ADVANTAGES OF INDUSTRIALIZED METHODS USED IN SMALL BRIDGE CONSTRUCTION

Romuald Rwamamara[1], Peter Simonsson[2] and Johan Ojanen[3]

ABSTRACT

Evaluating to what extent industrialized production methods used during the steel reinforcement, formwork and concrete casting of small bridges are beneficial to the construction industry. The study evaluates the economical value of the construction of small bridges in terms of design and constructability from a production point of view. Moreover, the health and safety issues of the production processes are considered.

The study method used is the internal documents study involved in the construction of the bridges. A comparison between data collected for previous studies on bridge construction projects and data collected from internal company documents will be performed. The study uses an economic analysis to evaluate alternative construction materials, assemblies, and bridge services with the objective to improve project planners or owners' decision making during the course of planning, designing and constructing a bridge. The use of bridge economic analysis to determine the most economically efficient choice among bridge design alternatives when it comes to steel reinforcement, formwork and concrete casting in regard to improved quality and working environment.

The study discusses and offers recommendations for a cost effective bridge construction process which reduces waste in the production process and keeps the project schedule.

KEY WORDS

Safety management, Waste reduction, Design and planning, Construction process, Quality, Economic analysis

INTRODUCTION

This paper is the result of research work that has been done as a response to the increasing demand for more efficient and competitive ways of constructing bridges. The development in bridge construction has not been very progressive in Sweden over the last decades; new techniques and methods have seldom been presented. Traditionally, bridges are usually cast *in situ*, involving a massive use of manpower and techniques that may be characterized as more or less craftsman-like (Harryson, 2008). Industrialized construction methods and techniques such as self-compacting concrete (SCC) casting and the use of prefabricated reinforcement steel structures, for example, are not used very often.

[1] Senior Researcher, Div of Architecture and Infrastructure, Luleå University of Technology, 971 87 Luleå, Sweden Phone +46 920 492353, FAX +46 920 491913, Romuald.Rwamamara@ltu.se

[2] Ph.D. Student, Div of structural Engineering, Luleå University of Technology, 971 87 Luleå, Sweden Phone +46 920 493140, FAX +46 920 491913, Peter.Simonsson@ltu.se

[3] Ph.D. Student, Div of structural Engineering, Luleå University of Technology, 971 87 Luleå, Sweden Phone +46 920 492263, FAX +46 920 491913, Johan.Ojanen@ltu.se

Although the industrial construction sounds off as if it was something new. Already in ancient Greece instances occurred where famous structures were erected with prefabricated components of stone, as reported by Warszawski (1999). It is also reported that in ancient Israel, "the stones used in the construction of the temple were finished at the quarry, so there was no sound of hammer, ax, or any other iron at the building site" (1Kings 6:7, New Living Bible Translation, 2007).

During the industrial revolution Victorian engineers could not have managed to build structures such as The Britannia Bridge without prefabrication. Although the components were not constructed in factories originally they were made in safe places (Mason and Ghavami, 1994).

After the Second World War, the reconstruction of destroyed bridges during the war was an intense construction program which also became an ideal laboratory for evolution in the way bridges were built and thus construction systems such as the use of pre-stressed structures and prefabricated components were developed to increase the degree of constructability and to avoid the need for costly dense castles of scaffolding pipes (Iori and Poretti, 2009).

Today, off-site prefabrication and modern construction methods is some of many innovative ways used in the construction industry to developers seeking cheaper construction. With the continually increasing costs of building structures, there are at least two ways of getting on top of this problem in the construction industry. Firstly, the way the procurement of materials is done and secondly the use of available modern construction methods which possible leads less employees on the construction site.

METHODOLOGY

When the Swedish government decided to relocate the European road E4 around a major city, there were, apart from the actual road construction, 115 bridges to be constructed. The whole construction project was to be carried out during approximately a five year period. On this new road construction project, it was decided, during the early design stage, that there should be 110 different bridges; the question is, was that really necessary? No one seemed to be thinking in such terms as standardization, simplicity, and repetitive work, as Adams (1989) suggested, but solely on the architectural part of the road, and hence it was decided that 110 different bridges were to be constructed. The total contract sum for the road was estimated to roughly € 300 million. How much of that cost could have been saved if solely simplicity, standardization and repetitive work had been considered?

HYPOTHESIS

The hypothesis for the research study presented in this paper is that standardization and simplicity of structural design reduces costs related to building materials and manpower working hours.

CASE STUDY

The data presented in this paper were collected through a review of internal company documents as well as reviewing previous case studies on industrialized construction of bridges. The authors have had the opportunity to study most of the material concerning the construction of small bridges on a 70km long section of the E4 highway rerouting. Documents studied include designer drawings and information on the amount of time the designers spent on each project, contractor's perceptions on each project in terms of suggested construction methods and work time consumption for most of the work to be carried out and client's expectation in terms of early design drawings to name some of the documents. This research study has limited its scope on the construction of concrete rigid frame bridges within this project.

PREVIOUS STUDIES

Similar studies of the benefits in using standardization, simplicity and repetitive work has been carried out on smaller roads in Sweden by the authors. During one study, when constructing merely 10 different concrete bridges, the possibilities were to save roughly 20% of the construction time and approximately 5% of the construction costs, this when introducing alternative construction methods at a very late stage of the process. Had these different methods of construction been considered in the early design stage, the potential for improvement in production time and cost would have been significantly larger.

INDUSTRIALIZED PRODUCTION METHODS

The need to be competitive in the emerging global economy is very important topic in Sweden today. The use of industrialized production methods, such as the prefabrication of building components, is critical to competitiveness. Modern methods of construction have never been more relevant. Industrialized methods such as off-site manufacturing utilizing technically advanced prefabrication processes as well as using high performance building materials for the improvement of build quality and efficiency with rising importance to increase both the infrastructure objects built and the efficiency with which they are built.

FORMWORK

Formwork is a structure that keeps the concrete in the accurate place until it gains sufficient strength to support itself (American Association of State Highway and Transportation Officials, 1995). Current formwork often consists of temporary wood structures manufactured at construction site, with low initial material cost but the amount of labour hours needed during the construction is very high. In the studied E4-project, the total formwork material cost for slab frame bridges only stands for 6% of the total building cost, while the labour cost for the formwork was as high as 17% of the total building cost. Problems associated with this kind of formwork are e.g. leakage, with bad surfaces and increased life-cycle as a result, and also health and safety issues.

Left formwork is an interesting formwork which today is mostly used in house building but should, because of its benefits, be a natural structure in industrialized bridge building. Left formwork can consist of e.g. prefabricated shell walls, as formwork for the support walls and the wing walls, or prefabricated concrete plates, which together with prefabricated edge girder, could provide the formwork for the superstructure. Pre-stressed elements, e.g. hollow core or massive slabs, can be used to make the deck thinner without making it weaker, which leads to less filling of the bank (Betongvaruindustin, 2009).

Benefits of using left formwork are that you shorten the building time, less traffic disruption, fewer labor hours could be used, concrete surfaces has a better chance of satisfying the costumer and of course the health and safety at the site would be better. The down side of using left formwork is the increasing material cost and the logistic challenges it brings because of elements being large they have to arrive to the site location just-in-time to be assembled.

CONCRETE

Traditional vibrated concrete is still used for most of today's castings for both housing and civil structures. Approximately ten years ago the anticipation for Self Compacting Concrete, SCC, a concrete that level it self by the force of nature, was, that it would now encompass at least 50% of the market share, but that is not the case. Roughly 5% of all civil engineering concrete used in Sweden is SCC, and the number for housing project is slightly larger. The benefits with using SCC are that the casting goes faster, it requires less personnel, a decrease of 67% of working hours can be foreseen (Simonsson and Emborg, 2007), and the working environment becomes much better. The work environment is improved by a factor of 3 as documented by Rwamamara & Simonsson (2007). There have been problems with SCC before, such as variation in quality, separation of the concrete. However, most of these problems have been dealt with and can be considered eliminated; now the problem is education of contractors in the advantages and how to handle the concrete and catch 22. With the latter part means that since no one is demanding it the suppliers will not get much confidence in manufacturing it and, hence, the previous problems can come back. Still, most companies prepare for traditional casting of concrete.

REINFORCEMENT

Reinforcement is used to strengthen concrete for tension forces in structures. Reinforcement bars are often delivered cut and bended in right amounts, however it still needs to be fixed piece by piece into its final location. This work is very heavy to do and is often done in awkward working positions. It is also somewhat weather dependant and the productivity of the work force can vary depending on different circumstances, such as the weather and geometry of the structure.

Prefabrication of reinforcement cages however, ensures a continuous supply of reinforcement regardless of weather since these cages are manufactured in a controlled quality assured environment. Prefabrication of components allows a reduction in on-site steel fixing work time and in the number of workers needed for that particular work on site (Rwamamara and Simonsson, 2009). Furthermore, it minimises the amount of storage space required on what is usually considered to be a very congested construction site. The offsite fabrication of steel reinforcement offers a number of advantages such as difficult construction tolerances, improved transport and handling as well as contributing to speed of construction.

HEALTH AND SAFETY IN PRODUCTION PROCESS

Sweden's construction industry employs 286 thousand people of which 180 thousand people work with building and civil engineering work, making it one of the country biggest industries (Samuelsson et al., 2009). It is also one of the most dangerous. In last 30 years, over 336 have died from injuries they received as a result of building and civil engineering work. Many more have been injured or made ill.

Some construction occupational injuries are much higher than others. For instance, work-related musculoskeletal injuries are more common than other occupational illnesses among construction workers. Work-related musculoskeletal disorders (WMSD) are injuries of the muscles, tendons, joints, and nerves caused or aggravated by work. The physically demanding nature of construction work helps explain why strains and sprains are the most common type of injury resulting in days away from work in construction. In 2008, about 65% of all nonfatal injuries and illnesses in the construction industry resulting in days away from work were due to sprains and strains (Samuelsson, 2009). Cross-sectional studies also have reported a high prevalence of WMSDs among construction workers (Engholm and Holmström, 2005).

Occupational injuries such as Work-related Musculoskeletal Disorders (WMSDs) are unquestionably wasteful and non-value adding events in construction production systems. These events contribute to unreliable workflow, which in turn creates havoc on any construction project. As stated by Howell and Ballard (1994), achieving reliable workflow is possible when sources of variability are controlled. It follows then that safeguarding construction workers from occupational hazards is an integral part of the lean construction ideal of maintaining reliable workflow (Abdelhamid et al., 2003). Human-oriented work structuring will better the occupational health and safety of the construction workforce while simultaneously reducing workflow unreliability and enabling lean conversion efforts (Abdelhamid and Everett, 2002).

Industrialization process through industrialized methods used in the construction production has been given credit for reducing health and safety problems such as WMSDs among construction workers (Rwamamara, 2005). Industrialization describes and encompasses all three aspects of offsite construction work namely, modularization, prefabrication, and preassembly. Further, this industrialization process can be defined as an investment in equipment, facilities, and technology with the intent of increasing output, decreasing manual labour, and improving quality (Warszawski 1990). It uses the concepts of manufacturing and applies them to construction.

IMPORTANCE OF DESIGN IN BRIDGE CONSTRUCTION

DESIGN FOR EASE OF CONSTRUCTION

The terms constructability and buildability are often used when considering ease of construction during the production phase. The two concepts have similarities and differences; constructability refers to the total concept of production entailing everything from design to planning and purchasing to make a project as uncomplicated to build as possible whereas buildability refers to how the design process can accomplish simple construction.

According to Wong et al. (2006) there are two major definitions accepted on the term constructability. The definitions were stated by; CII (1986) "the optimum use of construction knowledge and experience in planning, design, procurement and field operations to achieve overall project objectives" and by CII Australia (1996), "the integration of construction knowledge in the project delivery process and balancing the various project and environmental constraints to achieve project goals and building performance at an optimal level”.

The definition of buildability by Adams (1989) is well recognized and is stated as “the extent to which the design of a building facilitates ease of construction”. Also according to Adams (1989) there are three key concepts within buildability namely; simplicity, standardization and clear communication.

Womack and Jones (2003) suggests that there are five key concepts in Lean, they are; define customer value, identify the value stream, make value flow through production, use a pull system for production and strive for perfection. When constructing bridges in Sweden, the customer, e.g. the government, has a clear set of rules for the construction which need to be followed, consequently one can interpret these rules as a part of the stated customer value. However, to identify the value stream at a construction site, to make the value flow through production and to strive for perfection the design stage is important; hence a focus on buildability and constructability can be advantageous.

During the design stage many obstacles arising within the construction stage can be foreseen and prevented. Thus, if buildability is considered and design is taken seriously, with enough effort and time, it will increase the flow of production. Considering also the implementation of constructability, consequently the experience in planning, procurement and field operations, the concepts of pull and perfection can be utilized and hence the production can be optimized.

DESIGN FOR HEALTH AND SAFETY

The traditional separation between design and construct functions in construction has been a barrier to the improvement of health and safety of construction workers. The Commission of European Communities claims that over 60 percent of all fatal construction accidents can be contributed to decisions made before construction work on the site (Commission of European Communities, 1993). According to Lingard and Rowlinson, 2005), this suggests that decisions made early in a project’s life, particularly during design stages, may impact upon the health and safety of workers who must then construct the facility in accordance with design and specifications provided by the architect or design consultant. To strengthen this position further, 50 percent of the 71 contractors responding to a survey of the construction community in South Africa identified design as a factor that negatively affects health and safety (Smallwood, 1996).

Designer decisions made during the schematic and design development phases of a project directly impact the health and safety of the construction workers construction workplace. Many decisions also impact the safety of end users, maintenance and repair workers, and construction crews during renovation or deconstruction cycles. A safety analysis conducted during design phases is an effective means of identifying unnecessary hazards in the project design, many of which may be “designed out” through the use of alternative components, systems, or construction methods (Haas, 1999).

RESULTS

Distribution of total costs for the constructed bridges can be seen in Figure 1. It can be seen that the costs for material and labor for formwork, reinforcement and concrete is approximately 23 % each of the total costs. It can also be seen in Figure 2 that the labor cost for formwork and reinforcement stands for approximately 85% of all labor cost associated with the project. However, the work labeled remaining work (e.g. pile driving, railing, asphalting) is done by subcontractors and, hence, the main contractor has no labor costs for these activities.

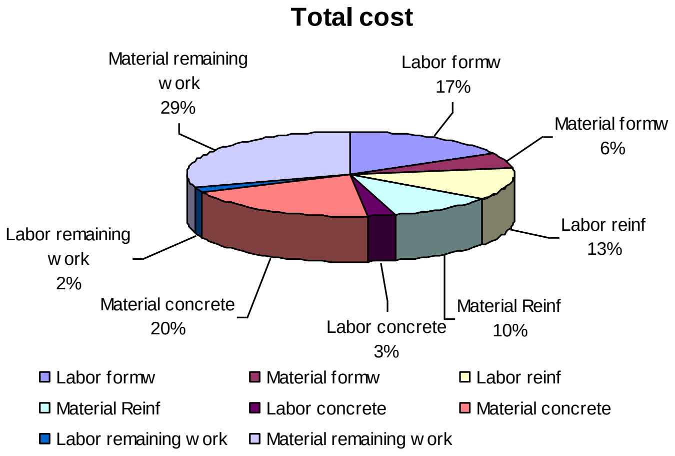

Figure 1: Distribution of total costs for the constructed bridges in the studied project.

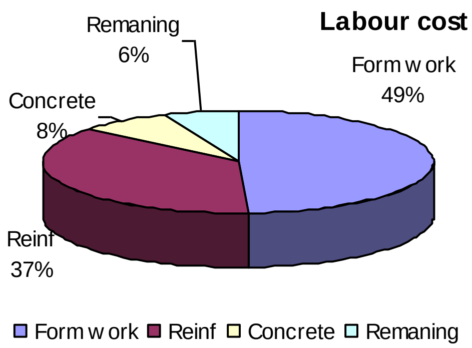

Figure 2: Distribution of labor costs for the different activities in the studied project.

STANDARDIZATION AND SIMPLICITY

It is possible to group the foundations of the studied bridges into different geometries and load capacities and consequently standardize them. Instead of constructing for instance 64 different reinforcement cages for the foundations required for the 32 studied bridges, it would have been possible to group the reinforcement cages for the foundations into 6 different groups. Hence, a standardization of one component for the bridges can be foreseen to have an impact on the construction schedule time and cost of the project. If a grouping of the foundations had been done there would have been a possibility to save more than 22 worker weeks at site and approximately 50 % of the anticipated labor costs for reinforcing the foundations, Table 1.

Table 1: Manufacturing time and labor costs for the three different solutions of the standardized foundations.

	Traditional	Subcontractor	Field factory
Manufacturing h	1728	643,2	960
Manufacturing cost €	60480	22512	33600
Mounting of rebar basket at site	0	16	16
Mounting cost €	0	3200	3200
Total work time at site	1728	16	976
Total cost for cages in form	**60480**	**25712**	**36800**

It would also have been possible to use a site factory for manufacturing of these foundations; the result would have been a reduction of approximately 50% of labor work time, Table 1. This work could have been used as buffer of work, as suggested by Ballard (2000) in the Last Planner of Production Control, to level out the demand of the work in production.

Table 2: Difference between using traditional concrete and SCC

Traditional	Volume m3	Casting time h	No. Workers	Worked h	Cost €
Foundation	2351	118	4	470	16457
Superstr.	7429	371	8	2971	104001
Linkplate	1470	74	4	294	10291
Sum	**11250**	**562**		**3736**	**130749**
SCC	**Volume m3**	**Casting time h**	**No. Workers**	**Worked h**	**Cost €**
Foundation	2351	78	1	78	2743
Superstr.	7429	248	5	1238	43334
Linkplate	1470	49	1	49	1715
Sum	**11250**	**375**		**1365**	**47792**

If traditional concrete had been replaced by SCC, the potential for saving in production time at site would have been considerable. Approximately 60 worker weeks could have been used more productively in total for all concrete casting activities and only for the foundations some 10 weeks could have been saved in production time at site, Table 2. This work time could have been used to e.g. reinforce the next part of the bridge and, hence, reducing the total production time. The link plate mentioned in Table 2 is used to even out any possible settlement of the filling material close to the bridge.

Formwork, as shown in figure 2 stands for approximately half of the labor hours used in the studied project. If left formwork have been used instead, there would have been a possibility to save more that 630 worker weeks at site and approximately 80 % of the estimated labor costs of the needed labor hours for formwork, see Table 3. As for the reinforcement, a site factory could have been used which means that this also could be used as buffer work. Using a site factory would also make the logistic issues easier to handle, which otherwise could be a problem due to large sizes of prefabricated elements.

Table 3: Needed labour hours for formwork during the construction of slab frame bridges in the E4-project.

Formwork	Labour hours	Cost €
Traditional	29578	990863
Left	4369	146362

DISCUSSION AND CONCLUSION

The size of the studied project makes it eminent for using industrialized production methods and for standardization of components to the bridges. The focus in the design phase in the early stage of the project should have been on standardization, simplicity and communication and consequently on constructability and buildability of the bridges. The potential, if the designing and the planning of the bridges had been done appropriately, would have been vast and this has been demonstrated by studying the results from the bridges foundations.

It can be concluded that when projects of this magnitude, which is fairly rare in Sweden, are to be constructed, they need to be treated differently than an ordinary project with a much less number of bridges. Consequently, the reduction of accidents will decrease and the health and safety at our work sites will increase if these parameters are considered during design.

The largest factor hindering the introduction of industrialized working methods is the late involvement of the contractor in the project process. According to answers of several contractors during interviews, "there is simply not enough time for site management to rethink production". It seems as if the organizational culture is not geared to implement changes at that time during a project. There is a sort of tradition of conservatism in the trade, and consequently there is a need for a paradigm shift in organizational culture with in companies and the in building trade for industrialization to succeed.

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