Industrialized construction: Benefits using SCC in cast in-situ construction

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ABSTRACT

As known the product SCC comprises many advantages compared with traditional concrete, but yet it has not changed the market of cast in place concrete as expected. This relates to some robustness problems of the concrete and to a general opinion that the product is considered to be expensive. However, manufacturers have improved their quality vastly and SCC has become more robust over the last few years.

To increase the use of SCC, the actors of the building trade need to be informed and convinced how to benefit from all the advantages of SCC: i.e. the working environment the health and safety of the workers, the productivity etc.

This paper deals with full-scale examples on the use and the realization of SCC obtaining several benefits during a project’s whole construction time. Specially, the economics and the working environment are treated.

Key words: SCC, benefits, economy, productivity, working environment, robustness

1. INTRODUCTION

Self-compacting concrete (SCC) is an important link in the development of the industrialization process of civil engineering projects; if managed properly it can, decrease the number of workers needed during casting and become economically profitable as well.

What happened with the expected development of SCC? In the late 1990’s many specialists argued that they expected SCC to have more than 50% of the total concrete market within a five year period. Today, almost ten years later however, the market shares of SCC in EU nations are clearly below 10% with large variations from country to country. For instance Cussigh [1] reports that only about 3% of all ready mixed concrete in France is SCC while in Denmark the
SCC market share is as high as 25%. In Sweden, the SCC market share is about 10% with very large local variations. However, the definition of SCC varies from country to country.

According to recent international findings [1], [2], SCC is on the cutting edge of scientific and technological developments, and it is essential to introduce the technique in a broader manner in cast in place concrete construction. However, still the adoption of SCC is very low and one important reason is, according the authors above, the economy. The need for high quality constituents of materials in SCC results in a more expensive product that not compensates for the possible economical benefits.

Thus, it is essential to clearly document all the direct and indirect benefits using SCC and this article is a contribution in this topic dealing with economic questions, working environment and industrialization possibilities in projects were SCC has been used.

2. OBJECTIVE OF THE PH D PROJECT

The research project “Industrialized civil engineering with in-situ cast concrete” at Luleå University of Technology aims at evaluating methods to increase the degree of industrialization in bridge construction. One of the objectives is to investigate possible productivity benefits using SCC at in-situ cast construction sites. Other objectives are to examine the economic potential of the product and the impact on the working environment.

3. ROBUSTNESS AND TARGET VALUES OF SCC

3.1 Benefits and hindering factors of SCC

Among the positive effects of SCC, the improved working environment and reduced noise level, easiness of placing, productivity enhancements, higher strength, faster construction and less man hours needed for production, can be especially mentioned.

Regarding civil engineering projects, there are certain parts where SCC is superior to traditional vibrated concrete: high walls, columns or plate structures [3]. Most often, when casting these structures with traditional vibrated concrete, concrete workers have to climb down inside the form to be able to carry out the compaction of the concrete properly resulting in low productivity and poor working environment.

However, according to Shah et al. [2] there are some issues hindering the introduction of SCC on a broader front; questions regarding the development of formwork pressure, problems related to static and dynamic segregation resistance, rapid loss of slump flow and doubtful robustness. Cussigh [1] has other explanations for the low adoption of SCC in Europe; the need for high quality materials, which in turn results in costs for SCC materials, clearly exceeds the traditional concrete, an insufficient accuracy of concrete production equipment, as well as a lack of quality control requirements and standards.

Another factor hindering the introduction of SCC is that it is especially important to establish a quality assurance system for difficult castings, especially when the structural section is narrow or the reinforcement is very dense as in most bridges today [4]. However, such systems are seldom established in praxis.
3.2 Robustness

Two reasons why SCC is not being used more frequently are the relatively large quality variations and the difficulty in keeping SCC robust. Though, concrete manufacturers in recent time have improved the quality and hence the robustness of SCC, still these negative effects are present with the result that contractors calculate the risk of using SCC to be too high. Therefore, the contractors simply do not use the product even though both costs and time can be saved.

According to Taguchi [5], robustness generally is defined as insensitive against disturbance. For SCC the disturbance can occur in the form of fluctuations of properties of the concrete constituents, mixing procedure and transport conditions. Thus, one important feature of SCC is the ability of the concrete to maintain its fresh properties and structure during transport and casting of a single batch or multiple batches, [6] and [7]. According to the European guidelines for SCC [8] a well designed and robust SCC can typically tolerate a variation of 5-10 liters/m$^3$ in mix water content, which in practice is about 3-6% of the total water content per m$^3$.

3.3 Target values

Different target values are preferable for different structural parts in a structure. For civil engineering applications this implies that concretes for slabs compared with concretes for columns or foundations have different properties. Figure 1 show possible target values and allowed variations of the filling ability expressed by slump flow and T50. The slump flow for bridge foundations, columns or walls should be greater than for a bridge slab. Hence, with a bridge slabs horizontal extensions a slightly less fluid concrete is preferred creating opportunities for its proper form filling.

Another example of target values has been suggested by Walraven [9], Figure 2, stating nine consistency classes for SCC regarding slump flow, T50, V-funnel time, segregation and passing ability. As seen the consistency class depends on the construction type, e.g. ramps, walls, floors. Walraven concludes that SCC can be tailor-made for any kind of construction including fairly steep inclination (up to 30°).

It is thus evident that, it is important to design and modify the concrete for a specific project and also for specific structural parts within the same project.

![Figure 1. Examples of criteria for SCC for walls and slabs in a workability diagram (slump flow vs. T50), where the ellipse represents target value and tolerance.](image-url)
<table>
<thead>
<tr>
<th>Viscosity (sec)</th>
<th>Stability / Passing ability</th>
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<tbody>
<tr>
<td>VS &gt; 2.5</td>
<td>Specify passing ability, for SF1 &amp; 2</td>
</tr>
<tr>
<td>VF 10 -25</td>
<td>Tall and slender</td>
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<tr>
<td>VS &gt; 2.5</td>
<td>Specify SS for SF 3</td>
</tr>
<tr>
<td>VF 6 -9</td>
<td>Floors and slabs</td>
</tr>
<tr>
<td>VS &lt; 1.5</td>
<td>Specify SS for SF 2 &amp; 3</td>
</tr>
<tr>
<td>VF 3 -5</td>
<td></td>
</tr>
</tbody>
</table>

SF 1               SF 2               SF 3               Slump-flow

Figure 2. Properties of SCC for various types of application [8], [9].

4. INDUSTRIALIZATION AND SCC

4.1 Possibilities for an enhanced concrete construction

Experience has shown that SCC not alone automatically implies a clear step into industrialization. Therefore, within the research project at LTU, feasibility studies were carried out to grade various measures for industrialization of bridge construction. Ten already constructed concrete bridges were followed up regarding unit times and costs for reinforcement, formwork and concrete and it was identified where major advancements in production can be achieved. Figure 3 shows estimations of effects on man power requirements if industrial methods regarding formwork, concrete and reinforcement theoretically were applied to these bridges.

Figure 3. Possible reduction of man power requirements if industrial methods are applied to concrete bridge construction. Theoretical estimations based on follow ups of ten Swedish concrete bridge objects 2003 – 2005 (i.e. “traditional” in the figure).

A large man power reduction was achieved with a more effective handling of reinforcement – a well known circumstance. Different solutions for effective reinforcement fixing can thus be applied at various parts of bridges. At e.g. geometrically more complicated parts, reinforcement can be traditionally placed piece by piece in the formwork. For major parts of the structures the
reinforcement can be prefabricated into cages in a controlled environment in a factory or at a manufacturing location at the production site and lifted directly into the form. Reinforcement can also be prefabricated into rebar carpets and rolled out at site (Figure 4), preferably at superstructures of the bridges, see e.g. [10].

![Figure 4: a and b) Manufacturing of carpet reinforcement in a controlled factory environment. c) Placing of carpet reinforcement on the superstructure.](image)

The formwork can be designed to be permanent on the construction, which often is the case in house production. Preferably, this method of production can be applied for foundations, columns and/or plate structures but a larger use of permanent formwork for bridges is rather complicated to realize.

Considering the potential for SCC, apart from largely reducing the number of man hours needed, as shown in Figure 3, the concrete also increase the casting rates, and improve the working environment, see e.g. Skarendahl [11].

### 4.2 Productivity according to Lean Construction

Another important component of industrialization is to change the organisation at the site and the attitude of the personnel. Philosophies of Lean Construction can thus be a useful tool. In Lean Construction waste (in Japanese: *muda*) plays a central role, whose definition is any human activity that absorbs resources without creating any value [12]. Two types of *muda* are defined: Type one *muda* creates no value but is necessary with current technologies while the type two *muda* creates no value at all and is immediately avoidable. Increased productivity is dependent on how much the *muda* can be eliminated.

Considering the concrete from this point of view, the vibrating moment is not waste when casting traditional concrete, but on the other hand not very productive either. Therefore, the compaction of the concrete can be graded as type one *muda* according to the definition above. On the other hand, in the case of SCC, the vibrating moment should be regarded as type two *muda*, because it creates no value at all and should immediately be avoided.

When using SCC, concrete workers are being released from their traditional assignment of vibrating the concrete and free to perform other tasks during the form filling. For example, the workers can fix reinforcement and prepare formwork for next section to be cast, i.e. a leap in productivity is near at hand.

Regarding the reinforcement a similar reasoning can be made. When traditional reinforcement is mounted for the bridge foundation for instance, the worker fetches and fixes each reinforcement bar at the correct location piece by piece. Traditional placing of reinforcement involves a lot of movement and carrying of reinforcement which can according to above be considered as type
one muda, since it is necessary with this technology but does not create any value. Using prefabricated reinforcement cages or rebar carpets, the element of movement/walking is reduced to a minimum or completely eliminated on site. If this still is done, the reinforcement handling ends up as a type two muda, i.e. a waste that creates no value and can immediately be avoided.

The productivity could consequently be improved simply by choosing the correct components, materials or prefabrication level to work with. Another method of improving the productivity is to increase standardisation, making structural parts more similar. It can be as simple as limiting the types of distance blocks for keeping the correct concrete cover layer, or to design foundations, columns or superstructures similarly in larger project to make them repeatable.

4.3 Working environment Ergonomic analysis through ErgoSAM

According to a study at the Danish Technological University [13] some 26% of a worker’s average day consists of concrete casting and reinforcement fixing ((approximately 10% and 16% respectively). 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 equipment such as the poker vibrators for the traditional concrete or with heavy material when placing the reinforcement piece by piece.

Today construction workers is one of the most exposed groups of employees when it comes to noise level, heavy lifts, poor ergonomics and varying weather conditions [14]. The conclusion is that a chance of improving the working environment often is denied because of the contractor only considers the short term prize for material and man power and not the total possible long term cost reduction from e.g. an enhanced working environment.

The difference in working environment between traditional casting of concrete and casting SCC has been debated recently; see e.g. Geel et al. [15], Nielsen et al. [16], Lecrux et. al. [17] to name a few; who all, debate the importance of introducing SCC in the workers point of view. However, there are few researchers presenting numbers which actually show the environment when casting traditional concrete compared to SCC.

To be able to perform the comparison between different working methods a model is needed. The ErgoSAM model [19] together with the Cube model [19] is such a tool. The ErgoSAM is based on the Cube Model that has been used on site observations to acquire the risk of Work-related Muscular Skeletal Disorders (WMSDs) in combinations of the variables; work posture, force and repetition. For every work task and for each variable separately, demand levels may be defined as low, medium, or high. The demand criteria are chosen so as to discriminate between good or poor work ergonomics, and assigned weight factors 1, 2, and 3 respectively. The combined value representing the load level or exposure level is obtained by multiplying the result of the three variables as illustrated in Figure 5, and the product determines the acceptability of the task [19].
Combinations of these demands will largely decide whether a work situation entails risks of strain injuries or musculoskeletal disorders [18]. The ErgoSAM model has been used by different Swedish companies within the manufacturing industry. For instance, studies have been carried out at Volvo Cars in Gothenburg [20]. At the full scale project in Kalix (see chapter 6.1) the observations were done by construction site-walkthroughs, video filming of identified steel reinforcement and/or concrete casting activity work cycles and interviews with the workers. These observations formed the basis for a further assessment with ErgoSAM, see chapter 6.4.

4.4 Economy

One of the drawbacks with SCC is that it is considered to be more expensive to manufacture compared to traditional concrete, a cost that is difficult to meet by a higher prize [1]. Hence, to be able to make SCC profitable also the casting phase needs to be overlooked. Therefore, the productivity when casting SCC should be high which means that the production system needs to be adapted to the “new” concrete. The difference between the manufacturing cost for the original concrete and the SCC cannot be too large if SCC is to become profitable [21].

There are factors reducing the cost for SCC; reduced energy consumption due to the absence of vibration, lower future maintenance cost, reduced illness of construction workers, as mentioned above [9], as well as lower over-head costs for projects due to decreased rental costs for various types of equipment and shorter construction time.

However, the probably most important factor when considering the economy of SCC is to have the whole life span of the project in mind when choosing material. SCC has an increased strength and durability which should be utilized when considering the reduction of maintenance needed for a project during its life span. This could also be utilised for the possible reduction of shear force reinforcement as well as minimization of the structures cross sections. This of course applies for any high strength concrete if chosen for a project. These factors and the faster casting and less labour needed during casting will result in considerable reduction in costs and risks and it will also reduce any possible traffic disruption during construction.

5. LABORATORY STUDIES

5.1 General

As mentioned earlier, to be able to produce a robust SCC product the focus should be on keeping the fluctuations of the different constituents as low as possible and to design a robust
concrete mix. Among possible fluctuations e.g. the quality of the coarse aggregate, cement or additives can be specially mentioned, whereas, the moisture content in the coarse aggregate might be the factor causing the most common and largest variations. Therefore, the recipes of the SCC used in the two full scale projects (chapter 7), were tested in the laboratory regarding sensitivity to fluctuation in water content corresponding to a moisture content variation of ± 0,5 % and ± 1,0 % without compensating done in the mix. Two test series were performed for mix proportions, according to Table 1. Variations of filler content were performed by adjusting the aggregate content. The fine and coarse grained aggregate curves featured ± 14 % deviations from the original curve at the fractions 1 mm. Figure 6 and 7 show documentations of workability (slump flow, T50 and V-funnel) and rheology (shear stress and viscosity) for the mixes.

Table 1. Concrete mix proportions at laboratory tests for two recipes. SCC 1 is the mix used in the Kalix project and SCC 2 is a mix used at the Nynäsvägen project however, here, with the same aggregate as SCC 1.

<table>
<thead>
<tr>
<th>Materials (kg/m³)</th>
<th>SCC 1</th>
<th>SCC 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-8 mm</td>
<td>1012</td>
<td>899</td>
</tr>
<tr>
<td>6-16 mm</td>
<td>545</td>
<td>651</td>
</tr>
<tr>
<td>Cem</td>
<td>450</td>
<td>430</td>
</tr>
<tr>
<td>Limestone filler</td>
<td>122</td>
<td>130</td>
</tr>
<tr>
<td>Water</td>
<td>175</td>
<td>172</td>
</tr>
<tr>
<td>Superplastcizer</td>
<td>0,8</td>
<td>0,6</td>
</tr>
<tr>
<td>Water / Cement ratio</td>
<td>0,39</td>
<td>0,40</td>
</tr>
</tbody>
</table>

5.2 Results

The first studies were carried out on SCC 1. The variations in moisture content varied between ± 1,0 % for this recipe, with one exception which is the mixture with the filler content of 80 kg/m³ were only ± 0,5 % water was added due to considerable separation and an unusable concrete as a result when + 1,0 % water was added.

Regarding the slump flow of SCC 1, it is observed that the concrete is not particularly sensitive to the moisture change of the aggregate. However, when studying the V-funnel test results it can be seen, that the flow time is noticeably longer for the drier mix than for the wetter and hence the moisture content clearly affects the concrete for this type of test. It is also observed that, the concrete gets less fluid when the filler content increases. Moreover, the concrete with the fine sieve curve is rather sensitive to moisture, as compared to the insensitiveness of the concrete with the coarse grained aggregate.
Figures 6 a to f. Workability and rheology tests on SCC 1: slump flow, V-funnel, T-50, shear stress, viscosity and shear stress / viscosity. Variations of moisture content in 0-8 mm; -1% (left) and +1% (right) from reference mix (middle) (80 kg/m³ filler: ± 5% variation).

Considering the T50-time it can be seen that the moisture content has a small effect, since the test time is markedly shorter for the wet mix than for the dry mix. Regarding the fine grain mix and T50, the test with reference moisture content was affected by the laboratory equipment and the value is therefore not relevant.

According to the shear stress values of Figure 6d, there is an obvious difference between the fine grain and coarse grained tests. The fine grained material is more sensitive to water content than the coarse grained aggregate.

The test results in Figure 6e (viscosity) and 6f (viscosity versus yield stress) does not show any apparent differences and no specific conclusions can be drawn. However, there is a difference in the filler content; the viscosity is larger with a higher amount of filler. Also, it can be observed that the drier mixes have higher viscosity values.
In the tests with SCC 2, the slump flow and V-funnel, Figures 7 a and b, were rather insensitive to the water content in the concrete. The slump flow for the mix with reference water content is declining with increasing filler content. On the other hand, regarding the v-funnel test, the reference filler content gives a long flow time while both high and low filler content lead to shorter flow times.

Figures 7 a to f. Workability and rheology tests on SCC 2 for filler variations: slump flow, V-funnel, T-50, shear stress, viscosity and shear stress / viscosity. Variations of moisture content in 0-8 mm: -1% (left) and +1% (right) for filler content 130 kg/m$^3$ and 170 kg/m$^3$ from reference mix (middle). Variations of moisture content for 90 kg/m$^3$: -0.5% (left) and +0.5% (right) from reference mix (middle).
Considering the viscosity test results, there is probably a break point between filler content 130 kg/m³ and 170 kg/m³, since there is a clear difference between these two test values. The T50 test results are very low and can be said to be within the margin of error and no clear conclusions can be drawn.

Generally, from the laboratory tests it is observed that both SCC mixes are relatively insensitive to the moisture variations studied even though the filler content was increased and decreased from the reference mix. However, SCC 1 is somewhat more sensitive than SCC 2 to the changes of moisture content.

Furthermore, some relation between slump flow and shear stress is present as well as between T50-time, V-funnel time and viscosity as similar observations can be observed for the rheology tests as for the workability tests when varying the mix.

6. FULL SCALE PROJECTS

6.1 General

Two full scale projects have been studied with two concrete suppliers that had different experience with the SCC product. The first supplier had never delivered SCC to a civil engineering project before and had accordingly little experience and no functioning recipe while the second supplier had more experience and several SCC mixes available as commercial products.

Study No 1: The Kalix bridge

Near the village Kalix, approximately 100 km NE of Luleå, the most comprehensive studies were carried out. The bridge “the industrial concrete bridge” featured a span of 10 m and a width of 15 m. The full scale project comprised “new” reinforcement solutions such as reinforcement cages for the foundations and rebar carpets for the superstructure. Also, prefabrication was chosen for some of the very dense shear force reinforcement and SCC was used for all parts of the bridge. To facilitate the introduction of these new working methods, the design and production planning of the bridge were carried out according to Lean Construction philosophy [22].

In total, the bridge consisted of approximately 280 m³ SCC cast at four occasions: foundation, plate structures, end walls and superstructure. The superstructure comprised 16 tons reinforcement of which 13 tons were placed using rebar carpets. The reinforcement for the foundation were prefabricated in two sections, one for each foundation plate, each weighing 2.7 tons. The cages were mounted in single pieces directly from the delivery truck into each of the foundation formwork, ready to be cast as soon as the connecting reinforcement had been installed.

Study No 2: The Nynäsvägen bridge

The project at Nynäsvägen (50 km SE of Stockholm) consisted of two identical bridges next to each other (bridge spans of 18 m and widths of 9 m). The total amount of concrete for the foundations, columns and superstructures for both bridges was approximately 550 m³. Each bridge was cast at five occasions and the largest single casting was approximately 210 m³ for the superstructures. SCC was used for the entire structure.
At these bridges the reinforcement were placed traditionally except some 1.8 ton of the superstructure where rebar carpets were used. The reason for the very low degree of prefabrication was that the possible use of rebar carpets was decided very late in the project and a proper redesign for this solution was not possible in such a short notice.

6.2 Documentation of concrete properties

The concrete properties, slump flow and T50, were recorded at the building site on all delivered batches at study no 1, after the pump see Figure 8. At study no 2, slump flow and air content were recorded on nearly half of the batches prior to the pump, Figure 9.

Figure 8 Slump flow and T50 documentation at study no 1. Castings of foundations and columns at two occasions (a). Casting of end walls and superstructure at one occasion (b).

At the casting of the substructures of the Kalix project some difficulties occurred in delivering the concrete with firm properties see Figure 8. This is probably depending on the inexperience of the concrete supplier and the relative small separate volumes. On the other hand, casting of the bridge superstructure was performed with a concrete of an even and high quality, Figure 8 b. Only some batches out of 24 featured properties just outside the criteria e.g. 720 ± 30 mm for slump flow and 3.5 ± 1 s for T50. For the two outlier values above the interval, the measuring can have been affected by disturbance and these two values can be neglected in the context.

Figure 9. a) Slump flow and air content measured on casting of foundations and columns at study no 2, cast at five occasions. b) Slump flow at concrete plant and at building site, casting of superstructure at study no 2.

At the second study the conditions for the slump flow were changed and the criteria were set to 700 ± 30 mm, T50 was not measured at all in this study. In Figure 9 a, there are five different
castings for the substructure, i.e. foundation and columns, accumulated. Almost 30 % of all delivered concrete batches were measured outside of the set conditions for slump flow (Figure 9 a). Nevertheless, there was only one recorded batch of separated concrete.

The air content is fluctuating during the castings with an average value of 4,8 %. There were never any specific values set for the air content in this project, although the air content for a civil engineering project is generally said to be accepted with in a span of 4-8 % and therefore was the air content acceptable.

Casting the superstructure at study No 2 on Nynäsvägen, Figure 9 b, the slump flow was measured both at the concrete plant and at the construction site. During the delivery from concrete plant to construction site the slump flow has increased in most cases. This probably indicates that the super plasticizer needs to be more thoroughly mixed into the concrete at the concrete plant. Furthermore, the first deliveries had less slump flow than the latter; this can be due to the fact that the buckets of the trucks were dry in the beginning.

It is also noted that very few batches delivered showed slump flow values just outside the criteria and they were accepted by the client.

6.3 Economy of SCC

Study No 1: Kalix project

As the Kalix project was a local pioneer full scale project, neither workers nor management had experience of working with SCC. Therefore, at the first two cast occasions (foundation and plate structures) the number of workers was too large, see Table 2 showing man power and costs of the full scale project. Also, some concrete delivery problems occurred, implying about 50 % longer casting times than expected. This had however, nothing to do with the SCC mix i.e. these problems would have occurred even if traditional concrete had been used. Thus, the comparison between traditional concrete and the outcome of SCC at these two castings as shown in the table is not representative.

When casting the superstructure at two different occasions the delivery problems were eliminated, and the workers had also become more experienced with SCC. Therefore, the castings went well and the outcome was almost as planned using SCC, see Table 2. Approximately € 1200 was saved at these castings as compared to conventional concrete. However, the concrete was more expensive (about € 15 per m³) resulting in a material cost increase of € 2000 and hence the total costs were enhanced with approximately € 800 in total.

On the other hand, the price difference of € 15 per m³ SCC is rather high, and if the difference had been the same as in the project at Nynäsvägen (€ 8) the result would have come out differently. The increase in material cost would have become roughly € 1100, with the decrease in placing cost of € 1200 mentioned above resulting in minor savings of about € 100.
Table 2. Expected time (h) and costs (€) for casting with traditional concrete, the actual outcome of using SCC at site and theoretical expectations of SCC castings when fully exploited at the Kalix project. Superstructure – left, bridge deck – right.

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Study No 2: Nynäsvägen

At the Nynäsvägen project the casting of the foundations and columns included a total of approximately 140 m$^3$ of SCC. While the traditionally planned casting involved approximately 38 working hours for casting the concrete, the theoretical casting of SCC would contain approximately 8 hours for casting, see Table 3. The actual outcome of the project ended up on a sum of 26 hours for the casting, i.e. a saving of 12 working hours from the planned work schedule could be made. However if the full potential of SCC would have been utilized (SCC theoretical) approximately 30 working hours or 80 % of the planned work time could have been saved. With an assumed construction worker cost of € 40 per hour, the saving in form filling costs is approximately € 500 for the outcome and € 1200 for the theoretical SCC.

For the superstructure the traditional casting was planned to be performed by 9 workers during 15 hours of production, ending up on 270 hours for the two bridges. A theoretical calculation using SCC shows that the actual time for casting can be considerably reduced. Savings of approximately 170 working hours can be realized. With € 40 per hour the saving of man power is roughly € 6800.

The actual outcome for the superstructure ended up in 90 work hour’s reduction due to faster casting and some € 3600 in cost savings. However, the material costs increased by approximately € 8 per m$^3$ for SCC compared with traditional concrete, which resulted in a more expensive concrete for the superstructure of almost € 3400.

Nevertheless, the overall result for the superstructure was positive as compared to a traditional concrete solution even though SCC’s potential was not fully utilized, and the total costs were reduced with roughly € 200. Hence, if SCC had been fully utilized as the theoretical calculation in Table 3 suggests the possible savings would become virtually € 3400 for the superstructure.
### Table 3. Expected time (h) and costs (€) for casting traditional concrete, the actual outcome of using SCC at site and theoretical expectations of SCC when fully exploited for the Nynäsvägen project. Superstructure- left, bridge deck – right

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<th>Work time (h)</th>
<th>Cost (€)</th>
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### 6.4 Working environment

Probably the largest benefit with SCC is, as mentioned earlier, the improvement in working environment. The improvement at our documentation on site is threefold in comparison with traditional concrete casting, Figures 10 and 11. The work cycle mean value is computed to 18.2 in our project if traditional vibrated concrete had been used at the Kalix project as should be compared with the actual outcome of 5.7 for SCC [23]. This when comparing the casting of relatively small and easy to produce plate structures. Considering the case with for instance a 10 meter high plate structure with dense reinforcement, the improvement is possibly even larger due to fact that the worker has to climb down inside the construction carrying the vibrating equipment. This result in exceptionally poor working environment, and also in a probable loss of productivity, due to much lower unit time for casting traditional vibrated concrete.
Figure 10: ErgoSAM analysis of concrete worker’s short work cycle during casting of traditional vibrated concrete. Below 6 is acceptable, 6 to below 9 is conditionally acceptable and 9 and above is unacceptable.

When the value in the Cube model reaches 27 in Figure 10, the worker lifts the heavy poker vibrator (Force = 3) repeatedly (repetition = 3) in awkward positions (Work posture = 3) resulting in the top value which is unacceptable. When the value reaches 18 in the figure the worker has the value three for two of the variables and the value two for the third variable. These individual values can vary during a work cycle.

The top value of 9 for SCC in Figure 11 is achieved when the worker pushes the pump hose from one place to another, resulting in the value three for force and working position and the value one for repetition.

Figure 11: ErgoSAM analysis of concrete worker’s short work cycle during SCC casting. The average value for the work cycle is 5,7 which is below 6 and hence acceptable.

Injury cost estimations according to the Swedish Social Insurance Agency [24], show that the single largest cause for sick leaves in general 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. Considering only the construction industry, Samuelsson and Lundholm [25] reported that out of all 1582 cases of sick leaves caused by occupational illnesses reported for 2004, 1342 cases of sick leaves were caused by ergonomic risk factors (including vibration and noise).

For concrete workers 279 cases of WMSDs were reported and their sick leave compensations is estimated up to 1 280 000 € for the taxpayers [26]. There are of course other direct and indirect costs such as productivity loss and hiring substitute workers that are not often included in such calculations.

Improved working environment also implies an increase in productivity given that the workers are at the site performing work tasks and there are no vacancies or unskilled substitute workers at the production sites.

7. CONCLUSIONS

The largest economic benefit from introducing SCC to a contractor in civil engineering projects is probably on the superstructure of a bridge, since the largest number of workers is needed during casting of traditional vibrated concrete and it is therefore associated with large casting costs. Hence, the number of workers needed for casting can be markedly reduced if SCC is introduced and proper planning has been carried out before casting.

However, controversially it is often easier to introduce SCC for foundations, columns or plate structures since these structural parts are less dominant in the construction and the “risk” related to using SCC is small. However, for these smaller less people demanding castings it is more difficult to achieve economical benefits in using SCC.

The overall risk using SCC is that the product it is not robust enough, which might result in the concrete does not enclose the reinforcement satisfactory and rework is needed. Also, after casting, it can be visual lines (inward bends) in the finished construction which is not acceptable. Therefore, most often, contractors calculates the risk enclosed in using SCC to be too high, especially for the more important superstructure and simply does not use the product even though both costs and time evidently can be saved.

The SCC delivered to the superstructures on both projects was robust and was of desired quality. The “risk” involved using this SCC was minimal and the contractors were satisfied with both the delivered product and the order of in which the casting was performed. Hence, the castings of the superstructures on both projects were carried out in shorter time and could have been carried out using fewer personnel than planned with traditional concrete. The SCC delivered to the substructures at both projects was not entirely acceptable, however, the SCC at the two projects differed and the quality was better at study 2.

Probably the largest benefit with using SCC is, as mentioned earlier, the improvement in working environment. Therefore, the economy of the Swedish construction industry and society can benefit significantly from using the right kind of working method during construction. As mentioned earlier, 1342 sick leaves were reported for 2004 due to ergonomic risk factors. If these sick leaves costs as much as expected above e.g. € 4600 per sick case, it suggests that the
total costs ends up on roughly € 6 170 000 annually! This is according to Lean Construction a great deal of muda!

To be able to utilize the redundant personnel during casting of SCC, projects need to be planned and managed properly. Hence, the organisation at the worksite needs to be optimized during the whole project, clear work instructions need to be formulated for all workers involved for all work tasks to be performed. Also, a list of buffer work needs to be logged so that workers can be temporarily occupied with other productive work tasks during casting but still within reach if needed during casting, Ballard [27].

REFERENCES


