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Ecological Profit for a Concrete Pipe Factory due to Self-Compacting Concrete Technology

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ABSTRACT

The production of high quality concrete pipes is an energy intensive process, leading to a high energy consumption, and to a lot of noise, vibration, and dust. This is to a large extent due to the fact that the concrete has to be compacted by vibration needles, or even by centrifugal techniques. Considering the new technology of self-compacting concrete, the working conditions in the factory can significantly be improved, and a lower energy consumption can be obtained. This paper tries to quantify the ecological profit when a concrete pipe factory is shifting its production to self-compacting concrete technology. Information on reduction of noise and vibration is given. The service life of the moulds will be increased. The energy consumption is estimated to be reduced with 1.0 GWh during one year of production for the case study considered. The energy savings are translated into an approach based on eco points.

INTRODUCTION

Concrete industry “is having big feet”. At least, the ecological footprint of the concrete industry on our blue planet is known to be quite large. Concrete is the most widely used building material in the world, and when properly designed, produced and placed, it enables the construction of long-lasting, durable structures. However, the production of Portland cement is energy consuming, and is responsible for 7% of the carbon dioxide production worldwide [Malhotra 2000]. Alternative cementitious materials can be applied in order to reduce the content of Portland clincker per cubic meter of concrete, thus reducing the amount of carbon dioxide produced [Malhotra 2000, Siddique 2008]. A summary of recent developments to improve the ecological footprint of concrete, by using alternative cementitious materials (reducing the CO_2-production) and by substituting aggregates by various recycled materials (reducing the need to quarry virgin aggregates), is presented by Meyer [Meyer 2009].

In addition to the ecological footprint related to cement production, a lot of energy is required for mixing, transporting, casting and finishing of the concrete. In this respect, new developments like self-compacting concrete [De Schutter et al. 2008] can provide attractive opportunities to help greening the concrete industry. This paper presents a first estimation of the ecological profit that can be obtained when a concrete pipe factory is shifting its production from traditional vibrated concrete to self-compacting concrete. The estimation is based on the situation of an existing production plant in Belgium.

CASE STUDY: BELGIAN CONCRETE PIPE FACTORY

The factory concerned produces high quality concrete pipes, with a diameter up to 1600 mm and a length up to 3200 mm (Figure 1). Two different production techniques are used: casting and vibration in vertical position (Figure 2), and casting in horizontal position including vibration by centrifugation. Both techniques give rise to a high noise production and vibrations. Especially in the case of centrifugation, the noise and vibration levels are extremely high, causing hindrance in the neighbouring offices and houses. Due to this reason, the factory would like to shift its production method to a more environment friendly method, implementing self-compacting concrete technology, making vibration obsolete.

Fig. 1. High quality concrete pipe

Fig. 2. Vertical casting position (inner mould)

SELF-COMPACTING CONCRETE

One of the key issues for traditional concrete is that it has to be properly compacted by providing external energy, e.g. using pokers, or special techniques like centrifugation. In order to overcome the problems related to badly vibrated traditional concrete, self-compacting concrete (SCC) has been developed in Japan in the 1980's [De Schutter et al. 2008]. Simply explained, SCC fills the formwork like a liquid without the need for external compaction energy. It is sometimes discussed whether SCC is a new material or a new placing technique, the conclusion being that it is both at the same time. On the one hand, the composition of SCC is significantly different from the composition of traditional vibrated concrete. This leads to changes in hydration and microstructure. On the other hand, the placing technique indeed is also new, not needing external vibration. This leads to substantial advantages concerning environment and working conditions: less energy consumption, less vibration, less noise, decreased absence of workers due to illness… The positive impact of self-compacting concrete is that large, that it is considered as a major development and a major improvement for our society.

TOWARDS A MORE AUTOMATED PRODUCTION

Since its development, SCC has been applied worldwide, both in precast and in ready-mix industry. Especially within precast industry, SCC is having a high market share at this moment. However, SCC is still cast in the moulds following traditional placing methods, mainly using crane skips. In some cases, it is pumped into the formwork from the top.

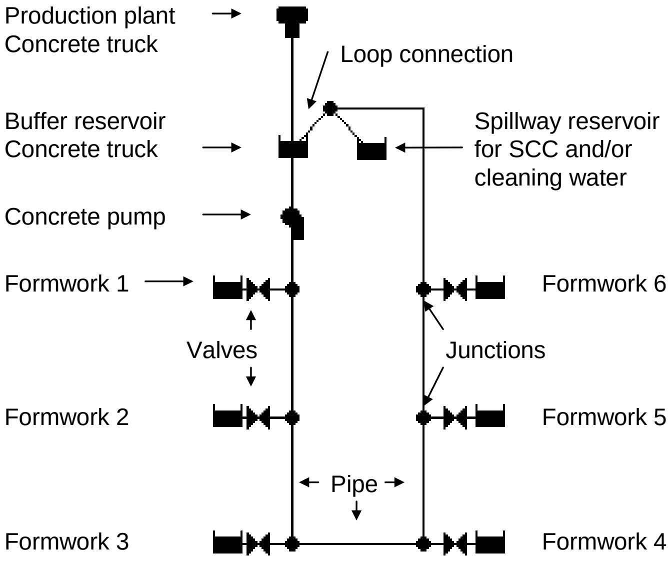

Fig. 3. Schematic presentation of the new production system, with pumping of SCC

Due to its specific properties, SCC is suitable for a new placing technique, pumping it in the formwork from the bottom [Feys et al. 2007]. This technique enables the production of several structural elements, using only one pump connected to a circuit of pipes. The setup is shown schematically in Figure 3. A set of six structural elements could be produced in one continuous operation. The buffer reservoir, positioned just in front of the pump, is a key element in obtaining a continuous pumping process. As a result, SCC is continuously flowing through the circuit, filling the formworks 1 to 6 in this order.

After completely filling one formwork, a switch valve makes the SCC flow to the next formwork. After filling the last formwork, the remaining SCC can be spilled into a reservoir, and the pipe circuit can be cleaned. The big advantage of this production method is its stationary properties. No concrete must be moved by a rolling bridge, and no pipes have to be repositioned during the process. The energy needed to place the concrete into the formwork is smaller following this new procedure compared to traditional casting methods. This will be quantified approximately further on in this paper.

ECOLOGICAL BENEFITS

The ecological benefits when using SCC instead of traditional vibrated concrete are manifold. Some of the profits will be mentioned hereafter without a detailed quantification. Coming to the energy savings however, a first attempt will be made to estimate the profit in terms of energy, eco-points, and money.

Reduction of noise and vibration

Measurements show that the actual casting operation in vertical position, combined with vibration, leads to a noise level of 85 to 90 dB, while the horizontal casting method including centrifugation leads to a noise level of more than 100 dB! The situation in some other factories, where SCC is already implemented (although with traditional casting using skips), shows that a noise level as low as 70 dB is achievable by shifting the production to self-compacting concrete technology. This is about the same level of noise as produced by the radio, which has been rediscovered in some factories where SCC has been introduced.

The level of vibrations will be substantially reduced when introducing SCC, especially compared to the situation of centrifugal compaction. According to recent measurements on site, health problems can occur for workers exposed for more than one hour to the existing vibration levels. By implementing SCC, the problem of vibration induced health problems is overcome. This is leading to a reduced absence level due to illness of the workers. Furthermore, the situation will also improve for some residents in the neighbourhood, who recently sued the concrete plant for being responsible for off-limit vibration levels.

Longer service life of moulds

By eliminating the negative influence of the powerful vibration equipment, the service life of the steel moulds can be increased. With the current production techniques, including heavy vibration, each year about 10 man-hours are needed per mould for repair works related to vibration induced damage. This can be fully avoided by the implementation of SCC. It is not immediately clear however whether the moulds have to be made stronger in order to resist the possibly higher formwork pressures due to the new pumping techniques.

Energy saving during production

In order to estimate the potential energy saving by the implementation of SCC combined with the pumping technique, four different aspects of the production cycle will be evaluated: mixing, transport, compaction, and finishing.

<u>Mixing energy</u>

The actual annual mixing energy for the production of traditional concrete, by means of a planetary mixer in the concrete factory, is about 0.4 GWh. The mixing energy when shifting the production towards self-compacting concrete will depend on the composition and the rheological properties of the SCC. On the one hand, one might argue that SCC is clearly more flowable than traditional concrete. On the other hand, it is also clear that SCC typically contains a much higher amount of fine powder and superplasticizer, giving rise to a longer mixing time needed to obtain adequate mixing. This latter aspect is important to consider. The comparison of different concrete recipes regarding the application of mixing energy is only valid when the homogeneity of the different recipes is equal at the end of the mixing process, as clearly stated by Daumann et al. [Daumann et al. 2009].

In their research, Daumann et al. [Daumann et al. 2009] measured the volume-related energy consumption when mixing different concrete compositions, including a traditional C50/C60 concrete, a self-compacting concrete (based on fly ash), and an ultra high performance concrete (UHPC). For the self-compacting concrete, the needed mixing energy when using a single-shaft mixer is about 30% higher than for the case of the traditional C50/C60 concrete. For UHPC, the mixing energy even increases by a factor of 3 (meaning an increase of about 200%). In case of a twin-shaft mixer, the increase in mixing energy for SCC is about 60%, while it is about 160% for UHPC.

For the actual case study of the concrete factory, the exact composition, and hence the exact rheological properties, still have to be determined. However, considering the research of Daumann et al. [Daumann et al. 2009] it seems thus realistic to estimate an increase in mixing energy of about 50% when shifting the production towards self-compacting concrete technology. This would mean an annual mixing energy of about 0.6 GWh.

Transport energy

Performing pumping experiments on traditional concrete, Kaplan [Kaplan 2001] showed that for a discharge of 26.7 m^3/h a pressure loss of 0.1 bar occurs per meter pipe length. In order to estimate the energy needed to pump the concrete over 100 m, we suppose that Bernoulli’s law is valid, neglecting kinetic energy terms. This leads to the equation:

$$E = \eta \rho g Q \Delta F \Delta t \quad (1)$$

with η the pump efficiency (= 0.65 to 0.70), ρ the concrete density (2400 kg/m^3), $g = 9.81$ m/s^2, Q the discharge (m^3/s), ΔF the head loss (in m water column), and Δt the time (s) needed to pump 1 m^3 of concrete at the given discharge. This equation leads to a needed transport energy of 0.95 kWh for pumping one cubic meter traditional concrete over 100 meter pipe length. In his doctoral research, Feys [Feys 2009] showed that for powder based SCC, showing shear thickening behaviour, somewhat higher pressure losses are noticed during pumping, leading to a higher pumping energy consumption. A needed transport energy of 1.2 kWh for pumping one cubic meter of SCC can thus be estimated.

Within the considered concrete pipe factory, about 35000 m^3 concrete are produced every year, leading to a total pumping energy estimation of about 42 MWh or 0.042 GWh. This energy is replacing the energy needed for the transport of traditional concrete by means of the rolling bridges following the actual production method. It is noticed that these rolling bridges show an annual energy consumption of 0.2 GWh.

Compaction energy

Measurements within the factory showed that the energy needed to vibrate 1 m^3 of traditional concrete is about 30 kWh. For the total annual production of 35000 m^3 of traditional concrete, the compaction energy adds up to about 1 GWh. This compaction energy is completely obsolete when shifting the production to self-compacting concrete technology.

Finishing energy

With the current production techniques, using traditional vibrated concrete, a relatively high number of pipes have to be finished manually, correcting some local defects and irregularities due to the incomplete filling of some corners or edges caused by insufficient vibration. This implies some mechanical actions in order to come to a final smooth surface. The finishing energy needed for these operations will be obsolete in the case of SCC. However, it is very difficult to quantify how much energy will be saved in this way. These saving are neglected in the further evaluation. However, one should realize that the absence of this activity when applying SCC will represent a substantial saving of man hours.

Total energy

Table 1 gives an overview of the required energy levels following the current production method using traditional vibrated concrete, and the newly proposed production method by pumping self-compacting concrete. The energy levels are valid for a total annual production of about 35000 m³ of concrete.

On an annual basis, an energy saving of the order of magnitude of 1 GWh (which equals 60 % of the actual energy consumption for the production of concrete pipes) will be obtained by shifting the production to self-compacting concrete technology. In terms of eco-points, for electrical energy in Europe (low voltage), 1 KWh can be represented by 26 millipoints. This means that when producing the pipes by pumping SCC, an annual bonus of 26000 eco-points can be obtained compared to the current situation. Considering an environmental cost of 3 EUR per eco-point, an environmental saving of about 78000 EUR is obtained annually.

This environmental profit is based on the energy savings only. Estimating the environmental saving due to other benefits, like noise reduction, limitation of vibration, reduction of health problems, etc. is not straightforward. It only shows that the environmental savings due to the reduction of the required energy level is an underestimation of the real environmental savings.

Table 1. Required energy levels for the annual production

	Current production method	**Pumping SCC**
Mixing energy	0.4 GWh	0.6 GWh
Transport energy	0.2 GWh	0.042 GWh
Compaction energy	1.0 GWh	0.0 GWh
Finishing energy	neglected	neglected
Total energy	**1.6 GWh**	**0.642 GWh**

CONCLUSIONS

For the situation of an existing plant producing high quality concrete pipes, the ecological profits are estimated when shifting the production to self-compacting concrete technology, including pumping under pressure.

A first category of profits can be obtained regarding noise reduction, limitation of vibration, reduced absence of workers due to illness, increased service life of moulds, … It is not easy to quantify these profits in terms of eco-points or economical value.

A second category of profits is related to energy consumption: mixing energy, transport energy, compaction energy, finishing energy. For the considered factory, producing about 35000 m³ concrete per year, it is estimated that the annual energy savings amount up to 1 GWh (or 60% of the actual energy consumption) when shifting the production to self-compacting energy. The increased energy levels for mixing are greatly overcompensated by the elimination of vibration energy. These energy savings can be translated to eco-points or to economical value.

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