanics.* J. Wiley, New York.

Construction Accidents: The Workers' Compensation Data Base 1985-1988. (1992). Occupational Health and Safety Administration (OSHA) U.S. Department of Labor, Washington, DC.

Construction Accidents: The Workers' Compensation Data Base 1985-1988. (1992). Occupational Health and Safety Administration (OSHA), U.S. Department of Labor, Washington, DC.

Cook, T. M., Rosecrance, J. C., and Zimmerman, C. L. (1996). *The University of Iowa Construction Survey, Report E1-96.* Center to Protect Workers' Rights, Washington, DC.

"Encouraging young women to enter the trades: a word for counselors." (1993). *Occupational Outlook Quarterly*, 37(1), 10-11.

Everett, J. G. (1991). *Construction automation: Basic task selection, and development of the CRANIUM.* Ph.D. thesis, Massachusetts Institute of Technology at Cambridge, MA.

Frankel, E. G. (1990). *Project management in engineering services and development.* Butterworths, London.

Gilbreth, F. B. and Gilbreth, L. (1924). "Classifying the elements of work." in Matteson, M. T. and Inancevich, J. M. (1977). *Management classics*, Goodyear Publishing Co., Santa Monica, CA.

Halpin, D. W. and Woodhead, R. W. (1976). *Design of construction and process operations.* J. Wiley and Sons, Inc. New York.

Healthy People 2000: National Health Promotion and Disease Prevention Objectives. (1991). Public Health Service, U.S. Dept. of Health and Human Services, Washington, DC.

Helander, M. (ed.) (1981). *Human Factors/Ergonomics for Building and Construction.* J. Wiley, New York.

Holmström, E., Moritz, U., and Engholm, G. (1995). *Musculoskeletal disorders in construction workers. Occupational medicine: State of the art reviews.* (Editors: Ringen, K., Englund, A., Welch, L., Weeks, J. L., and Seegal, J. L.) 10(2), 295-312.

Johnston, W.B. and Packer, A.H. (1987). *Workforce 2000, Work and Workers for the 21st Century.* Hudson Institute, Indianapolis, IN.

Karhu, O., Harkonen, R., Sorvali, P., and Vepsalainen, P. (1981). "Observing working postures in industry: Examples of OWAS application." *Applied Ergonomics,* 11(1), 13-18.

Keyserling, W.M. and Wittig, S. (1988). "An Analysis of Experts' Rating of Ergonomic Stressors." *International Journal of Industrial Ergonomics,* 2(4), 291-304.

Korman, R., Setzer, S.W., and Normille, D. (1992). "Learning to Love the Spotlight." *Engineering News Record,* October 19, 24-28.

Krantz, L. (1995). *The national business employment weekly jobs rated almanac.* J. Wiley and Sons, Inc. New York.

MASTERFORMAT - Master list of titles and numbers for the construction industry. (1988). Construction Specifications Institute (CSI), Alexandria, VA.

Maynard, H. B., Stegemerten, G. J., and Schwab, J. L. (1948). *Methods-time measurement.* McGraw-Hill, New York.

Method of Recording Basic Facts Relating to the Nature and Occurrence of Work Injuries. (1962). American National Standards Institute (ANSI), ANSI Z16.2-62. New York.

Occupational Injuries and Illness: Counts, Rates, and Characteristics, 1992. (1995). Bulletin 2455, Bureau of Labor Statistics, U.S. Department of Labor, Washington, DC.

Oglesby, C. H., Parker, H. W., and Howell, G. A. (1989). *Productivity Improvement in Construction*, McGraw-Hill, New York.

Projections 2000. (1988). Bureau of Labor Statistics, U.S. Department of Labor, Washington, DC.

"Repeat-motion Injuries Grow." (1989). *Engineering News Record.* 222(1), 14-15.

Schneider, S., Punnett, L., and Cook, T. M. (1995). "Ergonomics: Applying what we know." in Ringen, K., Englund, A., Welch, L., Weeks, J. L., and Seegal, J. L. "Construction Safety and Health," *Occupational Medicine, State of the art reviews,* 10(2), 385-394.

Schneider, S. and Susi, P. (1994). "Ergonomics and construction: A review of potential hazards in new construction." *American Industrial Hygiene Association Journal*, 55(7), 635-649.

Taylor, F. W. (1947). *Scientific management.* Harper and Brothers, New York.

Tucker, R. et al. (1990). *A methodology for identifying automation potential in industrial construction, Source document 56.* Construction Industry Institute, Austin, TX.

Waters, T. R., Putz-Anderson, V., Garg, A, and Fine, L. (1993). "Revised NIOSH equation for the design and evaluation of manual lifting tasks." *Ergonomics*, 36(7), 749-776.

Warszawski, A. (1990). *Industrialization and robotics in building.* Harper and Row, New York.

Warszawski, A. and Sangrey, D. A. (1985). "Robotics in building construction." *J. Const. Engrg. Mgmt.*, ASCE, 111(3), Sept., 260-280.

"Women 3% of Construction Trades." (1993). *Engineering News Record.* 230(1), 7.

Appendix A

International Association of Heat and Frost Insulators and Asbestos Workers

Table 1a - Install duct insulation

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	2	1	3	1	1
Measure	Measure duct/ insulation	1	1	1	1	2	1	1
Cut	Cut insulation	3	1	2	3	3	1	1
Spread	Spread adhesive	2	2	2	2	1	1	1
Cover	Apply insulation to duct	2	1	2	3	3	1	1
Inspect	Inspect insulation and align edges	1	1	1	1	3	1	1
Connect	Tape insulation	2	1	1	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Association of Heat and Frost Insulators and Asbestos Workers

Table 1b - Install Pipe Insulation Covers

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	2	1	2	1	1
Measure	Measure and mark pipe	1	1	1	1	2	1	1
Cut	Cut insulation	2	1	2	1	2	1	1
Place	Place insulation on pipe	2	1	1	1	3	1	1
Connect	Staple/ tape insulation	2	1	2	3	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Brotherhood of Boiler Makers, Iron Ship Builders, Blacksmiths, Forgers and Helpers

Table 2a - Install boiler

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Transport materials to work location	2	2	2	1	3	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Connect	Connect parts	2	1	2	1	2	1	2
Inspect	Inspect work	1	1	1	1	2	1	1

International Union of Bricklayers and Allied Craftsmen

Table 3a - Lay Brick (wall)

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Spread	Spread mortar on wall	3	1	1	2	2	1	1
Spread	Spread mortar on brick	3	3	2	2	2	1	1
Place	Lay brick	3	2	2	2	2	1	1
Inspect	Check level and plumb	1	1	1	1	2	1	1
Finish	Strike joints	3	2	1	2	3	1	2
Inspect	Inspect work	1	1	1	1	2	1	1
Occasional								
Cut	Cut brick with saw	1	2	2	2	2	1	3
Cut	Cut/ break brick with trowel	1	2	3	3	2	1	2

International Union of Bricklayers and Allied Craftsmen

Table 3b - Lay Block

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Spread	Spread mortar on wall	3	1	1	2	2	1	1
Spread	Spread mortar on block	3	2	2	2	2	1	1
Position	Lay block	2	2	3	3	3	1	1
Inspect	Check level and plumb	1	1	1	1	2	1	1
Finish	Strike joints	2	2	1	2	3	1	2
Inspect	Inspect work	1	1	1	1	2	1	1
Occasional								
Cut	Cut block with saw	1	2	2	2	2	1	3
Cut	Cut/ break block with trowel	1	2	3	3	2	1	2

International Union of Bricklayers and Allied Craftsmen

Table 3c - Wash down brickwork/ blockwork

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Spread	Brush acid on wall	2	2	2	2	2	1	1
Spray	Spray water on wall with hose	1	1	1	1	1	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Union of Bricklayers and Allied Craftsmen

Table 3d - Install Stone Panels

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure and mark position of panel ed	1	1	1	1	2	1	1
Position	Position panel on wall	2	2	3	2	2	1	1
Inspect	Check for level and fit	1	1	1	1	1	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Union of Bricklayers and Allied Craftsmen

Table 3e - Tile Setting (floor)

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Layout tile locations	1	1	1	3	3	1	1
Spread	Spread adhesive	2	2	2	3	3	1	2
Measure	Measure tile (only at the ends)	1	1	1	1	2	1	1
Cut	Cut tile (only at the ends)	1	1	2	2	2	1	1
Place	Place tile	3	2	3	3	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Union of Bricklayers and Allied Craftsmen

Table 3f - Tile (hard) Setting (wall)

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Layout tile locations	1	1	1	1	2	1	1
Spread	Spread adhesive	2	2	2	2	2	1	2
Measure	Measure tile (only at the ends/edges)	1	1	1	1	2	1	1
Cut	Cut tile (only at the ends/edges)	1	1	2	2	2	1	1
Place	Place tile	3	2	3	2	2	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Union of Bricklayers and Allied Craftsmen

Table 3g - Grout tile (wall and floor)

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Spread	Spread grout on tile surface	3	3	3	3	3	1	1
Spread	Wipe grout off	3	3	3	3	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Union of Bricklayers and Allied Craftsmen

Table 3h - Install brick pavers

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Layout paver locations	1	1	1	3	3	1	1
Place	Place paver	3	2	3	3	3	1	1
Cut	Cut paver (only at the ends/edges)	1	1	2	2	2	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4a - Light gauge steel partition framing

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	2	1	3	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Position	Carry materials to work location	1	2	2	2	3	1	1
Cut	Cut track	1	2	2	2	2	1	3
Position	Position track	1	2	2	2	3	1	1
Connect	Connect track to slab, deck	3	2	2	2	3	1	3
Cut	Cut studs	1	2	2	2	2	1	3
Position	Position studs	1	2	2	2	3	1	1
Connect	Connect studs to track	3	2	2	2	3	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4b - Install drywall

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	3	3	3	1	1
Measure	Measure and mark wall and drywall	1	1	1	1	2	1	1
Cut	Cut drywall	3	1	3	3	3	1	1
Position	Carry and position panel	2	3	3	3	3	1	1
Connect	Screw/nail panel to studs	3	2	2	2	3	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4c - Install suspended and acoustic ceiling grid

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Cut	Cut ceiling grid T's	2	2	2	2	2	1	1
Place	Move T's to correct location	2	3	2	1	3	1	1
Connect	Snap T's together	2	3	3	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4d - Install suspended and acoustic ceiling tiles

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	2	2	2	1	1
Measure	Measure tiles	1	1	1	1	3	1	1
Cut	Cut tiles	1	1	2	2	2	1	1
Position	Lay tiles in grid	2	2	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4e - Build modular concrete forms

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	3	2	3	3	3	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Position	Move panels to correct location	2	2	3	3	3	1	1
Connect	Connect panels, ties	3	2	3	2	3	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4f - Install millwork

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	2	1	3	1	1
Position	Move millwork into position	1	2	3	2	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Cut	Cut as needed	1	1	2	2	2	1	2
Position	Position millwork	1	3	3	2	2	1	1
Connect	Screw millwork to wall/ floor	2	2	3	2	2	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4g - Residential framing

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	3	2	3	3	3	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Cut	Cut wood members	2	2	2	2	2	1	3
Position	Position members	2	3	3	2	3	1	1
Connect	Nail members together	3	2	2	2	2	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4h - Interior trim

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Cut	Cut wood trim	2	2	2	1	3	1	3
Place	Place in correct location	1	1	1	2	3	1	2
Connect	Nail trim	3	2	2	2	3	1	2
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4i - Erect Scaffolding

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	3	3	2	1	1
Position	Position scaffolding sections	2	2	3	3	3	1	1
Connect	Connect sections	2	1	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4j - Pile driving

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Position	**Operate pile driving machinery**	**2**	**1**	**1**	**2**	**2**	**1**	**3**
Cut	**Cut piles as needed**	**1**	**2**	**2**	**2**	**2**	**1**	**2**
Connect	**Weld sections as needed**	**1**	**2**	**1**	**2**	**3**	**1**	**1**
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4k - Resilient Tile Setting

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Layout tile locations	1	1	1	3	3	1	1
Spread	Spread adhesive	2	2	2	3	3	1	2
Measure	Measure tile (only at the ends/edges)	1	1	1	1	3	1	1
Cut	Cut tile (only at the ends/edges)	1	1	2	2	2	1	1
Place	Place tile	3	2	3	3	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4l- Install carpet

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure floor/ pad/ carpet	1	1	1	1	2	1	1
Cover	Unroll pad	1	1	2	1	3	1	1
Cut	Cut pad to required dimensions	1	2	3	3	3	1	1
Cover	Roll pad	1	1	2	1	3	1	1
Position	Carry and lay pad	1	2	2	1	3	1	1
Cover	Unroll carpet	1	1	3	1	3	1	1
Cut	Cut carpet to required dimensions	1	2	3	3	3	1	1
Cover	Roll carpet	1	1	2	1	3	1	1
Position	Carry and unroll carpet	1	2	2	1	3	1	1
Spread	Spread adhesive	2	2	3	3	3	1	1
Connect	Nail tack strip	2	2	2	3	3	1	1
Position	Stretch carpet with knee kicker	3	2	3	3	3	1	2
Position	Stretch carpet with stretcher	2	1	2	2	2	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

United Brotherhood of Carpenters and Joiners of America

Table 4m - Install wood flooring

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	2	1	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Cut	Cut wood strips	1	1	1	2	2	1	3
Place	Place wood strips in position	3	1	2	2	3	1	1
Connect	Nail wood strips to sub floor	3	2	3	2	3	1	3

International Brotherhood of Electrical Workers

Table 5a - Install conduit

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	1	2	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Position	Bend, align, position conduit	1	1	2	2	2	1	1
Connect	Attach conduit to wall/ ceiling	2	2	2	2	3	1	3
Connect	Connect conduit to junction box	2	1	1	2	2	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Brotherhood of Electrical Workers

Table 5b - Install wiring

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Position	Pull wires	3	2	3	3	3	1	1
Cut	Strip end of wire	2	1	2	2	3	1	1
Finish	Bend wire to proper location	2	1	1	1	2	1	1
Connect	Connect wires	2	1	1	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Brotherhood of Electrical Workers

Table 5c - Install lighting systems and fixtures

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Position	Position fixture	2	2	2	2	3	1	1
Connect	Connect the fixture to wall/ ceiling	2	2	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Union of Elevator Constructors

Table 6a - Install rails

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	2	3	3	3	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Position	Position rail section	2	2	3	2	3	1	1
Connect	Attach to wall and other sections	3	3	2	3	3	1	1
Inspect	Inspect work	1	1	1	1	3	1	1

International Union of Elevator Constructors

Table 6b - Install cab/equipment

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	2	2	1	3	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Connect	Connect parts	2	1	2	1	2	1	2
Inspect	Inspect work	1	1	1	1	2	1	1

International Association of Bridge, Structural and Ornamental Iron Workers

Table 7a - Install rebar for slab or footing

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Position	Position rebar	2	1	2	2	2	1	1
Place	Wrap tie wire around rebar	3	2	2	2	3	1	1
Cut	Cut tie wire	2	1	3	3	3	1	1
Connect	Tie rebar	3	1	2	3	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1
Occasional								
Cut	Cut rebar	1	2	2	2	3	1	1
Finish	Bend rebar	1	1	2	2	2	1	1

International Association of Bridge, Structural and Ornamental Iron Workers

Table 7b - Install wall or column rebar in place

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Position	Position and hold rebar	2	2	2	2	2	1	1
Place	Wrap tie wire around rebar	3	2	2	2	3	1	1
Cut	Cut tie wire	2	1	3	3	2	1	1
Connect	Tie rebar	3	1	2	3	2	1	1
Position	Worker move to next position	1	1	2	2	2	1	1
Inspect	Inspect work	1	1	1	1	2	1	1
Occasional								
Cut	Cut rebar	1	2	2	2	3	1	1
Finish	Bend rebar	1	1	2	2	2	1	1

International Association of Bridge, Structural and Ornamental Iron Workers

Table 7c - Build rebar cages/ mats at work station

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Position	Position rebar	2	1	2	2	2	1	1
Place	Wrap tie wire around rebar	3	2	2	2	3	1	1
Cut	Cut tie wire	2	1	3	3	2	1	1
Connect	Tie rebar	3	1	2	3	2	1	1
Inspect	Inspect work	1	1	1	1	2	1	1
Occasional								
Cut	Cut rebar	1	2	2	2	3	1	1
Finish	Bend rebar	1	1	2	2	2	1	1
Position	Move entire cage/ mat	1	1	2	1	1	1	1

International Association of Bridge, Structural and Ornamental Iron Workers

Table 7d - Structural steel erection (ground crew)

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Connect	Rig member to crane	1	1	2	1	2	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Association of Bridge, Structural and Ornamental Iron Workers

Table 7e - Structural steel erection (erection crew)

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Position and align members	1	2	3	3	3	1	1
Connect	Install bolts	2	2	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1
Connect	Disconnect member from crane	1	1	2	1	2	1	1
Position	Worker move to next position	2	2	3	3	3	1	1
Position	Operate crane	2	1	1	2	2	1	3

International Association of Bridge, Structural and Ornamental Iron Workers

Table 7f - Structural steel erection (detailing crew)

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Connect	Bolt with spud wrench	3	1	3	3	3	1	1
Connect	Bolt with impact wrench	2	2	3	1	3	1	3
Connect	Weld	2	2	1	1	3	1	1
Position	Align members	2	2	3	3	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Association of Bridge, Structural and Ornamental Iron Workers

Table 7g - Metal Deck Installation

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry/position deck	2	3	3	2	3	1	1
Connect	Spot weld deck	3	2	2	1	3	1	1
Connect	Screw deck	3	2	2	2	3	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

International Association of Bridge, Structural and Ornamental Iron Workers

Table 7h - Precast Concrete Erection (ground crew)

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Connect	Rig precast member to crane	1	1	2	1	2	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Association of Bridge, Structural and Ornamental Iron Workers

Table 7i - Precast concrete erection (erection crew)

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Position and align precast members	1	2	3	3	3	1	1
Connect	Install bolts	1	2	2	2	3	1	1
Connect	Weld connections	1	2	1	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1
Connect	Disconnect from crane	1	1	1	1	1	1	1
Position	Operate crane	2	1	1	2	2	1	3

Laborer's International Union of North America

Table 8a - Place Concrete - slabs

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Transport concrete	2	1	3	2	2	1	1
Spread	Spread concrete	3	1	3	3	3	1	1
Finish	Vibrate concrete	2	2	2	2	1	1	3
Inspect	Inspect work	1	1	1	1	2	1	1
Finish	Screed/float (by other trade)	-	-	-	-	-	-	-

Laborer's International Union of North America

Table 8b - Place Concrete - walls, columns, beams

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Transport concrete	2	1	3	2	2	1	1
Spread	Spread concrete	3	1	3	3	3	1	1
Finish	Vibrate concrete	2	1	2	2	1	1	2
Finish	Screed/float (possibly by other trade)	2	1	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

Laborer's International Union of North America

Table 8c - Supply masons with brick/ block

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Position	Move brick/ block to scaffolding	3	2	3	2	3	1	2

Laborer's International Union of North America

Table 8d - Mix/ transport mortar for masons

Position	Mix mortar	3	2	3	2	3	1	1
Position	Transport mortar w/ motorized buggy	3	2	3	2	3	1	3

International Union of Operating Engineers

Table 9a - Operate cranes, dozers, scrapers, loaders, trucks, rollers, etc.

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Operate machinery	3	2	1	2	3	1	3

International Union of Operating Engineers

Table 9b - Operation of elevators

Basic Task	*Task Description*	*Repetitive Exertions*	*Static Exertions*	*Forceful Exertions*	*Local Mech. Stresses*	*Posture Stresses*	*Low Temp.*	*Vibration*
Position	Operate elevator	1	1	1	1	2	1	2
Position	Open / close door	2	1	2	1	2	1	1

Operative Plasterers and Cement Masons International Association of the United States and Canac

Table 10a - Manual Concrete Screeding

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry and position screed	1	1	1	2	1	1	1
Finish	Screed concrete	3	2	3	3	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

Operative Plasterers and Cement Masons International Association of the United States and Canac

Table 10b - Mechanical Concrete Screeding

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Finish	Operate mechanical screed	2	1	2	2	3	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

Operative Plasterers and Cement Masons International Association of the United States and Canac

Table 10c - Cement Finishing

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Finish	Float concrete	3	1	2	2	2	1	1
Finish	Trowel by hand	3	3	3	3	3	1	2
Finish	Float/ trowel with power float	2	1	1	1	2	1	2
Finish	Float/ trowel with ride on machine	1	1	1	1	2	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

Operative Plasterers and Cement Masons International Association of the United States and Canac

Table 10d - Sawcut concrete

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Layout cut locations	1	1	1	1	2	1	1
Position	Position saw	2	1	2	2	2	1	1
Cut	Operate concrete saw	2	1	2	2	2	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

International Brotherhood of Painters and Allied Trades

Table 11a - Spray Painting

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Finish	Sand/ scrape/ clean surface	3	2	2	3	3	1	2
Place	Mask areas not to be painted	1	1	1	1	2	1	1
Spray	Spray paint	2	2	2	3	3	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

International Brotherhood of Painters and Allied Trades

Table 11b - Brush and Roller Painting

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Finish	Sand/ scrape/ clean surface	3	2	2	3	3	1	2
Place	Mask areas not to be painted	1	1	1	1	2	1	1
Spread	Paint with brush	3	3	2	3	3	1	1
Spread	Paint with roller	3	3	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Brotherhood of Painters and Allied Trades

Table 11c - Drywall taping and finishing

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Connect	Screw protruding screws	1	2	2	2	2	1	1
Spread	Apply joint compound	3	2	2	3	3	1	1
Cover	Place tape (first coat only)	2	2	2	2	3	1	1
Finish	Sand surface	2	2	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Brotherhood of Painters and Allied Trades

Table 11d - Paper/ wall cover hanging

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure wall dimensions	1	1	1	1	2	1	1
Spread	Spread adhesive	2	2	2	2	2	1	1
Cover	Unroll paper	1	1	1	2	2	1	1
Cut	Cut paper	2	1	1	1	2	1	1
Cover	Apply paper to wall	3	2	2	2	3	1	1
Finish	Smooth surface	3	1	1	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Brotherhood of Painters and Allied Trades

Table 11e - Abrasive blasting

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Spray	Operate sand blasting equipment	3	2	2	2	2	1	3
Finish	Sweep up abrasive	3	2	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

United Union of Roofers, Waterproofers and Allied Workers

Table 12a - Install rigid insulation

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Cut	Cut insulation	2	1	2	2	3	1	2
Position	Position insulation	3	1	2	2	3	1	1
Connect	Attach to roof deck	3	2	2	2	3	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

United Union of Roofers, Waterproofers and Allied Workers

Table 12b - Install single ply roof membrane

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Membrane installation								
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	3	2	3	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Cover	Unroll membrane	1	1	3	1	3	1	1
Cut	Cut membrane	2	1	2	2	3	1	1
Spread	Spread adhesive	3	1	2	2	3	1	1
Cover	Roll out glued membrane	2	1	1	2	2	1	1
Finish	Smooth membrane	3	2	2	2	3	1	1
Inspect	Check for attachment	2	1	1	1	3	1	1
Ballast installation								
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Transport ballast with wheel barrel	2	2	3	3	3	1	1
Position	Rake out ballast	3	2	3	3	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

United Union of Roofers, Waterproofers and Allied Workers

Table 12c - Install shingle roof

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	2	3	3	3	1	1
Measure	Measure and layout	1	2	2	3	3	1	1
Cover	Roll out felt	2	2	2	3	3	1	1
Connect	Nail felt to roof deck	3	2	2	3	3	1	3
Cut	Cut felt	1	2	2	2	3	1	1
Cut	Cut shingle	1	2	3	3	3	1	1
Place	Place shingle	3	2	1	3	3	1	1
Connect	Nail shingle to deck	3	2	2	3	3	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

United Union of Roofers, Waterproofers and Allied Workers

Table 12d - Tear off built up roofing

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	2	3	3	3	1	1
Cut	Cut roofing into sections	2	1	2	1	1	1	3
Position	Pry out sections of roof	2	1	3	2	2	1	1
Position	Carry roofing to stockpile	3	1	3	3	1	1	1
Finish	Clean up	2	2	2	2	2	1	2
Inspect	Inspect work	1	1	1	1	2	1	1

United Union of Roofers, Waterproofers and Allied Workers

Table 12e - Install built - up roof

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Layer application								
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	2	3	3	3	1	1
Connect	Nail felt to deck (wood deck only)	3	1	2	2	3	1	3
Spread	Mop area with hot asphalt/ tar	3	2	2	2	3	1	1
Cover	Roll out felt	3	2	2	1	3	1	1
Cut	Cut felt	2	1	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1
Ballast installation								
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Transport ballast with wheel barrel	2	2	3	3	3	1	1
Spread	Mop with hot asphalt/ tar	3	2	2	2	3	1	1
Position	Rake out ballast	3	2	3	3	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

Sheet metal workers International Association

Table 13a - Install duct hangers

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	3	1	1
Cut	Drill holes	3	2	2	2	2	1	3
Place	Place hanger	2	2	3	2	3	1	1
Connect	Screw/ shoot into ceiling	3	2	2	2	2	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

Sheet metal workers International Association

Table 13b - Install ductwork

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	3	1	1
Position	Position duct section	2	1	2	1	3	1	1
Connect	Connect ductwork to hanger/ ceiling	3	2	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

Sheet metal workers International Association

Table 13c - Install equipment

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Position materials at required location	2	1	2	1	2	1	1
Measure	Measure and layout	1	1	1	1	3	1	1
Connect	Connect equipment to ceiling/ duct	3	2	2	2	3	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

International Brotherhood of Teamsters

Table 14a - Operate trucks

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Drive truck	3	2	2	2	3	1	3

United Association of Journeymen and Apprentices of the Plumbing and Pipe Fitting Industry of the United States and Canada

Table 15a - Install pipe hangers

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	3	1	1
Cut	Drill holes	3	2	2	2	2	1	3
Place	Place hanger/ fitting	2	2	3	2	3	1	1
Connect	Screw/ shoot into wall/ ceiling	3	2	2	2	2	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

United Association of Journeymen and Apprentices of the Plumbing and Pipe Fitting Industry of the United States and Canada

Table 15b - Install domestic water pipes, sanitary sewers, gas pipes, etc.

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure lengths of pipe	1	1	1	1	2	1	1
Cut	Cut pipe	2	2	1	2	1	1	2
Inspect	Check for burrs	2	1	1	1	1	1	1
Finish	Remove burrs, grind ends	3	2	2	2	2	1	3
Position	Move pipe to correct location	2	2	3	2	3	1	1
Connect	Weld, solder, braze, screw, bolt	2	2	2	1	2	1	1
Inspect	Inspect work	1	1	1	1	2	1	1

United Association of Journeymen and Apprentices of the Plumbing and Pipe Fitting Industry of the United States and Canada

Table 15c - Install fixtures

Basic Task	Task Description	Repetitive Exertions	Static Exertions	Forceful Exertions	Local Mech. Stresses	Posture Stresses	Low Temp.	Vibration
Plan	Formulate work sequence	1	1	1	1	1	1	1
Position	Carry materials to work location	2	1	2	2	2	1	1
Measure	Measure and layout	1	1	1	1	2	1	1
Cut	Drill holes	2	2	2	2	3	1	3
Position	Position fixture	1	2	2	2	3	1	1
Connect	Attach fixture to wall/ floor	2	2	2	2	3	1	3
Inspect	Inspect work	1	1	1	1	2	1	1

Appendix B

MEASUREMENT OF VIBRATION IN CLAW HAMMER HANDLES

John G. Everett, Asst. Professor, Center for Construction Engineering and Management, Dept. of Civil and Environmental Engineering, 2352 G. G. Brown Lab, University of Michigan, Ann Arbor, Michigan 48109 USA. (email everett@umich.edu)

Bernard J. Martin, Assoc. Professor, Center for Ergonomics, Dept. of Industrial and Operations Engineering, University of Michigan, Ann Arbor, Michigan 48109 USA

ABSTRACT

Vibration of hand tools is associated with hand, wrist, and upper limb disorders including carpal tunnel syndrome, white finger disease, and Raynaud's syndrome. The most basic of hand tools, the hammer, imparts vibration to the user's hand with very high acceleration (>>1000m/s^2) but with a duration of only a few milliseconds each time the hammer strikes a nail. Steel handled hammers are more durable than wood handled hammers, but it is widely believed among construction craft workers that wood handled hammers transmit less vibration to the user than do steel handled hammers. Fiberglass, and more recently graphite, handles have been introduced as a compromise between the durability of steel and the feel and natural vibration damping characteristics of wood.

This paper describes an experiment to measure and compare the vibration levels of eight different claw hammers, all with 0.45 kg (16 ounce nominal) heads. Five professional carpenters drove 16 d (penny) (8.9 cm) nails into plywood and 2x4 wood framing studs. Handle vibration was measured by means of a small piezoelectric shock accelerometer placed on the hammer handle, adjacent to the user's hand. Vibration was measured perpendicular to the axis of the handle, parallel to the driving direction. Signals were fed into a charge amplifier, displayed on an oscilloscope, and captured by computer.

Sampling frequency was 10,000 Hz. Weighted and unweighted one-third octave band frequency spectra were obtained with a signal analyzer.

A statistically significant difference was found for only one pair of hammers, but the finding is in direct contrast to the widely held notion that wood handles vibrate less than steel handles. The Craftsman steel hammer with a wood core in the head had an average weighted rms acceleration of 0.86 m/s^2, while the Stanley wood handled hammer had 1.13 m/s^2.

Key words: hammer, vibration, construction, occupational health and safety, tools

MEASUREMENT OF VIBRATION IN HAMMER HANDLES

by John G. Everett and Bernard J. Martin

I have seen
The old gods go
And the new gods come.

Day by day
And year by year
The idols fall
And the idols rise.

Today
I worship the hammer.

-Carl Sandburg

INTRODUCTION

The claw hammer is perhaps the most basic of all tools used in construction. Its design has changed little over thousands of years. A professional carpenter's hammer is literally and figuratively an extension of his/her body.

Hammers are commercially available in a wide variety of sizes, shapes, and materials. Hammers are classified according to the nominal weight of the head and the shape of the claw. The vast majority of hammers sold in the United States fall into three nominal weight groups: 16 ounce (0.45 kg), 20 ounce (0.57 kg), and framing hammers ranging from 22 to 30 ounces (0.63 to 0.85 kg).

The claw side of the head can be either curved (curved claw) or relatively straight (rip claw). The curved claw seems to be more popular among do-it yourselfers, probably due to its better leverage in pulling out nails. The rip claw is the overwhelming choice among professional carpenters.

Hammers work by releasing kinetic energy during impact with a nail or other workpiece. At impact, large working forces are released by the rapid deceleration of the hammer head. For most typical hammering operations, impact time is often less than one millisecond, with peak accelerations of several thousand meters per second squared.

Fortunately, the tool handle serves as an attenuator so that most of the vibration is not transmitted to the user's hand (Suggs 1982).

Steel hammers with one-piece head and handle construction are popular among some professional carpenters primarily because they are virtually indestructible. The steel shafts do not splinter when the shaft, rather than the striking surface, hits a nail or other object. However, many carpenters believe that the steel shafts cause a variety of musculoskeletal problems, particularly tendinitis in the elbow, from the vibration and impact transmitted to the user's hand each time the hammer strikes a nail.

It is widely believed among carpenters that wood handled hammers transmit less vibration to the user. So despite the tendency of wood handles to splinter and break, wood handled hammers also have a following among professional carpenters. Fiberglass, and more recently graphite, handles are often viewed as a compromise between the durability of steel and the feel and natural vibration damping characteristics of wood. These perceptions about hammers are consistent with the general feelings of similar materials used in other striking implements such as tennis rackets and golf clubs

One veteran carpenter informed the authors that many young carpenters start their careers with steel handled hammers and eventually switch to wood or fiberglass when their elbows can no longer take the punishment. However, hammer selection is a personal choice based on a number of factors besides vibration characteristics, including: balance, weight, handle size, grip, and price.

In order to cash in on the $90 million annual hammer market, manufacturers have been promoting their hammers with a variety of colors, grips, materials, and claims of reduced vibration (Welsh 1996).

There is no question that the swinging of hammers and striking of nails and other objects results in biomechanical stresses, including vibration, imposed on the hand, wrist, and upper limb. Suggs (1982) reported peak accelerations of 14,000 m/s^2 with high frequency (>1000 Hz) ringing with some combinations of workpieces and handles.

Vibration of hand tools is associated with hand, wrist, and upper limb disorders including carpal tunnel syndrome, white finger disease, tendinitis, and Raynaud's syndrome.

The objectives of this paper are to measure the vibration transmitted by claw hammers, to investigate the beliefs and claims that certain materials offer superior vibration damping characteristics, and to correlate craft workers' subjective assessments of hammers' characteristics with the experimental results.

METHODOLOGY

Subjects

A group of five male professional carpenters served as subjects for this research. The mean height was 1.82 ± 0.10 m (mean $\pm$ standard deviation); the mean weight was 92 $\pm$ 16 kg; and the mean number of years of professional carpentry experience was 16 ± 11 years. All subjects were right handed.

All subjects were informed of the purpose of the tests and signed a statement of informed consent before undertaking the tests. The experimental protocol was approved by the appropriate human subjects committee. All subjects and investigators were required to wear eye protection during the tests.

Procedure

The tests were conducted using the general format of ISO 8662-1:1988, Hand-held portable power tools - Measurement of vibrations at the handle - Part 1: General, and ISO Working Draft 8662-11, Hand-held power tools - Measurement of vibrations at the handle - Part 11: Fastener driving tools (nailers, staplers, pinners...) (ISO 1988, 1994) with modifications to accommodate manual claw hammer operation.

Eight hammers were chosen to represent a cross section of the vast number of hammers available. Each hammer was assigned a letter two letter designation corresponding to the initials of the manufacturer and the handle material. Data on the test

hammers is shown in Table 1. Two of the hammer's manufacturers made claims that their hammer reduced vibration. The Craftsman Steel hammer with a wood core in the head has a sticker on the head stating "shock absorbing hickory core" The Stanley Steel I-Beam hammer came with a tag that states, "unique head to handle assembly designed to absorb shock/vibration - reducing user fatigue."

Subjects were instructed to drive 16 penny common nails (length = 8.9 cm) that had been pre-driven approximately 1.5 cm into a test structure consisting of 1/2 in (1.3 cm) plywood over 2x4 (actual dimensions = 1.5 in x 3.5 in, 3.8 cm x 8.9 cm) spruce-pine-fir stud grade lumber. Figure 1 shows the experimental setup. This operation closely simulates nailing of sheathing onto floor or roof joists in wood frame construction. To minimize vibration of the test structure itself, the structure was supported on a bed of sandbags. The top of the structure was approximately 90 cm above the floor.

Subjects were instructed to drive each nail until approximately 1.5 cm remained exposed. Preliminary testing showed markedly different vibration characteristics during the last blow or two when the hammer was hitting the wood structure as well as the nail.

Subjects were given an opportunity to warm up and practice until they could maintain a pace of 1 Hz (paced by an audible metronome) for a 30 sec test period. Each subject performed the 30 sec test five times in succession for each of the eight hammers. A rest interval of approximately 1 minute was given between tests, and 3 minutes between the sets of five tests for each hammer. The longer interval allowed the investigators time to move the accelerometer to the next hammer and for the subjects to fill out an evaluation described below and to warm up with a new hammer. Hammers were presented to the subjects in random order.

Subjects were instructed to hammer at an intensity that could be maintained consistently for the approximately 1 hour duration of the full battery of tests. The pace and intensity are much lower than the carpenters would use in the field for framing work, but

were chosen to minimize any effects of fatigue. For full time professional carpenters, these tests were easy to perform. No fatigue was reported, and very few misses occurred.

Vibration was measured by a small piezoelectric shock accelerometer. The accelerometer and a low pass mechanical filter were attached to the test hammer handle with a hose clamp adjacent to the subject's index finger. Measurements were made in a direction parallel with the driving direction. The charge output from the accelerometer was fed into a charge amplifier and converted to voltage signals which were sampled at 10,000 Hz. Third-octave band frequency spectra data were obtained with a BK model 7667 signal analyzer.

RESULTS AND DISCUSSION

For each 30 sec test, a weighted rms acceleration value was calculated applying the weighting values in Table 2 (*American* 1986). The experimental results are summarized in Table 3 and plotted in Figure 2. Each entry in Table 3 and each data point on Figure 2 represents the mean of five, thirty second test runs for each subject and hammer pair. The rms acceleration values are given in m/s^2.

It can be seen that there was an obvious difference in weighted rms acceleration values among the subjects. Subject JG produced accelerations approximately 2.5 times as large as subject BD. The other three subjects were relatively close to each other. These results are a direct result of how hard each subject was hitting the nails. Again, no attempt was made to control the intensity of hammering, but the subjects were instructed to be as consistent as possible.

Less obvious is the difference in weighted rms acceleration values among the eight hammers. The only pair of hammers that exhibited a statistically significant difference ($p < .05$) was the Craftsman Steel hammer (mean = 0.86 m/s^2) and the Stanley Wood hammer (mean = 1.13 m/s^2).

The experimental protocol was designed to simulate real world conditions as much as possible, and therefore included many of the variables carpenters would face at work.

While the professional carpenters rarely missed the nail entirely, each strike was different. The exact angle of strike, the point on the hammer's striking surface that made contact with the nail head, the depth that the nail was penetrating the wood, and the effort imparted to the hammer by the subject varied with each strike.

Wood is a natural material that varies in moisture content, density, stiffness, and resistance to nail penetration. Each 2x4 is different and even within one piece of wood, there are differences in grain orientation and the presence or absence of knots. The distance from the nail to the edge of the 2x4 also varied slightly from nail to nail.

However, one important conclusion can be made. The widely held belief that wood handled hammers vibrate less that steel handled hammers has been shown to be incorrect, at least in one case. The only statistically significant difference found was that a steel handled hammer vibrated less than a wood handled hammer. All the other pairs had no statistically significant difference. It should also be noted that the Stanley I-Beam hammer did not exhibit the reduced vibration claimed by the manufacturer. The Craftsman steel handled hammer and the Estwing steel handled hammer appear similar with the exception of a wood core in the head of the Craftsman hammer. It appears that there is some validity to the manufacturer's claim that the wood core reduces vibration.

At the end of each set of five tests with a given hammer, each subject was asked to make a subjective assessment of the hammer according to the parameters shown in Table 4.

The subjective parameters were compared to each other and to the measured acceleration values to determine any differences and correlations. The only statistically significant correlation ($p < .05$) was that balance and overall assessment were positively correlated. The Stanley I-Beam hammer received a low score for balance ($p < 0.05$), while the Craftsman fiberglass hammer received a high score for balance ($p < 0.05$). There was no correlation between the subjective vibration assessment and the measured vibration values.

CONCLUSION

This paper has reported on experiments to measure the vibration of eight claw hammers. The Craftsman steel handled hammer had a significantly lower average weighted rms acceleration (0.86 m/s^2) than the Stanley wood handled hammer (1.13 m/s^2). This is in contrast with the widely held belief among construction craft workers that wood handled hammers vibrate less than steel handled hammers. No significant differences were found among all other pairs of hammers. The experimental results support the claim of the Craftsman steel hammer's manufacturer that the wood core reduces vibration. Significant positive correlation was found between subjects' assessment of a hammer's balance and its overall assessment.

The measured weighted acceleration values for all of the hammers are approximately 1 m/s^2. Even for the worst hammer, this value is well below the recommended limit for vibration exposure for 8 hours per day exposure (*American* 1986). However, the values reported are based on intermittent very high accelerations (>>1000 m/s^2) with very short durations (2-4 ms), and the remaining 99+% of the time with no vibration exposure. The overall average accelerations may be within recommended exposure levels, but still there is no question that carpenters who use hammers of all types regularly experience musculoskeletal problems. This may be a function of the peak acceleration levels and/or the duration of the shocks rather than the average acceleration levels. No widely accepted standards have been developed for this type of shock exposure. This topic would be worthy of future research.

ACKNOWLEDGMENTS

The research reported in this paper was supported under NIOSH Grant R03-OH03154-02.

REFERENCES

Welsh, J. (1996). "Age-old task: Making a better hammer." *Wall Street Journal*, June 19, B1.

Suggs, C. W. (1982). "Vibration of manual tool handles," in Brammer, A. J. and Taylor, W. (editors), *Vibration effects on the hand and arm in industry*, John Wiley and Sons, New York.

American national standard, Guide for the measurement and evaluation of human exposure to vibration transmitted to the hand. (1986). Acoustical Society of America, New York.

ISO. (1988). *ISO 8662-1:1988, Hand-held portable power tools - Measurement of vibrations at the handle - Part 1: General.* International Organization for Standardization (ISO), Geneva, Switzerland.

ISO. (1994). *ISO Working Draft 8662-11, Hand-held power tools - Measurement of vibrations at the handle - Part 11: Fastener driving tools (nailers, staplers, pinners...).* International Organization for Standardization (ISO), Geneva, Switzerland.

Hammer ID	Manufacturer	Handle material	Model #	Actual weight (kg)	Length (cm)
CF	Craftsman	Fiberglass	3823	0.715	32.9
CS	Craftsman	Steel (wood core in head)	38095	0.810	32.0
CW	Craftsman	Wood	38092	0.623	34.4
ES	Estwing	Steel	E3-16S	0.752	32.7
SF	Stanley	Fiberglass	51-518	0.724	33.3
SG	Stanley	Graphite	51-441	0.783	33.1
SS	Stanley	Steel I-Beam (Contractor Grade)	51-641	0.825	33.6
SW	Stanley	Wood (Contractor Grade)	51-351	0.633	33.4

Table 1. Test hammer characteristics. All hammers are nominal weight 16 ounces (0.45 kg)

Third-octave band center frequency, Hz	Weighting factor, Wf
6.3	1.000
8.0	1.000
10.0	1.000
12.5	1.000
16.0	1.000
20.0	0.794
25.0	0.630
31.5	0.500
40	0.397
50	0.315
63	0.250
80	0.198
100	0.157
125	0.125
160	0.099
200	0.079
250	0.063
315	0.050
400	0.039
500	0.031
630	0.025
800	0.020
1000	0.016
1250	0.012

Table 2. Frequency weighting factors for hand transmitted vibration (*American* 1986).

Hammer	Subject					Mean by hammer
	BD	JG	MV	SV	TM	
CF	0.54	1.50	1.02	0.70	0.95	0.94
CS	0.55	1.30	0.92	0.66	0.87	0.86
CW	0.52	1.56	0.85	0.78	1.09	0.96
ES	0.64	1.72	1.17	0.83	0.99	1.07
SF	0.59	1.54	1.10	1.11	0.97	1.06
SG	0.56	1.78	1.01	0.75	0.90	1.00
SS	0.60	1.62	0.84	0.76	0.95	0.95
SW	0.77	1.76	0.99	0.85	1.30	1.13
mean by subject	0.60	1.60	0.99	0.81	1.00	

Table 3. Weighted rms acceleration (m/s^2), mean of 5 tests for each pair of 8 hammers and 5 subjects.

Parameter	Rating scale
Balance	Worst (0) - Best (10)
Weight	Too light (0) - Too heavy (10)
Handle size	Too small (0) - Too large (10)
Grip	Too smooth (0) - Too rough (10)
Vibration	None (0) - Unbearable (10)
Overall assessment	Poor (0) - Excellent (10)

Table 4. Subjective assessment parameters

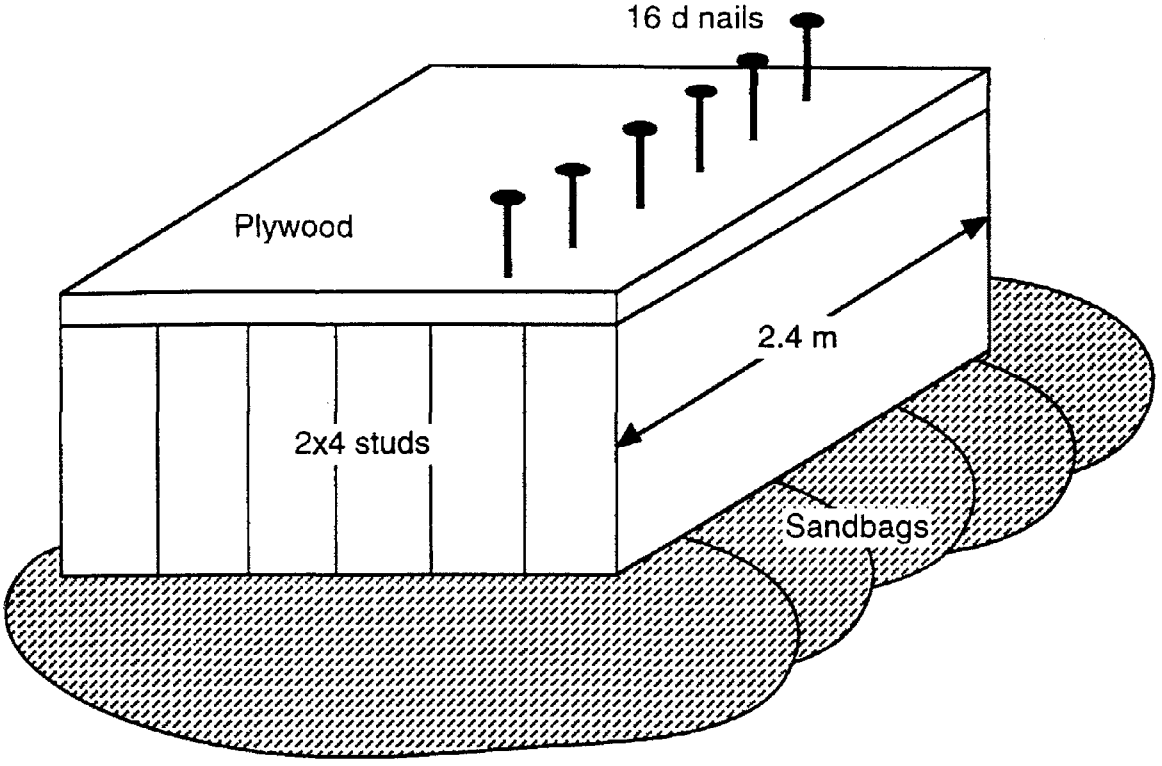

Figure 1. Experimental setup.

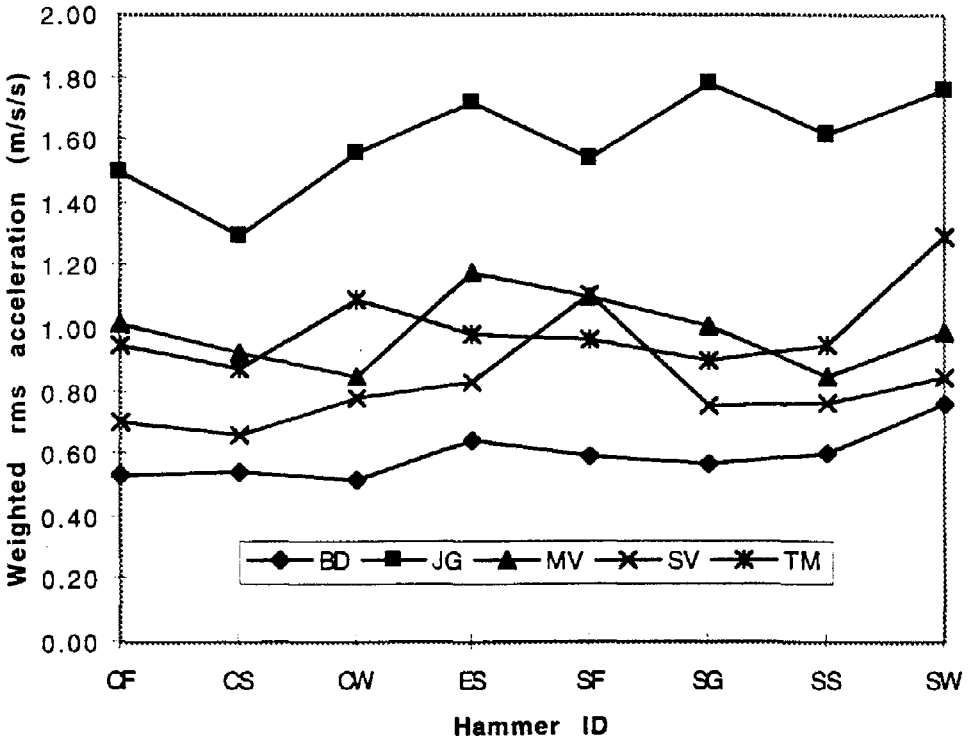

Figure 2. Weighted rms acceleration values for 8 hammers and 5 subjects.

Appendix C

DRYWALL JOINT FINISHING: PRODUCTIVITY AND ERGONOMICS

by John G. Everett and Dennis L. Kelly

ABSTRACT

Gypsum drywall panels are used extensively for wall cladding and structural fireproofing. Most interior building walls are of sufficient length and width to require at least two panels of drywall for complete coverage. Generally speaking, in residential construction, boards are placed horizontally (perpendicular to framing) and in commercial construction, boards are placed vertically (parallel to framing). This paper analyzes the effect of drywall panel and joint orientation on joint finishing operations. Productivity comparisons are made by investigating the total quantity of joint produced, production rates for various types of horizontal and vertical joints, and total time required to finish the joints. For typical residential applications, horizontal joints require less time to finish. For many commercial applications, vertical joints require less time to finish. However, there are many exceptions. Contractors and designers can save time and money by selecting the proper orientation. The locations of the joints on the wall also affects the motions and positions the craft worker must endure to complete the work. Professional finishers prefer horizontal joints because they greatly reduce the ergonomic stresses associated with bending down and reaching overhead.

INTRODUCTION

Gypsum and drywall

Mineral gypsum has long played an important role in the construction industry due to its bonding and fire retarding properties. One of the earliest recorded uses of gypsum is found in Egypt where it was mixed with lime for use as mortar and plaster to bond and cover the large stones of the Pyramids. Early Roman records indicate an appreciation for the fire retarding qualities of gypsum plaster (Erwin 1990).

Over the centuries, gypsum has grown in popularity as a construction material. In the late 1920's and early 1930's narrow gypsum lath panels were introduced as a replacement for wood or metal lath for wall plaster. The late 1930's saw the development of wider gypsum panels with an integrated joint treatment system (*Gypsum* 1992). This simple, innovative system has virtually replaced earlier wood or metal lath and plaster systems.

Today, gypsum panels are used extensively for wall cladding and structural fire proofing. Also known as drywall, gypsum wall board, plaster board, or by the registered US Gypsum brand name SHEETROCK, gypsum panels are common wall cladding materials in both residential and commercial construction.

The early popularity of gypsum panels was largely due to its considerably lower job site water requirement and rapid finishing time compared to the wet plaster system. This allowed for more expeditious sequencing of subsequent construction activities and project completion. Today, the popularity of drywall is largely due to its low overall cost due to material inexpense and low labor demand. Speed of installation, flexibility, fire resistance and high sound attenuating qualities attribute to and assure the continued popularity of drywall.

Gypsum panel production in the United States since 1987 has been nearly 19 billion square feet of regular and Type X gypsum panels annually (*Construction* 1996). This is an area equivalent to the greater Detroit metropolitan area. If the annual production of 4 foot wide panels were placed end to end, the ribbon would circle the earth 36 times. In construction dollars, drywall material and installation accounts for about $8.7 billion of construction annually.

The principle ingredient of drywall is mineral gypsum. Gypsum is a commonly occurring sulfate mineral of composition $CaSO4 \cdot 2H2O$ of which 21% is water. It is found in sedimentary deposits formed as sea water evaporites or in association with limestones, shales, marles and clays (Hurlbut and Klein 1977). Drywall is manufactured through a process of heating mineral gypsum to drive off the combined water. The product of this process is called calcined gypsum (calcium sulfate hemihydrate (*Standard* 1991)) which is mixed with starch, water, pregenerated foam (for density reduction) and other additives to form a thick paste. This mix is sandwiched between a heavy finish paper and backing paper and passed through rollers to form the desired shape and thickness. The slurry of gypsum and additives bonds to the paper and sets in 3 to 4 minutes. It is then cut to length and heated to drive of residual water (Allen 1990). The finished product has a smooth finished surface, paper wrapped beveled side edges, and cut unfinished ends. Type X, a special fire-resistant drywall, differs from other drywall in that it contains fiberglass or other reinforcement to provide support for the gypsum when exposed to the calcining effects of fire. Type X rated drywall 1/2 inch and 5/8 inch thick provide 3/4 and 1 hour fire-resistance respectively (*Standard* 1991).

The typical drywall system consists of 1/2 or 5/8 inch thick, 4 foot wide by 8, 9, 10, 12, 14, or 16 foot long gypsum panels cut to length and nailed, screwed and/or glued to wood or metal framing or firring. The panels can be oriented either parallel or perpendicular to the framing members (studs). Orientation of the panels will be discussed in detail below. The panels are cut using a knife to score the face paper then bent to break the board along the cut. The backing paper on the reverse side is then cut and rough edges of the broken gypsum surface trimmed. Panels may also be cut using a variety of saws. Most boards are hung with the beveled edges abutting the beveled edges of the adjacent board. In some cases butt joints are required when the wall length or height exceeds the length of the longest panel available. Hanging drywall constitutes roughly 50% of the total labor cost involved in the system (*Building* 1996).

Joints

After the drywall is hung, the joints between panels must be treated for concealment and fire protection. The treatment typically consists of a three coat application of specially formulated

joint compound. The base or embedding coat consists of a paper or fiberglass reinforcing tape embedded in joint compound and centered over the seam. This is applied by hand using a drywall knife or through the use of dispensing tools known as the "Banjo" and the "Bazooka." A second coat fills the remainder of the beveled depression between panels. The third or finish coat is applied and trowel finished to give the wall a smooth finished surface. The second and final coats are applied after sufficient time is allowed for the drying and light sanding of previous coats to assure a surface free of defects.

A mid-wall joint can be either a beveled edge joint or an end-of-panel (or cut edge) butt joint. A beveled edge joint results when the beveled edges of vertically or horizontally oriented panels are placed side by side. A butt joint results from the abutment of the unfinished panel ends when panels are placed end to end. Butt joints require additional finishing time as the reinforcing tape and joint compound sit on the surface of the panel rather than in the depression formed by the adjacent pre-formed beveled edges. Butt joints must be made approximately twice as wide as a beveled edge joints so that joint compound can be feathered out over the surface of the panel to conceal the joint.

The process of filling and sanding drywall joints requires a minimum of 6 separate occasions for the craft worker to physically work or pass along the length of the joint. Each occasion can involve 1 to 4 passes of a handheld tool over the joint. This can result in a total of 8 to 14 passes of the hand over the total length of the joints. Joint orientation and quantity therefore have a significant impact on the time required to finish a drywall clad wall. The finishing process constitutes the remaining 50% of the labor costs involved in installing drywall (*Building* 1996).

Objective

The objective of this paper is to analyze the effect of drywall panel and joint orientation on joint finishing operations. Productivity comparisons will be made by investigating the total quantity of joint produced, production rates for various types of horizontal and vertical joints, and total time required to finish the joints. The locations of the joints on the wall also affects the motions and positions the craft worker must endure to complete the work. Ergonomic

comparisons of horizontal and vertical joints will be made by evaluating the number of times the finisher must bend down and reach overhead.

PANEL ORIENTATION

Most walls are of sufficient length and width to require at least two panels of drywall for complete coverage. Drywall panels may be placed either parallel or perpendicular to wall framing members (studs) spaced 24 inches or less on center. A decision is made at the time material is ordered regarding the orientation of the board with respect to framing members. Factors that influence this decision are the designed fire rating requirements of a wall, ease of application, material waste, wall stiffness, ease of subsequent joint treatment, and appearance of the finished surface. Considerable differences in opinion and practice exist between workers and management in commercial and residential construction as to which board orientation is better. Generally speaking, in residential construction, boards are placed horizontally (perpendicular to framing) and in commercial construction, boards are placed vertically (parallel to framing).

Some of the reasoning offered by several drywall contractors for these practices is given in Table 1. Not all the above reasoning is entirely sound and some is contradictory.

Numerous fire resistant wall designs are presented in the Gypsum Association publication, *Fire Resistance Design Manual.* For example, 32 metal and wood stud wall designs for drywall placed parallel to framing and 12 metal and wood stud wall designs with drywall placed perpendicular to framing have 1 hour fire ratings. Eight of these designs are proprietary to specific drywall manufacturers (*Fire* 1994). This indicates that while fire ratings must be considered, they are not a critical factor in the decision.

Joint orientation and quantity

The orientation and location of the drywall panels dictates the orientation and location of the joints to be finished. Vertically hung drywall panels produce vertical joints that run from the floor to the top of the wall. The lateral position of vertical joints on the wall depends on the location of the drywall panels, but the vertical joints will be spaced 4 ft on center due to the 4 ft width of the panels. The joints may be positioned to fall over any stud, but will always extend from the floor to

the top of the wall. To finish the joint, the craft worker is required to bend over to the floor and to step up on stilts or a bench to reach the joint at the top of the wall.

Horizontal joints run from corner to corner. Adjustment to the height of the joint from the floor can be made by varying the height (panel width) of the panel nearest the floor. Most horizontal joints can be installed at a height within the reach of most craft workers resulting in less bending and stepping up on stilts or a bench compared to vertical joints.

The quantity of joint for a given wall varies depending on the orientation of the drywall and the dimensions of the wall. Figure 1a shows a wall 8 ft high by 12 ft long. If the panels are hung horizontally, there will be 12 linear ft of joint to finish, indicated by the heavy line. Figure 1b shows the same 8 ft high by 12 ft long wall with the panels hung vertically. In this case there will be 2 vertical joints, each 8 ft in length, for a total of 16 linear ft of joint, as shown by the two heavy lines. For this size wall, horizontal panels require substantially less joint finishing than vertical panels.

For other wall dimensions, vertically hung panels produce less joint. Figure 1c shows a 9 ft by 12 ft wall with horizontal panels. Here there are 2 joints, each 12 ft in length, or 24 linear ft of joint to be finished. The incremental 1 ft of height (compared to the 8 ft wall) adds a second horizontal joint, the full width of the wall. Figure 1c shows the two horizontal joints at 4 ft and 8 ft from the floor, but this is not the only, nor even necessarily the most desirable configuration. This issue will be discussed below.

If the panels are hung vertically as shown in Figure 1d, there will be 2 joints, each 9 ft in length, for a total of 18 linear ft of joint. Clearly, in this case, vertical panels produce less joint to be finished.

If the 9 ft wall is lengthened to 13 ft, the situation changes again. Figure 1e shows that the wall has 26 linear ft (2 joints, each 13 ft) of joint with horizontal panels. Figure 1f shows that vertical panels produce 27 linear ft (3 joints, each 9 ft) with vertical panels. Here the horizontal orientation produces slightly less joint.

From Figures 1c and 1f, it can be seen that an increase in wall dimension perpendicular to the joint orientation produces a whole new joint at each 4 ft increment. Additional increase in this

dimension does not change the quantity of joint until the next 4 ft module is reached. For increases in wall dimension parallel to the joint orientation, the total joint length increases, but remains proportional to the wall dimension.

This type of analysis can be performed for any size wall to determine quantities of mid-wall joints to be finished. To facilitate comparison of different size walls to each other, the term *joint ratio* is introduced. *Joint ratio* is defined as the quantity of joint (linear feet) divided by the area of the wall (square ft). Figure 2 shows a plot of joint ratio (lf joint / sf wall) versus wall length for four different wall configurations.

The lowest curve (squares) shows the joint ratio for an 8 ft high wall with a horizontal joint. The joint ratio is constant at 0.125 lf joint / sf wall until the wall reaches 16 ft in length. Here it is assumed that 16 ft panels are used. A slight increase in wall length, say to 16'-6", requires a full wall height vertical butt joint, so there is a quantum jump in joint ratio just above 16 ft in wall length. With increasing wall length beyond 16 ft, the joint ratio decreases as the additional joint length gets divided over a larger wall area. Another jump occurs at 32 ft.

The top curve (triangles) shows a similar plot for an 8'-6" wall with horizontal joints. In this case there would be a second horizontal joint (as in Figure 1c) and the joint ratio would be nearly twice as large as for an 8 ft wall. As for the 8 ft wall, an increase in joint ratio occurs each time the wall length exceeds a multiple of 16 ft. A 9 ft wall with horizontal joints (Xs) is similar to an 8'-6" wall, but the joint ratio is slightly lower because the total joint length is the same while the wall area is larger.

The curve representing vertical joints (diamonds) applies to any wall height below 16 ft (where a horizontal butt joint would be required). In this curve, the jumps in joint ratio occur at each 4 ft increment, corresponding to the addition of a full height vertical joint.

Similar plots can be developed for any height and length wall, or for different length drywall panels, but the basic pattern remains as shown. From this chart it can easily be seen that for certain sized walls, one joint orientation clearly produces a lower joint ratio (and lower total joint) than the other joint orientation. To return to the examples in Figure 1, for an 8 ft by 12 ft

wall, horizontal orientation has a lower joint ratio. For a 9 ft by 12 ft wall, vertical orientation has a lower joint ratio. For a 9 ft by 13 ft wall, the joint ratios are quite close for the two orientations.

It should be noted that the wall dimensions used throughout this paper are approximate. Normal drywall panels are exactly 4 ft wide, but they are usually installed slightly raised off the floor, so a horizontal joint is more likely to be found at 4'-0-1/2" rather than 4' off the floor. This may not appear to make much of a difference, but the next joint up would then be at 8'-0-1/2", allowing a finished suspended ceiling to be installed at 8'-0".

Contractors can fudge an inch or two in wall width if necessary. For example, if a wall were 12'-1" wide, it might appear necessary to install three full vertical sheets plus a one inch strip. This would be labor intensive and impractical because the thin strip would break during cutting, installation, or fastening. In practice, the installer would probably leave a one-half inch gap on either end which would be filled in by the finisher. The installer could also install the adjacent, perpendicular wall panels first, thereby reducing the width of the wall by an inch or so, depending on the panel thickness.

The dimensions are also somewhat ambiguous because it may not be clear whether the dimensions refer to the size of the wall before the drywall is installed, or after. The room will shrink by an inch or so in both directions in plan after all the drywall is installed. These differences only shift the plots in Figure 2 to the left or right slightly, but at some point as the wall dimension increases, there will be a quantum jump in the joint ratio as a whole additional joint is added.

PRODUCTIVITY MEASUREMENT

Total joint length and joint ratio are measures of quantity of joint to be finished. Probably of more interest to most construction engineers and managers is the time or cost to finish the joints. This requires that productivity rates be known for different joint orientations and locations. The time required to finish a vertical joint and a horizontal joint of the same length are not necessarily equal, and the location of the joint (i.e., near the floor, 4 ft off the floor, at full reach, beyond full reach) must be considered.

This paper analyzes only mid-wall joints. The finisher must also work the inside and/or outside corner joints around the perimeter of the wall, but these are constant for a given wall regardless of drywall orientation and are therefore not included in calculations here. Similarly, the finishing of nail or screw heads is assumed to be equal for both orientations, and is not included in this analysis.

Vertical and horizontal beveled joint finish rates for the first (base), second (fill) and third (finish) coats were measured for several professional finishers. Finishing productivity rates, measured as minutes per linear foot of joint (min/ft), were determined from field observations of drywall finishers on jobs with joints in both orientations.

This is easier said than done. It is easy enough to find residential contractors finishing horizontal joints and commercial contractors finishing vertical joints, but difficult to find situations where the same finishers could be observed finishing both horizontal and vertical joints. The goal was to compare finishing rates for different joints without having to account for differences among craft workers.

Most of the data was collected at the School of Social Work building project on the University of Michigan campus. This project was typical of many office buildings with many small offices around the perimeter of each floor. Many of the offices were configured such that the owner and drywall subcontractor were willing to install the drywall panels horizontally. Normally the entire building would have had the panels hung vertically.

Field measured productivity rates are shown in Table 2. Data were collected for the first, second, and third coats for Horizontal Low, Horizontal High, and Vertical beveled joints, and Vertical butt joints.

An average worker (50th percentile male) with a drywall knife in his hand can reach comfortably to 6'-10" from a standing position (Differient et al. 1981). Therefore, a distinction is made between work performed standing on the floor and work performed standing on stilts, a bench, or an inverted 5-gallon joint compound bucket. For horizontal joints, low typically means the joint was 4 ft above the floor, and high means the joint was 8 ft above the floor.

For vertical joints, the finisher can work the joint from the floor to about 6'-10" above the floor. This range was originally considered the Vertical Low range. The portion of the vertical joint above this height requires standing on one of the above mentioned devices. This was originally considered the Vertical High range. However, great differences in work "style" occur among workers. Some work the entire height of the joint continuously, stepping up and down from a bucket as they work. Others work the low portions of several vertical joints at one time, and come back later to complete the all high portions. Some prefer stilts, others prefer a bucket or bench, or whatever is handy. Because of all these differences, especially the inability to separate the high and low portions for some workers, all the data for vertical joints was combined into a single value for each coat for each finisher.

Limited data was collected for butt joints, however drywall installers avoid these joints whenever possible and therefore they make up only a small fraction of the total joints. Butt joints take roughly twice as much time to finish compared to an equal length beveled joint, but more importantly, they are nearly impossible to hide because there is always a ridge in the finished wall. For long walls with horizontal panels and joints, butt joints (which will be vertical) are inevitable. In this case the contractor may elect to install the panels vertically and avoid the problem. In residential construction, where the panels are almost always installed horizontally, the walls sizes are usually short enough that few butt joints are required.

In commercial construction, where the walls are more likely (compared to residential construction) to be longer than the drywall panels, and the ceilings are more likely to exceed 8 ft (requiring a second horizontal joint), the panels are almost always installed vertically. In this case, butt joints only occur at heights greater than the length of the panel. Few ceilings are high enough that this is a problem. Most of the butt joints that do occur are above the height of the finished (suspended) ceiling. Some of these joints may need a base coat for fire resistance (sometimes called *firetaping*), but the appearance is not critical, so they receive less careful craftsmanship than a joint that would show. Second and third coats are typically not required and not applied.

The total time required to finish the mid-wall joints on a given wall may be calculated by the following equation:

$$\text{Time} = \sum_{i=1}^{2}\sum_{j=1}^{3}\sum_{k=1}^{3}(A_i \times JR_i \times P_{ijk}) \qquad (1)$$

where A_i = wall area

JR_i = joint ratio

P_{ijk} = productivity rate

and $i = 1$ for wall area below 6'-10"

$i = 2$ for wall area above 6'-10"

$j = 1$ for horizontally oriented beveled joints

$j = 2$ for vertically oriented beveled joints

$j = 3$ for vertically oriented butt joints

$k = 1$ for the 1st (base) coat

$k = 2$ for the 2nd (fill) coat

$k = 3$ for the 3rd (finish) coat.

Equation 1 is simply the sum of the products of the total quantity of each type of joint multiplied by the appropriate productivity rate. Combining the wall areas and joint ratios from Fig. 2 and the productivity rates from Table 2 produces Fig. 3 which shows the total time (minutes per square foot of wall area) required to finish each type of wall. The general shape of the plots in Fig. 3 is similar to those in Fig. 2, but the differences in productivity rates have shifted the plots relative to each other.

From Fig. 3 it can be seen that for 8 ft high walls up to 16 ft in length, horizontal joints require less finishing time. Additional length beyond 16 ft introduces the vertical butt joint and makes horizontal orientation less desirable relative to vertical. Using the joint ratios alone (Fig. 2), horizontal orientation is always preferred for 8 ft walls. From Fig. 3, for 8'-6" and 9' walls, vertical orientation is always preferred. Using joint ratios alone (Fig 2), one might pick either orientation.

In residential construction, walls are typically 8 ft high and less than 16 ft long, so it is appropriate that the drywall panels are installed horizontally. In commercial construction, walls are

often more than 8 ft high and often more than 16 ft long. It is appropriate that they be installed vertically.

Despite the fact that no drywall contractor interviewed had ever considered the concepts presented in this paper, industry practices seem to have evolved to minimize finishing times in most cases. However, in most residential construction projects, there are some walls, such as those in living rooms with cathedral ceilings, that would have reduced finishing times if panels were placed vertically rather than horizontally. In commercial construction, many walls can be found that would be finished in less time with horizontal panels. Offices and small rooms often have 8 ft ceiling heights and wall lengths less than 16 ft. Designers and contractors wishing to minimize costs and maximize speed of construction should evaluate each wall for the most efficient panel orientation rather than simply installing all panels in the entire building the same way.

ERGONOMICS

The analysis above has focused strictly on productivity analysis and estimating finishing times. This is typically the primary concern of the contractor. However, interviews with the finishers reveals that they overwhelmingly prefer horizontal joints, and are relatively unconcerned with productivity rates. The reason is that horizontal joints allow the finisher to work at a constant, and often comfortable, height. Much of the time, they are standing on the floor working on a joint at a comfortable 4 ft above the floor. For high horizontal joints, the finisher must strap on a pair of stilts or step up on a bucket, but once that is done, they work at a constant height which may be quite comfortable, especially with tall (but illegal) stilts. (Many finishers are quite adept at "walking" a bucket around by shifting their weight and twisting their feet, and therefore they do not have to constantly step up and down from the bucket.) With vertical joints, there is constant bending down to the floor and reaching well overhead, and stepping up and down from a bucket.

It is difficult to quantify the ergonomic stresses in terms compatible with the productivity figures, but in the long run, worker fatigue and musculoskeletal injuries of the knees, low back, shoulder, and neck will have a serious negative impact on productivity and project costs.

Ergonomists recommend that standing work be performed between 30 and 42 inches above the floor, depending on the task, while reaching over the head should be avoided (Waters 1994,

Rogers 1983). Using these rough guidelines, one can divide the typical wall into three roughly equal height ranges. The lowest third of the wall (floor to 32 in) requires continuous bending down, the middle third (32 to 64 in above floor) is relatively comfortable, and the upper third (above 64 in) requires constant reaching overhead. Two thirds of the time the worker is in a very uncomfortable position and at risk for developing overexertion injuries (Armstrong 1993).

To estimate the actual number of times a finisher bends down and reaches up during a day of finishing vertical joints, videotapes of the workers were reviewed. Over the course of an 8 hour day, the typical finisher bent down 746 times and reached up 835 times. While standing on the floor, the finisher bends down relatively more often; while working on stilts, the finisher reaches up more often. This count agrees with a statement one of the finishers made that in the course of a morning's work taping one hallway, he bent down three hundred fifty times. After that he stopped counting.

DRYWALL WIDTHS OTHER THAN 4 FEET

Standard drywall panels are 4 ft wide and vary in length up to 16 ft. Recently, 54 in wide panels have become available in limited lengths (8, 10, and 12 ft) (*Gypsum* 1996). These panels offer the possibility of a single horizontal joint on walls up to 9 ft in height, however, drywall installers who have used the 54 in wide panels emphasize that they are even heavier than normal 4 ft panels and have not gained much popularity among craft workers.

It would be possible to manufacture drywall panels in smaller widths as well. For example, if panels were made 3 ft wide, three panels could be installed horizontally for walls up to 9 ft in height. There would still be two horizontal joints so the joint ratio would be the same as for 4 ft wide panels. However, the joints would be at 3 ft and 6 ft above the floor, both of which could be easily reached by a finisher standing on the floor.

Fig. 4 shows the projected finishing times for four configurations of 9 ft high walls. The vertical joints (diamonds) and 4 ft horizontal panels (Xs) are identical to the corresponding plots on Fig. 3. The open squares show the projected finishing times for the hypothetical 3 ft wide panels assuming all joints can be finished at the Horizontal Low rate in Table 2. For walls from 8 to 16 ft

in length, 3 ft panels would be about the same as 4 ft panels from a productivity standpoint, but superior from an ergonomic standpoint.

The open circles show the 54 in panels, and assumes they would be available in 16 ft lengths. The finishing time would be much less than either of the current choices. These extra wide, extra long panels would be a bear to install, but with improved manipulators and handling devices, they may someday be competitive.

CONCLUSION

This paper has analyzed the effect of drywall panel and joint orientation on joint finishing operations. Productivity comparisons were made by investigating the total quantity of joint produced, production rates for various types of horizontal and vertical joints, and total time required to finish the joints. It was shown that for 8 ft high walls up to 16 ft in length, horizontal joints require less finishing time than vertical joints. For most walls higher than 8 ft, vertical joints require less finishing time. This analysis confirms that the general use of horizontal panels among residential contractors and vertical panels among commercial contractors is appropriate. However, the paper also demonstrates that contractors and designers can save time and money by evaluating each wall for the most efficient panel orientation rather than simply installing all panels in the entire building the same way.

In addition to the productivity concerns, the paper has examined the joint orientation from an ergonomic standpoint. Horizontal joints are superior to vertical joints and are preferred by the craft workers. Horizontal joints greatly reduce the bending down and reaching overhead compared with vertical joints.

FUTURE RESEARCH

The effects of orientation on drywall hanging and the resulting quality of the finished surface have not been analyzed in this paper. Further research in this area may be desirable to determine the effect of joint orientation on overall drywall productivity. This paper has examined joint finishing performed by hand with a drywall knife. Other tools, including the bazooka, banjo, and box may sped up the application of the joint compound and tape, but the joint compound must

still be smoothed and wiped by hand. Local practice varies in the use of these tools. Some union collective bargaining agreements forbid the use of these tools.

REFERENCES

Allen E. (1990). *Fundamentals of building construction: Material and methods*, J. Wiley and Sons, Inc., New York, N.Y.

Armstrong, T. A. (1993). *Analysis and Design of Jobs for Control of Upper Limb Musculoskeletal Disorders*. University of Michigan, Ann Arbor, MI.

Building construction cost data (1996). 54th Annual Edition, R. S. Means Company, Inc., Kingston, MA.

Construction review. (1996). U. S. Department of Commerce, Washington, DC, Vol. 42.

Differient, N., Tilley, A., and Harman, D., (1981). *Human scale manual 7/8/9*, MIT Press, Massachusetts Institute of Technology, Cambridge, MA.

Erwin, A. E. (1990). "The evolution of space enclosure from mud and reeds to modern walls and ceilings." *ASTM Standardization News*, ASTM, 18(12), 44-48.

Fire resistance design manual. (1994). 14th edition, Gypsum Association, Washington, DC.

Gypsum construction handbook. (1992). United Sates Gypsum Company, Chicago, Ill.

Gypsum panel products types, uses, sizes, and standards. (1996). GA-223-96. Gypsum Association, Washington, DC.

Hurlbut, C. S., and Klein, C. (1977). *Manual of mineralogy, 19th edition.* J. Wiley and Sons, Inc., New York, NY.

Rogers, S. H. (ed.) (1983). *Ergonomic design for people at work.* Van Nostrand Reinhold, New York.

Standard specification for gypsum wallboard. (1992). ASTM C36-92, Philadelphia, PA.

Standard terminology relating to gypsum and related building materials and systems. (1991). ASTM C11-91, Philadelphia, PA.

Waters, T. R., Putz-Anderson, V., and Garg, A. (1994). *Applications manual for the revised NIOSH equation.* US Dept. of Health and Human Services, Cincinnati, OH.

LIST OF TABLES AND FIGURES

Horizontal Orientation (perpendicular to framing)	Vertical Orientation (parallel to framing)
Residential contractor and labor preferences	
• Less joint to finish - lower finish cost • Majority of mid-wall joints accessible from standing position • Produces a better finish by concealing waves due to warping and irregularities in wood stud framing • Less control over stud locations, not always 4 ft on centers • Produces less waste • reduces bending and reaching overhead	
Commercial contractor and labor preferences	
•Produces a stiffer wall •Minimizes length of joint needing treatment •Yields a better looking wall •Reduces bending and reaching overhead	• Continuous edge support from studs • Required for fire rating • Reduces quantity of undesirable butt joints • Less waste on large jobs (board may be ordered from factory to exact length needed) • Required by some architects for better wall finish • Panels do not have to be lifted to top of wall, they are supported by floor
Manufacturers' perspective	
• The *US Gypsum Construction HandBook* states that perpendicular (horizontal) placement of panels relative to framing places the strong direction of drywall perpendicular to framing and therefore produces a stiffer wall (*Gypsum* 1992). • Either orientation is OK as long as there is proper backing allowing for proper fastener and support spacing. • Care should be taken to avoid placing wrapped (beveled) edges against unwrapped edges. This leads to differential expansion and eventual cracking.	

Table 1. Construction industry reasoning for the horizontal or vertical application of drywall.

Coat	Horizontal Low	Horizontal High	Vertical	Vertical Butt
1	0.13	0.16	0.15	0.30
2	0.11	0.19	0.11	0.22
3	0.11	0.17	0.11	0.22

Table 2. Field measured productivity rates for finishing drywall joints (min/ft).

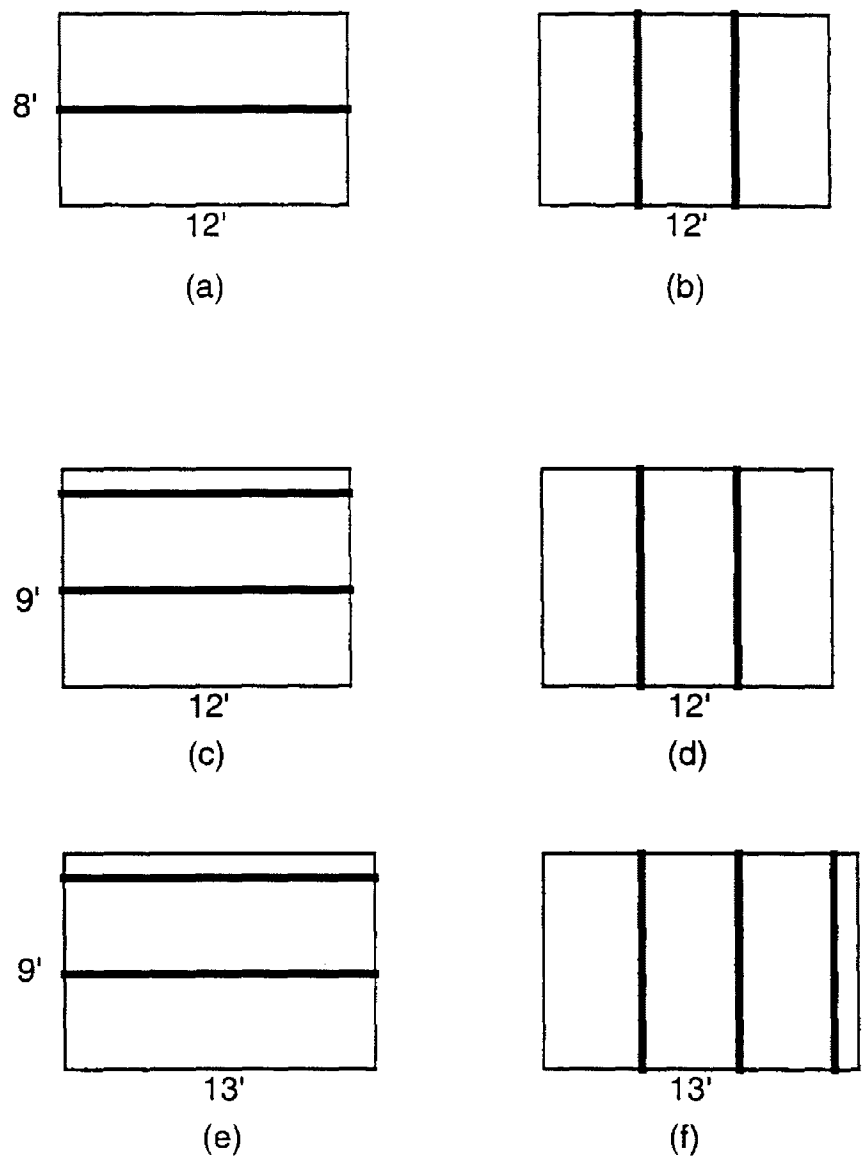

Figure 1. Joint length varies with different wall dimensions.

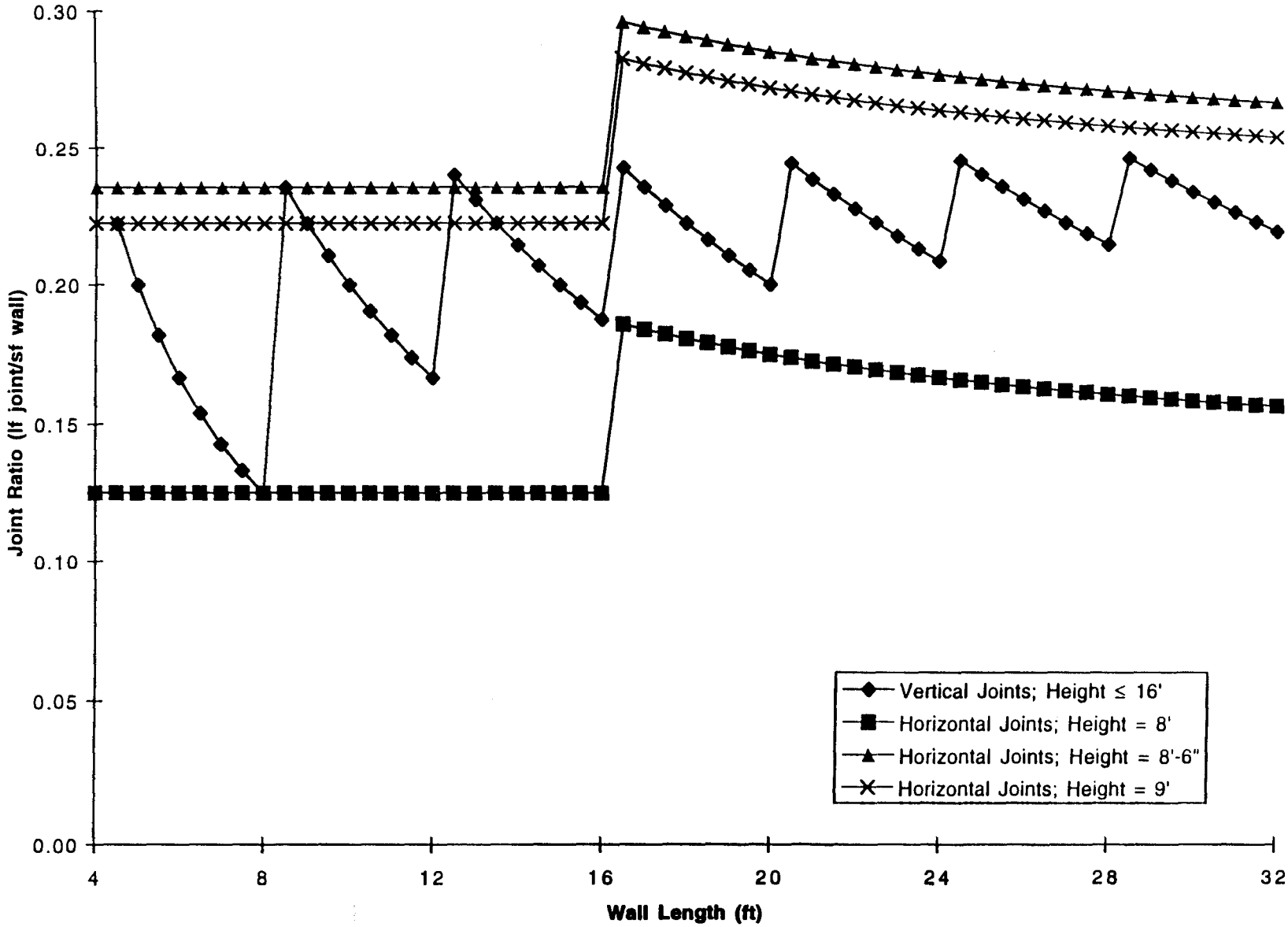

Figure 2. Joint ratio (lf joint / sf wall area) versus wall length for various wall configurations.

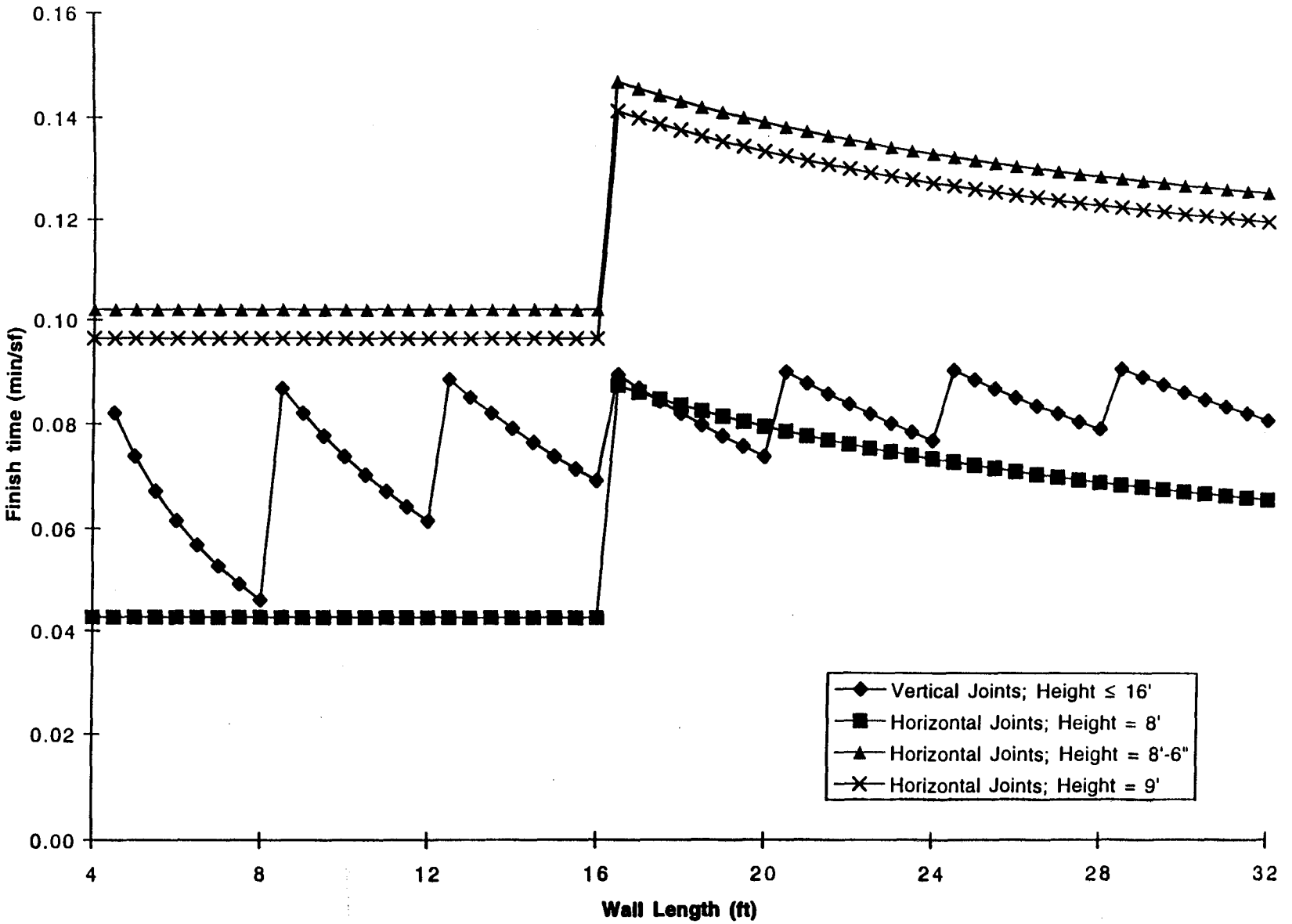

Figure 3. Joint finishing times (min / sf wall area) for various wall configurations.

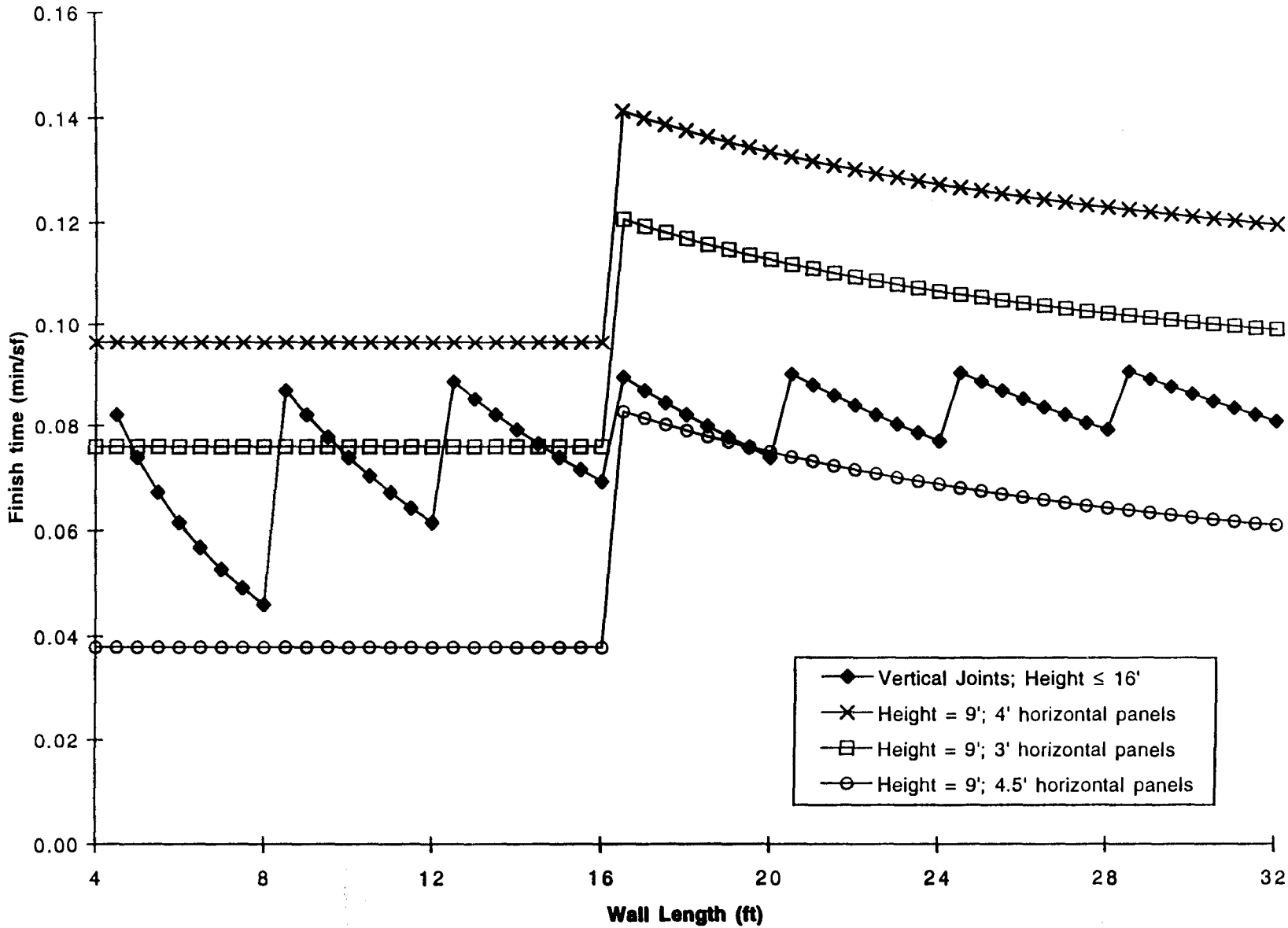

Figure 4. Joint finishing times (min / sf wall area) for hypothetical new panel sizes compared to conventional panels.