CONSEQUENCE OF INDUSTRIALIZED CONSTRUCTION METHODS ON THE WORKING ENVIRONMENT

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ABSTRACT

Traditionally, the working environment has been poor especially when it comes to steel reinforcement and concrete casting on construction sites. Industrialised construction methods such as self compacting concrete (SCC) casting and prefabricated steel reinforcement are creating a basis for an improved working environment. By using these methods, it is assumed that the cost for sick leaves due to ergonomic injuries and accidents are reduced as health and safety risks inherent to the traditional working methods are decreased.

Observations along with video filming and informal interviews were performed. With a sequence-based activity method ErgoSAM, an ergonomic risk analysis was conducted. The analysis showed that industrialised methods reduced ergonomic workload on concrete workers.

The industrialisation of the production process through the introduction of innovative construction methods has benefited the construction workplace environment as well as the customer value in terms of improved material handling, elimination of additional adverse affect on health of handling vibrating tools, reduced on site congestion and reduced over all material costs.

KEY WORDS

Working environment, Steel reinforcement, Concrete casting, Industrialisation, Lean construction

INTRODUCTION

The Swedish construction work environment is regarded as the safest in the world on the subject of physical health, working conditions, illnesses and accidents (Flanagan et al., 2001). Nevertheless, there are still work environment related health problems to be tackled. Stress and other mental strains at work present the most dramatic development in recent years in Sweden, but the most common cause of work-related disorders throughout a nine year period 1996-2005, has been the physical strain (e.g. heavy manual handling, strenuous work postures and short, repetitive operations) on the musculoskeletal system. In the construction industry more than one man in five, twice as many as for all men employed, reports musculoskeletal disorders of the musculoskeletal system. This corresponds to 50,000 men in Sweden. Musculoskeletal ergonomics studies concerned with the effects of work postures, working movements, physical loads and other conditions on the muscles and joints indicate that more than 1.5 million workers find their

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daily work ergonomically strenuous. In the construction industry this experience is shared by over 130,000 men, and it is obvious that musculoskeletal illness is the construction industry's biggest problem (69% of all reported work-related injuries in 2005). These injuries are caused by the so-called ergonomic risk factors, and the most common risk factors are heavy lifting, strenuous work postures and prolonged one-sided work (Samuelsson and Lundholm, 2006; Lundholm and Swartz, 2006). Different occupational groups in the Swedish construction industry are affected by work-related musculoskeletal disorders (WMSDs) at different frequency levels; however the highest relative frequency of reported WMSDs belongs to the concrete workers (Lundholm and Swartz, 2006). The cost to the worker of WMSDs is pain, along with loss of income through being unable to work. This results in significant costs to organisations through sick leave or ill-health retirement, and to the tax payers in general that may have to support a person unable to work (European Agency for Safety and Health at Work OSHA, 2004).

Public debate in recent years has focused increasingly on work environment issues, not least in view of the dramatic rise in the cost of ill-health. Health and safety problems in the form of work-related illnesses and accidents cause relatively high costs influencing the projects. Safety costs will ultimately be paid for by the client either directly or indirectly. The financial, economic, environmental and social costs of deaths, injuries, disabilities and diseases to the industry, in particular, and to the society in general, is colossal (Larcher and Sohail, 1999). Work-related accidents significance for a company reputation and personnel turnover is difficult to measure for construction companies.

Many companies have little knowledge about the costs associated with work environment risks. For example, if only sick-leave costs and social contributions are included in the economic assessment, the cost picture is incomplete. Cost for overtime, decreased production, increased administration, rehabilitation and productivity loss due to reduced working ability need to be taken into account as well (Rose and Örtengren, 2000). Therefore, 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 (estimated to be about 8.5 percent of the total construction costs) a year, claims the European Agency for Safety and Health at Work (OSHA 2004).

Direct and indirect costs resulting from a poor work environment have compelled both researchers and practitioners to look for adequate strategies and plan of actions to tackle safety issues in the production planning in the construction process. Koskela (2000) states that occupational safety is notoriously worse in the construction industry than in other industries and that a number of solutions have been offered to relieve the chronic problem in construction.

The industrialisation of the construction process reflects the use of technology to change the sector's work environment for the better. Industrialised construction methods such as the use of the prefabricated steel reinforcement and the Self Compacting Concrete (SCC) have been introduced into the construction workplace for among other reasons the improvement of the work environment. These methods although often referred to as new, they are not new in principle, as they have had their applications in the industry since the early 1980's.

This paper will share some insights obtained from an investigation study on the use of these industrialized methods impact on the construction site work environment.

WORKING ENVIRONMENT AND ECONOMY

Injury cost estimations, according to the Swedish Social Insurance Agency (2004), the single biggest cause for sick leaves is back pain which accounts for 15 % of all sick leaves among men and 12 % of sick leaves among women. The average of the total back pain illness compensation per case for men (focusing on men which constitutes 92 % of the construction industry's workforce) is about 4 600 €, this cost denotes 45 € per sick leave day. Back pain being the most common illness among men does account for 17 % of all sickness compensations. Considering only the construction industry, Samuelsson and Lundholm (2006) reported that out of all 1582 cases of sick leaves caused by occupational illnesses reported in the year 2004, 1342 cases of sick leaves were caused by ergonomic risk factors (including vibration and noise).

Furthermore, taking into account the 279 cases of WMSDs reported among concrete workers (Lundholm and Swartz, 2006), their sick leave compensations could approximately cost up to 1 280 000 € for the taxpayers. There are of course other direct and indirect costs such as productivity loss and hiring substitute workers that are not often calculated.

RISK IDENTIFICATION METHODS

Risk assessment methods determine the risk level that employees face from exposure to hazards at work and can help establish measures that are necessary to control the risk and to protect workers health and productivity. In the study two risk identification methods were used to complement each other.

OBSERVATION AND ERGOSAM

Observations at the bridge were done in a form of site-walkthroughs, video films of identified steel reinforcement and concrete casting activity work cycles. These observations were the basis for a further risk assessment; the ErgoSAM analysis.

ErgoSAM is based on SAM (a sequence-based activity method), and a higher-level method-time-measurement (MTM) system. The SAM system is the result of work carried out in Sweden to shorten the time needed for analyses made with MTM systems (Swedish Productivity Centre, 1995). In SAM, the main activities are Get and Put. For each SAM activity, a standard time is given. In addition to the SAM information, the ErgoSAM method considers two additional pieces of information: the zone relative to the worker' s body in which the activity is carried out or ends; and the weight of the objects handled or the force exerted in the activity (Laring et al, 2005). The output of ErgoSAM is the product of three types of demands namely, work posture, force and repetition (frequency), according to a scientific model, the Cube model (Sperling et al., 1993).

The Cube Model is used on the site observations to acquire the risk of WMSDs on combinations of the variables mentioned (posture, force and repetition). For a specific working task, and for each dimension separately, demand levels may be defined as low, medium, or high, where the demand criteria are chosen so as to discriminate between good or poor work ergonomics, and assigned weight factors 1, 2, and 3 respectively. Combinations of demands are evaluated by multiplication of the three weight factors, and this product determines the acceptability of the task (Sperling et al., 1993). ErgoSAM is implemented as a macro program in Microsoft Excel.

FULL SCALE STUDY

A full scale study was carried out on a bridge construction with focus on the industrialised methods and their impact on the work environment. The bridge consists of a span of 10 metres with a width of 15 metres, Figure 1. One objective of the study was to examine the changes on the working environment when “new” construction methods, (use of prefabricated steel reinforcement and Self Compacting Concrete) were introduced. Other objectives presented in Simonsson and Emborg (2007), were to study the productivity at site, site logistics, economics of the changed working methods and planning process.

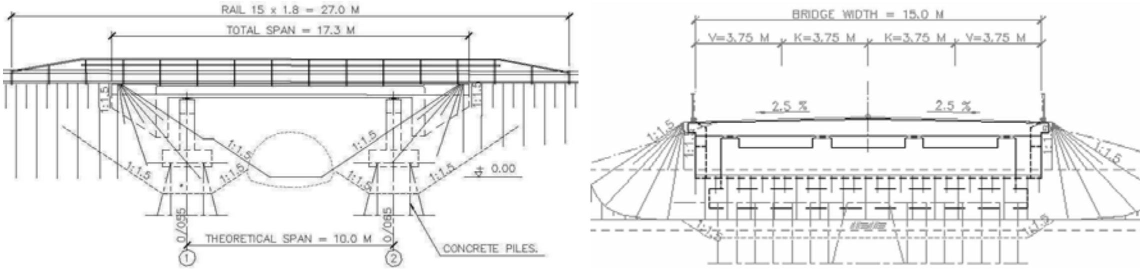


Figure 1: Full scale bridge in elevation and section (no scale).

CONSTRUCTION METHODS

According to a study by the Danish Technological University, DTU (Nielsen, 2006) some 26 % of a workers average day consists of concrete casting and reinforcement fixing. If this is translated into time, it will be just over 2 hours per working day, or 57 full working days a year. This work is often done in awkward postures with heavy equipments such as the vibrator used to compact the conventional (traditional) concrete or with heavy material when placing the reinforcement piece by piece.

STEEL REINFORCEMENT

Traditionally, steel reinforcement is fabricated on the construction site at its final destination involving a large labour force and a considerable amount of steel wastage. Current methods for installing steel reinforcement in concrete structures involve interpreting steel positions from plans and installation of individual bars by site workers.

If manufacturing of the steel reinforcement could be moved from its final position, i.e. in the formwork, to a more controllable position, a reinforcement workshop, the working environment could be drastically improved. Prefabricating steel reinforcement cages offers that possibility through the use of scissor lift tables, which makes it possible for the worker to work at the right height all the time instead of a bent posture as shown in Figures 2 a and b. Prefabricating steel reinforcement does not necessary equal manufacturing it in a factory, the reinforcement shop could also be located at the construction site. In this case, the benefit would be that the production flow for the worker can become even and possible waiting times can be eliminated through using this work as a buffer. During the construction of the full scale bridge, the industrial prefabrication of steel reinforcement partly replaced the manual installation on site. The prefabricated reinforcement was easily placed in the formwork, using cranes, before concrete casting commenced, see Figure 3.

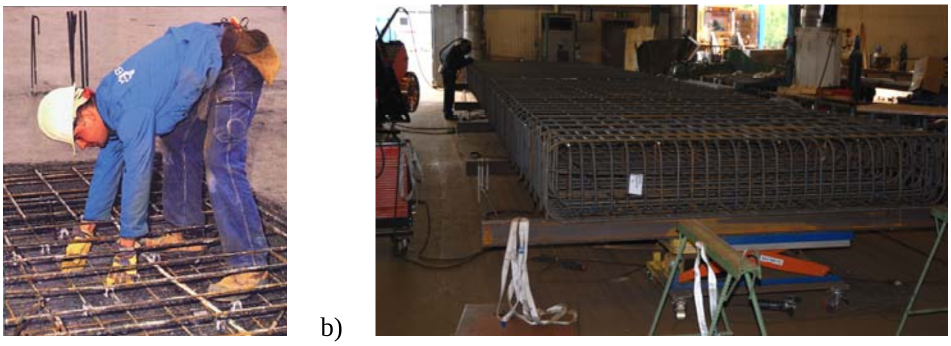


Figure 2: a) Traditional working position when placing reinforcement piece by piece. b) Steel reinforcement prefabricated in the factory and shipped to construction site.

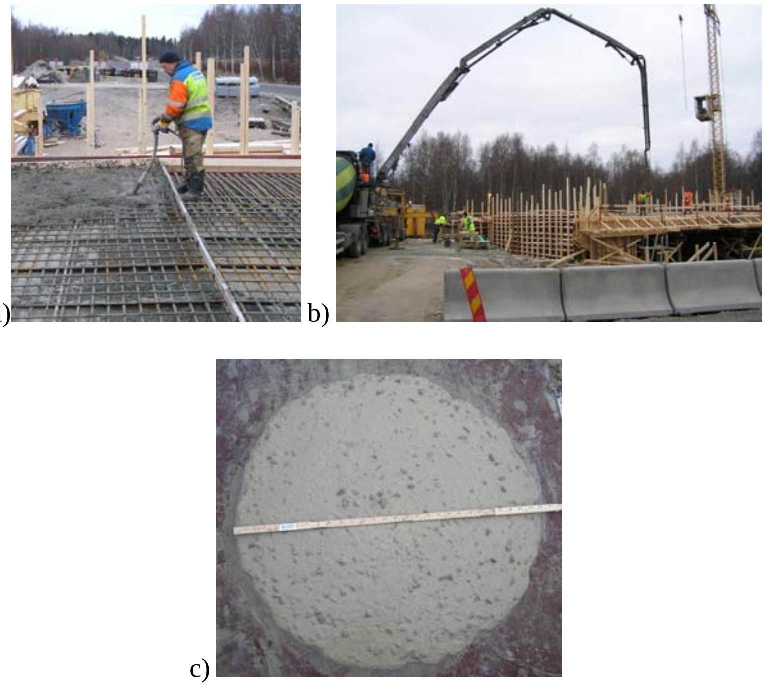
Figure 3: a) Placing prefabricated reinforcement for a foundation. b) Reinforcement carpet lifted into place.

Some of the benefits highlighted when using prefabricated steel reinforcement structures are improved safety and reduced on-site congestion, reduction in site fixing resulting in less exposure time, ease of identification of reinforcement with less stressful situations and improved material handling with less heavy lifting and carrying of material (http://www.bamtec.co.nz/elements/BAMTECsystem.pdf).

CONCRETE CASTING

Traditional concrete casting produces high noise levels and the vibrating tools used for compaction of the concrete often lead to unhealthy working postures (Figure 4a). As mentioned earlier, a typical concrete worker spends on average 10 % per day casting concrete, thus working in stressful working postures and being exposed to back pains.

Self Compacting Concrete (SCC) is a concrete to which no additional inner or outer vibration is necessary for the compaction. SCC compacts itself alone due to its self-weight and is de-aerated almost completely while flowing in the formwork. For the success of SCC, it is crucial to define the performance of the product, which can, according to the Growth project Testing-SCC (Emborg et al., 2005), be discerned into three main parameters: 1) *Filling ability* 2) *Passing ability* and 3) *Segregation proneness*. For these parameters, criteria should be established to be met by a proper mix design depending on geometry of structure to be cast, reinforcement, form type and, method and local tradition on how to pour the concrete (Figure 4).



a) b) c)

Figure 4: a) Worker using a vibrator for compacting normal concrete. b) SCC being pumped into formwork. c) Slumpflow test on SCC measuring approximately 740mm.

In general SCC offers many advantages for cast-in-place construction as well as for the pre-cast and pre-stressed concrete industry. In regard to the working environment, there is less noise-level i.e. easier communication, eliminated vibration problems, improved quality and durability results in less rectification work and reduced concrete volumes due to higher strength.

RESULTS AND DISCUSSION

IMPROVEMENT OF WORK ENVIRONMENT THROUGH TECHNOLOGY INPUTS

With the increasing technology inputs into the construction workplace ergonomic intervention, not only does one enhance productivity but also adds value to the whole construction project. Velasco (1998) states how productivity is brought about by the technical inputs and the quality of the performance of the worker (physiological abilities of the worker (Abdelhamid and Everett, 2002)). Prior to the production start, the main contractor and the client agreed on the technology that will fit workers in the construction workplace. Off-site produced steel reinforcement and SCC were shipped into the construction site and lifted into the site by cranes, thus avoiding any manual material handling. The construction project presented in this paper had basic objectives of production and safety management depending on each other; therefore an integration of Lean Construction and safety management were emphasised on as in Saurin et al. (2006).

ECONOMIC BENEFITS OF 'NEW' CONSTRUCTION METHODS

From the full scale bridge project it was observed that prefabrication of components allowed a reduction in work time for on-site steel fixing and dedicated labour and minimised the amount of storage space required on what is normally considered to be a congested site. Using prefabricated steel reinforcement elements accelerated the installation process at the construction site and made the construction more economical in terms of material waste. The off-site fabrication of steel reinforcement structures ensured continuous supply regardless of inclement weather which meant the structures was ready for immediate transportation to site to complement the construction process.

The cost related to the reinforcement can be viewed from two perspectives, the production cost of the reinforcement and the construction cost for placing the reinforcement before casting concrete. For the full scale bridge carpet reinforcement, the placing cost varied from 0,02€ to 0,04€ per kilogram (bottom and top reinforcement respectively of the superstructure), the traditional price for reinforcement fixing on the superstructure is approximately 0,65€ per kilogram. The purchase price for the carpet reinforcement rose with approximately 50% in comparison with traditional reinforcement bars, but still some 35% of the total costs were saved.

Concerning the use of SCC, not only workers were pleased to have a non-vibrating and noise-free work environment, but also costs related to the concrete compaction equipment use were eliminated and vibrators are often used inefficiently. They often run wastefully, or at a reduced efficiency, for about 70 % in total of their operating time, this being made up as follows (Hong Kong City University, 2007): out of concrete and left running 15 %, wrongly positioned in the concrete 35 % and vibrating already compacted concrete 20 %. This means that the vibrator is doing useful work only 30 % of the time.

ERGONOMIC ANALYSIS, ERGOSAM RESULTS

After several weeks of observing concrete workers performing their jobs on the construction site, and after informal interviews with concrete workers, it became obvious what were classic work cycles for different methods of steel reinforcement and concrete casting. Based on this information, video films were taken and analyses of representative short work cycles were performed to identify any risks for WMSDs for concrete workers performing their tasks using different construction methods namely conventional and industrialised methods. Results of the analyses for representative work cycles are presented in Figures 5 and 6, where different loads on concrete workers are represented by Cube values.

The Cube value or the load level falls within three levels; where under 6 is acceptable, 6 to under 9 is conditionally acceptable and 9 and above is unacceptable. For example, the work cycle mean value of 7.4 obtained in ErgoSAM analysis in Figure 5 falls into the conditionally acceptable area. The situations which still fall short of being acceptable are attributable to those tasks that have high degree of repetition and bending, such as fixing the steel structure and cutting metal rings off the rolled out carpet reinforcement. When the worker performed tasks with the manual steel rebar work. The concrete worker is exceedingly exposed to WMSD risk factors which contribute to very high cube values with a mean value of 21. This number denotes almost three times higher risk exposure to WMSDs when working with the traditional rebar reinforcement than when working with the prefabricated steel reinforcement with 7.4 for a mean value (figure 5).

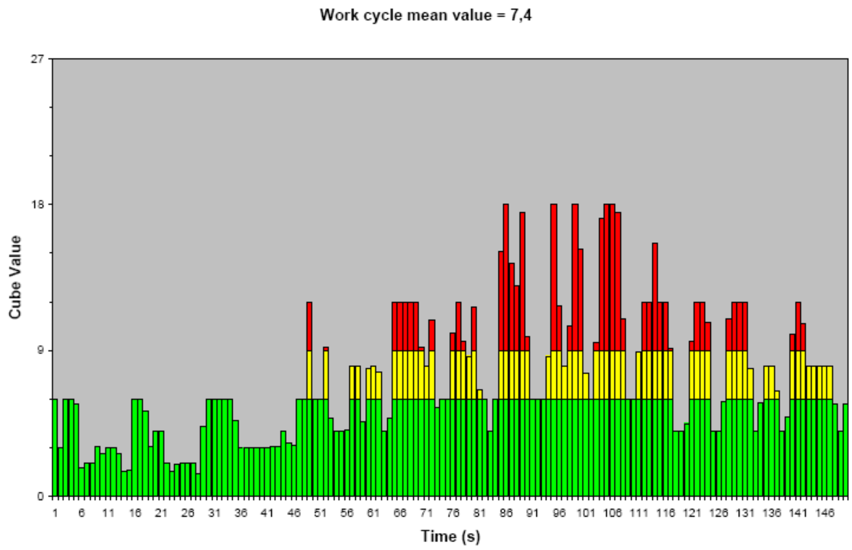


Figure 5: ErgoSAM analysis of a short work cycle of a concrete worker working with prefabricated steel reinforcement. A cube value under 6 is acceptable, 6 to under 9 is conditionally acceptable and 9 and above is unacceptable.

The work cycle mean value of 5.7 was obtained in the ErgoSAM analysis in the case of SCC casting (figure 6), thus making these work tasks acceptable as far as the workers work-related musculoskeletal health is concerned, and hence entails no risk factors for WMSDs.

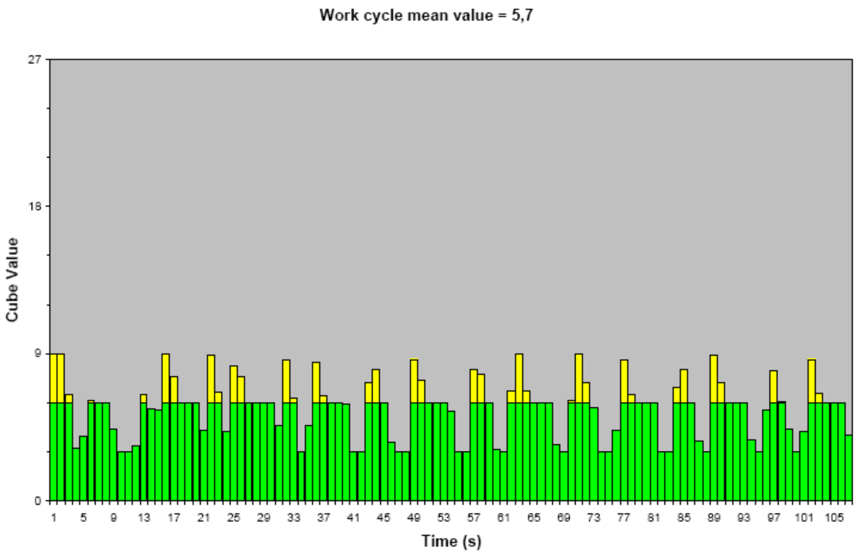


Figure 6: ErgoSAM analysis of concrete worker‘s short work cycle during SCC casting.

When the traditional concrete casting work cycle was compared to that of the SCC casting, the ErgoSAM analysis showed a mean value of 18.2, thus it became obvious that the normal concrete casting work exposed the worker to WMSD risk factors, over three times higher than working with SCC casting.

CONCLUSIONS AND FURTHER COMMENTS

The risk analysis on steel reinforcement and concrete casting work tasks by the ErgoSAM method, has indicated that working with the prefabricated steel reinforcement and SCC reduced a great deal of physical loading on the musculoskeletal system of the worker due to the elimination of physical strain due to the common risk factors that are generally part of the traditional methods of rebar reinforcement and the use of conventional concrete.

The prefabrication of steel reinforcement structures allowed a significant reduction of on-site steel fixing and associated labour costs as well as providing a much safer working environment without risk factors such as heavy lifting and working in bent, awkward and repetitive postures. The SCC cast into a frame of reinforced steel without the need for the labour intensive mechanical vibration usually associated with concrete placing, has led to the improvement of construction work environment and the promotion of health and safety of concrete workers. In a project such as a bridge construction in areas with heavy traffic, the project completion time can be extremely important. As the new steel reinforcement was prefabricated, there was higher quality control than the traditional rebar system. The off-site fabrication of steel reinforcement accomplished difficult construction tolerances, improved handling as well as it contributed to the speed of construction and minimized wastage of material. All mentioned above contributes to the customer value, in this case to the National Road Administration in Sweden.

The use of SCC in the full scale project offered many benefits to the construction: the elimination of the compaction work resulted in reduced costs of placement, a shortening of the construction time and the number of involved workers during casting, and therefore in an improved productivity. Considering the economics of SCC, the material cost was higher than traditional concrete; however the total cost was slightly lower for SCC. The largest benefit though was the reduction in man hours used for casting the concrete, man hours that can be used for preparing upcoming work.

Finally, when working with these industrialized and innovative working methods it does give significant benefits both in terms of a healthy and safe work environment for the workers, reduced staff-related costs for the company as well as the client and the society as a whole, both in short term and long term perspectives.

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