HEALTH AND SAFETY IN CONCRETE CASTING PROCESSES

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Construction injuries lead to human tragedies, disrupt construction processes and adversely affect the cost, productivity, and the reputation of the construction industry. Therefore, the use of ergonomic production methods to prevent this can have a significant human, social and financial impact. This paper presents a case study of comparative analyses of ergonomic situations for concrete workers performing concrete casting processes. Ergonomic risk assessment methods were used to assess the physical strain, hand-arm vibration and noise affects risks involved in concrete casting work tasks. The combination of technical and managerial factors results in a system where workers are as efficient and safe as possible during their work tasks, and thus, makes the construction work environment sustainable. The preliminary study presented in this paper concludes that the present ergonomic risks emanating from work methods used in the normally vibrated concrete (NVC) casting can be significantly reduced. With the use of self-compacting concrete (SCC) awkward work postures, hand-arm vibration and noise are eliminated. Thus musculoskeletal injuries can be reduced if not eliminated among concrete workers during their concrete casting work tasks.

Keywords: work environment, worker safety, concrete casting, risk management, ergonomic risk.

INTRODUCTION

Although there has been a gradual decline in the prevalence of reported work-related musculoskeletal disorders (WMSDs) in the construction industry over the past decade (Samuelson and Lundholm, 2007), WMSDs remain the most common form of work-related ill health in the Swedish construction industry, comprising 71% of all reported cases of occupational diseases (Samuelson, 2008). Sweden has about a quarter of a million construction workers, and among these there are about 150 000 workers who on a daily basis are exposed to ergonomic risk factors such as forceful exertions, awkward work posture, repetition and vibration work tasks and the stress associated with work performance (Lundholm *et al.*, 2007). In the European Union musculoskeletal disorders are particularly prevalent across a range of construction industry trades with estimates suggesting that as many as 30% of the workforce may be affected (OSHA, 2004). Concrete workers are the most affected occupational group in regard to construction trades with a high relative frequency of reported musculoskeletal illness and injuries (Lundholm *et al.*, 2007). These workers are furthermore exposed to noise and hand-arm vibration due to the nature of their work tasks. The financial, economic, production and social costs of fatal accidents, injuries, disabilities and diseases to an industry, in particular, and to a society in general, are

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colossal. Promoting safety is a prudent managerial decision and it is worth paying the financial costs rather than suffering from economical or production losses associated with a lack of health and safety (Larcher and Sohail, 1999). Furthermore, cutting the sector's high incidence of accidents and work-related illnesses could save for example the EU and its taxpayers up to 75 billion Euros which is estimated to be about 8.5 percent of the total construction costs a year according to the European Agency for Safety and Health at Work (OSHA 2004).

Consequently, there remains a pressing need to examine why the prevalence of WMSDs remains so high among concrete workers, and therefore, how attempts to reduce risks can be made more effective. Risk assessment of musculoskeletal disorders risk factors is a vital part of the management and prevention of work-related musculoskeletal disorders. Risk management should lead to controlling the risk assessed through changes to the workplace, tools, equipment and working methods, and with that to eliminate or at least minimise the levels of exposure to WMSDs risks and the adverse effects of noise and vibration. Ergonomic improvements to reduce accidents and work-related disorders usually improves productivity and vice versa, thus establishing ergonomically optimal working conditions to prevent injuries leading to disability and absence from work leads to a sustainable profitability (Hendrick, 2008).

In this paper, we evaluated the impact of two types of concrete casting on the working conditions of concrete workers through the analysis of the physical strain, vibration and noise.

ERGONOMIC RISKS

Concrete casting work tasks cover a substantial amount of the concrete worker's workday. Table 1 shows three ergonomic risks are recognised from both the research literature and everyday tasks observations of the concrete workers at various work sites:

Table 1. Table of ergonomic risks involved in the normally vibrated concrete (NVC) casting

Ergonomic risks	Task observations
Physical strain	Concrete compaction requires worker to lift and drag the concrete vibrator around
Hand-arm vibration	When placing the NVC, the worker uses a concrete vibrator for concrete compaction
Noise	In addition to the concrete pump noise, when a concrete vibrator comes into contact with the reinforcement cage, a considerable noise is produced

CONCRETE CASTING

According to a study at Danish Technological University, DTU (Nielsen, 2006) some 26 % of a worker's average day consists of concrete casting (10 %) and reinforcement fixing (16 %). Traditionally, e.g. reinforcement and form work are done at its final location, using a substantial number of workers and lots of excess material resulting in a large amount of wastage. Furthermore, when casting NVC the workers need to compact the concrete with poker vibrators to make it fill the form properly. This results in a number of workers carrying around and using heavy equipment to compact the concrete. On the contrary, most often projects are under staffed due to a lack of qualified workers. This somewhat negative balance results generally in a poor working environment, unnecessary stress during different working operations, lower productivity, and a more expensive production when compared to other parts of the construction industry and other lines of work e.g. manufacturing industry.

Casting NVC generates high noise levels by the vibrating tools used for compaction of the concrete. Also, when using these poker vibrators it often leads to unhealthy working positions for the workers (Figure 1a).

Figure 1. a) Work posture when compacting NVC in wall structures. b) Casting of SCC on slab

SCC is a concrete which needs no extra energy i.e. vibration to compact itself and fill out the form properly, Figure 1b. This entails that SCC compacts itself due to its self weight and de-aerates while flowing in the form. In structural members with a high percentage of reinforcement it also easily fills all form voids and steel gaps.

In general SCC offers many advantages for cast-in-place construction as well as for the precast and pre-stressed concrete industry. In regard to the working environment the following are worth mentioning, less noise-level problems in the plants and construction sites, i.e. easier communication, eliminated problems associated with heavy vibrating equipment, improved quality and durability results in less rectification work and reduced concrete volumes due to higher strength (Cussigh, 2007, Emborg *et al.* 2007). According to recent international findings, SCC is on the cutting edge of scientific and technological developments, Shah *et al.* (2007) and Cussigh (2007). A number of ergonomic methods are available for assessing the work environment such as the one where SCC and conventional concrete are used.

INJURY RISK ASSESSMENT METHODS

PLIBEL

PLIBEL -- The PLIBEL method (Kemmlert, 1995) is a checklist method that links questions concerning awkward work postures, work movements, and design of tools and the workplace to specific body regions. In addition, any stressful environmental or organisational conditions should be noted. In general, the PLIBEL method was designed as a standardised and practical assessment tool for the evaluation of ergonomic conditions in the workplace. PLIBEL is a method for the identification of musculoskeletal stress factors that may have injurious effects and was designed to meet such needs (Kemmlert, 2006).

QEC (Quick Exposure Check)

The QEC allows the four main body areas to be assessed and involves practitioners and workers in the assessment. The tool focuses primarily on physical workplace factors, but also includes the evaluation of psychosocial factors. It has a scoring system, and exposure levels have been proposed to guide priorities for intervention. Subsequently it should be used to evaluate the effectiveness of any interventions made. The QEC can contribute to a holistic assessment of all the elements of a work system (David *et al.*, 2008). The QEC method enables a range of the most important risk factors for WMSDs to be assessed. It is straightforward to use, applicable to a wide range of tasks. Importantly, the QEC facilitates a partnership between the practitioner and the worker to make the assessment, thereby encouraging participative ergonomics. The QEC is of value in prompting improvements and in evaluating the benefits (reduction in exposure to WMSD risk factors) by providing a structured process to help prioritise the need for change. It can form a basis for communication between management, production engineers and designers when evaluating interventions and allocating resources to fund improvements (David *et al.*, 2008; David, 2005).

Hand and arm vibration dosimeter

To assess the hand and arm vibration among concrete workers, a vibration gauge (HealthVib HAV) designed in accordance to procedures specified in ISO 5349 was used to measure hand and arm vibration exposure among concrete workers at work sites, Figure 2 a.

Figure 2. a) Hand-arm vibration gauge, attached to a working glove. b) Workers vibrating the concrete slab, having the poker vibrators approximately 1 meter from the ears

The Vibration Directive sets an exposure action value for daily vibration exposure, above which it requires employers to control the hand-arm vibration risks of their workforce and an exposure limit value above which workers must not be exposed; a daily exposure action value of 2.5 m/s^2 and a daily exposure limit value of 5 m/s^2. However, there is some risk of hand-arm vibration injury where exposures are below the exposure action value (Directive 2002/44/EC).

Noise

According to the Swedish Arbetsmiljöverket (2005), there are limit values of exposures to sound for workers, Table 1. There are different limit values depending on whether the worker is using hearing protection or not. The lower limit of Leq 80 dBA implies that no action is needed. When the value increases and is in between 80 - 85 dBA the worker needs to use hearing protection. When the sound increases over 85 dBA specific action needs to be taken. This can include information and education, a specific plan of action, regular hearing checks and using other technical solutions. By using SCC the compacting work is eliminated and therefore the sound associated with the vibrating moment is eliminated, Shah *et al.* (2007).

Table 2: Limit values for sound exposure according to the Swedish Arbetsmiljöverket AFS 2005:16.

	Lower limit	Upper limit
Daily exposure level Lex, 8h	80	85
Maximum A-adjusted value LpAFmax	-	115
Impulse value	135	

	Limit value
Daily noise exposure level Lex,8h	85
Maximum A-adjusted value LpAFmax	115
Maximum value Lmax	135

RESULTS AND DISCUSSION

Physical strain assessment: PLIBEL output

The PLIBEL checklist for concrete workers task of casting the normally vibrated concrete reports a moderate percentage (38.1%) for risk factors present for the lower back, and low percentage (36.4%) of risk factors present for the neck, shoulder, upper back, elbow, forearm and hands. For the worker's SCC casting task, the PLIBEL checklist reports a low percentage (between 23 and 25%) of risk factors present for the feet, knees, hip and low back. Table 5 shows that both methods of concrete casting share several environmental and organisational modifying factors with one exception regarding the hand-arm vibration risks which are particular to the compacting of NVC casting.

Table 3. PLIBEL results for environmental and organisational factors

Environmental / Organisational Risk Factors Score	
SUM (NVC casting)	7
SUM (SCC casting)	6
Percentage (NVC casting)	70
Percentage (SCC casting)	60

Table 4. PLIBEL score for musculoskeletal risk factors

	Neck, Shoulder, Upper Back	Elbows, Forearms Hands	Feet	Knees and Hips	Low Back
SUM NVC casting	9	4	2	2	8
SUM SCC casting	4	1	2	2	5
Percentage NVC casting	34.6	36.4	25	25	38.1
Percentage SCC casting	15	9	25	25	23.8

Physical strain assessment: QEC output

In accordance with the QEC exposure scores in Table 5, the results in Table 6 shows that in the three case studies (three bridges), and all normally vibrated concrete casting work tasks have high levels of exposure for the back, especially when using concrete vibrators. These high levels of exposure should be reduced.

QEC exposure scores are high for the shoulder/arm body area, and the exposure levels are especially very high when using the concrete poker. Performing the concrete casting tasks on a horizontal level (floor) or vertical level (wall) does seems to have the same effect on the shoulder/ arm, except when the concrete vibrator is used, then there are indications that the exposure levels were slightly reduced when vibrating the concrete on the floor in comparison to vibrating the concrete in the wall.

Table 6 also shows the pattern found in previous exposure scores, and that is the high exposure scores in wrists and hands when the NVC casting especially the concrete poker is used. There is still no major distinction between the exposure levels during concrete casting on the floor or on the wall.

Furthermore, Table 6 indicates that all work tasks have high exposure levels for the neck except for the work task of smoothing SCC surface. These high exposure levels are explained by the time factor (4 to 8 hours workday) which did not change for the concrete worker on the three bridges building sites.

Table 5. QEC exposure levels for body regions

Score	Low	Moderate	High	Very High
Back (static)	8-15	16-22	23-29	29-40
Back (dynamic)	10-20	21-30	31-40	41-56
Shoulder/arm	10-20	21-30	31-40	41-56
Wrist/hand	10-20	21-30	31-40	41-46
Neck	4-6	8-10	12-14	16-18

Table 6. Concrete worker's QEC exposure levels for body regions

	Back	Shoulder /arm	Wrist/ Hand	Neck
SCC casting (floor)	14	18	24	4
Smoothing SCC surface (floor)	30	26	26	12
NVC casting (floor)	32	36	32	12
Vibrating NVC (floor)	40	40	34	14
NVC casting (wall)	32	30	28	12
Vibrating NVC (wall)	46	46	38	14
SCC casting (wall)	30	26	26	12

According to the QEC guideline of exposure scores in Table 7, it is shown in Table 8 that other work-related health risks (such as vibration, work pace, stress and driving at work) due to the environmental and organisational factors are present in both concrete casting work methods. The vibration risk factor, in this case hand-arm vibration only affects the workers while casting the NVC as it requires a compacting process.

Table 7. QEC exposure levels for environmental and organisational factors

Score	Low	Moderate	High	Very high
Driving	1	4	9	-
Vibration	1	4	9	-
Work pace	1	4	9	-
Stress	1	4	9	16

Risk to musculoskeletal injury due to the work pace adopted during SCC concrete casting was quasi absent; however for the NVC casting, QEC results reported moderate exposure levels. This is explained by the fact that the concrete worker has to vibrate the NVC as soon as it is casted and before the concrete settles with the air bubbles in it.

Table 8. Concrete worker's exposure levels for environmental and organisational factors

	Driving	Vibration	Work pace	Stress
SCC casting (floor)	1	1	1	1
Smoothing SCC surface (floor)	1	1	1	1
NVC casting (floor)	1	1	1	1
Vibrating NVC (floor)	1	9	4	2
NVC casting (wall)	1	1	1	1
Vibrating NVC (wall)	1	9	4	4
SCC casting (wall)	1	1	1	1

Hand-arm vibration assessment

Hand-arm vibration measurements were taken on both hands (right and left) and the results in Table 9 were obtained in vector sums, A rms (Aeq) using different concrete vibrators, namely a pneumatic vibrator and an electric vibrator. Using the pneumatic concrete vibrator with the right hand had a higher value and this is possibly due to the way the concrete worker holds the concrete vibrator.

Table 9. The partial exposure A(8) values (m/s^2) for estimated exposure time

	Pneumatic vibrator	Electric vibrator
Left hand	1.93 m/s^2	1.57 m/s^2
Right hand	1.67 m/s^2	4.12 m/s^2

The estimated exposure time for concrete workers was 4 hours and when the exposure over 4 hours of work measured is extrapolated to an 8 hour workday, then the following values in Table 10 were achieved.

Table 10. Vector sum values for hand-arm vibration exposure level

	Pneumatic vibrator	Electric vibrator
Left hand	1.36	1.11
Right hand	1.18	2.91

In regard to the measured A(8) action values in Table 10, the allowed work time in hours is indicated in Table 11.

The risk assessment of the concrete worker's hand-arm vibration exposure and the allowed work time in regard to the action value are presented in Table 12.

Table 11. The allowed work time with the different vibrators

	Pneumatic vibrator	Electric vibrator
Left hand	>8 hours	>8 hours
Right hand	>8 hours	5.9 hours

Table 12. Total hand-arm vibration exposure and allowed work time

	Pneumatic and Electric vibrators	Pneumatic and Electric vibrators
Left hand	2.69 A rms (Aeq)	6.9 hours
Right hand	1.81 A rms (Aeq)	>8 hours

Sound measurements

The measurements of sound or rather noise are presented in Table 13, there the equivalent value Leq and the maximum value Lmax are presented for some different situations. All values were measured during a period of one minute. The worst circumstance is in measurement number two when the reinforcement bars were unintentionally vibrated while the worker did the compaction of the concrete. The maximum value went over the scale at this point. This noise carried on for approximately 20 seconds each time it occurred. Furthermore, the noise of the edge beam being vibrated, when measured at the same distance as the other workers were located, approximately 4 m away, the values achieved were high.

Table 13. Sound measurements, Leq is the A-weighted values and Lmax is the top values.

	No of vibrators	Other equipm	Distance (m)	Leq	Lmax	Part vibrated	Comment
1	1	Pump hose	1	83,6	98,1	Edge beam	
2	1		1	93,3	112,5	Edge beam	OVER 112,5!
3	1	Pump hose	4	80,1	89,7	Edge beam	
4	1	Pump hose	1	86,5	101,3	Superstructure	
5	1		3	83,2	97	Superstructure	
6	3		1	85,1	97,2	Superstructure	
7	3		1	83,5	97,7	Superstructure	
8	3		1	82,6	99,8	Superstructure	
9	3		5	78,4	94,5	Superstructure	
10	4		1	88,1	104,9	Superstructure	
11	4		1	83,4	95,5	Superstructure	

There is only one measured value that is below the lower limit of 80 dBA suggested by the Arbetsmiljöverkets (2005) standards, and that is when the measuring equipment is 5 meters away from the source of the sound, value 9 in Table 13. The worker's ears are however positioned approximately 1 meter from the source of the noise, Figure 2 b. Two different poker vibrators were used at the specific project; no effort has been done to establish which one is better from a noise and vibration point of view. Four out of eleven measures in total or four out of eight of the values within 1 m distance indicates that specific action is needed. This should, out of the working environment and the workers point of view, result in a specific action plan and the adoption of new technical solutions e.g. SCC.

CONCLUSIONS

With these industrialised construction methods, it is assumed that the cost for sick leaves due to ergonomic injuries and accidents are reduced because health and safety risks usually inherent to the traditional working methods are greatly reduced.

A new development in the industrial construction process, such as self compacting concrete (SCC) is creating a basis for an improved working environment.

Two work processes within a concrete casting operation were assessed to determine the presence of risk factors associated with musculoskeletal disorders. The concrete casting and other related tasks were analysed using two exposure assessment checklists. The high amount of effort required to vibrate the NVC between the steel reinforcement structures is a risk factor associated with this process. Possible interventions include using a mix of steel fibres and concrete or using SCC in order to eliminate the pulling and pushing of concrete vibrators through narrow steel reinforcement cages. SCC is currently being used for practical structures in order to shorten the construction time period of large-scale construction, but it is also used in various projects to eliminate vibration noise, thus improving the working environment on the site (Brite Euram, 2000). In this study, the comparison between NVC and SCC has indicated that the impact of SCC on working conditions (physical strain, hand-arm vibrations and noise) is very interesting in terms of concrete workers' musculoskeletal health as the SCC casting eliminates hand-arm vibration and reduces strenuous physical work which is usually an integral part of the NVC casting.

The concrete worker often bends at the waist to force the vibrator through the reinforcement structure. Manually lifting the vibrator or pulling it to a new location results in undue stress on the back of the workers. By using cordless and light vibrators one can minimise the stress on the workers' backs. It is recommended that further action be taken to mitigate the exposure to musculoskeletal risk factors within each of the identified concrete casting tasks. The implementation of ergonomic interventions has been found to reduce the amount and severity of musculoskeletal disorders within the working population in various industries (Hendrick, 2008). It is recommended that ergonomic interventions may be implemented in the concrete casting process of bridge construction projects in Sweden to minimise hazards in the identified job tasks.

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