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Assessing the ergonomic hazards for Pile Drivers

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Abstract. *Objective*: The study was conducted to assess the physical/ergonomic exposures that may lead to musculoskeletal injuries of Pile Drivers.
Participants: Pile Drivers in the Greater Boston area.
Methods: A hierarchical taxonomy for pile driving work was developed with tasks and activities defined within each of seven main pile driving operations. Exposures were characterized for the pile driving work with the PATH (Posture, Activity, Tools, and Handling) method. Data on working posture were collected for three main body parts: legs, arm and trunk.
Results: A total of 8,301 observations were made on 29 Pile Drivers, on a total of 6 work sites. The lagging operation had the highest percentage of observations with non-neutral trunk (46.8%), and leg (41.0%) postures, as well as one of the lowest percentages for working on stable ground (9.0%) as observed during the lagging operation. The bracing operation had the lowest percentage for working on stable ground (0.3%). The slurry wall operation also had a low percentage of work on stable ground (6.0%). Compared to the awkward trunk and leg postures, the arm postures were less frequently observed as being awkward or non-neutral.
Conclusion: The results indicate of significant exposures that could lead to musculoskeletal injuries of the back and legs for the Pile Drivers. The unstable ground conditions seemed to be one of the main concerns for this job.

Keywords: MSDs, construction, occupational MSD exposure for Pile Drivers

1. Introduction

Pile driving is a construction trade that historically evolved from Carpenters work. In New England, Pile Drivers are part of the umbrella organization, the New England Council of Carpenters. Pile Drivers install piling to set the base of buildings, skyscrapers, docks, wharfs and bridges, to give a firm base to these structures. To achieve that, pile driving rigs drive metal, concrete or wood piles into the earth by various methods including vibration and impact force. The pile driving step is often the very first stage of the entire carpentry process.

The term 'Pile Driver' is used to describe both the workers and the machines that are used to drive piles into the ground. Pile driving machines are huge that look like cranes; generally these include a heavy weight placed between guides to ensure that the driver can freely slide up and down in a single line. To raise the weight of the pile through the pile driving machine, hydraulics, steam, diesel or manual labor is used. The first work related hazard for Pile Drivers was reported as early as 1866 [1]. The pile driving work at that time was performed by running a strong rope over a pulley. The rope was attached to the upper part of a block which was lifted and then dropped onto the pilings.

The challenge of the pile driving job, in some ways, remains in its outdoor location. The Pile Drivers face various workplace and environmental challenges like dust, mud, extreme humidity, extreme cold, wind chill, noise, etc. Musculoskeletal disorders (MSDs) in carpenters have been widely reported in the literature [2–6]. Heavy manual material handling (MMH), awkward

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Table 1
Pile Drivers' focus group qualitative data

Activity	Hazard	Exposure Area
Place and chip concrete piles	Heavy MMH	Knees, back, low back, shoulder
All outdoor activities	Yellow boots, walking and kneeling in uneven muddy surface, extreme heat and cold weather, dust, whole body fatigue, heat & cold stress	Feet, knees, back

postures, overhead work and kneeling are often reported as the main exposures for MSDs in the carpentry trades. These disorders occur in different body regions including the back, neck, shoulder, wrist and knees. However, very little research has been focused exclusively on Pile Drivers.

In the administrative database of the Carpenter's Health and Welfare Fund (HWF), a high percentage of osteoarthritis (OA) (32.6%) and meniscal injuries (33.7%) was shown for Pile Drivers relative to other knee injuries. The HWF data do not typically include acute injuries that normally are more likely processed through the state's Workers' Compensation System [7].

As a prelude to this study, our research team has conducted several focus groups with the Pile Drivers where they have talked about the uncomfortable yellow boots they need to wear in the poor ground conditions, knee problems, feet getting stuck in the muddy surface and slipping on both of icy and muddy surfaces during their work (Table 1).

The hypothesis of our research was that specific operations and tasks of pile driving are associated with distinctive profiles of musculoskeletal stressor exposures. The aim of this paper was to report the physical/ergonomic exposures for pile driving which might lead to musculoskeletal injuries of Pile Drivers.

2. Methods

2.1. Study site

The study took place at 6 construction sites in the greater metropolitan area of Boston, Massachusetts. Most of the data were collected during the fall, spring and summer when temperatures were generally well above freezing, though some were collected during the winter. Data were collected between 7 a.m. to 2 p.m. The sites were selected by convenience, but we attempted to sample as broadly as possible with respect to different pile driving operations.

2.2. Taxonomy

A hierarchical taxonomy [8] was used to describe the pile driving process and to systematically categorize this construction work into small units. The stage was defined as a large engineering process, the beginning and end of which are marked by at least one important change in the construction process. Each operation is a component of a stage that is performed by at least one crew and is comprised of one or more job tasks that are each performed by a specific trade, which is defined jurisdictionally for unionized construction work. Task is the functional work unit and the exposures are thought to be characteristic of a task. Tasks are a sequence of activities, which are performed to accomplish a specific single work goal or functional objective.

The researchers, prior to data collection, defined this taxonomy, although items in the taxonomy were added during the observation period, as needed by the researchers. The information about operations and job tasks were obtained from contractor documentation, direct observation, and interviews with contractor personnel, foremen and Pile Drivers.

2.3. PATH data collection

To meet the challenge of our hypothesis, we chose a method, which allowed quantification of biomechanical exposures to be linked with the tasks. PATH (Posture, Activities, Tools, and Handling) is an observational work sampling-based analysis method and is useful for non-routinized and irregular cycle jobs [9]. This method was used to collect quantitative ergonomic exposure data for the eight main pile driving operations. We used fixed intervals to make direct observations and coded postures into a PDA. The observations were recorded at the end of every minute based on the activity and task codes that are predefined in the PDA. The PATH posture codes are based on OWAS [10,11]. Codes for task, activity, tools, and weights of loads handled were included based on our preliminary observations. The postures, activities and other codes were recorded on a template (Pen Fact, Boston, MA) for the PDA, before actual PATH data collection. The worker number and job task were also coded for each observation. This strategy gives the researchers an opportunity to observe a specific Pile Driver at a random interval.

Table 2
Various activities comprised within each Pile driving task

Pile driving task (n = number of PATH observations made)	Activity
Bracing ($n = 923$)	– Attach seat – Attach waler – Fit seat – Attach seat – Attach strut – Fit strut – Fit waler – Jack and shim
Slurry wall ($n = 532$)	– Build end cap – Build guidewall – Install guidewall – Pour concrete
Install piling ($n = 612$) Install secant pilings ($n = 1763$) Install pif piling ($n = 60$)	– Drive caisson – Drive PIF piles – Drive secant piles – Drive steel piles – Equipment maintenance – Fabricate PIF piles – Fabricate steel piles
Lagging ($n = 96$)	– Attach timber – Fit timber – Prepare wall
Demolish/remove ($n = 1411$)	– Demo structure – Torch cut
Retaining wall ($n = 2506$)	– Fit sheet – Install sheet
Mobilization/demobilization ($n = 368$)	– Mobilization of piles

2.4. *Inter-observer agreement*

A total of 5 observers collected PATH data on Pile Drivers. Prior to data collection, inter-observer agreement was measured between pairs of observers for 1-hour periods. Data collection commenced when the percent agreement was over 80% for all PATH variables.

3. Results

A total of 8,301 PATH observations were made on 29 Pile Drivers, on a total of 6 work sites. All study subjects were male with age ranged between 20 and 60 years.

The researchers observed seven main pile driving operations. They were: 1) Bracing, 2) Slurry Wall, 3) Installation of Pilings, 4) Lagging, 5) Demo/Remove, 6) Retaining Wall and 7) Mobilization/Demobilization. These operations are described in Table 2. The numbers of PATH observations for each pile driving operation are also included in Table 2. The various activities comprised within each pile driving task are listed in Table 2.

The percentage of observation is the proportion of PATH observation made for a particular task or operation as a ratio to the total PATH observation made for all the operations. It therefore signifies the average percent of time per day a Pile Driver spends for any particular task or operation.

3.1. *Trunk postures*

Non-neutral trunk postures included severe flexion, mild flexion, laterally bent and flexed, laterally bent or twisted positions of the back. The highest proportion of work time in non-neutral trunk posture was observed during the lagging operation (46.8%) (Fig. 1). The operations with the longest work time in neutral trunk postures were bracing (79%) and installation of pilings (77.7%). Figure 2 shows the highest proportion of work time in non-neutral trunk postures obtained during specific tasks within operations. The 'prepare wall' activity of the lagging operation showed the highest proportion of work time in non-neutral trunk posture (89%) among all tasks observed.

3.2. *Arm postures*

Non neutral arm postures were defined as either one or both arms elevated more than 60 degrees. The highest proportion of time for postures with one arm > 60 degrees was observed for the mobilization/demobilization (20%) and lagging operations (19%) (Fig. 3). Inter-task variability among different operations for arm postures was not observed. The task "drive secant piling" had 38% observation time for workers working with one arm up (greater than 60 degrees). The equipment maintenance task showed 42% observation time for both arms up. Figure 3 shows the percent of time combined for postures with one or both arms elevated more than 60 degree. Figure 3 also shows that neutral arm postures were observed more frequently than non-neutral arm postures.

3.3. *Leg postures*

Any of the following leg postures were identified as non-neutral leg postures (bucking, crawling, deep squat, shallow squat, kicking with foot, kneeling on one or both knees, sitting on heels, legs not support-

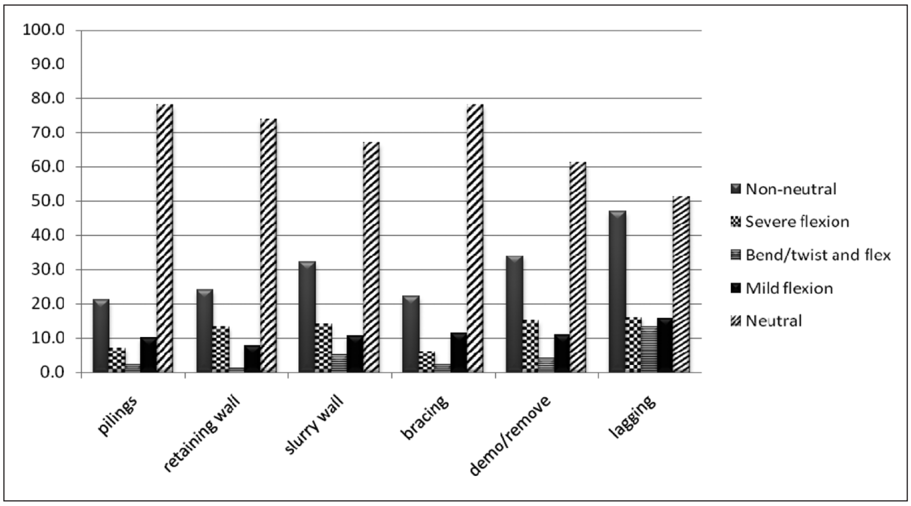

Fig. 1. Proportion of time spent in different trunk postures during the pile driving operations (Severe flexion, bent/twist and flex, mild flexion are part of non-neutral trunk posture).

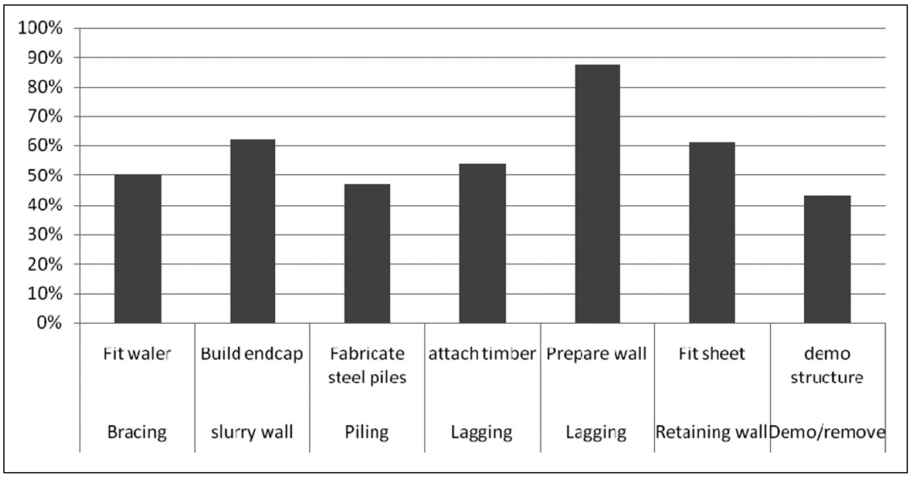

Fig. 2. The higher proportion of time for non neutral trunk postures during different activities and corresponding operations.

ing). The operation lagging showed the highest proportion of time (41%) for non-neutral leg posture (Fig. 4) among all operations observed. The second highest proportion of time for non-neutral leg posture was only 15% and was for the operation demo/remove. Non neutral leg posture was frequently observed during the attach timber (54%) activity of the lagging operation. Kneeling was not frequently observed among the operations. The only operation that showed a large proportion of time for kneeling was lagging (26%). Attach timber within the lagging operation showed the highest amount of kneeling (39.6%). The operations that showed frequent standing were bracing, slurry wall and installation of piling. Postures like deep squat and shallow squat were not frequently observed among the operations. The 'fit waler' task of the bracing operation showed the highest proportion of time for deep squat (29%). The Pile Drivers were observed for a considerable amount of time in squatting, standing or walking in the work surface. This is shown in Fig. 5.

3.4. Ground stability

"Rocky", "icy", "muddy" or "soft" ground conditions were grouped together as "unstable ground conditions". Pile Drivers generally work on unstable ground for most of their work time. Lagging was the operation with almost 90% of the time working on rocky,

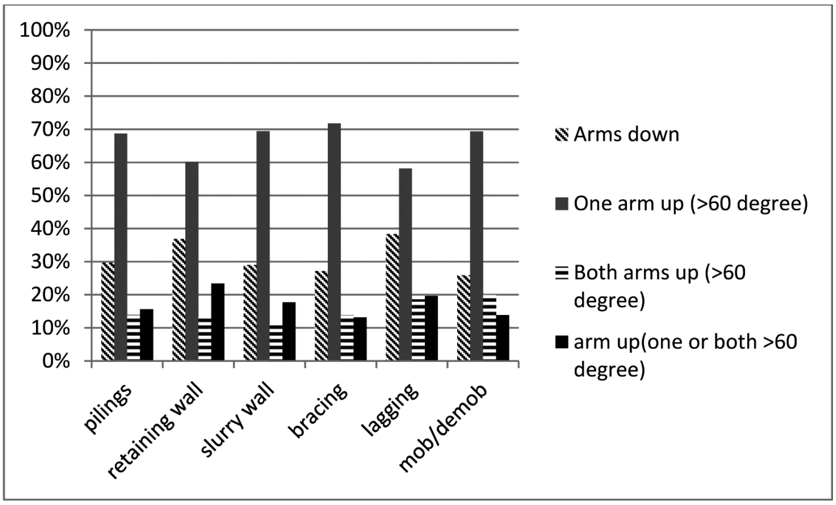

Fig. 3. Arm postures during different operations (arms down means the neutral arm posture, one arm up/both arms up are non-neutral arm posture).

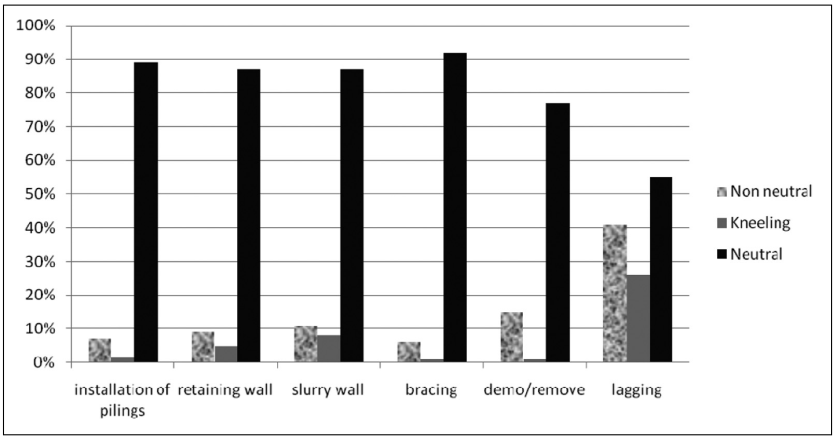

Fig. 4. Proportion of time observed for all non-neutral (either of deep or shallow squat, kneel, stand on one leg, buck) compared to kneeling leg postures in different operations.

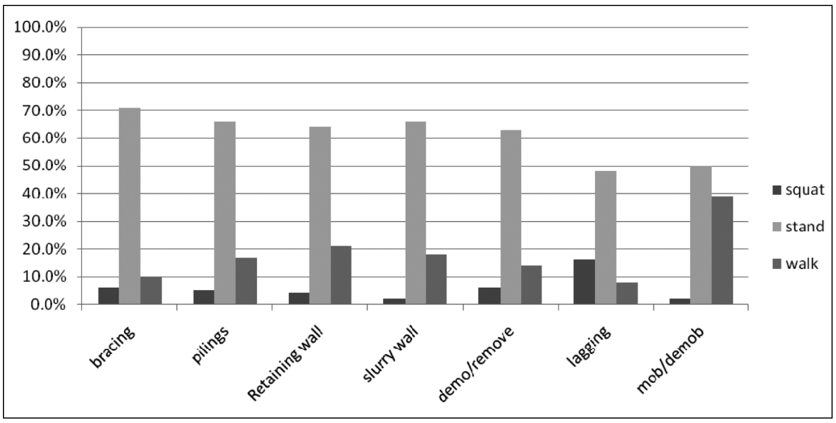

Fig. 5. Proportion of time observed for squatting, standing and walking leg postures.

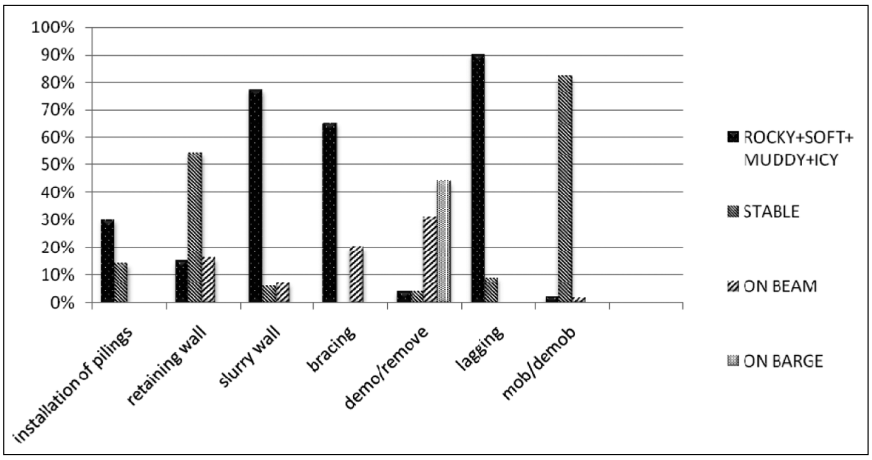

Fig. 6. Percentages of observations of different operations during working on stable, non-stable ground (rocky, icy, muddy or soft), beam and barge.

icy, muddy or soft ground (Fig. 6). For the bracing operation, observations on non-stable ground were most common (> 99% of the time). Unstable surfaces were present frequently in some tasks of the bracing operation and all tasks of the lagging operation. In particular, almost all of 'fit waler' was performed on muddy ground. The muddy ground is a result of both the weather and features of the task itself, because the task is performed in the earth but the weather dictates whether it is muddy or not. Work on a beam, which requires extra effort to maintain balance, was frequently observed for the 'jack and shim' task of bracing, demo structure of demolish/remove, fit sheet of retaining wall and install sheet of retaining wall. However, when they were observed, (weight in hands, materials etc.), the tools were in a hand of the Pile Drivers for some amount of time, which, depending on the tool, was a static load. (such as with welding or torch cutting).

3.5. Manual material handling

Manual material handling (MMH) activities (lifting, lowering, carrying, moving and pushing/pulling) were not observed frequently in any of the operations. The proportion of time for medium or heavy manual material handling was not frequent although medium (loads exceeding 5 lb) or heavy manual handling (loads exceeding 30 lb) was observed in the mobilization/demobilization operation for 3% and 9% of the time, respectively.

4. Discussion

Pile-driving remains a challenging carpentry trade as, unlike many other trades, this job is done entirely in outside conditions, encountering many weather as well as field hazards in addition to the work hazards. Our study has identified work related hazards for this job such as non-neutral trunk, leg and arm postures and working on unstable ground. These are primary ergonomic exposures with the potential to lead to musculoskeletal injuries for the pile driving tasks/operations.

4.1. Pile-driving operations which have high awkward postures

The operation 'lagging' seem to contain the highest amount of awkward trunk, leg and arm postures. Other operations which have high amount of awkward body postures are retaining wall, installation of pilings, slurry wall and bracing. The lagging operation requires the worker to install horizontal timber sheeting which is done almost simultaneously with the excavation. This process needs the workers to bend down a lot as the height of the H pile starts from the base level on the ground and goes up to the chest level of workers with an average height. The workers need to see both the outer and inner sides of the timbers and severely flex and even extend the back (Fig. 2). The reason that we found high amount of squatting and kneeling for the "lagging" operation specially for the tasks 'attaching timber' and 'preparing the wall', is mainly due to the fact that those require the workers to kneel and squat a lot at the ground level. The 'build end cap' task

Table 3
Percent time on knees, during walk, squat and standing

Operation	%time on knees	%time walk	%time squat	%time stand
Bracing	1.0	9.2	5.2	65.0
Demo/remove	8.4	13.7	6.0	59.9
PIF piles	0.7	20.1	1.5	63.7
Steel piles	2.1	19.1	6.0	67.2
Secant piles	0.0	10.0	1.7	88.3
Lagging	26.0	8.3	15.6	46.9
Mob/demob	2.7	39.4	2.4	50.3
Retaining wall	4.9	20.8	4.2	63.4
Slurry wall	9.0	18.2	2.3	66.0
Total	4.5	18.3	4.7	63.2

of the ‘slurry wall’ operation shows high non-neutral trunk posture. This task requires digging the earth to prevent the concrete wall from collapsing and hence the workers need to undergo some non-neutral leg and awkward arm postures (Figs 3 and 4). For the retaining wall operation, the workers need to install steel or wood sheets into the ground. Approximately, one-third of the sheet remains above ground and two-thirds goes below. To install these materials the workers often lifts one or both arms to greater than 60 degrees or have to undergo awkward posture of the trunk. The installation of pilings are done primarily with pile driving equipment and the Pile Drivers only ensure correct alignment of the pilings. Hence there are fewer instances that individual awkward postures for the workers were observed.

4.2. Working on unstable ground

The unstable ground condition is an unavoidable work condition for the pile driving job. The operations “lagging”, “bracing” and “slurry wall” all have considerable amount of time spent on unstable ground with the subjects undergoing awkward postures of the trunk and leg. Table 4 shows that the operations bracing and installation of secant & PIF pilings were carried out in muddy surfaces for majority of the work time. The lagging operation was mostly done on soft ground. During collection of the data, we observed that the surface becomes wet and muddy after the bracing frames are inserted. Depending on the construction plans of the site, the lagging operation might get started after the bracing operation. In such case, the ground still remains soft as a result of its previous muddy state and the continuous excavation of the ground. The lagging operation seemed to be one of the main concerns as it not only involves the highest amount of kneeling (26.0%), squatting (15.3%) and awkward trunk postures but also has the high amount of time spent on the soft ground surface (Tables 3, 4). Thus kneeling and squatting on soft ground for a high amount of work time remains a particular issue for the lagging operation. The bracing operation is also of particular concern for the pile driving job as a majority of time is spent on either muddy or soft ground surfaces or on a beam. Figure 7 illustrates the muddy state of the ground surface during the bracing operation.

4.3. Possible musculoskeletal risk factors for the pile driving job

Kneeling, squatting and climbing stairs have been identified as potential risk factors for knee pain, strain and other knee morbidities in carpenters, especially in floor coverers whose job require kneeling for long hours [12–14]. Also, carpentry trades that include minimal kneeling usually do not report any knee morbidities. As an example, drywall work, that includes overhead work mainly, has been associated with a high amount of back injuries but knee morbidities have not been a primary focus of their MSD injuries [15,16]. We did not observe as much kneeling in the results as expected, looking at the high proportion of knee OA (almost 33%) in the Pile Drivers in the HWF data [7]. In the focus groups, we came across the concerns of the Pile Drivers about their knees, which might be due to the fact that most part of their job is done on unstable ground conditions. In this study, although the overall proportion of time for kneeling is only 4.8%, a higher proportion of time is observed to be spent on walking, squatting and standing on unstable work surfaces, which included muddy, oily, icy, rocky and soft ground. Thus the challenge of keeping balance on the unstable ground while working in squatted or kneeled leg postures with the trunk bent, with arms elevated could be considerable threats for the development of lower extremity MSDs. Simple walking or standing for such long hours on the uneven surface could be hazardous for the lower extremity of the workers.

Although we did not see a lot of MMH ($>$ 10% of work time) in the pile driving operations, under such uneven working surfaces, it might still represent a significant exposure. One reason that less MMH was observed might be that the pile driving job is slower in pace compared to other carpentry trades as a lot of time was spent on digging the ground and fitting the slurry walls into the ground. So the amount of MMH could not be carried out for big amount of time.

Table 4
Percent time spent on different work surface

Operation	Percent within operation									N
	Icy/wet/oily	Muddy	Barge	Beam	Ladder	Rocky	Soft	**Stable**	Vibration	
Bracing	0.1	43.3	0.0	19.9	7.0	0.1	21.5	**0.3**	0.0	923
Demo/remove	0.0	0.0	44.2	31.5	0.2	0.1	4.6	**4.0**	0.0	1,411
PIF piles	24.5	42.8	0.0	0.0	9.6	7.4	7.4	**0.5**	2.0	612
Steel piles	0.0	10.8	0.0	1.2	2.8	17.6	20.8	25.9	15.0	1,763
Secant piles	20	62	0.0	3.0	0.0	0.0	0.0	**3.0**	0.0	60
Lagging	0.0	0.0	0.0	0.0	0.0	0.0	90	**9.4**	0.0	96
Mob/demobilization	0.0	0.0	0.0	1.6	0.0	0.5	1.6	82.6	0.0	368
Retaining wall	1.4	0.6	0.0	16.2	0.7	1.1	12.3	54.3	4.8	2,506
Slurry wall	9.2	5.8	0.0	7.1	0.0	16.7	45.0	**7.0**	0.0	532
Total	3.0	11.3	7.5	13.3	2.3	5.7	15.9	26.9	4.8	8,301

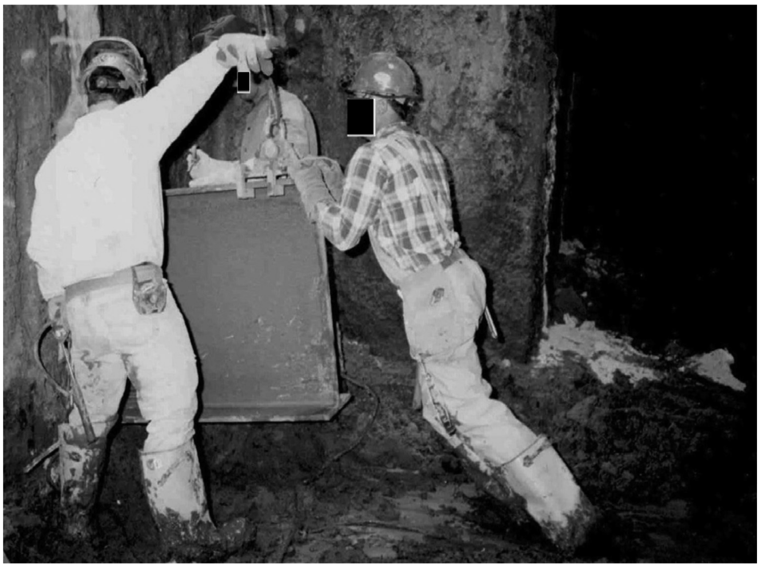

Fig. 7. The bracing operation being carried out in muddy surface.

4.4. Issues on existing yellow boots

Pile Drivers wear yellow overboots during most of their work which was reported in the focus groups as being "uncomfortable to work with", by the workers. The yellow boots might be insufficient to work on varied work surfaces such as unstable ground surfaces including the beams and barges, and in some cases the boots might itself add to the hazard of the unstable ground conditions.

4.5. Participatory Action Research (PAR) with the Pile Drivers

Researchers are performing PAR with different carpentry trades to find out solutions to different work related hazards [17–19]. Since there is scarcity of published literature on Pile Drivers, a Participatory Action Research might be an efficient way to find out the single specific or multiple exposure sources behind the lower extremity MSDs specially the knee morbidities of Pile Drivers. Considering the different ergonomic hazards present in different pile driving operations associated with high percentage of work time on uneven surface, carrying out a PAR might help Pile Drivers to identify their perception of the most hazardous task/operation and to propose solutions considering their preference and scientific feasibility. Some of the solutions might be tested in laboratory simulation that would provide an opportunity for using bioinstrumentation. The Pile Drivers' concern on "uncomfortable feeling" while using the yellow overboots might be, in some parts, related with these issues of work on uneven surface. It could be a potential discussion topic in PAR to redesign their working boots in order to make it suitable for the pile driving operations. Also, there would be opportunity for us to have more qualitative information, for example, work demands per day and per operation which might add to the psychosocial risk factors of the Pile-driving job.

4.6. Strength and limitation of the study

Random misclassification of the PATH codes is likely to be limited because of the PATH training and high acceptable inter-rater reliability and hence the amount of exposure illustrated by our data remain valid in terms of the PATH method. Less PATH data were collected for the lagging operation compared to the other pile driving operations. This does not necessarily rule out the reliability of the results. The lagging operation is usually done on a soft surface as a nature of the work.

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References

[1] Donders FC (1866) On the Work Performed in Pile-driving (by Dr. Moore's translations). Dublin Quarterly Journal, 471.
[2] Kucera KL, Lipscomb HJ, Silverstein B Cameron W (2009) Predictors of delayed return to work after back injury: A case-control analysis of union carpenters in Washington State. American Journal of Industrial Medicine 52, 821-830.
[3] Lemasters GK, Atterbury MR, Booth-Jones AD, Bhattacharya A, Ollila-Glenn N, Forrester C, Forst L (1998) Prevalence of work related musculoskeletal disorders in active union carpenters. Occupational and Environmental Medicine 55, 421-427.
[4] Lipscomb HJ, Cameron W, Silverstein B (2008) Back injuries among union carpenters in Washington State, 1989-2003. American Journal of Industrial Medicine 51, 463-74.
[5] Lipscomb HJ, Dement JM, Loomis DP, Silverstein B, Kalat J (1997) Surveillance of Work-Related Musculoskeletal Injuries Among Union Carpenters. American Journal of Industrial Medicine 32, 629-640.
[6] Lipscomb HJ, Dement JM, Silverstein B, Cameron W, Glazner JE (2009) Compensation costs of work-related back disorders among union carpenters, Washington State 1989-2003. American Journal of Industrial Medicine, 52, 587-595.
[7] Yuan L, Buchholz B, Fulmer S, Jing X (2009) Knee Disorders Among Union Carpenters. Proceedings of International Ergonomics Association Conference. Beijing, August.
[8] Moir S, Paquet V, Punnett L, Buchholz B, Wegman D (2003) Making sense of highway construction: a taxonomic framework for ergonomic exposure assessment and intervention research. Applied Occupational and Environmental Hygiene, 18, 256-267.
[9] Buchholz B, Paquet V, Punnett L, Lee D, Moir S (1996) PATH: a work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. Applied Ergonomics, 27, 177-187.
[10] Karhu O, Härkönen R, Sorvali P, Vepsäläinen P (1981) Observing working postures in industry: Examples of OWAS application. Applied Ergonomics, 12, 13-17.
[11] Karhu O, Kansi P, Kuorinka I (1977) Correcting working postures in industry: A practical method for analysis. Applied Ergonomics 8, 199-201.
[12] Kirkeskov JL,Eenberg W (1996) Occupation as a risk factor for knee disorders. Scandinavian Journal of Work, Environment & Health, 22, 165-175.
[13] Kirkeskov JL, Mikkelsen S, Loft IP (2000) Radiographic Knee Osteoarthritis in Floorlayers and Carpenters. Scandinavian Journal of Work, Environment & Health, 26, 257-262.
[14] Kivimäki J, Riihimäki H, Hänninen K (1992) Knee disorders in carpet and floor layers and painters. Scandinavian Journal of Work, Environment & Health 18, 310-316.
[15] Pan CS, Chiou SS, Hsiao H, Wassell JT, Keane PR (1999) Assessment of Perceived Traumatic Injury Hazards During Drywall Hanging. International Journal of Industrial Ergonomics 25, 29-37.
[16] Welch LS, Hunting KL, Nessel-Stephens L (1999) Chronic symptoms in construction workers treated for musculoskeletal injuries. American Journal of Industrial Medicine, 36, 532-540.
[17] De Jong AM, Vink P (2002) Participatory ergonomics applied in installation work. Applied Ergonomics, 33, 439-48.
[18] Hess JA, Kincl L, Amasay T, Wolfe P (2010) Ergonomic evaluation of masons laying concrete masonry units and autoclaved aerated concrete. Applied Ergonomics, 41, 477-83.
[19] Van der Molen HF, Sluiter JK, Hulshof CT, Vink P, Van Duivenbooden C, Holman R, Frings-Dresen MH (2005) Implementation of participatory ergonomics intervention in construction companies. Scandinavian Journal of Work Environment and Health, 31, 191-204.