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CONCRETE LEVELING TECHNIQUES - A COMPARATIVE ERGONOMIC ASSESSMENT

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Removing excess concrete and leveling concrete to grade – a.k.a. concrete screeding – can be accomplished using a number of different techniques. Five concrete screeding techniques were evaluated to characterize construction workers exposures to risk factors for developing work-related musculoskeletal disorders (WMSD). Workers were videotaped using manual, vibratory, roller, and laser screeding equipment on new construction sites. WMSD risk factors for the five screeding techniques were analyzed using the following ergonomic assessment methods: Posture, Activity, Tools, and Handling (PATH), ACGIH® Hand Activity Level TLV®, Strain Index, Washington State Ergonomic Rule, Liberty Mutual Manual Material Handling Tables and the NIOSH revised lifting equation. The most serious risks for developing musculoskeletal injuries of the upper extremity and back were observed during manual and roller screeding. Powered screeding techniques generally presented less risk than manual screeding, but these techniques can require brief periods of medium to high exertion for lifting tasks. Vibratory screed operators are exposed to hand-arm vibration, but vibration levels were not measured. Operating the walk-behind and the cab operated laser screeds presented the least risk. Suggestions are provided to limit the use of hand screeding, and to minimize potential exposure to risk factors related to operating and handling the powered screeding equipment.

INTRODUCTION

Cement masons and concrete finishers level and finish surfaces of poured concrete. Concrete work “is fast-paced and strenuous, and requires continuous physical effort” (BLS, 2001). In 2002, an estimated 178,000 cement masons and concrete finishers were employed in the US (BLS, 2004). During 1990-1998, concrete work ranked among the top ten industries reporting compensable work-related musculoskeletal disorders (WMSDs) in Washington State (SHARP, 2000). A majority of cement masons reported 12 month prevalence of ‘job related ache, pain or discomfort’ for the shoulders (53.3%), low back (81.8%), wrists and hands (65.6%), and knees (75.8%) (Cook et al, 1996). Physiological demands are high for hand screeding and troweling (Abdelhamid and Everett, 2002).

Screeding techniques

Immediately after pouring concrete for slabs or decks, excess concrete must be removed and the surface must be leveled to grade. This activity is called striking off or screeding the concrete. The five screeding techniques evaluated in this study are described below. Manual screeding is the simplest and most widely used method of screeding. Typically, two workers repeatedly pull a long two-by-four (12’-16’) over the discharged concrete while gradually stepping backwards until the section is completed (Figure 1). The motorized vibratory screed consists of a blade or plow that floats on the concrete,

one or two fuel-powered motors that vibrate the blade and the metal support tubing and handles to hold when pulling it backwards. (Figure 2). The roller screed is a seamless pipe (6’ to 43’ long) that spins in the opposite direction it is pulled. It is powered by a motor and is pulled over a surface between guide rails containing the concrete. Roller weight is a function of pipe length (Figure 3). The walk-behind laser screed is a 660 lb., self-propelled, laser-guided, two-wheeled machine with a 10’ wide vibrating plow (Figure 4). The cab operated laser screed is a self-propelled, four-wheel drive, four-



Figure 1 Manual screeding



Figure 2 Two engine vibratory screed.



Figure 3 Roller screed



Figure 4 Walk-behind laser screed

wheel steer unit with a 12' screeding and compacting head mounted on an aluminum telescopic boom (Figure 5). This paper characterizes and compares the musculoskeletal exposures of workers using the five concrete screeds.

METHODS

Three concrete contractors in the Pacific Northwest participated in the study. Owners, supervisors and hourly workers in each firm were interviewed regarding the screeding tools, equipment, and work practices. Five common techniques, including manual, vibratory, and roller screeding and two types of laser screeds, were selected for the study. Workers were videotaped screeding for a minimum of sixty minutes. On the basis of interviews and observation, researchers concluded the taped periods were representative of each technique used. Maximum sustained pull forces were measured using an analog push/pull gauge (Chatillon, Largo, FL, USA).

The primary screeding activities were analyzed using some or all of the following ergonomic assessment tools: Posture, Activity, Tools, and Handling (PATH) (Bucholz et al, 1996), Strain Index (Moore and Garg, 1995), Hand Activity Level TLV® (ACGIH, 2002), Liberty Mutual Tables (Snook and Ciriello, 1991), Washington State Ergonomics Rule (WISHA, 2000), and the NIOSH revised lifting equation (Waters et al, 1991). Summary statistics were calculated.

In order to more accurately compare musculoskeletal loading during screeding tasks, only actual screeding activities were analyzed. PATH was used to analyze the videotapes at 5 second intervals for manual, roller, and walk-behind laser screeding (total of 10 minutes/120 samples) and 45 second intervals for vibratory screeding (total of 1 hour/80 samples) The cab operated laser screed was informally assessed by observing the videotape, because postures, activities, and tools used were limited and rarely changed. Secondary screed activities that could not be quantified by observation were given descriptive terms reflecting the frequency of activity (i.e., "light/off-on" or "intermittent").

RESULTS

PATH

PATH criteria used to identify potential musculoskeletal loading for the five techniques are shown in the first column of Table 1. Severe forward flexion ($> 90^\circ$) occurred 77% of the time during manual screeding. Roller screed operators leaned back (trunk extension) 82% of the time. The highest pull forces (41-50 lbs.)

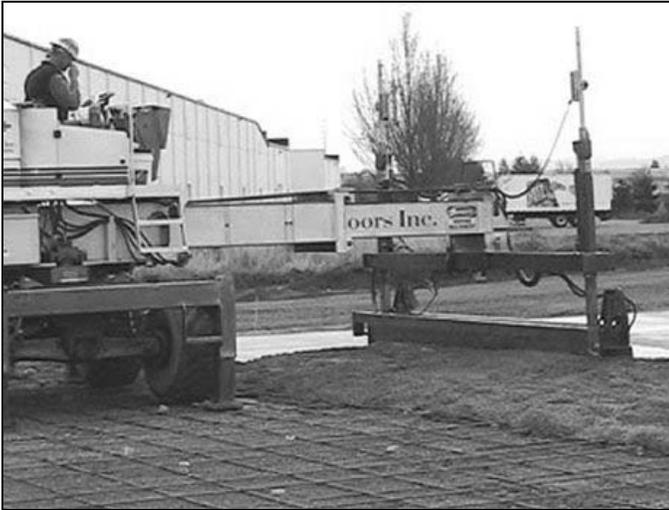


Figure 5.

were used pulling the 24 ft long tube cab operated laser screed during roller screeding. The highest push forces (51-60 lbs.) were used to operate the walk-behind laser screed. Nearly half of the operators' time was spent repositioning the 660 lb. walk-behind screed. Workers gripping the vibratory, roller, and walk-behind laser screeds were exposed to segmental vibration and the operator of the cab operated laser screed was exposed to whole body. Vibration levels were not measured.

Other assessment methods

The results of the remaining assessment methods are summarized in Table 2. Four screeding techniques, excluding the cab operated laser screed, involved intensive hand activity. The ACGIH® Hand Activity Level (HAL) TLV® and the Strain Index guidelines were exceeded during manual and roller screeding. Manual screeding exceeded three of the Washington State 'hazard zone' criteria (back bending, gripping and repetitive wrist motion) and roller screeding exceeded one (>1 70 lbs. lift/day). Force requirements were high for pulling, carrying, and lifting the roller screed, and for carrying and lifting the two engine motor screed. Using the Liberty Mutual tables, these forces were found to be acceptable to a limited number of males and unacceptable to most women. The NIOSH lifting index was exceeded during the manual lifting of the motor and roller screeds.

DISCUSSION

Two techniques - manual and roller screeding - were found to expose workers to the greatest number of back and upper-extremity WMSD risk factors. Workers operating the vibratory and walk-behind laser screeds typically work in neutral trunk posture, but must pull heavy equipment while walking backwards. Operators of

the walk-behind laser screed frequently exerted high forces to push down on the screed to reposition it. Workers lifting the vibratory and roller screeds exceeded the recommendations of the NIOSH lifting guideline. Workers are exposed to hand-arm or whole body vibration when operating the four powered screeds, although analysts believed only the vibratory screed posed a potential hazard.

Operating the cab operated laser screed involves the least exposure to WMSD risk factors. All of the risk factors were low to negligible, although static sitting for long hours can be considered a risk factor for back strain (although it is not factored into any of the assessment tool criteria). The cab operated laser screed is also the most costly in terms of the initial investment and maintenance. However, the cost may be recouped by virtue of its high production capabilities and low labor needs. The laser screed is also limited by its inaccessibility to many sites.

Conversely, manual screeding is the least expensive and most accessible method, but it is the most labor intensive, least productive, and presents the highest WMSD risks. The vibratory and walk-behind laser screeds are similarly versatile and efficient, while the latter is less labor intensive but more expensive. The roller screed, by crew accounts, appears best suited for long and narrow projects and those with an incline. It is efficient and productive, but can incur high risks as noted above. Mechanical power, e.g., a winch powered by a gasoline engine, can be used to pull the roller screed. Although vibration levels were not measured in this study, vibration exposure was identified as a potential WMSD risk factor. One vibratory screed manufacturer reports in-house hand-arm vibration (HAV) measurements for their screed ranged from 5-7 m/s^2 (MBW, 2004). The ACGIH (2004) suggests limiting HAV levels around 6 m/s^2 to 2-4 hours/day.

CONCLUSION

In the present study, manual and roller screeding posed the greatest risk to workers. In order to reduce workers' exposure to risk factors for back and upper-extremity WMSDs, manual screeding could be limited to small areas. High risk activities found in roller screeding can be eliminated or reduced, if powered material handling equipment (e.g., fork lift trucks) are substituted for manual handling, and mechanical power (e.g., electric winch) is used to pull the roller. Contractors can consult manufacturers to ascertain the vibration levels emitted by the equipment they use in order to take the necessary precautions to protect operators. Future studies should measure and compare the biomechanical loading of the

Table 1
Results of PATH Analysis of Screeding Techniques

PATH Category	PATH Position/Task	Manual Screed	Vibratory Screed (2-Person)	Laser screed (walk-behind)	Roller Screed	Laser (cab operated)
Trunk	Neutral	21%	92%	95%	17%	100% ^e
	Moderate	1	8	5	0	0
	Severe	77	0	0	0	0
	Lean back	0	0	0	82	0
Neck	Neutral	21	42	100	100	100
	Neutral-bent over at waist	77	0	0	0	0
	Non-neutral	1	58	0	0	0
Legs	Neutral	20	97	100	100	100 ^e
	Bent legs	80	3	0	0	0
	Stand	0	8	18	0	0
	Sit	0	0	0	0	0
	Walk forward	0	0	23	16	0
	Walk backward	0 ^a	92	60	83	0
Shoulders	Neutral	29	100	100	100	100
	Reach > 90°	70	0	0	0	0
Materials Handling	Pull/drag	73	100	55	99	0
	Push downward	0	0	43	0	0
	Lift	1	^b	0	^c	0
	Lower	4	0	0	0	0
	Carry	11	^b	0	^c	0
	Grasp-right	86	100	98	100	Light/on-off
Forces-Pulling ^d	Grasp-left	86	97	98	72	Light/on-off
	1-10 lbs.	84	0	56	0	0
	11-20 lbs.	0	97	0	0	0
	21-30 lbs.	0	0	0	39	0
	41-50 lbs.	0	3	0	(14' tube) 59 (24' tube)	0
Forces-Pushing Down	51-60 lbs.	0	0	41	0	0
	81-90 lbs.	0	0	2	0	0
Activity	Operate screed	93	100	52	99	0
	Reposition screed.	0	0	48	0	0
Vibration	Tool	0	97	100	99	0
	Whole body	0	0	0	0	100

^a Manual rodding requires the worker to move backwards, but it is nearly always done slowly and intermittently from a bent-legged position and, therefore, differentiated from “walking backwards.” ^b Lifts/carries 52-60 lbs. each when moving screed to next section.

^c Lifts/carries tubes when moving screed to next section – 24 ft. roller weighs 213 lbs. ^d The maximum sustained forces, per person, required to pull the vibratory and walk-behind laser screeds was estimated based on worker observation and report; the maximum sustained pull forces required of the roller screed were measured using a Chatillon analog push/pull gauge. ^e Seated posture.

operators and measure hand-arm vibration exposure during screeding.

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Table 2
Risk factor assessment results for screed methods

	Manual Rodding	Motor Screed (Twin Engine)	Walk-Behind Screed (Copperhead)	Laser Roller Screed	Laser Screed (Cab Operated)
TLV Hand Activity ^a	> TLV (1.66)	Between AL and TLV (0.75)	Between AL and TLV (0.6)	> TLV (1.75)	< AL (0.14)
WA L&I Ergo Rule ^b	<p><u>CZ</u>: Back bending >30° without support for >2hrs/day.</p> <p><u>HZ</u>: Back bending >45° for >2 hrs/day.</p> <p><u>CZ</u>: Grip ≥ 10 lbs for >2hrs/day.</p> <p><u>HZ</u>: Grip ≥ 10 lbs highly repetitively for > 3 hrs/day.</p> <p><u>CZ</u>: Repetitive motion of arms for >2 hrs/day.</p> <p><u>HZ</u>: Repetitive motion, wrists flexed >30° or extended >45° for >2 hrs/day.</p>	<p><u>CZ</u>: Lifting >55 lbs. for > 10/day.</p> <p><u>HZ</u>: none</p>	<p><u>CZ</u>: none</p> <p><u>HZ</u>: none</p>	<p><u>CZ</u>: Grip ≥ 10 lbs for >2hrs/day.</p> <p><u>CZ</u>: Lifting > 75 lbs. 1/day.</p> <p><u>HZ</u>: if one person lifts >70 lbs.</p>	<p><u>CZ</u>: none</p> <p><u>HZ</u>: none</p>
Strain Index ^c	SI= 15.0 “Hazardous”	SI= 3.4 “Uncertain”	SI= 3.4 “Uncertain”	SI= 6.8 “Some Risk”	SI= 1.5 “Safe”
Push/Pull Analysis ^d	h	h	h	Pull 150 lbs. M-0% F-0%; Pull 100 lbs : M-5% F-0%	h
Carry Analysis ^e	h	104 lbs. - 2-person carry: M 58% F 0%	h	24’ roller ,213 lbs., 3-person carry M-38% F-0%	h
Lift/Lower Analysis ^f	h	104 lb. - 2-person lift M 78% F 1%	h	24’ roller, 213 lbs., 3-person carry M-67% F-0%	h
NIOSH Lifting Equation ^g	LI< 1.0	LI = 2.0	LI < 1.0	LI = 3.1	LI < 1.0

^a TLV = Threshold Limit Value and AL = Action Level. ^b CZ = Caution zone; HZ = Hazard zone. ^c SI = Strain Index. ^d Percent males (M) and females (F) for which the force level is acceptable using Liberty Mutual Tables (Snook and Ciriello, 1991) adapted by Bernard (2002) for Push/Pull Analysis program. ^e Percent males (M) and females (F) for which the sustained force level is acceptable using Liberty Mutual Tables (Snook and Ciriello, 1991) adapted by Bernard (2002) for the Carry Analysis program. ^f Percent males (M) and females (F) for which the sustained force level is acceptable using Liberty Mutual Tables (Snook and Ciriello, 1991) adapted by Bernard (2002) for the Lift/Lower Analysis program. ^g LI = Lifting Index ^h Forces and conditions are less than lowest test criteria; minimal risk to virtually all workers.

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