Risk assessment and analysis of workload in an industrialised construction process

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ABSTRACT

With the increasing industrialisation of the construction process, the intensity and the nature of production activities are changing due to the application of cost-effective industrialised production methods such as off-site prefabrication and on-site assembly. However, the impact of these production methods on safety and health of the worker has not been methodically investigated and is often assumed to be positive for the construction workplace. The goal of the study was to measure the workload associated with the assembly / building of inner walls using prefabricated components or gypsum wall panels and its affects on musculoskeletal system of construction workers.

The methods used in the study are the Quick Exposure Checklist (QES) system and ErgoSAM, a method used to identify situations of high workload and risk for musculoskeletal injury.

The results of the study revealed that the installation of inner walls entails a number of work tasks that are physically demanding due to awkward work postures and lifting of heavy gypsum panels. The use of both methods to analyse the impact of industrialised systems on the workers was methodically investigated and is often assumed to be positive for the construction workplace. The design principles which may refer to the existing best practices' publications.

Keywords: Industrialised process, exposure assessment, health and safety, design, best practices

INTRODUCTION

Industrialisation of the construction processes in which industrialisation changes from an on-site construction process to a more controlled factory-like construction process has been encouraged for reasons such as the attractiveness of workplaces that will strongly be enhanced by vigilant organisation, new manufacturing methods, new architectural typology based on 2D and 3D components, new components, new connections and interfaces, and new on-site assembly methods (ECT, 2005). Increased use of off-site manufacturing furthers the industrialisation of the construction process.

Building parts are manufactured in an environment suited for effective production, where advanced equipment can be used and the working conditions are good. The manufactured elements are of a high level of completion in order to minimise work at the building site. As many parts of the building as possible are manufactured in off-site production and finally assembled at the building site (Lessing et al., 2005).

By preassembling parts of buildings or constructions, or even whole constructions, the construction process becomes more standardised and less dependent on weather conditions (European Foundation for Improvement of Living and Working Conditions, 2005). This could speed up construction, improve quality, reduce waste and even the degree of waste control, and reduce the cost of constructions (Ong, 2004). The industrialisation of the construction process also reflects the use of technology to change the sector. Through advanced use of prefabricated elements and off-site construction, the sector is hoping to avoid mistakes, to lower costs and reduce completion times (Pasqure and Connally, 2002).

Transferring as many as possible on-site activities into the factory is probably one of the most promising approaches in regard to the improvement of health and safety on the construction site (Wright et al., 2003; Gibb et al., 2004; McKay et al., 2005; Blismas et al., 2006). However, it is a fact that some construction activities requiring awkward postures and heavy lifting still remain part of the on-site construction work tasks. Therefore, when planning new industrialised construction process, measuring the interaction between the workers physical capacity and the work tasks, tool usage through ergonomic analysis is of great importance. In the manufacturing industry, production engineers are often urged to consider the ergonomic aspects of work when planning for production (Christiansson et al., 2000).

Understanding the relationships between workplace exposure parameters and the health outcomes of the musculoskeletal system is the basis for preventing and reducing work-related musculoskeletal disorders (WMSDs) (Bao et al., 2006). Awkward, repetitive postures and heavy lifting can increase the risk of musculoskeletal disorders; therefore cost-effective quantification of the magnitude for physical exposure to poor working postures is important and needed, if the potential for injury as a result of postures is to be reduced (Andrew et al., 1998). Assessing exposure to risk factors for WMSDs is an essential stage in the management and prevention of WMSDs (David, 2005). Additionally, it is desirable to use assessment tools that are able to predict the risk of future WMSDs so that the monetary costs and human suffering can be averted through remediation efforts before they are incurred (Harrick, 2006).

The design principles which may refer to the existing best practices in industry may also be applied as way of prevention in efforts to eliminate or reduce risk factors for WMSDs (Rwamamara, 2005). In this case, the job task or equipment may be altered to facilitate the task and reengineer it such that it falls within the limitations of the worker (Amell and Kumar, 2001).
METHODS FOR EXPOSURE ASSESSMENT

During the research study reported on in this paper, two risk assessment methods, namely ErgoSAM and QEC were used in the study to measure potential exposure to risk factors for WMSDs.

ErgoSAM is based on a sequence-based activity method (SAM), 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 Center, 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: (1) the zone relative to the worker’s body in which the activity is carried out or ends, and (2) the weight of the objects handled or the force exerted in the activity (Christmansson et al., 2000; Laring et al., 2005). The output of ErgoSAM is the product of three types of demands namely, work posture, force and repetitivity (frequency), according to a scientific model, the Cube model (Sperling, 1993).

For every work task, the three factors in the Cube model are given a value between 1 and 3, where the values 1 and 3 are respectively the lowest and the highest. The combined value representing the load level or exposure level is obtained by multiplying the three components illustrated in figure 1.

![Figure 1 The Cube model (Sperling, 1993).](image)

Combinations of these demands will largely decide whether a work situation entails risks of strain injuries or musculoskeletal disorders (Christmansson et al., 2000). ErgoSAM is implemented as a macro program in Microsoft Excel.

The Quick Exposure Check (QEC) system for work-related musculoskeletal risks has been developed by Li and Buckle (1998). The method includes the assessment of the back, shoulder / upper arm, wrist / hand and neck, with respect to their postures and repetitive movement. Information about task duration, maximum weight handled, hand force exertion, vibration, visual demand of the task and subjective responses to the work is also obtained from the worker. The magnitude of each assessment item is classified into exposure levels (Tables 1 and 2), and the combined exposures between different ‘risk factors’ for each anatomic region are implemented by using a score table, in which higher scores are given to the combination of two higher-level exposure of risk factors than the combination of two lower-level exposures (Li and Buckle, 1999; David et al., 2005).

| Table 1 Exposure scores for anatomic regions (David et al., 2005) |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| 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           | 41-56           |
| Neck                            | 4-6             | 8-10            | 12-14           | 16-18           |

| Table 2 Exposure scores for other factors (David et al., 2005) |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Exposure level                  | Score           | Low             | Moderate        | High            | Very High       |
| Driving                         | 1               | 4               | 9               | -               |
| Vibration                       | 1               | 4               | 9               | -               |
| Work pace                       | 1               | 4               | 9               | -               |
| Stress                          | 1               | 4               | 9               | -               |

GENERAL BACKGROUND OF THE RESEARCH STUDY

For many years now, lengthy production times in combination with high production costs have been a problem in the construction industry. A large Swedish construction company engineered a concept that is based on the principle that a large portion of building components should be prefabricated, and thus a large portion of production work is transferred to the prefab factory, a change that has a lot of advantages. Moving construction work activities from the construction site to a factory has not only shortened production time as an advantage, but it is also worth to mention that the factory is a controlled environment and more safer than the traditional construction site. Furthermore, the factory’s controlled work environment is conducive to the workers health in a sense that injury risk is not as high as an construction site, and thus implying a decrease in the production mistakes and the defect frequency is reduced. Consequently, large construction companies such as company X evolved a new industrialized building concept to change the construction workplace into an ‘assembly site’ instead of a construction worksite. The industrialised construction approach suggests that different work tasks can be standardised which makes it possible to analyse and suggest changes with the objective of minimising musculoskeletal risks among construction workers.

SCOPE AND OBJECTIVE OF THE STUDY

A pilot multi story residence building project was the object of the research study presented in this paper. The study was limited to the assembly of inner walls using prefabricated gypsum panels. An apparent failure to convert the whole system in order to benefit from the manufacturing input prompted this study. The primary objective was to analyse physical workloads on construction workers using different risk assessment methods.

PROCEDURE

To perform the exposure assessment of inner wall assembly, 35 work cycles were observed and a representative work cycle was video-recorded by the researcher / author, and specific attention was paid to work methods used by workers to perform their work tasks. Interviews...
were also conducted with construction carpenters on forces, physical stress, vibration, and work tempo. Using the digital video recordings of two carpenters doing the work tasks required in the assembly of prefabricated inner walls elements, the researcher conducted ErgoSAM and QEC analyses of the inner walls assembly work cycle.

**RESULTS AND DISCUSSION**

The work cycle (Figure 2) of inner walls assembly is repeated 35 times per day, which equates to approximately two apartments in this project, and lifting, drilling and screwing activities occupy a larger time portion in the work cycle. During the typical 8 hour workday other wall assembly-related work tasks such as the cutting of gypsum panels and the assembly of doorframes are performed as well.

**ErgoSAM analysis:** An ErgoSAM analysis was performed, to assess the risk exposure for each of the two carpenters working with inner wall assembly. In general the ErgoSAM diagram, 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. These load levels are respectively represented by green, yellow and red colours. The highest peaks in the ErgoSAM diagram (Figure 3) represent the work tasks that contribute most to the work cycle’s mean value of 11.5. This mean value is above 9 and indicates that the work load during the inner wall assembly’s work cycle is not acceptable, therefore the work cycle needs to be improved in order to reduce the musculoskeletal system loading to an acceptable level. By reviewing each inner wall assembly’s work tasks on the video film, and method description used to generate the ErgoSAM diagram, it becomes easier to identify which work tasks are ergonomically detrimental to workers and thus these should be the first addressed in terms of improvement measures.

The ErgoSAM analysis diagram in figure 3 shows a lot of ‘red peaks’ indicating that the inner wall assembly work cycle entails a number of physically demanding work tasks, particularly lifting wall panels and working in awkward work postures while drilling and screwing screws into concrete. During the analysis using ErgoSAM, the frequency of work tasks performed repetitively contributed significantly to the

**Figure 2** Eight main phases of inner walls assembly’s work cycle.

**Figure 3** ErgoSAM analysis of a work cycle of inner wall assembly.

| Phase 1: | Lifting and carrying of a 45 kg heavy wall panel to be installed. |
| Phase 2: | Kneeling down and holding the gypsum panel against the ceiling with a crowbar. |
| Phase 3: | Kneeling down and screwing two screws in a steel angle that attach firmly the panel to the floor. |
| Phase 4: | Kneeling down and hammering a wedge under the panel. |
| Phase 5: | Climbing on a stool and screwing two screws into a steel angle to attach firmly the panel to the ceiling. |
| Phase 6: | Drilling two holes for the steel angle in concrete floor. |
| Phase 7: | Drilling two holes in the concrete ceiling and then nailing in two plugs. |
| Phase 8: | Kneeling down and nailing two plugs into the steel angle attaching firmly the panel to the floor. |
loading value or exposure level, especially in the case of drilling and screwing. The work posture adopted by the worker also influenced the loading value outcome. It was observed that a poor or good work posture was often dictated by the work method adopted in the performance of a certain work task. For example, the drilling and screwing tasks were performed either with hands closer to or further from the body, and the ErgoSAM analysis showed that these different work methods have a different impact on the worker’s musculoskeletal system as far as the exposure level is concerned. The drilling and screwing work tasks performed with hands or forearms closer to the body generated acceptable cube values or loading levels.

Quick Exposure Check (QEC) analysis: In Figure 4, QEC analyses show different exposure levels for different work tasks in the assembly of inner walls cycle.

In Figure 4, according to Table 1 which shows how to determine different exposure levels, there are a number of work tasks in the assembly of inner walls that have exposure levels ranging from Moderate to High. The QEC analysis indicated that lifting the 45 kg inner walls panels has a high exposure level for the workers’ shoulders and arms, whereas other body areas i.e., the back, hands, wrists and the neck have a moderate and even low exposure levels. Furthermore, QEC analysis showed that drilling and screwing of concrete ceilings and floors have low exposure levels, but these exposure levels could have been high if for some reasons the work pace or stress was increased and thus scored high.

QEC analysis which considers the workers’ own assessment of their inner wall assembly work tasks has indicated that there is no risk of whole body vibration as their work tasks do not require driving. Hand and arm vibrations due to concrete drilling were estimated as low exposure levels which do not contribute to the worker’s ergonomic loading. Carpenters interviewed expressed that work pace and stress were low and therefore did not have any negative effect on their musculoskeletal system.

USING ERGONOMIC TOOLS AS A BEST PRACTICE

After the risk assessment, work tasks with WMSDs risks were identifiable, and it was possible to develop adequate solutions to eliminate the risk exposures. The use of ergonomically-designed tools or aid devices has been shown to be one of the best practices that the Swedish construction industry uses to reduce WMSDs (Rwamamara, 2005). Therefore, in the case of inner wall installation, using specific user-centred designed aid devices for demanding work tasks should reduce risk factors. For instance, to set the inner wall at the ceiling level where the worker (Figure 5) usually works with hand-held tools above shoulder level which generates static loading on the worker’s musculoskeletal system, the drill and the screw-gun should be used with a tripod / stand (Figure 6) to reduce risk factors associated with work above the shoulders. Using a human as a hand tool tripod leads often to musculoskeletal injuries. Static work restricts blood circulation to body parts and causes fatigue and time studies does indicate the influence of fatigue on efficiency at work. Therefore, it pays off to use a tripod while the body is spared from risk exposures.
Similarly, to avoid bending work postures that strain the back during work tasks at the floor level (Figures 7a and 7b), a worker should consider using a drill with an extension structure (Figure 8a) and a screw gun cradle (Figure 8b) which fits many of the drills and screw guns found on many construction sites.

CONCLUSIONS

In regard WMSDs in construction industry, the assessment of exposure to risk factors is an important part of the surveillance of the industrialisation of construction processes and the preventive work. Risk assessment should be an integral part of the concept of designing for construction workers safety and health as indicated in the European Union directive (CEC, 1992; Hinze et al., 1999). The exposure assessment of risk factors is based on well-established risk factors for a number of WMSDs according to the fairly recent research findings (Hagberg et al., 1995; Moon and Sauter, 1996; Johansson et al., 2003 and Lund et al., 2006). This assessment can help in regard to planning a healthy construction workplace and introducing changes in the construction workplace in order to eliminate when possible or otherwise minimise exposure levels. If construction planners and designers have taken into account the health and safety aspects as stated in the European directives (CEC, 1992), the industrialised system investigated in the study should result in significant benefits.

Both ErgoSAM and QEC risk assessment methods showed that inner wall assembly work involves some easy work tasks but also entails of demanding work tasks specifically the lifting of gypsum panels and the drilling of the concrete slab and the screwing of screws into both the concrete and the wall panel. It is possible however to improve the way these work tasks are performed through anticipatory planning work and using user-centered designed aid devices.

If the new industrialised construction process investigated in the study had been the old traditional process, it is certain that many construction work tasks in the inner wall building job would have been rated high in exposure levels. It could however be interesting to investigate further through a comparison of the traditional and industrialised construction methods. Moreover, because this industrialised method is not particularly advanced, the findings of this paper should not be inappropriately applied to the whole of the industrialised building sector.

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