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Identification and Assessment of Musculoskeletal Disorders (MSDs) Risk for Concrete Formwork Systems

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Abstract

Musculoskeletal disorders (MSDs) account for more than half of all the injuries and illnesses in the construction industry. Concrete formwork construction is recognized as one of the work tasks in which workers have a high risk of developing MSDs. Previous research has focused extensively on the use of conventional job-built formwork. Given the growing use of prefabricated/engineered (including modular) formwork systems, this research study was designed to investigate the differences in work tasks and activities for different types of formwork systems, assess MSD risks associated with different types of formwork systems, and determine the prevalence and nature of MSDs in concrete formwork construction. A mixed-method research approach was adopted that included surveys of form workers, site observations, and worker posture evaluations using the Rapid Entire Body Assessment (REBA) method. The findings reveal a high prevalence of work-related MSD symptoms among form workers, and the majority of formwork tasks and activities impose medium- to high- MSD risk on workers. The use of modular formwork systems may create less ergonomic exposure to workers because modular forms are pre-assembled and relatively lightweight. The study provides an improved understanding of formwork activities, as well as the prevalence of work-related MSD symptoms in workers who perform formwork operations, and can be used by formwork designers and constructors to improve worker health and safety.

Keywords: Worker safety and health, musculoskeletal disorder (MSD), concrete formwork, REBA method

Key Points

- The work tasks and activities for conventional job-built and prefabricated/engineered (including modular) formwork systems are similar; however, prefabricated/engineered (including modular) formwork requires less work or effort during specific tasks, such as sawing/cutting materials and nailing/screwing/drilling formwork components or other materials.
- A high prevalence of work-related MSD symptoms exists among form workers regardless of the types of formwork systems they use.
- Repetition, awkward working postures, and use of force were rated by form workers as the three physical factors that contribute the most to the development of MSD-related symptoms.
- Form workers are at high risk of developing MSDs in their lower back, upper back, neck, and shoulder.
- Based on the REBA assessment results, most of the formwork tasks and activities, such as main and secondary beam installation and shoring post installation, create medium- and high-level MSD risk to form workers, with REBA scores ranging from 4 to 10.
- Placing sheathing panels may impose very high MSD risks on workers (REBA score = 11) due to their heavy weight and large size and the awkward postures needed to place them.
- Compared to prefabricated/engineered formwork systems, modular formwork systems require less time and physical effort, which creates less ergonomic exposure to workers, especially in their upper arms and legs.
- Suggestions for MSD prevention and improvements associated with form construction include four levels of control: (1) substitution—for example, use modular formwork systems, (2) engineering improvements—for example, use lift assists and/or lifting devices (e.g., forklifts, hoists, cranes) whenever possible to help workers move and manipulate form components, (3) administrative controls—for example, rotate form workers through several different tasks during a work shift, and (4) work practice modifications—for example, use a two-person lift team when handling form components that are heavier than 51 pounds (e.g., shoring posts or sheathing panels).

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Introduction

Construction operations are physically demanding which puts construction workers at significant risk of developing musculoskeletal disorders (MSDs). At the time this study was being proposed, the MSD incidence rate in the construction industry was 28.9 per 10,000 full-time workers, compared to an MSD incidence rate of 27.2 for all private industries combined (BLS, 2020). With more than seven million employees in the industry (BLS, 2019), the number of construction workers who suffered from MSDs in 2018 was 19,380 (BLS 2020). MSDs are associated with injuries to soft tissues such as muscles, tendons, ligaments, joints and cartilage, and the nervous system (Akinnuli et al., 2018). MSDs can cause the development of common forms of injury such as low back pain, shoulder disorders, distal upper extremity disorders, and other debilitating health impacts (Waters, 2004).

Musculoskeletal disorders are revealed through MSD-related signs and symptoms—"sprains and strains" and "soreness, pain"—and, in 2017, represented 27.3% and 17.3% of all construction worker injuries and illnesses, respectively (CDC, 2018). In a 2014 study (Dong et al., 2014), the researchers found that during their working lives, 21% of construction workers experienced "overexertion" injuries, a type of MSD-related injury that poses lifetime risks. More recently, using multi-year data from the Medical Expenditure Panel Survey, Dong et al. (2020) pointed out that about 34% of construction workers had at least one type of MSD symptom. MSDs may severely impact work performance and worker long-term health and well-being. Research has also shown that MSDs are an important cause of functional impairment and disability among construction workers (Boschman et al., 2012).

MSD rates among construction workers vary by age, occupation, and work activities (Paquet et al., 1999; Welch et al., 2000; Pinder et al., 2001; Holmström and Engholm, 2003; Boschman et al., 2012; Wang et al., 2017; Hajaghazadeh et al., 2019). Construction workers who are frequently exposed to awkward postures and motions such as lifting, bending, and twisting are most likely to suffer from MSDs (Valero et al., 2016). Among all construction activities, concrete formwork construction is recognized as an operation in which workers have a high risk of developing MSDs (Spielholz et al., 1998).

Formwork is used to support permanent concrete during its placement and curing until the structure gains sufficient strength to support itself, as well as to support construction materials and construction live load (i.e., personnel and equipment). There are many types of formwork on the market, and their selection depends on the availability of materials, the application, cost, and site-specific conditions. Formwork can be roughly categorized into conventional (job-built timber/plywood) formwork and prefabricated/engineered (including modular) formwork. The former requires intensive labor effort on the construction site as the formwork is hand-built in place. The latter is relatively easier and faster to assemble and dismantle because the formwork panels are prefabricated offsite and then erected on the site. Job-built forms are more commonly used on smaller projects and where just a single use is required, while prefabricated/engineered (including modular) formwork systems tend to be used on larger projects and where repetitive uses are required. Contractors selecting a formwork type should consider contractor size, project type and size, the regional location across the US, and whether the forms will be used to construct slabs, walls, beams, or columns (Johnston, 2014).

Formwork operations are physically demanding and associated with high rates of ergonomic injuries in new construction (Schneider and Susi, 1994). The physical demands are the most important factor associated with MSDs (Sobeih et al., 2009). Carpenters, who are typically responsible for and in charge of constructing the forms, have to squat, kneel, bend their legs, and carry heavy loads repetitively and frequently (Hajaghazadeh et al., 2019), which place them at high risk of MSDs (Spielholz et al., 1998). They also have a high prevalence of "sprains and strains," and their injuries are most likely to be to their upper extremities (shoulder/hand/wrist), ankle/foot, low back, and knee/leg/hip (Lemasters et al., 1998; Welch et al., 2000). Laborers, who are mostly responsible for placing the concrete and removing the forms after the concrete has cured, were found to be likely to experience an injury to the ankle/foot area and also more likely to be injured due to being struck by a falling object (Welch et al., 2000). In another study, Tak et al. (2011) reported that concrete form building requires a high proportion of time in non-neutral trunk postures (forward or sideways flexion or twisting), kneeling, carrying loads of 15-50 lbs., and having both arms above the shoulder, an arm position that exposes workers to ergonomic factors that increase their MSD risk.

Over the years, a large volume of research on the causation, prevention, and control of MSDs has been conducted for construction operations. Only a few research studies (Spielholz et al., 1998; Welch et al., 2000; Pinder et al., 2001; Ahankoob and Charehzehi, 2013) have discussed MSD risks associated with concrete formwork operations, and these studies focused mainly on conventional, job-built formwork. With concrete being the most commonly used material in the industry and the growing use of prefabricated/engineered (including modular) formwork systems, the investigation of MSD risks for workers who interact with different types of formwork systems is necessary to identify hazardous exposures and to ensure the well-being of the workers. Assessing exposure to MSD risk factors has proven to be one of the most feasible approaches to alleviate the MSD incidence rate (Wang et al., 2015). However, the researchers have not found any studies that investigate the differences in MSD risks associated with different types of formwork systems that are commonly used on sites.

The present study focused on MSD risks for workers in horizontal (e.g., slab formwork) concrete formwork operations, comparing conventional and prefabricated/engineered (including modular) formwork systems. It concentrated on the erection and removal stages of the formwork operation, two of the stages associated with high safety and health risks (Gambatese et al., 2014).

Research Objectives

The goal of the present study was to expand the construction industry's understanding of the health and safety risks associated with formwork activities. The researchers compared the typical use cycles of conventional and prefabricated/engineered (including modular) formwork systems, surveyed/interviewed workers about work-related MSD symptoms and risk factors, and rigorously identified and assessed MSD risks associated with the use of different types of formwork systems.

Based on observations during site visits and conversations with industry professionals, the research team categorized slab formwork systems—based on their design features and construction process—into three groups: job-built, prefabricated/engineered, and modular (see Table 1). Modular formwork, while a type of prefabricated system, was made a separate group to allow for further comparison. Job-built slab forms are now rarely used on larger commercial projects because their construction is labor-intensive and cost-inefficient. Contractors typically prefer to rent or purchase the next two groups, prefabricated/engineered and modular formwork systems, from suppliers. For the present study, the comparison of the typical activities and tasks of formwork systems is made between job-built forms and prefabricated/engineered (including modular) forms, while the comparison of MSD risks is made between prefabricated/engineered and modular forms.

The specific objectives of the proposed study to attain the research goal were to:

1. Identify activities related to job-built forms and prefabricated/engineered (including modular) form systems, with an emphasis on horizontal concrete formwork (e.g., slab formwork) during formwork erection;
2. Identify work-related MSD symptoms and risk factors of workers who construct concrete formwork;
3. Determine major causes of work-related MSDs experienced by form workers;

4. Quantify MSD risks associated with the use of different types of formwork systems (prefabricated/engineered and modular forms); and
5. Provide recommendations for MSD prevention during formwork construction.

Table 1. Slab Formwork Types and Identifiers

Design Features and Construction Process	Formwork Component	Formwork Type		
		Job-Built	**Prefabricated / Engineered**	**Modular**
Material	Sheathing	Wood	Wood	Wood
	Joists	Wood	Aluminum / Steel / Other	Aluminum / Steel / Other
	Stringers	Wood	Aluminum / Steel / Other	Aluminum / Steel / Other
	Shores	Wood	Aluminum / Steel / Other	Aluminum / Steel / Other
Pre-Assembly	Sheathing	No	No	Module/Panel (e.g., ALUMA CC4 or PERI SKYDECK)
	Joists	No	No	
	Stringers	No	No	No
	Shores	No	No	No
Field Modification and Fabrication	Sheathing	Yes	Yes, if needed	No
	Joists	Yes, if needed	Not typically	No
	Stringers	Yes, if needed	Not typically	Not typically
	Shores	Yes, if needed	Not typically	Not typically
Field Erection/Installation Method	Sheathing	Hand and Manlift	Hand and Manlift	Hand and Crane/Manlift
	Joists	Hand and Ladder/Manlift	Hand and Ladder/Manlift	
	Stringers	Hand and Ladder/Manlift	Hand and Ladder/Manlift	Hand and Ladder/Manlift
	Shores	Hand and Ladder/Manlift	Hand and Ladder/Manlift	Hand and Ladder/Manlift

The outcomes of the study (i.e., the identification and assessment of MSD risks for concrete formwork systems) are expected to provide an improved understanding of the MSD risks posed to workers during formwork operations for concrete projects. The results are likely to be valuable to concrete contractors when identifying intervention measures that lower MSD risk factors for workers, and for both designers and concrete contractors when selecting safer and "healthier" formwork systems in the planning phase.

Research Methods

A mixed-method approach consisting of a combination of surveys and onsite observations was used to attain the research goal and objectives. Multiple sets of both qualitative and quantitative data were collected to improve the validity and reliability of the research design, results, and findings (Abowitz and Toole, 2009). In addition, self-reports from workers (collected through surveys and interviews) and observational data (collected via researcher onsite observations and through video recording of onsite operations) are the two most commonly-used ergonomic research methods to collect physical workload and associated exposure data to assess MSD risks (David, 2005; Wang et al., 2015). The results obtained from self-reports may be subjective, but self-reporting is a cost-effective and practical method to investigate the prevalence of MSDs, and also allows workers to report health issues that are difficult to observe directly without medical examination (Wang et al., 2015). Furthermore, observation creates minimal disturbance to worker task performance, and a number of observational tools are available that allow researchers to record and evaluate MSD risk based on worker postures.

Self-Reports using Survey Questionnaire

A survey questionnaire was developed to collect self-reported data from form workers. The questions covered three main topics: background information (e.g., age group, work experience, workload, and job title), formwork construction, and MSD discomfort. In the second section, formwork construction, participants were asked whether they had experience with different types of formwork and the formwork activities they commonly perform. The design of the third section, MSDs discomfort, built upon the questionnaires in other occupational and epidemiological studies, such as the Nordic musculoskeletal questionnaire (NMQ) (Kuorinka et al., 1987), Cornell musculoskeletal discomfort questionnaires (CMDQ) (Cornell University Ergonomics Web, n.d.), and worker discomfort survey (University of Western Ontario, 2011).

Similar to the worker discomfort survey conducted by the University of Western Ontario (2011), a body map, which contains a body segment graph, was used to assist with workers pointing out the specific parts of their body where they have MSD-related symptoms. Figure 1 presents the body map used for upper body parts to record MSD symptoms in terms of the level of severity, the frequency of the aches, pain, or discomfort, and whether the pain was work-related (specifically related to concrete formwork construction). A similar map (shown in Figure 2) was used for lower body parts. This section of the questionnaire was intended to answer the following research questions related to MSDs [modified based on Boschman et al. (2012)]:

1. What is the prevalence of MSDs symptoms among concrete formwork workers?
2. To what extent are the MSD concerns perceived as work-related by the worker?
3. What is the extent of the MSD symptoms experienced during work in terms of frequency and severity?
4. What occupational tasks or activities are perceived as causes or aggravating factors for the MSD concerns reported?

A copy of the survey questionnaire that was developed and used in the present study is available in Appendix I. The data collection and analysis using the survey questionnaire was designed to meet research objectives #1, #2, and #3.

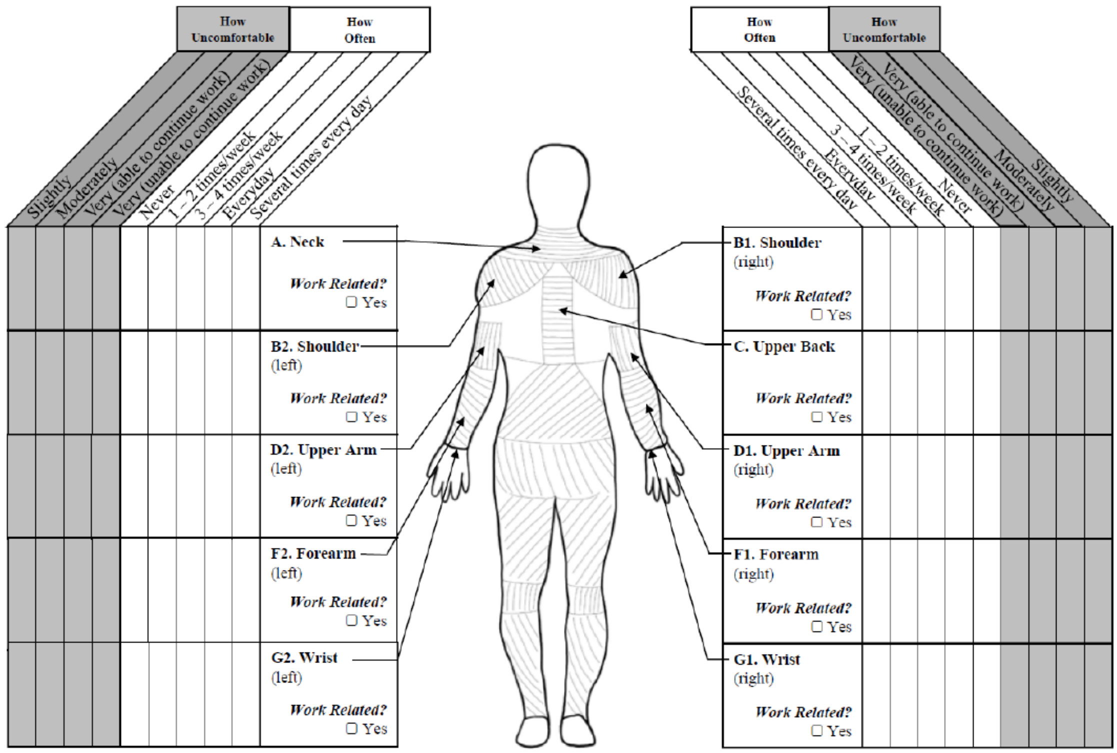


Figure 1. Body Map Used in Survey Questionnaire to Record MSD Risks for Upper Body Parts

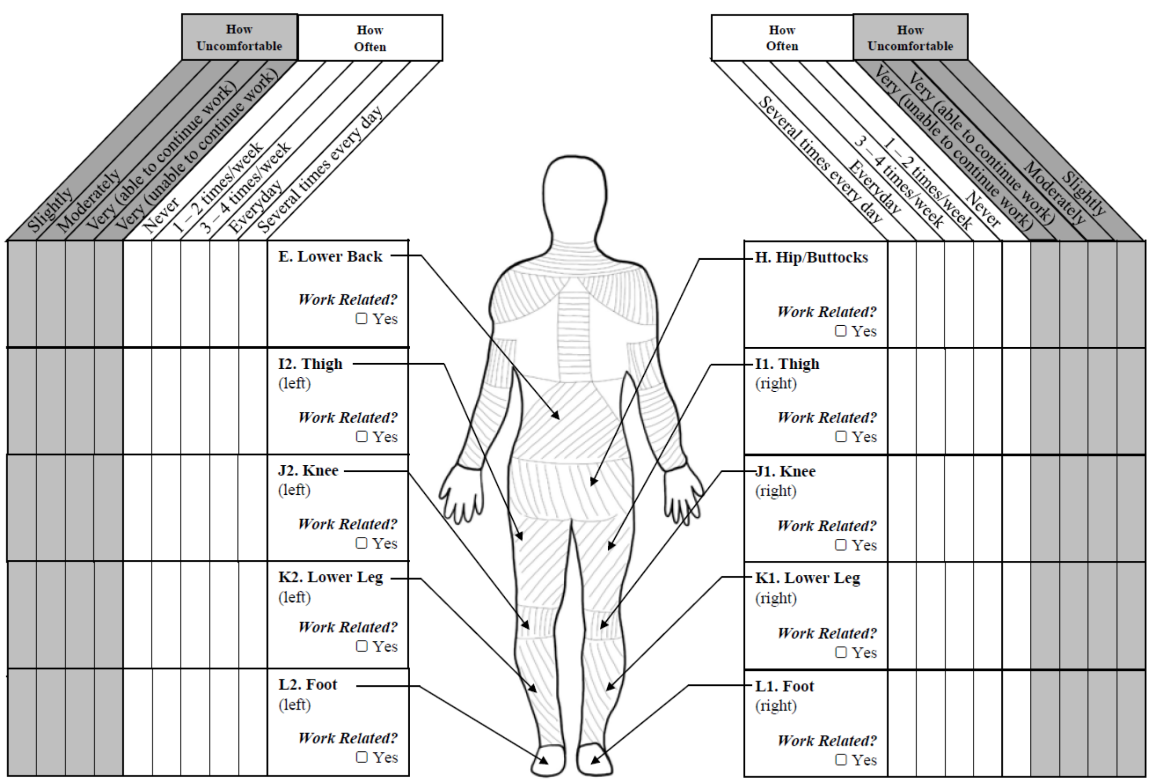


Figure 2. Body Map Used in Survey Questionnaire to Record MSD Risks for Lower Body Parts

Observational Method for Postural Analysis

Observational methods may be based on either researcher observations or video recordings (Spielholz et al., 2001). For the present study, field data from both researcher observations and video recordings were collected to allow for more detailed and reproducible evaluations.

In addition, the Rapid Entire Body Assessment (REBA) method was adopted to assess the MSD risks during formwork operations. Developed by Hignett and McAtamney (2000), the REBA method is a whole-body postural analysis system that assesses the selected posture (e.g., the most awkward posture, the most common posture, and the posture that has the highest force exerted) by scoring each body region, and provides a single score based on the posture evaluated and factors related to load, coupling, and activity. The postures that are analyzed using the REBA method often include: (1) the most frequent posture utilized, (2) the posture maintained the longest in the working cycle, (3) the posture that requires the greatest physical effort, (4) the posture that causes the most discomfort, and (5) the most extreme posture (Torghabeh et al., 2020). The REBA method also divides loads into three categories "< 11 lbs," "Between 11 and 22 lbs," and "> 22 lbs." Based on the REBA scores, MSD risk levels can be quantified as shown in Table 2.

Table 2. REBA Scores and Corresponding MSDs Risk Levels and Actions

Action Level	REBA Score	Risk Level	Action
0	1	Negligible	None necessary
1	2-3	Low	May be necessary
2	4-7	Medium	Necessary
3	8-10	High	Necessary soon
4	11-15	Very High	Necessary now

In addition to the REBA assessments conducted during onsite observations, the video recordings used an ergonomic risk assessment app by KineticaLabs (https://kineticalabs.com/) to assist and quicken postural analysis. Selected videos were pre-processed and trimmed into two-minute segments, uploaded to the app, which then analyzed them. The sample rate of the tool is 15 frames/second; a maximum of 1,800 frames are analyzed for a two-minute video. Figure 3 presents a screenshot of the postural analysis of back angles taken during sheathing panel removal, along with a chart plotting the back angle over the course of the video. The chart's horizontal axis shows the time (in seconds) during the two-minute video, and the vertical axis indicates the back angle in degrees from the vertical. Green areas in the plot represent safe periods of work in which no concern for MSDs is present. Sections of the plot in yellow represent periods when caution should be taken, and red areas are hazardous periods when the worker is exposed to potential MSDs associated with their back.

The REBA method has been used in previous studies to scale the risk of developing MSDs for construction workers who perform various operations, such as bar benders (Drisya et al., 2018), masonry workers (Ryu et al., 2018), and glass and glazing workers (Torghabeh et al., 2020). The assessment with the REBA method using the field data was designed to meet research objective #4.

Figure 3. Posture Analysis Results (Back Angles) Using the KineticaLabs App

The REBA assessments were then completed by using the generated posture analysis results, with the verifications and the input regarding the weights on muscles, coupling scores, and activity scores from the research team. For data collection purposes, a data entry space was created using Qualtrics so that each posture, along with its information and REBA assessment result (e.g., pictures of working postures, corresponding tasks and activities, and scores for body regions), could be entered and viewed as a single record. Data collected from the REBA method were then downloaded and analyzed using Excel.

Prior to survey distribution and field data collection, study documents, such as the survey questionnaire and consent letters for video recording and on-site observations, were approved by the researchers' Institutional Review Board (IRB) for research involving human subjects. The approved documents can be found in Appendix I. The research team then contacted general contractors in the Pacific Northwest to identify and select qualified concrete construction projects that had ongoing formwork operations (formwork erection and/or removal) within the timeframe of the study. Data gathered from the survey questionnaire and through field observations and video recordings were analyzed and used as foundation knowledge to suggest MSD prevention measures, thereby fulfilling research objective #5.

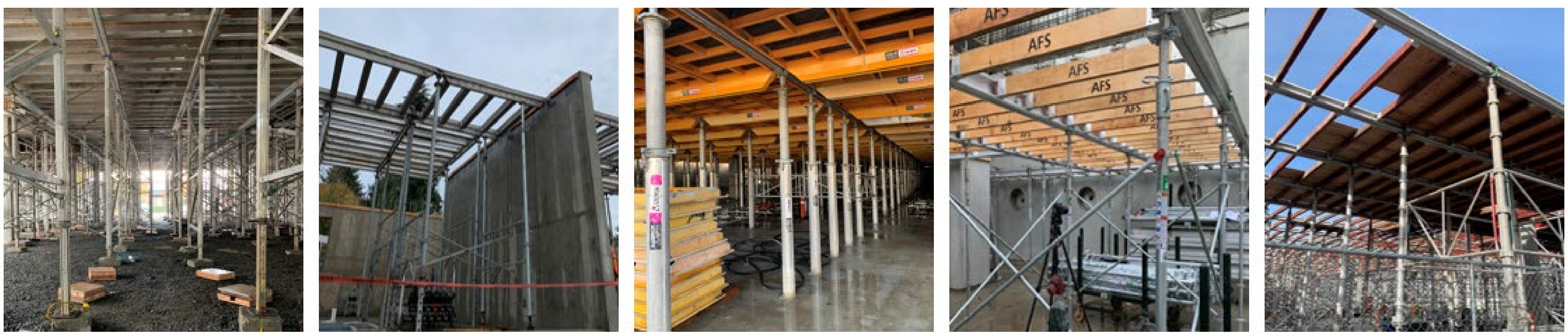
Accomplishments and Results

As shown in Table 3 and Figure 4, five construction projects were selected and visited, and nearly 60 working hours of formwork operations were observed. During the site visits, the research team explained the purpose of the research study to the workers and then obtained their consent to observe and video record them performing their work. The researchers also discussed the on-going formwork operations with the superintendents and form workers while taking notes. Discussions included questions regarding tools and equipment used, typical formwork activities, weights of form components, and working postures that were frequently used or made them feel uncomfortable. The research team then distributed paper copies of survey questionnaires for workers to self-report their working experiences with formwork systems and work-related MSD symptoms, and observed and video recorded formwork construction activities. Figure 5 shows an example of how a camera was used to videotape formwork operations on a construction site.

It was observed that the form workers usually started working as early as 7:00AM and worked as late as 3:00PM. Their timing of breaks throughout the shift varied between days, operations, and sites. For formwork operations, workers are usually part of a three- to five-person crew that erects or removes form components.

Table 3. Case Study Projects

Project	Location	Project Description	Type of Formwork Used	Formwork Operation Observed	Days of Visits	Worker-Hours of Observations (Approx.)
A	Beaverton, OR	Four-story apartment building	Prefabricated/ Engineered	Removal	2	9
B	Tigard, OR	Six-story apartment building	Prefabricated/ Engineered	Erection and Removal	2	13
C	Portland, OR	Two new structures and one cast-in-place underground parking structure (long-term care facilities)	Modular	Erection and Removal	3	12
D	Portland, OR	25-story mixed-use building, with four below grade floors for parking	Prefabricated/ Engineered	Erection	2	10
E	Tacoma, WA	Six-story mixed-use building (retail space on the ground, and apartments above)	Prefabricated/ Engineered	Erection and Removal	3	14



Project A Project B Project C Project D Project E

Figure 4. Site Photos from Case Study Projects

Figure 5. Camera in Use during Field Observation

Survey Results

Participant Background Information

A total of 29 male workers across the five projects filled out the survey questionnaire. Nearly half of the participants (45%) had 1 - 4 years of experience with formwork construction, and 14% had more than 20 years of experience. The majority of the participants (59%) were between 30 and 39 years old, followed by 24% in the age group 20 to 29, and only one participant was in the 60 or older group. In the previous 12 months, 12 of the participants (41%) had worked, on average, 40 to 49 hours per week, with more than 90% of the total work hours devoted to activities related specifically to formwork construction. The remaining participants worked slightly less on average. The job title/position of the participants varied—carpenters or carpenter apprentices (76%), foremen (17%), and laborers (7%).

Activities and Tasks Involved in Formwork Construction

In terms of experience with different types of formwork (i.e., conventional job-built formwork and/or prefabricated/engineered (including modular) formwork), 16 participants had experience working with both types, and the other 13 participants had experience with one type. Based on the survey responses, the researchers did not identify a distinct difference in the activities required by the two types of formwork, either the number of activities associated with each type or the extent to which the activities are performed. Both types require stockpiling, preparing, transporting, assembling, erecting, inspecting, stripping, and cleaning/dismantling components. These activities are in line with the findings of Hallowell and Gambatese (2009) and Gambatese et al. (2014).

However, at the task level, there is a notable difference between the two types of formwork. The typical tasks involved with conventional job-built formwork construction are:

- lifting/lowering materials,
- carrying materials,
- nailing/screwing/drilling formwork components or other materials,
- holding materials or components in place,
- hammering using a hammer, sledgehammer, or other equipment,
- plumbing and/or leveling forms using bodyweight, pry bar, or other equipment,
- ascending and descending ladders, formwork, or other structures,
- sawing/cutting materials,
- cleaning/maintaining formwork panels, and
- pushing/pulling formwork or other components.

When constructing with prefabricated/engineered (including modular) formwork, the tasks related to sawing/cutting and nailing/screwing/drilling components or other materials are performed significantly less than with conventional job-built formwork.

Participants were also invited to express their opinions on the primary differences in working with the two types of formwork. They considered the required physical effort the main difference. Compared to conventional job-built formwork, participants said that prefabricated/engineered (including modular) formwork is generally easier and faster to build, as the formwork systems are usually machine-loaded/unloaded and lifted/lowered. They felt that conventional job-built formwork is more versatile but takes longer to build, as components must be field-crafted. However, one participant felt that the physical effort of constructing both types is about the same, and only depends on how hard a person works.

MSD Discomfort

Among the 29 survey participants, 27 (93%) had experienced aches, pain, or discomfort during the previous 12 months. Six participants (21%) had visited a doctor, physiotherapist, or other medical professional because of MSD-related symptoms during that period.

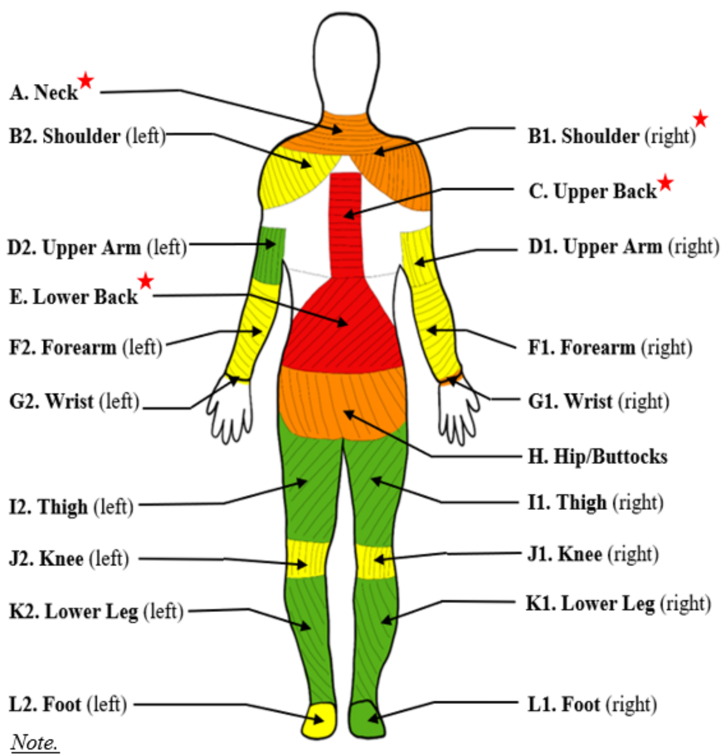
Using the body map included in the survey, participants were asked to rate the aches, pain, or discomfort they experienced in different body parts (a total of 20 body parts) based on the level of severity (slightly uncomfortable, moderately uncomfortable, very uncomfortable but able to continue work, and very uncomfortable and unable to continue work) and the frequency (never, 1-2 times/week, 3-4 times/week, every day, and several times every day). Among the 29 participants, four (14%) reported complaints about all 20 body parts and more than half reported discomfort in seven or more body parts. The average number of body parts for which they sustained aches, pain, or discomfort is 8.9 out of 20 body parts. To analyze the consequences of MSD symptoms (MSD risk) associated with each body part, a risk score was calculated using Equation:

$$MSD\ Risk\ Score = \frac{1}{n}\sum_{1}^{n}(Frequency_i \times Severity_i) \tag{1}$$

where $Frequency_i$ = frequency score of the i^{th} participant (never = 0, 1-2 times/week = 1.5, 3-4 times/week = 3.5, every day = 5, and several times every day = 10), $Severity_i$ = severity score of the i^{th} participant (slightly uncomfortable = 1, moderately uncomfortable = 2, very uncomfortable but able to continue work = 3, and very uncomfortable and unable to continue work = 4), and n = total number of survey participants. The scoring system used is adapted from the CMDQ (Cornell University Ergonomics Web, n.d.).

Figure 6 presents the summary results of the analysis. The estimated MSD risk for each part of the body was categorized into low risk, moderate risk, high risk, and critical risk, based on the obtained score. It was found that most body parts at high or critical risk for developing MSDs were in the upper body. Most prevalent among participants was discomfort in the lower back (score = 6.66), which is consistent with the findings of Spielholz et al. (1998). The upper back was the second most risky area (score = 3.71). The lower back and upper back were considered to be the two areas associated with critical risk of developing MSDs. The neck (score = 3.17), hip/buttocks (score = 3.17), right shoulder (score = 2.98), and right wrist (score = 2.60) are considered to be high risk body parts.

In addition to the level of severity and the frequency of the aches, pain, or discomfort, the participants were also asked whether they felt the physical impacts were work-related (specifically related to concrete formwork construction). In this study, if more than half of the participants agreed that the discomfort with a body part was work-related, the discomfort in the body part was perceived as a result of formwork construction operations. In particular, pains in the neck (16/29), right shoulder (16/29), lower back (20/29), and upper back (17/29) were typical complaints reported by participants as being work-related (denoted with red stars in Figure 6).



Note.
★ The aches, pain, or discomfort in the body part is considered to be ***work-related*** (specially related to concrete formwork construction)

MSD Risk Score	MSD Risk
Risk Score < 1.5	Low Risk
1.5 ≤ Risk Score < 2.5	Moderate Risk
2.5 ≤ Risk Score < 3.5	High Risk
Risk Score > 3.5	Critical Risk

Body Part	MSD Risk Score	MSD Risk
A. Neck ★	3.17	High
B1. Shoulder (right) ★	2.98	High
B2. Shoulder (left)	2.26	Moderate
C. Upper Back ★	3.71	Critical
D1. Upper Arm (right)	2.34	Moderate
D2. Upper Arm (left)	1.07	Low
E. Lower Back ★	6.66	Critical
F1. Forearm (right)	1.84	Moderate
F2. Forearm (left)	2.19	Moderate
G1. Wrist (right)	2.60	High
G2. Wrist (left)	1.62	Moderate
H. Hip/Buttocks	3.17	High
I1. Thigh (right)	0.98	Low
I2. Thigh (left)	1.28	Low
J1. Knee (right)	1.52	Moderate
J2. Knee (left)	1.66	Moderate
K1. Lower Leg (right)	0.76	Low
K2. Lower Leg (left)	1.00	Low
L1. Foot (right)	1.24	Low
L2. Foot (left)	1.93	Moderate

Figure 6. MSD Risks for Formwork Construction from Self-Report

MSD-Related Formwork Operation Tasks and Physical Factors

Two survey questions explored the relationship between formwork operations and the development of MSDs. Participants were asked whether they felt that typical tasks in formwork operations expose them to potential MSD risks. Participants identified holding materials or components in place, lifting/lowering materials, pushing/pulling formwork or other components, carrying materials, and hammering using a hammer, sledgehammer, or other equipment as tasks that cause or lead to the development of MSDs, as shown in Table 4.

The second question asked participants about their perceptions of physical factors that contribute to the development of MSD-related symptoms. The factors include repetition, use of force, awkward posture, vibration, contact stresses, static loading, and extreme temperature, which were identified by Jaffar et al. (2011) and Wang et al. (2015) as leading to MSDs. The top three contributing factors identified by participants were repetition (93%), awkward posture (86%), and use of force (83%). When asked about methods for MSD prevention, participants frequently mentioned stretching, having more breaks, understanding lifting limits, lifting with the help of a machine, and working as a team.

Table 4. Formwork Tasks that Lead to Potential MSD Risk (n = 29)

Formwork Operation Task	Respondents who felt that the task exposes them to potential MSD risks	
	Number	Percentage
Holding materials or components in place	21	72%
Pushing / Pulling formwork or other components	20	69%
Lifting / Lowering materials (< 20 lbs)	20	69%
Lifting / Lowering materials (> 20 lbs)	20	69%
Carrying materials (< 20 lbs)	19	66%
Carrying materials (> 20 lbs)	19	66%
Hammering using a hammer, sledgehammer, or other equipment	19	66%
Nailing / Screwing / Drilling from components or other materials	14	48%
Pouring and vibrating concrete	14	48%
Plumbing and/or Leveling forms using bodyweight, pry bar, or other equipment	13	45%
Ascending and descending ladders, formwork, and other structures	12	41%
Sawing / Cutting materials	10	34%
Cleaning / Maintaining formwork panels	7	24%

Posture Analysis Results using Rapid Entire Body Assessment (REBA)

As stated in Section 3.2, the REBA method was used to conduct postural analysis by observing and recording formwork erection and removal tasks. Therefore, the study first summarized typical formwork erection and removal tasks observed during site visits. The tasks and their associated formwork operation activities are listed in Table 5, and they are consistent with those listed in the survey questionnaire (Table 4) which were identified from relevant formwork studies.

Table 2. Construction Tasks in Formwork Erection and Removal

Task Name	Description	Related Activity
Carry Form Components	Manually transport form components (e.g., main and secondary beams, shoring posts, sheathing panels and modularized panels, and other accessories) from one location to another	Installation: a. Shoring posts b. Main and secondary beams c. Modular panels/sheathing panels Removal: a. Modular panels/sheathing panels

Table 3. Construction Tasks in Formwork Erection and Removal (continued)

		b. Main and secondary beams c. Shoring posts
Lift/Lower Form Components	Manually lift or lower form components into place during formwork erection and remove them from the formwork frame	Installation: a. Main and secondary beams Removal: a. Modular panels/sheathing panels b. Main and secondary beams
Place Sheathing /Modular Panels	Lay sheathing panels/modular panels on the top of formwork frames	Installation: a. Modular panels/sheathing panels
Plumb Shoring Posts	Plumb shoring posts using body weight	Installation: a. Shoring posts
Hold Form Components in Place	Static hold form components in place while other workers connect other pieces	Installation: a. Shoring posts
Adjust Form Components with Body Parts	Tighten or loosen form connections, adjust the length of shoring posts, and/or make minor placement changes of formwork without the use of tools	Installation: a. Shoring posts b. Main and secondary beams c. Modular panels/sheathing panels Removal: a. Modular panels/sheathing panels b. Main and secondary beams c. Shoring posts
Adjust Form Components Using Tools (e.g., hammers or pry bars)	Tighten or loosen form connections and/or make minor placement changes of formwork with tools	Installation: a. Main and secondary beams b. Modular panels/sheathing panels Removal: a. Modular panels/sheathing panels b. Main and secondary beams
Ascend/Descend a Ladder or Use a Scissor Lift	Ascend/descend a ladder or use a scissor lift during formwork operation to reach the work location	Installation: a. Main and secondary beams Removal: a. Modular panels/sheathing panels b. Main and secondary beams
Nail/Screw/Drill	Nail or screw form components or materials using a hammer, electric screwdriver, or other tools	Installation: a. Sheathing panels
Inspect	Inspect the placement of form components with the use of a tape measure, carpenter's level, plumb bob, or other tools	Installation: a. Shoring posts b. Main and secondary beams c. Modular panels/sheathing panels

For this study, through careful review and selection, a total of 389 working postures were assessed using the REBA method to ensure comprehensive coverage of all possible postures used for formwork erection and removal. The assessment data including the project information, the formwork activities and tasks, the pictures of the analyzed working postures, and the REBA scores were stored in Qualtrics, and then exported to Excel for further analysis. The key findings of the posture analysis comparing prefabricated/engineered forms to modular forms are presented in Table 6. Appendix II provides examples of the working postures used to perform different formwork tasks.

Table 4. REBA Assessment Results

Task	REBA Assessment Results	
	Prefabricated/Engineered Forms (n = 250)	**Modular Forms (n = 139)**
Carry Form Components	• REBA scores ranged between 4 and 10 (between medium and high MSD risk levels), and the median score was 5.5 (medium risk level) • Carrying sheathing panels creates higher risk to the worker's trunk than carrying other form components, including main beams, secondary beams, and shoring posts • Carrying shoring posts creates higher risk to the worker's neck and legs than carrying other form components including main beams, secondary beams, and sheathing panels • Trunk postures (bent and/or twisted), upper arm posture (at/above shoulder height), and excessive force/load (weight > 22 lbs.) were the contributory factors to the development of MSDs	• REBA scores ranged between 4 and 10 (between medium and high MSD risk levels), and the median score was 6 (medium risk level) • Carrying modular panels creates relatively lower risk to the worker's upper arms, neck, and trunk, but higher risk to the lower arms, than carrying other form components, including main beams, secondary beams, and shoring posts • Compared to carrying sheathing panels, carrying modular panels creates relatively lower risk to the worker's upper arms and trunk • Truck posture (bent and/or twisted), and excessive force/load (weight > 22 lbs.) were the contributory factors to the development of MSDs
Lift/Lower Form Components	• REBA scores ranged between 4 and 10 (between medium and high MSD risk levels), and the median score was 7 (medium risk level) • Upper arm posture (raised shoulder, at/above shoulder height), neck posture (in extension, side-bent and/or twisted), trunk posture (bent and/or twisted), and excessive force/load (weight > 22 lbs.) were the contributory factors to the development of MSDs	• REBA scores ranged between 4 and 9 (between medium and high MSD risk levels), and the median score was 7 (medium risk level) • Upper arm posture (raised shoulder, at/above shoulder height, at/above shoulder height), neck posture (in extension, side-bent and/or twisted), trunk posture (bent and/or twisted), and excessive force/load (weight > 22 lbs.) were the contributory factors to the development of MSDs

Table 6. REBA Assessment Results (continued)

Tasks	REBA Assessment Results	
	Prefabricated/Engineered Forms (n = 250)	**Modular Forms (n = 139)**
Place Sheathing/ Modular Panels	• REBA scores ranged between 6 and 11 (between medium and very high MSD risk levels), and the median score was 9 (high risk level) • Truck posture (bent and/or twisted), upper arm posture (at/above shoulder height), neck position (in flexion, side-bent and/or twisted), and excessive force/load (weight > 22 lbs.) were the contributory factors to the development of MSDs	• REBA scores ranged between 4 and 9 (between medium and high MSD risk levels), and the median score was 5 (medium risk level); • Truck posture (bent and/or twisted), upper arm posture (at/above shoulder height), neck position (in flexion, side-bent and/or twisted), and excessive force/load (weight > 22 lbs.) were the contributory factors to the development of MSDs • Compared to placing sheathing panels, placing modular panels creates less risk to the upper arms and legs
Plumb Shoring Posts	• REBA scores ranged between 5 and 10 (between medium and high MSD risk levels), and the median score was 8 (high risk level) • Upper arm posture (raised shoulder, at/above shoulder height), neck position (in extension, side-bent and/or twisted), trunk posture (bent and/or twisted), and excessive force/load (weight > 22 lbs.) were the contributory factors to the development of MSDs	• REBA scores ranged between 4 and 10 (between medium and high MSD risk levels), and the median score was 7 (medium risk level) • Upper arm posture (at/above shoulder height), neck position (in extension, side-bent and/or twisted), trunk posture (bent and/or twisted), and excessive force/load (weight > 22 lbs.) were the contributory factors to the development of MSDs
Hold Form Components in Place	• REBA scores ranged between 5 and 10 (between medium and high MSD risk levels), and the median score was 9 (high risk level) • Upper arm posture (raised shoulder, at/above shoulder height), neck position (in extension, side-bent and/or twisted), excessive force/load (weight > 22 lbs.), and static holding for a long period of time (more than one-minute) were the contributory factors to the development of MSDs	• REBA scores ranged between 5 and 9 (between medium and high MSD risk levels), and the median score was 7 (medium risk level) • Neck position (in extension, side-bent and/or twisted), excessive force/load (weight > 22 lbs.), and static holding for a long period of time (more than one-minute) were the contributory factors to the development of MSDs

Table 6. REBA Assessment Results (continued)

Tasks	REBA Assessment Results	
	Prefabricated/Engineered Forms (n = 250)	**Modular Forms (n = 139)**
Adjust Form Components with Body Parts	• REBA scores ranged between 4 and 10 (between medium and high MSD risk levels), and the median score was 7 (medium risk level) • Trunk posture (bent and/or twisted), neck position (in extension, in flexion, side-bent and/or twisted), upper arm posture (at/above shoulder height), excessive force/load (weight > 22 lbs.), and repetitive small range actions were the contributory factors to the development of MSDs	• REBA scores ranged between 4 and 10 (between medium and high MSD risk levels), and the median score was 7 (medium risk level); • Trunk posture (bent and/or twisted), upper arm posture (at/above shoulder height), neck position (in extension, in flexion, side-bent and/or twisted), and repetitive small range actions were the contributory factors to the development of MSDs
Adjust Form Components Using Tools (e.g., hammers or pry bars)	• REBA scores ranged between 4 and 9 (between medium and high MSD risk levels), and the median score was 5 (medium risk level) • Trunk posture (bent and/or twisted), neck position (in extension, in flexion, side-bent and/or twisted), and repetitive small range actions were the contributory factors to the development of MSDs	• REBA scores ranged between 4 and 10 (between medium and high MSD risk levels), and the median score was 6 medium risk level) • Trunk posture (bent and/or twisted), neck position (in extension, in flexion, side-bent and/or twisted), and repetitive small range actions were the contributory factors to the development of MSDs
Ascend/Descend a Ladder or Use a Scissor Lift	• REBA scores ranged between 2 and 8 (between low and high MSD risk levels), and the median score was 4 (medium risk level) • Trunk posture (bent and/or twisted) was the contributory factor to the development of MSDs	• REBA scores ranged between 2 and 4 (between low and medium MSD risk levels), and the median score was 4 (medium risk level) • Trunk posture was the contributory factor to the high MSD risk

Table 6. REBA Assessment Results (continued)

Tasks	REBA Assessment Results	
	Prefabricated/Engineered Forms (n = 250)	**Modular Forms (n = 139)**
Nail/Screw/Drill	• REBA scores ranged between 4 and 10 (between medium and high MSD risk levels), and the median score was 6 (medium risk level); • Truck posture (bent and/or twisted), neck position (in flexion, side-bent and/or twisted), and repetitive small range actions were the contributory factors to the development of MSDs	Not applicable
Inspect	• REBA scores ranged between 4 and 7 (medium MSD risk level), and the median score was 4 (medium risk level); • Trunk posture (bent and/or twisted) and neck position (in extension, in flexion, side-bent and/or twisted) were the contributory factors to the development of MSDs	• REBA scores ranged between 4 and 6 (medium MSD risk levels), and the median score was 5 (medium risk level); • Trunk posture (bent and/or twisted) and neck position (in extension, in flexion, side-bent and/or twisted) were the contributory factors to the development of MSDs

Discussion of Key Findings

The survey results indicate that there is a difference between conventional job-built formwork and prefabricated/engineered (including modular) formwork in the required work tasks and workloads for each type of formwork. Compared to conventional job-built formwork, prefabricated/engineered (including modular) formwork requires significantly less time and effort to saw/cut materials, and to nail/screw/drill formwork components or other materials because the forms are designed and manufactured in standardized sizes, which reduces the need for cutting material on the project site. In particular, modular formwork systems, which are integral units that are pre-assembled and connected with hardware, fasteners, and accessories (e.g., nails, bolts, clamps, etc.), can be erected and removed with minimal cutting and nailing effort from form workers.

The study reveals a high prevalence rate of MSD symptoms among form workers. More than 90% of the surveyed workers had experienced discomfort in one or more locations on their body, and more than 20% of them had received professional treatment because of MSD-related symptoms during the past 12 months. These findings are similar to those in previous ergonomic studies about formwork construction (Spielholz et al., 1998; Welch et al., 2000). Out of the 20 body parts identified on a body map that assisted the participants in self-reporting their discomfort, the participants reported, on average, discomfort in more than eight regions of the body. The body parts with the highest MSD risks are the lower back and upper back, and with high risks are the neck, right shoulder, right wrist, and hip/buttocks. In addition, pains in the neck, right shoulder, lower back, and upper back were considered specifically related to formwork construction. Similar results were reported for workers who specialize in concrete formwork construction in studies by Spielholz et al. (1998), Lemasters et al. (1998), and Welch et al. (2000)—the workers had a high prevalence of symptomatic disorders in the lower back, forearms/wrist, shoulder, elbow, and knee/leg/hip.

The high prevalence of MSD-related symptoms could be related to the nature of work in formwork construction and are consistent with the postural analysis results generated using the REBA method (Table 6). Regardless of which type of formwork system is used, the majority of formwork tasks expose workers to between medium and high MSDs risk levels. Formwork construction is physically demanding—the weight of the majority of the form components used in the investigated projects falls into the category of "load > 22 lbs." Only the secondary beams used in Projects C and D fall into the category of "load is between 11 to 22 lbs." Handling heavy materials in formwork construction is a primary contributory factor leading to the development of MSDs.

Furthermore, form workers have to bend and twist their body often, wear heavy safety harnesses and tool bags, work at height with frequent overhead reaching (working with hand(s) at/above shoulder), and use hammers repetitively and forcefully. The task requirements and characteristics entailed by formwork construction expose workers to MSD-related physical risk factors - repetition, awkward posture, and force. The REBA assessment results (Table 6) reveal that form workers are at high risk of developing disorders in their shoulders, neck, and back, findings which are consistent with the MSD symptoms they self-report (Figure 6).

The comparison between prefabricated/engineered forms and modular forms shows that placing the sheathing panels used in prefabricated/engineered forms may expose workers to higher risk levels. The heavy weight (over 40 lbs.) and the size (usually 4' x 8') of a sheathing panel make it awkward to handle and place. As for modular forms, the size of a modular panel is relatively small (the panel investigated in the present study is approximately 5' x 2.5'), and the weight is relatively light (less than 35 lbs.). Compared to sheathing panels, handling and placing modular panels is easier and, more importantly, exposes workers to fewer risks to the upper arms and legs. Additionally, since a modular panel is an integrated assembly, there is no need to place a substantial number of secondary beams to support the modular panels above, or to connect and fix the panel with the supporting beams with nails. Therefore, significantly less manual and time and effort are needed when utilizing modular forms.

MSD Prevention

There are ergonomic interventions that concrete contractors and form workers can adopt and formwork and tool manufacturers can develop to prevent MSDs from workers in formwork construction. Based on the findings of this study and resources provided by NIOSH (2018) and CPWR (2021), the recommendations below may help prevent MSD-related injuries and minimize the symptoms of those injuries that do occur. Adapted from Dwyer and Lotz (2003) in combination with the hierarchy of controls (NIOSH, 2015), the controls are organized into four categories: (1) substitution, (2) engineering improvements, (3) administrative controls, and (4) work practices modifications.

- Substitution consists of measures taken to reduce ergonomic hazards by replacing features or conditions with something that is less hazardous. An example of a substitution related to formwork is:

    - Construction contractors selecting modular panel systems, which significantly reduce the amount of hammering, drilling, nailing, and placing of supporting beams and thereby lower their formwork employees' exposure to repetitive movements and awkward postures associated with these tasks.

- Engineering improvements are physical changes to equipment, workflow, or the work environment. Examples include:

    - Construction contractors providing their formwork employees lift assists and/or lifting devices (e.g., forklifts, hoists, and cranes) to reduce lifting and overreaching requirements and help workers move and manipulate form components, as well as tools (e.g., hand tools with extension clamps) designed to reduce bending, working on knees, and twisting whenever possible. Additionally, employers can tag/label the weight of form components on the components and inform their employees about the components' weight. Before carrying and lifting the components, form workers should test them for stability.

    - Formwork system designers and manufacturers incorporating handles and/or grips into formwork components, without unduly increasing the weight or compromising the strength and stability of the components, to reduce form workers' wrist-related disorders and prevent components from slipping out of a worker's hand.

    - Tool manufacturers developing ergonomic tools to reduce the need for form workers to bend over, work on knees, or overreach. For example, tools could incorporate extension clamps so that workers can complete these tasks standing up, without raising their shoulders, and without bending extensively.

- Administrative controls restrict the way workers work to limit their exposure to ergonomic hazards. Examples of administrative actions concrete contractors can take include:

    - Having a well-planned, clear workspace and sequencing tasks to minimize the time workers spend carrying loads, and helping them avoid twisting, flexing, or extending their trunk too much.

    - Rotating form workers through several different tasks during a shift to prevent them from performing the same repetitive tasks for a long period. From site observations, the research team noticed that employers commonly assign form workers one or more specific form component at the start of the workday; it is very rare for employers to rotate workers between tasks.

  - Building frequent and short rest breaks into the work schedule, instead of long breaks, to help reduce workers' overuse of the same muscles for sustained periods without adequate recovery time. Form workers in turn should take time to stretch to ease discomfort during breaks.

- Work practice modifications are improvements made at the individual level to improve working postures and prompt long-term health. Some examples of work practice modifications include:

  - When lifting/lowering form components, workers need to make sure the work area is within their comfortable reach zone, with minimal overreaching, body twisting, and bending needed, by adjusting the height and/or the location where they are standing. Whenever possible, workers should bend at the knees, not the waist, and keep their elbows and the load close to their body.

  - When handling form components that are heavier than 51 pounds (e.g., shoring posts and sheathing panels), employers should assign at least two people to lift the load.

  - When conducting tasks such as adjusting the height of shoring posts during the preparation stage before they are plumb, form workers should place the posts at a comfortable level, i.e., on the top of a stack of form components or similar places and not on the ground level, to minimize bending and reaching.

Conclusions

This study was conducted to: (1) identify differences in constructing conventional job-built and prefabricated/engineered (including modular) formwork systems, (2) investigate the prevalence of MSDs in form workers, (3) identify critical physical factors and formwork activities that expose workers to high rates of MSDs, and (4) assess MSD risks associated with the use of different types of formwork systems (prefabricated/engineered and modular forms). Five construction sites in the Pacific Northwest that had on-going formwork operations were visited and on-site form workers were invited to participate in a written survey to self-report their work experiences with formwork construction and MSD symptoms. In addition, their working postures were observed and video recorded for ergonomic analysis using the REBA method.

The study results indicate that work tasks and activities for conventional job-built and prefabricated/engineered (including modular) formwork are generally similar, except that prefabricated/engineered (including modular) formwork requires less work and effort for tasks related to sawing/cutting and nailing/screwing/drilling formwork components or other materials. However, regardless of the type of formwork system they predominantly work with, form workers have a high prevalence of work-related MSD symptoms. Formwork construction is associated with the three primary physical factors that cause MSDs (repetition, awkward working postures, and force), putting workers at high risk of developing MSDs in the lower back, upper back, neck, right shoulder, right wrist, and hip/buttocks. Compared to working with prefabricated forms, working with modular forms requires less time and physical effort (due to their integral pieces), which also creates less ergonomic exposure. Based on the research findings, recommendations are provided to employers (construction contractors), form workers, form designers and manufacturers, and tool manufacturers that fit within four hazard control categories: substitution, engineering improvements, administrative controls, and work practices modifications. The recommendations offer various opportunities, tools, and techniques to help prevent MSDs in form workers.

Changes/Problems that Resulted in Deviation from the Methods

The research study was conducted during the COVID pandemic in 2020/2021. To prevent COVID-19 transmission, the research team decided not to conduct in-person interviews of field construction workers or managers. Instead, the team distributed paper copies of survey questionnaires for workers to self-report their work experiences with formwork systems and work-related MSD symptoms.

In addition, because of the limited availability of and access to training materials associated with the Posture, Activity, Tools and Handling (PATH) work sampling approach, the research team decided to change the assessment method from the PATH method to the Rapid Entire Body Assessment (REBA) method (Hignett and McAtamney, 2000). The REBA method is a commonly-used method, and provides a means of evaluating MSD risk similar to the PATH method. One difference with the PATH method, however, is that the REBA method is not a work sampling-based approach that is able to quantify MSD risk based on the proportion of time workers spend on formwork tasks in non-neutral postures of the trunk, legs, and arms. Rather, the REBA method provides an overall assessment of individual whole-body postures and does not consider the duration of exposure and the frequency of postures. Therefore, a direct quantitative comparison of ergonomic hazard exposure to workers when working with different types of formwork systems using statistical analysis is infeasible with the REBA method. Instead, the present study makes a comparison of the required tasks, and a comparison of the REBA scores of the working postures used to complete these tasks, for different types of formwork systems.

Future Funding Plans

The results of the study provide preliminary assessments of MSD risks for form workers when using different types of formwork systems, which could serve as the foundation for future ergonomic hazard exposure evaluation and MSD prevention. It should be noted that the present study has some limitations due to time and funding constraints. The primary limitations lie in the small number of projects (among the five projects visited, only one project adopted a modular formwork system) and limited locations (all in the Pacific Northwest) and survey participants. These limitations inhibit the generalization of the study findings. Future studies with more form workers and construction sites and with other ergonomic assessment methods (e.g., direct measurement with wearable devices) are needed to evaluate MSDs risk. In this way, studies can overcome the limitations of the REBA method (e.g., analysis of individual postures only, subjective assessment, and neglect of the duration and frequency of postures) and draw conclusions when quantifying MSD risks for workers using different types of formwork systems. Further studies based on experimental methods to explore ways to reduce the high MSD risk levels to which form workers are exposed, and to investigate the effectiveness and value of the proposed MSD prevention measures, are also recommended.

Dissemination Plan

The research team plans to extract and submit a conference paper and a journal article from the study. A paper titled "Musculoskeletal Disorders for Concrete Formwork Construction" was developed based on the survey responses and submitted for presentation in the ASCE Construction Institute and Construction Research Congress Joint Conference to be held in March 2022 in Arlington, Virginia. Additionally, the researchers plan to submit a journal article, which will be developed based on the postural analysis using the REBA method, for publication in a peer-reviewed, occupational health-related journal such as the *International Journal of Occupational Safety and Ergonomics*. The researchers recommend that the results of the research be published by CPWR in a *CPWR Updates* newsletter, Key Findings from Research announcement, and other applicable online resources.

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APPENDICES

Appendix I

IRB Documents and Survey Questionnaire

Appendix II

Formwork Erection and Removal Example Tasks and Working Postures

Appendix I: IRB Documents and Survey Questionnaire

This appendix contains the survey questionnaire, and the consent forms for site observations and video recording, used during the site visits.

Musculoskeletal Disorders (MSDs) Risk for Concrete Formwork Systems

Explanation of Research Study

Project Name: Musculoskeletal Disorders (MSDs) Risk for Concrete Formwork Systems

Study Sponsor: The Center for Construction Research and Training (CPWR)

Principal Investigator: John A. Gambatese / Oregon State University

Student Investigator: Ziyu Jin / Oregon State University

Why am I being invited to take part in this study?

You are invited to take part in this research study as you are identified as having extensive knowledge of formwork construction, and/or experience in this discipline.

What is the purpose of this study?

Musculoskeletal disorders (MSDs), such as muscle strain and lower back pain, account for more than half of the total injuries and illnesses in the construction industry. Among all construction activities, concrete formwork construction is recognized as a work task in which workers have a high risk of developing MSDs. Previous research has focused extensively on the use of conventional job-built timber/plywood formwork. Given the fact that prefabricated formwork has been increasingly adopted in the industry, the investigation of MSDs risks for workers who interact with different types of formwork systems is necessary to ensure the well-being of workers.

The goal of the study is to investigate the prevalence and nature of MSDs with respect to concrete formwork construction, and assess MSD risks associated with the use of different formwork systems. It is expected the results from the study can be used by constructors when identifying effective intervention measures to lower MSD risk factors for workers, and for both designers and constructors when selecting safer and “healthier” formwork systems in the planning phase for concrete construction.

What will happen during this study and how long will it take?

In the survey, you will be asked to express your opinion and share your experience related to concrete formwork construction, and the extent of MSDs symptoms experienced during work in terms of frequency and severity. It is expected that the survey will take approximately 10 minutes to complete.

What are the risks of this study to the participants?

Accidental disclosure of the written responses: None. Personal identities are not required to complete the survey, and personal identification information will not be asked. Thus, survey responses cannot be traced to individual companies or people.

Internet: The security and confidentiality of information collected from you online cannot be guaranteed. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

What are the benefits of this study to the participants?

There are no direct benefits to you from this study. However, the overall benefit to the industry will be to have further knowledge that can help improve worker health and wellbeing in the construction industry.

Do I have a choice to be in the study?

Participation in the study is voluntary. Participants may refuse to answer any questions and/or may withdraw from the study at any time.

What if I have questions?

Participants are encouraged to ask any questions at any time about the study and its procedures, or his/her rights as a participant. The Investigators' names and contact information are included below so that the participant may ask questions and report any study-related problems.

- John Gambatese, School of Civil and Construction Engineering, Oregon State University, 101 Kearney Hall, Corvallis, OR 97331, john.gambatese@oregonstate.edu

- Ziyu Jin, School of Civil and Construction Engineering, Oregon State University, 101 Kearney Hall, Corvallis, OR 97331, jinzi@oregonstate.edu

If you have any questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office at 541-737-8008 or by e-mail at irb@oregonstate.edu.

Acknowledgement:

By continuing the survey, I have read the above description of the research. If I had questions or would like additional information, I contacted the researchers and had all of my questions answered to my satisfaction. I agree to voluntarily participate in this research. By answering the survey questions and responding to this survey, I affirm that I have read the above information, agree to participate in the research, and am at least 18 years of age or older.

Background Information

Q1. Is concrete formwork construction a part of your job tasks?

- Yes
- No

Q2. How many years of work experience with formwork construction do you have?

- Less than 1 year
- 1 – 4 years
- 5 – 9 years
- 10 – 20 years
- More than 20 years

Q3. On average, how many total hours per week did you work in the past 12 months? Include all work, not just formwork construction.

- Less than 20 hours/week
- 20 – 29 hours/week
- 30 – 39 hours/week
- 40 – 49 hours/week
- 50 or above 50 hours/week

Q4. On average, approximately what percentage of your total work hours (selected in the previous question) was spent on activities related specifically to concrete formwork construction in the past 12 months?

- Less than 10%
- 10% - 24%
- 25% - 49%
- 50% - 74%
- 75% - 89%
- More than 90%

Q5. Which age group do you belong to?

- Less than 20 years old
- 20 to 29 years old
- 30 to 39 years old
- 40 to 49 years old
- 50 to 59 years old
- 60 or above 60 years old

Q6. What is your title/position?

- Foreman
- Laborer
- Carpenter
- Superintendent

- Other, please specify: ____________________

General Formwork Questions

Q7. Do you have experience constructing conventional job-built formwork and/or prefabricated formwork? Please select all that apply.

- Conventional job-built formwork
- Prefabricated formwork

Q8. Based on your work experience, please indicate whether each of the following formwork construction **activities** applies to conventional job-built formwork and/or prefabricated formwork construction.

	Conventional Job-built Formwork	Prefabricated Formwork
Stockpiling formwork materials		
Preparing formwork materials (e.g., cutting formwork materials, form lubrication and preparation, etc.)		
Transporting formwork materials		
Assembling formwork panels		
Erecting formwork		
Inspecting formwork		
Stripping formwork		
Cleaning/Dismantling formwork		
Other activities related to conventional job-built and/or prefabricated formwork (please specify): ________________		

Q9. Please indicate whether each of the following formwork construction **tasks** applies to conventional job-built formwork and/or prefabricated formwork construction.

	Conventional Job-built Formwork	Prefabricated Formwork
Lifting / Lowering materials (< 20 lbs)		
Lifting / Lowering materials (> 20 lbs)		
Carrying materials (< 20 lbs)		
Carrying materials (> 20 lbs)		
Nailing / Screwing / Drilling from components or other materials		
Holding materials or components in place		
Hammering using a hammer, sledgehammer, or other equipment		
Plumbing and/or leveling forms using body weight, pry bar, or other equipment		
Ascending and descending ladders, formwork, or other structures		
Pouring and vibrating concrete		
Sawing / Cutting materials		
Cleaning / Maintaining formwork panels		
Pushing / Pulling formwork or other components		

Other tasks (please specify):		

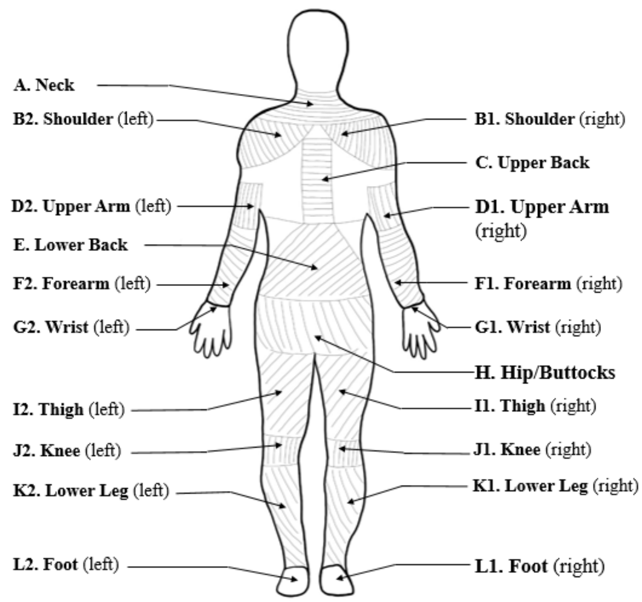
Q10. Based on your knowledge and experience, what are the primary differences in the construction work required when working with conventional job-built formwork and prefabricated formwork? For example, there may be a difference in workload, activities, tasks, pace of the work, physical effort, etc.

____

MSDs Discomfort Questions

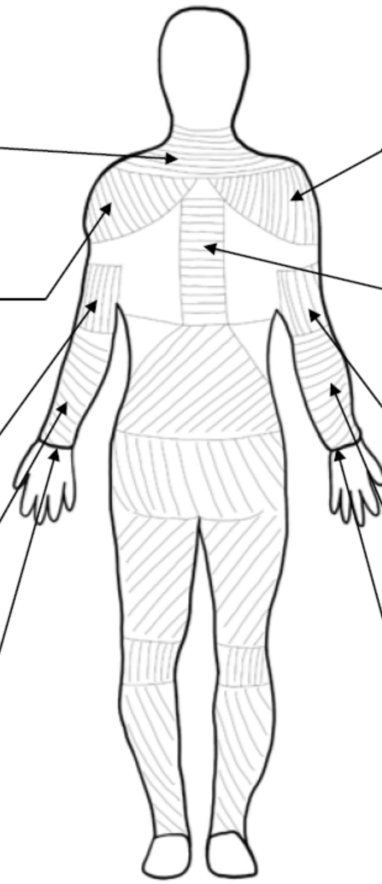
Q11. Have you experienced any ache, pain, or discomfort in your body during the past 12 months? (Please just select Yes or No for this Question)

- o Yes
- o No



Q12. For each **upper body part** in which you experienced aches, pain, or discomfort, please indicate **the level of severity**, the **frequency** of the aches, pain, or discomfort, and if it was **work-related** (specifically related to concrete formwork construction).

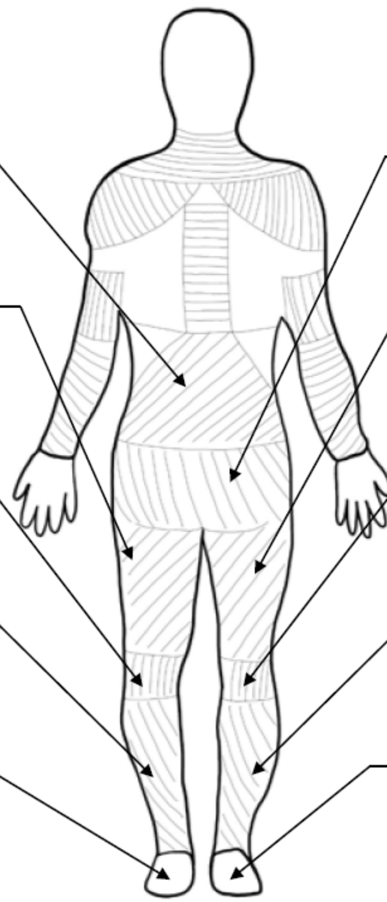
How Uncomfortable				How Often					
Slightly	Moderately	Very (able to continue work)	Very (unable to continue work)	Never	1 – 2 times/week	3 – 4 times/week	Everyday	Several times every day	
									A. Neck ***Work Related?*** ☐ Yes
									B2. Shoulder (left) ***Work Related?*** ☐ Yes
									D2. Upper Arm (left) ***Work Related?*** ☐ Yes
									F2. Forearm (left) ***Work Related?*** ☐ Yes
									G2. Wrist (left) ***Work Related?*** ☐ Yes



	How Often					How Uncomfortable			
	Several times every day	Everyday	3 – 4 times/week	1 – 2 times/week	Never	Very (unable to continue work)	Very (able to continue work)	Moderately	Slightly
B1. Shoulder (right) ***Work Related?*** ☐ Yes									
C. Upper Back ***Work Related?*** ☐ Yes									
D1. Upper Arm (right) ***Work Related?*** ☐ Yes									
F1. Forearm (right) ***Work Related?*** ☐ Yes									
G1. Wrist (right) ***Work Related?*** ☐ Yes									

Q13. For each **<u>lower body part</u>** in which you experienced aches, pain, or discomfort, please indicate **the level of severity**, the **frequency** of the aches, pain, or discomfort, and if it was **work-related** (specifically related to concrete formwork construction).

How Uncomfortable: Slightly	Moderately	Very (able to continue work)	Very (unable to continue work)	How Often: Never	1 – 2 times/week	3 – 4 times/week	Everyday	Several times every day	
									E. Lower Back ***Work Related?*** ☐ Yes
									I2. Thigh (left) ***Work Related?*** ☐ Yes
									J2. Knee (left) ***Work Related?*** ☐ Yes
									K2. Lower Leg (left) ***Work Related?*** ☐ Yes
									L2. Foot (left) ***Work Related?*** ☐ Yes



	How Often: Several times every day	Everyday	3 – 4 times/week	1 – 2 times/week	Never	How Uncomfortable: Very (unable to continue work)	Very (able to continue work)	Moderately	Slightly
H. Hip/Buttocks ***Work Related?*** ☐ Yes									
I1. Thigh (right) ***Work Related?*** ☐ Yes									
J1. Knee (right) ***Work Related?*** ☐ Yes									
K1. Lower Leg (right) ***Work Related?*** ☐ Yes									
L1. Foot (right) ***Work Related?*** ☐ Yes									

Q14. Among the following **activities** for conventional job-built formwork construction and/or prefabricated formwork construction, which activities do **you personally** commonly perform? Please select all that apply.

Activity	Conventional Job-built Formwork	Prefabricated Formwork
Stockpiling formwork materials		
Preparing formwork materials (e.g., cutting formwork materials, form lubrication and preparation, etc.)		
Transporting formwork materials		
Assembling formwork panels		
Erecting formwork		
Inspecting formwork		
Stripping formwork		
Cleaning/Dismantling formwork		
Other activities related to conventional job-built and/or prefabricated formwork (please specify):		

Q15. Among the following formwork construction **tasks** associated with job-built formwork construction and/or prefabricated formwork construction, which tasks do **you personally** commonly perform? Please select all that apply.

Task	Conventional Job-built Formwork	Prefabricated Formwork
Lifting / Lowering materials (< 20 lbs)		
Lifting / Lowering materials (> 20 lbs)		
Carrying materials (< 20 lbs)		
Carrying materials (> 20 lbs)		
Nailing / Screwing / Drilling from components or other materials		
Holding materials or components in place		
Hammering using a hammer, sledgehammer, or other equipment		
Plumbing and/or Leveling forms using body weight, pry bar, or other equipment		
Ascending and descending ladders, formwork, and other structures		
Pouring and vibrating concrete		
Sawing / Cutting materials		
Cleaning / Maintaining formwork panels		
Pushing / Pulling formwork or other components		
Other tasks (please specify):		

Q16. In your opinion, which of the following physical factor(s) commonly contribute to the development of MSD-related symptoms in construction workers? Please select all that apply.

- Repetition: using the same muscles all the time with limited rest
- Force: the physical effort required to perform a task or to maintain control of tools
- Awkward posture: any joint of the body bending or twisting excessively or any muscles stretched beyond a comfortable range of motion
- Vibration: any repetitive movement that a body makes as a result of external vibration
- Contact stress: Contact stress: impingement or injury by hard, sharp objects when grasping, balancing, or manipulating
- Static load: maintaining any body position against an external load without change over extended periods
- Extreme temperature: extremely cold or extremely hot
- Other (please specify): ____________________
- None

Q17. In your opinion, which **tasks** in formwork operations commonly expose you to potential MSD risks? Please select all that apply.

- Lifting / Lowering materials (< 20 lbs)
- Lifting / Lowering materials (> 20 lbs)
- Carrying materials (< 20 lbs)
- Carrying materials (> 20 lbs)
- Nailing / Screwing / Drilling from components or other materials
- Holding materials or components in place
- Hammering using a hammer, sledgehammer, or other equipment
- Plumbing and/or Leveling forms using body weight, pry bar, or other equipment
- Ascending and descending ladders, formwork, and other structures
- Pouring and vibrating concrete
- Sawing / Cutting materials
- Cleaning / Maintaining formwork panels
- Pushing / Pulling formwork or other components
- Other activities (please specify): ____________________
- None

Q18. Have you visited a doctor, physiotherapist, or other medical professional because of any MSD-related symptoms that you have experienced during the past 12 months?

- Yes
- No

Q19. Please share any opinions that you may have for reducing your level of discomfort during formwork construction operations. Are there any changes or recommendations you would make to the **design** of formwork, the formwork **construction operation**, and/or the **work environment** to reduce the risk of MSD-related injury?

____

Once again, we are extremely grateful for your participation in this survey, your honest information, and your thoughtful suggestions. Your responses are vital for improving worker health in formwork construction operations. If you have any questions or want to learn more about our research, please feel free to reach us at: jinzi@oregonstate.edu, or john.gambatese@oregonstate.edu. Thanks again!

Study Information for Participants

Title: Musculoskeletal Disorders (MSDs) Risk for Concrete Formwork Systems

Purpose. The goal of the study is to investigate the prevalence and nature of Musculoskeletal disorders (MSDs), such as muscle/tendon strain and lower back pain, with respect to concrete formwork construction, and assess MSD risks associated with the use of different formwork systems.

Voluntary. Participation in the study is voluntary. Participants may refuse to answer any questions and/or may withdraw from the study at any time.

Activities. Research team member(s) will come to your workplace to watch how concrete form worker's work. The purpose of the research is not to assess or audit staff performance. No information about individuals will be reported back to managers at your organizations. You verbal consent must be obtained before the research team begin observing. The observer(s) will sit or stand somewhere out of the way so that they do not interfere with your work and they will watch and take notes. If you want them to stop observing or move to another location you can ask them to do so at any time. If you do not want to take part in this part of the study you can tell the researcher before or during the observation and they will not include you.

Time. Your participation in this study will last about 2 hours.

Risks. No personal and company information will be documented during the observations. There are no foreseeable risks.

Benefits. This study is not designed to benefit you directly. However, the overall benefit to the industry will be to have further knowledge that can help improve worker health and wellbeing in the construction industry.

Confidentiality. No personal identities are not documented during observations. Observation

Study Information for Participants

Title: Musculoskeletal Disorders (MSDs) Risk for Concrete Formwork Systems

Purpose. The goal of the study is to investigate the prevalence and nature of Musculoskeletal disorders (MSDs), such as muscle/tendon strain and lower back pain, with respect to concrete formwork construction, and assess MSD risks associated with the use of different formwork systems.

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Time. Your participation in this study will last about 2 hours.

Risks. No personal and company information will be documented during the observations. There are no foreseeable risks.

Benefits. This study is not designed to benefit you directly. However, the overall benefit to the industry will be to have further knowledge that can help improve worker health and wellbeing in the construction industry.

Confidentiality. No personal identities are not documented during observations. Observation

notes will only be accessed by the study team and will be kept in password-protected computer files and/or a locked cabinet in the principal investigator's office.

Payment. You will not be paid for being in this research study.

Contact information. We would like you to ask us questions if there is anything about the study that you do not understand. You can call us at John Gambatese (541) 737-8913 or email us at john.gambatese@oregonstate.edu.

Sponsor. The Center for Construction Research and Training (CPWR)

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Sponsor. The Center for Construction Research and Training (CPWR)

RESEARCH CONSENT FORM

Study Title: Musculoskeletal Disorders (MSDs) Risk for Concrete Formwork Systems

Principal Investigator: John A. Gambatese / Oregon State University

Study team: Ziyu Jin / Oregon State University

Sponsor: The Center for Construction Research and Training (CPWR)

Version: June 30, 2020

We are inviting you to take part in a research study.

Purpose: This study is about Musculoskeletal disorders (MSDs), such as muscle/tendon strain and lower back pain, which account for more than half of the total injuries and illnesses in the construction industry. Among all construction activities, concrete formwork construction is recognized as a work activity in which workers have a high risk of developing MSDs. Previous research has focused extensively on the use of conventional job-built timber/plywood formwork. Given the fact that prefabricated formwork has been increasingly adopted in the industry, the investigation of MSD risks for workers who interact with different types of formwork systems is necessary to ensure the well-being of workers.

The goal of the study is to investigate the prevalence and nature of MSDs with respect to concrete formwork construction, and assess MSD risks associated with the use of different formwork systems. It is expected that the results from the study can be used by constructors when identifying effective intervention measures to lower MSD risk factors for workers, and for both designers and constructors when selecting safer and “healthier” formwork systems in the planning phase for concrete construction.

We are asking you if you want to be in this study because you are identified as having extensive knowledge of formwork construction, and/or experience in this discipline.

Voluntary: You do not have to be in the study if you do not want to. You can also decide to be in the study now and change your mind later.

Activities: The study activities include

- Research team member(s) will come to your workplace to take video recordings and/or photographs how concrete form worker’s work. The purpose of the research is not to assess or audit staff performance. No information about individuals will be reported back to managers at your organizations.
- You written consent must be obtained before the research team begin taking video recording(s).
- The research team member will take recording(s) and photographs from somewhere out of the way so that they do not interfere with your work.

- If you want them to stop videotaping or photographing or move to another location you can ask them to do so at any time. If you do not want to take part in this part of the study you can tell the researcher before or during the videotaping and they will not include you.
- The research team will be happy to answer any questions you have about the videotaping or the study.

Time: Your participation in this study will last about 2 hours.

Risks: There is a chance that we could accidentally disclose information that identifies you. However, the recordings and/or photographs will only be accessible by the study team and will be kept password-protected computer files and/or a locked cabinet in the principal investigator's office. Once video recordings are coded and transcribed, they will be destroyed. No names or other identifying information will be used when discussing or reporting data. Thus, the research findings cannot be traced to individual companies or people.

Benefit: This study is not designed to benefit you directly. However, the overall benefit to the industry will be to have further knowledge that can help improve worker health and wellbeing in the construction industry.

Confidentiality: The recordings and/or photographs will only be accessible by the study team and will be kept password-protected computer files and/or a locked cabinet in the principal investigator's office. Once video recordings and/or photographs are coded and transcribed they will be destroyed. No names or other identifying information will be used when discussing or reporting data. If video recording(s) or photograph(s) will be used in publications/conference presentations, identifying details will be obscured.

Payment: You will not be paid for being in this research study.

Study contacts: We would like you to ask us questions if there is anything about the study that you do not understand. You can call us at John Gambatese (541) 737-8913 or email us at john.gambatese@oregonstate.edu.

You can also contact the Human Research Protection Program with any concerns that you have about your rights or welfare as a study participant. This office can be reached at (541) 737-8008 or by email at IRB@oregonstate.edu

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Signatures:

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant Name:____

Participant Signature: ____

Date Signed:______________________________

Name of Person Obtaining Consent:____

Signature of Person Obtaining Consent:__________________________________

Date Signed:______________________________

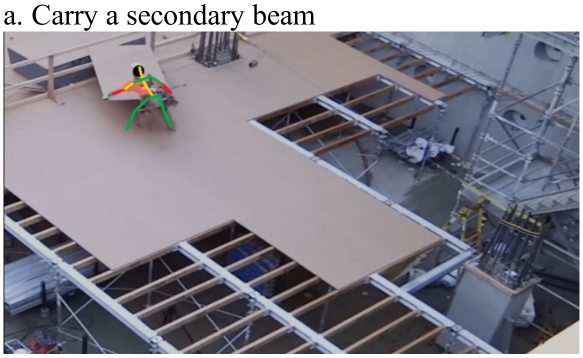
Appendix II: Formwork Erection and Removal Example Tasks and Working Postures

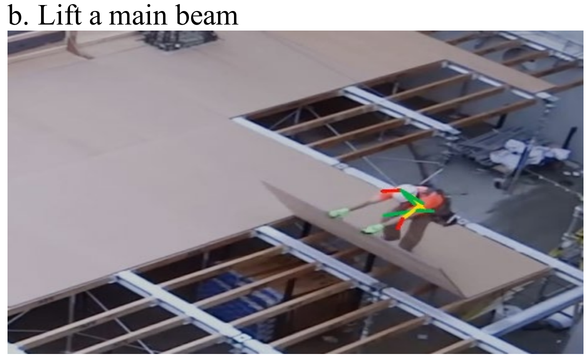
This appendix contains examples of the work tasks and associated working postures used during the formwork erection and removal processes.

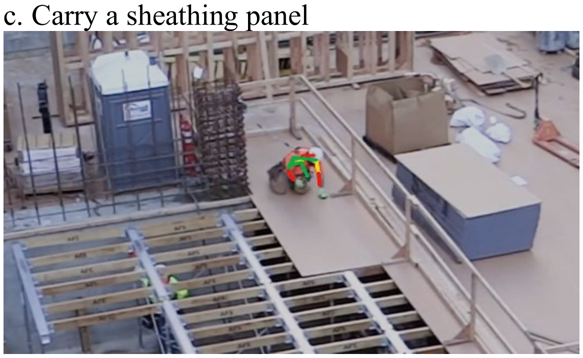
- ***Formwork Erection***


a. Carry a secondary beam


b. Lift a main beam


c. Carry a sheathing panel


d. Place a sheathing panel


e. Nail a sheathing panel to supporting members


f. Carry a modular panel


g. Place a modular panel


h. Hammer a modular panel in place


i. Adjust the height of a shoring post by hand


j. Inspect with a tape measure

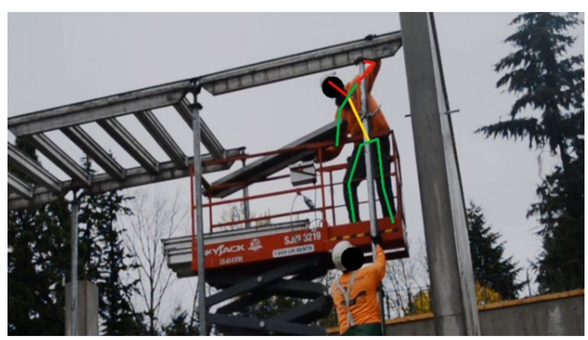

k. Carry a shoring post


l. Plumb a shoring post


m. Hold a shoring post in place


n. Inspect with a level


o. Ascend a ladder


p. Operate a scissor lift

- ***Formwork Removal***

a. Loosen formwork connection with a hammer

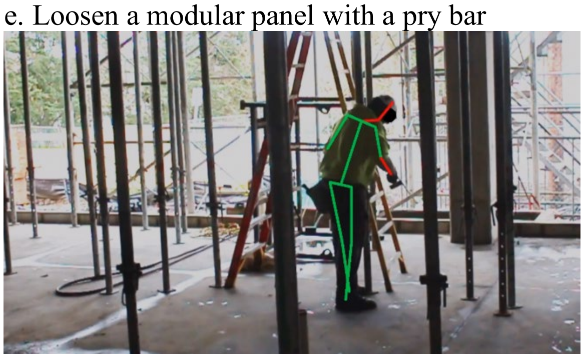
b. Lower a secondary beam

c. Loosen a sheathing panel with a pry bar

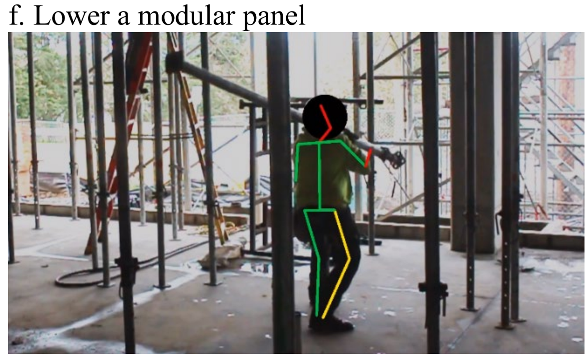
d. Loosen a sheathing panel by hand

e. Loosen a modular panel with a pry bar

f. Lower a modular panel



g. Loosen a shoring post connection with a hammer



h. Carry a shoring post