SCC: Challenges and Successes

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Abstract

Recent advancements in concrete technology especially through the introduction of self-compacting concrete (SCC) have changed the way concrete construction is perceived. Within a very short period of time SCC was adopted worldwide. Self-compacting concrete is a material requiring new approaches for casting techniques, but, at the same time, offering novel and innovative opportunities for engineers and architects. In some countries this technology is well established as some are going through a great deal of uncertainties. SCC is not just an alternative to conventional concrete it opens the opportunities for fundamental changes to the whole concrete construction processes. We already see it in concrete precast industry when new production facilities are designed for the use of SCC. SCC is here to stay and a great number of successful construction projects, business ventures, and extremely valuable research projects is a solid evidence of it. On the other hand, SCC is a more demanding and susceptible than traditional vibrated concrete. The choice of constituent materials, mix design, mixing process, formwork, casting methods presents challenges. Some effort is necessary to meet the challenges and to gain the benefits SCC technology offers.

A Technological Leap Forward

The basic technique of placing fresh concrete has remained unchanged for many decades. Concrete transport equipment and compaction tools have become more sophisticated and reliable. Admixtures for concrete allow for better control of concrete properties; they also made it possible to consolidate concrete with much less effort. Despite all these the basic concept of concrete compaction by using vibration energy has remained unchanged. One of the problems associated with manual compaction by vibration is the assurance of quality especially in complex structures, resulting from insufficient compaction during casting. Limitations of current concrete construction methodologies often impose considerable restrictions on the project architects and their structural designers. Another significant problem is related to the impact of conventional handling and placing techniques on the health and safety of construction workers. These two factors combined in were driving the need for some significant breakthrough improvements in concrete construction from the point of view of quality assurance and increased efficiency, as well as improved working conditions.

Self Compacting Concrete (SCC) Technology has shown to be the most technological quantum leap in construction for many decades. The introduction of SCC has significantly changed the material technology and the way the concreting is executed. New material properties would permit for some organisational changes. It enables improvements in the concrete construction techniques for increased and efficient results. Elimination of discontinuous mechanical vibration makes concrete structures with more consistent and reliable properties. General enhancement of the working environment is paid off by improvement of health and safety of workers, which also adds to the increase of productivity. Another advantage the SCC technology brings to the industry is specialist knowledge, which has not been in demand before.

Why SCC?

Consolidation of concrete plays a significant role in the development of hardened concrete properties. Design properties of concrete structures are associated with well compacted and homogenous concrete; the purpose of compaction therefore is to achieve the highest possible density. Vibration, which is still the most common way of compacting concrete, has the effect of fluidifying the mortar component of the mix so that internal friction is reduced and closer packing of concrete aggregate takes place. But compaction

via vibration is a discontinuous process resulting in hardened concrete with uneven compaction and therefore with different mechanical and durability properties.

If we look back at the SCC development, the avoidance of vibration was not a prime motivation. However, the starting point was a growing concern about difficulties of assuring the quality of complex concrete structures because of poor compaction of in-situ concrete. This led to increased construction costs and jeopardized long-term durability of structures. The only practical option was to eliminate the reliance of the concrete compaction on concrete workers and to replace it with the ability of concrete itself to guaranty the full filling of formwork, perfect compaction, and the full encapsulation of all reinforcing bars.

After a period of fundamental research and development work, the new SCC technology was tested in full scale applications in practice in late 1980s. In Japan, the development of SCC has been strongly focused in improving the concreting process of complicated structures and developing concrete for demanding situations.

The achievements in Japan raised a great interest in Europe, where the development of SCC started in early-middle 1990's. The driving force in Europe, however, was the possibility of increasing productivity of this new technology. The European precasting industry, where single player is normally in full control from constituent materials to the delivery of finished product was quick to recognize the advantages of SCC. There is also some evidence in European markets of the concrete supplier taking responsibility of the cast structure instead of just the fresh concrete.

User Values

SCC is not a new material, but rather new and improved way of executing the concreting operation. Like conventional (vibrated) concrete, self compacting concrete has wide varieties of properties and can be designed to suit specific requirements of strength and other mechanical properties, application and casting methods. High deformability of SCC opens unique opportunities to a great number of construction advancements:

- easiness of placement – high flowability and filling ability allow to cast concrete structures much faster; in some cases SCC allows to cast complex structures (confined, limited or no access for vibration, complex shape, etc.) which cannot be made with traditionally vibrated concrete;
- considerable health and safety (working environment) improvements – the improvements are significant on both human and social levels; elimination of vibration and noise creates positive working environment; the cost to the society for health care is reduced as well as to the company for sick leave and early retirement; furthermore, the reduction of physical loading from lifting and carrying (vibrating) equipment and concrete is as significant as improvement in safety due to elimination of cables, vibrators, transformers, etc. on the job sites; another positive effect of vibration nose elimination is that it creates less disturbance to the construction site neighbours;
- productivity enhancement – casting with SCC is much faster, which makes concreting process no longer a "critical phase" as far as construction timing is concerned; the limitation is rather logistics of concrete supply;
- improved surfaces – reduction of surface defects, like honeycombing, blowholes, discolouration, etc. caused by the concrete construction processes is of a great importance; experience show that there are good possibilities of obtaining smooth and clean surfaces with SCC, but the choice of formwork material, release agents as well as some other factors, like temperature, casting methods, etc. are vital;
- more reliable mechanical properties of hardened SCC – because of the improved and more uniform microstructure the mechanical properties of SCC becomes more reliable and in some instances improved: bond to steel reinforcement, durability, compressive strength;
- new design options – traditional vibrated concrete technology is setting limits to the shape of the structure to be built; filling a formwork with easily deforming (flowing) concrete requiring no external compaction efforts presents possibilities of casting against negative formwork, inclined

double sided formwork, curved structures and so on; SCC offers opportunities and freedom to architects and engineers to create new shapes in concrete.

But these opportunities are not presented by themselves. Self-compacting concrete itself is only a media. There are other elements that need to be considered and realised to convert the opportunities to the real benefits and values. There would be not much benefit gained when SCC was considered as a replacement for traditionally vibrated concrete, but the traditional design, planning and construction methods were still in use. It is not self-compacting concrete, but self-compacting concrete technology which uncovers all the potentials for the concrete construction industry. With all its potential values and benefits, self-compacting concrete, however, should not be used to compensate for poor design, planning, or execution.

Barriers

Success with SCC is based on two big 'C's – Competence (knowledge) and Confidence (experience). The later develops with former, and both grow together with time. It is very well known that implementation of innovation into the construction industry is a very difficult process. SCC technology is no different.

Lack of standardisation is seen as one of the major obstacles for the engineers to specify and for users to verify SCC properties at fresh state. Fresh properties of SCC are far more complex than those of traditional vibrated concrete. In addition to the slump flow, viscosity properties very often have to be taken into account for specific applications of SCC. Moreover, simple ways of assessing flow characteristics of SCC do not seem to be as reliable (simply because results are dependent on the operator and the quality of the testing equipment) as true rheological, using viscometers and rheometers, but these apparatuses are expensive and cannot be easily used outside of the research laboratories.

New technologies require extensive research and development. SCC technology is the most 'researched' concrete material. But, yet, traditional technologies and construction methods offer 'safe' and established practices which need far less investment into research. And of course the message to the users of SCC might be that SCC is not 'safe' and risky, simply because it is 'under investigation'.

There are many other barriers and obstacles on the way of SCC technology implementation, like high price of concrete, increase in quality control measures and so on, but the most significant are remaining fragmentation of concrete construction industry and responsibility transfer.

It is well known that concrete construction industry is fragmented and diverse. The fragmented structure of the industry is a major problem to change or adapt to new technologies[1]. The industry fragmentation is associated with the fact that many involved disciplines (design, production, construction, specialist contractors and consultants) are separated and, therefore, damage innovation perspectives. Supply chain is long and complex, which makes it extremely difficult to bring all the parties together.

The concrete workability check on the construction site is normally a responsibility borderline, and fresh concrete properties are expected to be maintained within specified tolerances until concrete is placed. With traditional vibrated concrete, the concrete manufacturer's responsibility is confined to manufacture and delivery of concrete to construction site. It is expected that concrete manufacturer would maintain required fresh concrete properties during the placement, but, usually, acceptance occurs at the time of workability check. This process is well established and responsibility boundaries are very clear: from accepting the concrete, it is up to the concrete contactor how the concrete is placed. Placing SCC no longer requires as much effort as it would with traditional concrete, which means that the concrete contractor's role in placing SCC is very minimal. The quality of concrete structures made with SCC depends much more on the fresh concrete properties, placing more responsibility onto concrete supplier. Although it is still the contractor's responsibility to make sure that formwork is suitable for SCC, the boundaries of responsibilities are becoming unclear, as workability check is now part of concrete

[1] Construction 2020 – A Vision for Australia's Property and Construction Industry, Keith Hampson and Peter Brandon, 2004

supplier's internal quality assurance procedure and contractor becomes an observer rather than active actor in placing concrete.

Breaking the Barriers

There is no secret that the level of education and skills on construction site is diminishing. Coupled with fragmented structure of concrete construction industry, this calls for more robust technologies. As for SCC technology, the main focus is on robustness of mix designs. This ensures that normal variations in concrete production do not greatly affect the quality and consistency of SCC. This can be achieved through

- applying more science into mix engineering,
- improving quality and consistency of raw materials through closer cooperation, training and education of the raw material suppliers,
- training and education of concrete production and concrete delivery personnel,
- optimising concrete production and delivery processes and gradually upgrading concrete production facilities.

As it was mentioned before the great interest in SCC initiated a vast number of research projects all around the world, but the majority of these projects focus on technical aspects of SCC technology. The results of this research are very valuable, but they do not seem to be transferring easily to the construction industry, to those who actually doing the work. Local industries need to gain their own experience and knowledge through the industry R&D activities. Combined industry competence and confidence are obtained through collective and applied research projects and technology development. Such research should not be limited to the technical aspects only, but rather technological: design, production, construction, as well as evaluation of advantages and drawbacks.

New Business Organisation

Innovative technologies demand innovative business organisations.

It has been shown lately that construction industry tries to break its fragmentation management and procurement structures creating new innovative business organizations like design-and-build. This certainly allows for easier implementation of innovations and the use of advanced technologies. This also tolerates the use of more advanced project specifications, like performance based, rather than obsolete prescriptive types, which have not been changed much for the last 30-40 years or more in some instances. Performance based specifications are free of process limitations and construction methods, which opens the doors to innovations in construction processes, like self-compacting concrete.

The responsibility transition on the concrete construction site offers new opportunities and challenges for both concrete supplier and the contractor. For example, the contractor can reduce the amount of work needed for casting, as concrete supplier may start taking responsibility to deliver SCC directly into the formwork as it ensures more control over fresh concrete properties. This in return offers the supplier a number of benefits. For example, an opportunity to optimise the truck fleet utilization. This might progress further and also include subcontracting to the readymix concrete supplier more of the sub-processes, that is formwork construction, finishing, curing, demoulding, etc. This may sound absurdly, but it has its positive moments. Maintaining required fresh properties of concrete is critical for the quality of the complete structure. The timing issue is very sensitive as far as acceptance of concrete workability is concerned. And, in reality, the workability testing and acceptance is more linked to the responsibility rather than quality. One single business unit would be responsible for the complete process including concrete mix design, concrete manufacture, concrete delivery, casting and curing. The product delivered to the next business unit would be a complete concrete structure. Similar to an independent precast

operation[2]. Here we've got concrete mix design, concrete manufacture, concrete delivery, concrete placement and curing are all under one roof. The main focus of such operation is on its efficiency and the quality of the final product – precast elements. On the top of that, specifiers do not normally interfere with precast manufacturers as far as fresh concrete properties are concerned.

Future

We can confidently say now that self-compacting concrete technology is here to stay.

SCC potential is high and it is used every day and nearly every day new opportunities and applications are discovered. As technology progresses, especially with development of surface active, stabilising (also known as viscosity modifying), and other types of admixtures, SCC researchers, designers, and users come about new ideas of utilising technological benefits. The range is from SCC for slip-cast paving to ECO-SCC (economical, low cement content)[3] and curved walls with differently coloured concretes[4]. Needles to mention very successful use of SCC for architectural concrete structures

The fresh properties of SCC are far more complex than those of conventionally vibrated concrete. Understanding the behaviour of SCC at fresh state is the vital competency. Knowledge in rheology of cement pastes, mortars and concrete will help material designers to improve robustness of self-compacting concrete and process designers to develop improved production processes. As with traditional vibrated concrete, SCC is designed with the use of local materials. Every mix is unique and there is a very little chance that SCC mix designed elsewhere could be applied. Hence, there is a need for sufficient competence at concrete mix design and concrete batching plant levels.

The worldwide combined knowledge in main aspects of SCC technology is huge. And it is still growing. The scientist and researchers from all over the world will continue provide support to the construction industry to better understand SCC technological advances and offer assistance in realizing new opportunities and applications. The big task now is to transfer such combined knowledge to all the players in the local construction industries. The industry should be well aware about the benefits and opportunities as well as limitations and drawbacks of the new technology. There is an urge for the local concrete industries to be more integrated and united in the R&D work and such work should become more state of practice with the focus on technological and productivity enhancement developments.

Innovations and new technology developments lead to new test methods and standartisation. SCC is acting as a liquid not requiring any other external influence during the test procedure. This implies the possibilities of carrying testing directly on concrete during production (in the mixer) or transportation (pump line). Developments in this area will most certainly simplify the concrete acceptance and allow assurance without process interruption, as it will eliminate concrete sampling. Developments in SCC acceptance methods and standartisation will also change the way concrete is specified shifting more towards performance based specifications.

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[2] 'From Research to Routine Practice. The European Experience with Self-Compacting Concrete', Ake Skarendahl, Managing Director, Swedish Construction Sector Innovation Centre. Proceedings, NZ Concrete Society Conference 2003, Concrete – Function and Form.

[3] The Third North American Conference on the Design and Use of Self-Consolidating Concrere, Chicago, November 2008

[4] Upcrete® and SCC –a new technology for precast units with stringent requirements. CPI – Concrete Plant International, #1 February 2009