ERGONOMIC EXPOSURES FROM THE USAGE OF CONVENTIONAL AND SELF COMPACTING CONCRETE

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ABSTRACT

The use of ergonomic production methods in concrete casting does have a significant human, social and financial impact in terms of the reduction of occupational injuries and related injury compensations. This paper presents a case study of comparative analyses of the ergonomic situations for concrete workers casting with two different types of concrete, namely the conventional concrete and the self-compacting concrete (SCC).

Analyses were conducted with two methods for the identification of ergonomic hazards; and in comparison to conventional concrete, the analysis results have shown that SCC consistently gave significant improvements in work postures and led to less workload and noise exposure among concrete workers.

The combination of lean thinking and ergonomics result in a system where the worker is as efficient, safe, and comfortable as possible during the concrete casting work process. Material handling plays a significant role in lean construction by keeping the worker at the center and ameliorating many of the ergonomic problems that would otherwise remove the person from the production process. Transportation and unnecessary motion are two of the seven types of wastes that can be significantly reduced with the implementation of an ergonomic production system such as SCC that eliminates awkward work postures and vibrating tools. With the correct ergonomic material/product used in production of concrete structures, waste can be removed from the production system, thus creating an increase in production, decreased costs, an increase in quality of the product and less absence of workers in the future due to less stressful work.

KEY WORDS

Work environment, worker safety, concrete casting, risk management, lean thinking, and ergonomics.

INTRODUCTION

Employees who are well and content with their work are a key factor in a successful company. It is vital for the company to ensure that the working environment and conditions provide the right setting for employees to achieve peak performance in their work. Apart from the personal discomfort involved, work-related problems and ill-health

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cost money in the form of impaired quality, productivity losses, and increased employee turnover and sick leave. Occupational safety costs will ultimately be paid for by the client either directly or indirectly. 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, is 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).

Poor health and safety among construction workers is a problem for the society; and ergonomic risks and stress constitute contributing factors to this situation. In order to prevent accidents and illnesses, the employer has to be aware of which kinds of risks are found in the work environment and implement corrective measures to prevent injuries such as work-related musculoskeletal disorders (WMSDs) (Arbetsmiljöverket, 2004). In Sweden, accessible occupational injuries statistics indicate WMSDs constitute approximately 37% of the total number of reported occupational injuries. Although occupational diseases have been consistently decreasing since year 2000; WMSDs are still common and making up 71% of all cases of reported occupational diseases (Samuelson, 2008).

The assessment of exposure to musculoskeletal disorders risk factors is a vital part of the management and prevention of work-related musculoskeletal disorders (WMSDs). Exposure assessment relies on the acceptance of established “risk factors” for a number of musculoskeletal disorders, based on current “state of the art” research findings. This assessment should lead to consideration of the changes to workplaces, tools, equipment and working methods that are possible to eliminate or at least minimize the levels of exposure. Ergonomic improvements to reduce accidents and work-related disorders usually improves productivity and vice versa. To establish *ergonomically* optimal working conditions to prevent musculoskeletal injuries leading to disability and absence from work leads to a sustainable profitability (Hendrick, 2008).

In this paper, we tried to evaluate the impact of two types of concrete (i.e. the Self-compacting concretes (SCC) and the conventional concrete) on working conditions of concrete workers through the analysis of the physical work and noise.

CONCRETE CASTING WORK-RELATED RISK FACTORS

PHYSICAL STRAIN

Construction workers perform many physically demanding tasks that expose them to risk factors for musculoskeletal or soft tissue, injuries. Previous research studies have shown the association between occupational factors, such as awkward postures, repetitive motions, heavy lifting, and low-back disorders among concrete workers (Hess et al., 2003; Goldsheyder et al., 2004). In 2007 concrete workers ranked first among all construction occupational groups in the frequency of reported number of work related musculoskeletal disorders and injuries (Lundholm et al., 2007).

NOISE

Noise is generally emitted as a by-product of the processes in construction and other industrial settings. Construction work involves many work situations where noise might be harmful to construction workers hearing ability. The Council of European Communities (2003) in its directive 2003/10/EC lays down the minimum health and safety requirements to protect workers from the risks rising up from the exposure noise. The basic parameters of environmental noise that affects human subjective response are: 1- intensity or level, 2- frequency content, and 3- variation with time. Sound intensity or level is determined by how greatly the sound pressure fluctuates above and below the atmospheric pressure and is expressed on a compressed scale in units of decibels (dB). The sensitivity of human hearing varies with frequency expressed in Hertz (Hz), the *A weighting* system is commonly used when measuring environmental noise to provide a single number descriptor that correlates with human subjective response. Sound levels measured using this weighting system are called A-weighted sound levels and are expressed in dB notation as dB(A). The *A-weighted* sound level is widely accepted by acousticians as a proper unit for describing environmental noise (Druga et al., 2007). The daily and weekly noise exposure levels (LEX,8h) dB(A) measured relative to 20 µPa are the time-weighted average of the noise exposure levels for a nominal eight-hour working day or a nominal week of five eight-hour working days as defined by international standard ISO 1999: 1990 (EC, 2003).

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 if the worker is using hearing protection or not. The lower limit of Leq 80 dB(A) implies that no action is needed. When the value increases and is in between 80 - 85 dB(A) the worker needs to use hearing protection. When the sound increases over 85 dB(A) 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. Using SCC, a different technical solution, the compacting work is eliminated and therefore the sound associated with the vibrating moment is eliminated, Shah et al. (2007).

Table 1: 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

INJURY RISK ASSESSMENT METHODS

PLIBEL method

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 organizational conditions should be noted. In general, the PLIBEL method was designed as a standardized 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 was designed to meet such needs (Kemmlert, 2006).

QEC (Quick Exposure Check) METHOD

The method is based on epidemiological evidence and investigations of Occupational safety and health practitioners' aptitudes for undertaking assessments. It has been tested, modified and validated using simulated and workplace tasks, in two phases of development, with participation of 206 practitioners. The QEC allows the four main body areas to be assessed and involves practitioners and workers in the assessment. Trials have determined its usability, intra- and inter-observer reliability, and validity which show it is applicable to a wide range of working activities. The tool focuses primarily on physical workplace factors, but also includes the evaluation of psychosocial factors. Tasks can normally be assessed within 10 min. 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)

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 prioritize 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).

CONCRETE CASTING

In the late 1990s there was a step taken towards a more industrialized casting of concrete in Sweden, when Self Compacting Concrete (SCC) was introduced. The development of SCC started in Japan during the 1980s. There were two main reasons for developing SCC, firstly to be able to ensure the increasing demand on quality of structures, and secondly there were problems finding competent personnel for castings, Okamura and Ouchi (1999).

SCC is an important link in the development of the industrialization process of civil engineering projects. This, since it can, if managed properly, e.g. planned with the Last Planner system of production control, decrease the number of workers needed during casting. Also, the concrete workers can perform other activities during casting and the construction site becomes less congested during casting with a possible reduced risk for accidents as a result, Figure 1a. Also, an improvement of the working environment in general will be realized through lower noise level and less heavy lifting of material.

According to recent international findings, SCC is on the cutting edge of scientific and technological developments, Shah et al. (2007) and Cussigh (2007), and it is essential to introduce the technique in a broader manner in cast in place concrete construction.

Conventional concrete needs compacting work to settle properly in the form, Figure 1b. There are two reasons for this, namely; it contains entrapped air and it is not enclosing the reinforcement and filling out the formwork properly. If this surplus air is not removed and the reinforcement is not enclosed properly there can be a weakening in the compressive strength of the concrete structure. Concrete vibrators also called poker vibrators are therefore needed to compact the concrete. These pokers have amplitudes of 8000 – 15000 vibrations per minute. The weight of the vibrators varies from approximately 8 – 30 kg. The vibration of the pokers affects the workers working environment negatively. Considering the term waste or “muda” as interpreted by

Womack and Jones (2003), the compacting work of the conventional concrete can be perceived as muda.

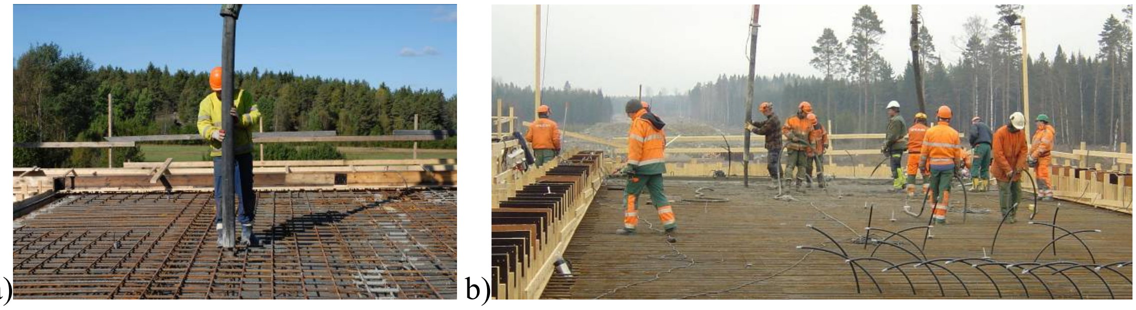
a) b)


Figure 1: Typical Work Situation When a) Casting SCC. and b) Casting of Normal Concrete

MEASUREMENTS RESULTS AND DISCUSSION

PHYSICAL STRAIN

Both QEC and PLIBEL methods were used to assess 12 workers (average age 36 years old) randomly selected from 30 concrete workers involved in 3 bridge building projects.

QEC CHECKLIST

In accordance with the QEC exposure scores in Table 2, the results in Figure 2 shows that in the studied case study all conventional concrete casting work tasks have high levels of exposure for the back especially when using the concrete vibrator. These high levels of exposure should be reduced.

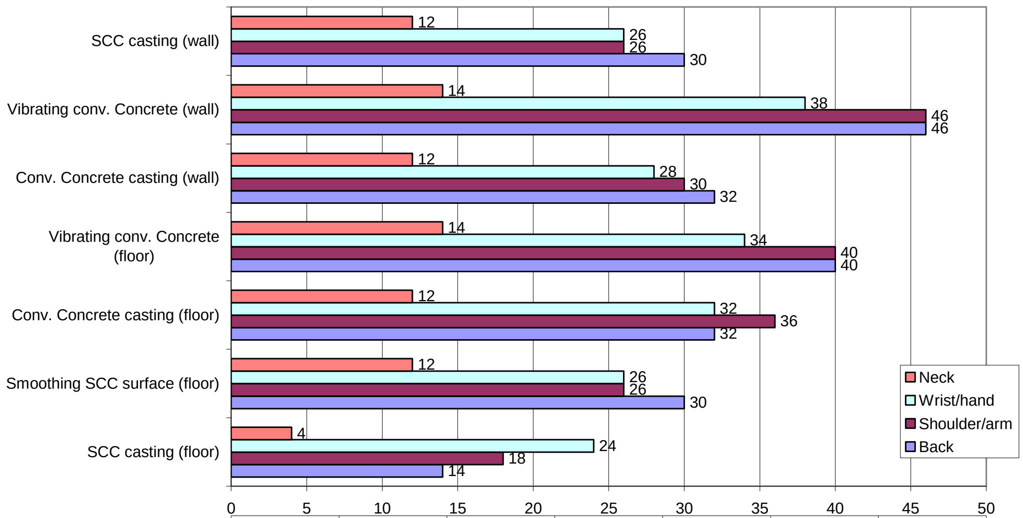
The average exposure scores are high for the shoulder/arm body area, and the exposure levels are especially very high when using the concrete poker. Performing the concrete casting tasks on horizontal plan (floor) or vertical plan (wall) does seems to have the same effect on the shoulder/ arm, except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

Table 2: QEC Exposure Levels for Body Regions

	QEC Exposure level			
Score	**Low**	**Moderate**	**High**	**Very High**
Back (static)	8-15	16-22	23-29	29-40
Back (moving)	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

Figure 2 also shows the pattern found in previous exposure scores, and that is the high exposure scores in wrists and hand when the conventional concrete casting especially when the concrete poker is used. There is still no major distinctive difference between the exposure levels during concrete casting on the floor or on the wall.

Furthermore, figure 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 does not change for the concrete worker.



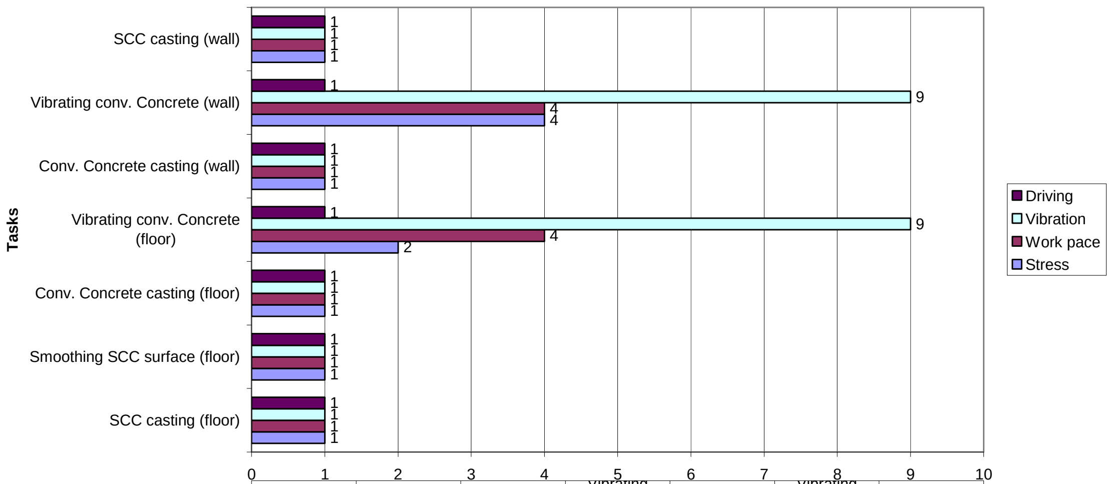
	SCC casting (floor)	Smoothing SCC surface (floor)	Conv. Concrete casting (floor)	Vibrating conv. Concrete (floor)	Conv. Concrete casting (wall)	Vibrating conv. Concrete (wall)	SCC casting (wall)
Neck	4	12	12	14	12	14	12
Wrist/hand	24	26	32	34	28	38	26
Shoulder/arm	18	26	36	40	30	46	26
Back	14	30	32	40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

Figure 2: QEC Results for Exposure Levels for Body Regions

According to the QEC guideline of exposure scores in Table 3, it is shown in Figure 3 that other work-related health risks (such as vibration, work pace, stress and driving at work) due to the environmental and organizational factors are present in both concrete casting work methods, except that vibration risk factor, in this case hand-arm vibration does only affect the workers while casting the conventional concrete which requires a compacting process. Risk to musculoskeletal injury due to the work pace adopted during SCC concrete casting was quasi absent; however for the conventional concrete casting, QEC results reported moderate exposure levels. This is explained by the fact that the concrete worker has to vibrate the conventional concrete as soon as it is cast and before the concrete settles with the air bubbles in it.

Table 3: QEC Exposure Levels for Environmental and Organizational Factors

QEC exposure levels				
Score	**Low**	**Moderate**	**High**	**Very High**
Driving	1	4	9	-
Vibration	1	4	9	-
Work pace	1	4	9	-
Stress	1	4	9	16



	SCC casting (floor)	Smoothing SCC surface (floor)	Conv. Concrete casting (floor)	Vibrating conv. Concrete (floor)	Conv. Concrete casting (wall)	Vibrating conv. Concrete (wall)	SCC casting (wall)
Driving	1	1	1	1	1	1	1
Vibration	1	1	1	9	1	9	1
Work pace	1	1	1	4	1	4	1
Stress	1	1	1	2	1	4	1

Average QEC exposure scores

Figure 3: QEC Results for Exposure Levels for Environmental and Organizational Factors

PLIBEL CHECKLIST

The PLIBEL checklist for concrete workers task of casting the conventional concrete reports a moderate percentage (38.1%) Table 4, 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. For both tasks, according to Table 5, several environmental and organisational modifying factors are present as well and are generally shared except the hand-arm risk which particular to the compacting of conventional concrete casting.

Table 4: PLIBEL Checklist's Musculoskeletal Risk Factors scores for Concrete Casting

Musculoskeletal Risk Factors Scores					
	Neck, Shoulder, Upper Back	Elbows, Forearms, Hands	Feet	Knees and Hips	Low Back
SUM (Conventional concrete casting)	9	4	2	2	8
SUM (SCC casting)	4	1	2	2	5
Percentage (Conventional concrete casting)	34.6	36.4	25	25	38.1
Percentage (SCC casting)	15	9	25	25	23.8

NOISE MEASUREMENTS

In Table 6 and Figure 4, the equivalent value Leq and the maximum value Lmax for different measuring situations are presented. All values were measured during a period of one minute. As can be seen in the table, the worst case scenario is when the edge beam is being vibrated. This is due to reinforcement being vibrated before the poker vibrator slips through into the concrete. This noise carried on for approximately 20 seconds each time it occurred. Also, when measuring the vibration of the edge beam when standing at the same distance, approximately 4 m away, as the other workers was located the values are high.

Table 5: PLIBEL Checklist's Environmental and Organisational Risk Factors Scores for Concrete Casting

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

Table 6: Sound Measurements From A Railway Bridge Building Project. Leq Is the A-weighted Values and Lmax Is the Top Values During the Same Measuring Period

	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	

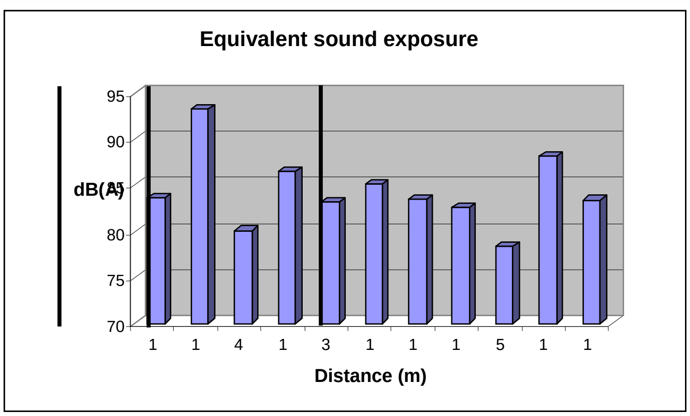


Figure 4: Sound Measurements From A Railway Bridge Building Project.

When it comes to being under the lower limit of 80 dBA, when nothing needs to be done according to the Arbetsmiljöverkets (2005) standards, the only accepted value is when the measuring equipment is 5 meters away from the poker vibrators. 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 workers point of view, result in a specific action plan and the adoption of new technical solutions.

CONCLUSIONS

NOISE

At a railway bridge building project the equivalent measured values reaches from 78,4 dBA when the measuring equipment were 5 meters away up to 93,3 dBA when situated 1 meter away from the worker vibrating the concrete in the edge beam. When the measuring equipment is only 1 meter away 50% of the values are over the threshold of 85,0 dBA which indicates that this is, for the hearing ability, a hazardous environment to work within.

According to a Brite Euram project (2000) the difference between using conventional vibrated concrete and SCC when considering the noise level is 10 dBA. Keeping in mind that a 10 dBA decrease in sound is a halving of the sound level as suggested by Druga et al. (2007), this is a vast improvement in the sound level of the working environment.

PHYSICAL STRAIN

Two work processes within a concrete casting operation were surveyed to determine the presence of risk factors associated with musculoskeletal disorders. The concrete casting and other related tasks were analyzed using two exposure assessment techniques. The high amount of effort required to vibrate the conventional concrete between the steel reinforcement structures is a risk factor associated with this process. Possible interventions include using steel fibers mixed with concrete or using SCC in order to eliminate the pulling and pushing of vibrators through narrow steel reinforcement cage.

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 minimize the stress on the workers' backs.

Both PLIBEL and QEC checklists methods have identified the level of work-related musculoskeletal risk exposure in the two concrete casting work processes, and it was found that the conventional concrete casting process had high levels of risk exposure at the back and shoulders due to the manual handling of concrete vibrators in combination with awkward work postures adopted when pulling or inserting the vibrator into concrete through the reinforcement cage.

The Swedish Work Environment Act (AFS 1999:3) requires of the employer to investigate occupational injuries, draw up action plans, and organize and evaluate work tasks modifications. Thus, 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. It is recommended that ergonomic interventions may be implemented in the concrete casting process of bridge construction projects in Sweden to minimize hazards in the identified job tasks.

As a concluding remark there can be a vast improvement in the working environment and an increase in productivity, quality and a reduction in waste when shifting from conventional concrete to SCC; thus contributing to ergonomic hazards' reduction in the concrete casting work tasks.

REFERENCES

Arbetsmiljöverket (2005), Arbetsmiljöverkets författningssamling AFS 2005:16, Buller. In Swedish

Brite EuRam Proposal No. BE96-3801 (2000) Task 8.5. SCC Environment and ergonomics.

Cussigh F, (2007). SCC in practice: opportunities and bottlenecks. 5th international RILEM symposium on SCC 3-5 sept 2007, Ghent. PP 21-27.

David, G.; Woods, V.; Li, G. and Buckle, P. (2008) The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. Applied Ergonomics, 39, 1, pp. 57-69.

David, G.C. (2005) Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occupational Medicine*, No. 55, pp. 190-199.

Druga, C.; Barbu, D. and Lache, S. (2007) Correlation between noise, vibrations and people's health. Annals of the Oradea University. Fascicle of Management and Technological Engineering, Volume VI (XVI).

EC (2003) Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). Brussels: EC.

Goldsheyder, D., Weiner, S.S., Nordin, M. And Hiebert, R. (2004) Musculoskeletal symptom survey among cement and concrete workers. Work, 23, 2, pp. 111-121.

Hendrick, H.W. (2008). Applying ergonomic lessons to systems: Some documented "lessons learned". Applied Ergonomics, 39(4), 418-426.

Hess, J.A., Hecker, S., Weinstein, M. And Lunger, M. (2003) Ergonomics in construction A participatory intervention to reduce the risk of low-back injury in concrete laborers.

Kemmlert, K. (2006) *PLIBEL – A method Assigned for Identification of Ergonomic Hazards.* In W.S. Marras and W. Karwowski (eds.) (2006) "The Occupational

Kemmlert, K. A. (1995) Method Assigned for the Identification of Ergonomic Hazards – PLIBEL. *Applied Ergonomics*, 1995, 26(3):199-211.

Larcher, P. and Sohail, M. (1999), WELL Study; Review of Safety in Construction and Operation for the WS&S Sector: Part I. Task No:166; London School of Hygiene & Tropical Medecine and WEDC, Loughborough University, UK.

Lundholm, L.; Swartz, H. And Weiner, J. (2007) Belastningsergonomi i byggverksamhet. Arbetsmiljöverket, Korta sifferfakta, Nr 13.2007.

Okamura H, and Ouchi M, (1999). Self-compacting concrete. Development, present use and future. Proceedings of the First International RILEM Symposium on SCC, Stockholm Sweden 1999.

Samuelsson, B. (2008) Arbetsskador I byggverksamhet 2007. Privat och offentlig verksamhet. BCA 2008:2

Shah S P, Ferron R P, Ferrara L, Tregger N, Kwon S, (2007). Research on SCC: some emerging themes. 5th international RILEM symposium on SCC 3-5 sept 2007, Ghent. PP 3-14.

Womack, J P and Jones, D T (2003), Lean Thinking-Banish waste and create wealth in your organisation, ISBN 0-7432-3164-3.