Application of Self-Compacting Concrete, Worldwide Experiences

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Abstract

Due to its various advantages of Self-Compacting Concrete, SCC have been successfully used in some large projects in many countries in the past decades. In fact(In fact,) SCC has transformed the way that concrete construction is performed through the world. While SCC may no longer be considered a "new concrete" there are still significant challenges to overcome before there is a broader of SCC in both cast-in-place and precast industry. This paper discussed the application of SCC in various countries, their successful experiences, problems that have been solved and lesson learned when using this type of concrete.

Key words: Self-Compacting Concrete, SCC, Concrete, Quality Control, Workability.

1. Introduction

ACI committee 237 (2007) defines SCC as “highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation.” ASTM C 09.91 (2006) defines SCC as “concrete that can flow around reinforcement and consolidates under its own weight without additional effort and without exceeding specified limits of segregation.”

By the early 1990’s Japan had developed and used SCC that did not require vibration to achieve full compaction (Ouchi et al., 2003).

The application of concrete without vibration in some large projects such as underwater seal concrete placement is done by the use of a termite without vibration, mass concrete has been placed without vibration, shaft concrete can be successfully placed without vibration and Highway Bridge and tunnel construction is not new. These concretes are generally of lower strength, less than 34.5 MPa and

difficult to attain consistent quality. New application of self-compacting concrete (SCC) is focused on high performance-better and more reliable quality, dense and uniform surface texture, improved durability, high strength and faster construction.
Lack of uniformity and complete compaction of concrete by vibration, researchers at all over the world, started out in late 1980's to develop SCC. By the early 1990's, some countries such as Japan has developed and used Self-Compacting Concrete that does not require vibration to achieve full compaction. More and more applications of SCC in construction have been reported in some Literatures. The amount of SCC used for prefabricated products (precast members) and ready-mixed concrete (cast-in-place) in Europe particularly Scandinavia and United States and other Asia pacific countries have been reported. It is clear from the proliferation of publications both in journals and in major international conferences in the past decades that the volume of research in this exciting new technology has been steadily increasing and has been spreading throughout the world.
However, in the past decades, SCC still remains as a relatively limited technology, despite the many benefits that have been demonstrated in numerous construction application.
Mix design, material selection, quality control and cost are all important factors for the successful production of SCC [4].

TRANSPORTATION

• The truck drivers should be given oral and written instructions for handling SCC. The truck drivers must check the concrete drum before filling with SCC to make sure that the drum is clean and moist, but with no free water. Extra care must be taken for long deliveries. In addition to the usual information, the delivery note should show the following information:

- o Slump flow . Target value and acceptable range.
- o Production time . Time when it was produced.
- o Instruction for adding admixtures at the site, if allowed.

• The truck drivers should not be allowed to add water and/or admixtures during transit.

FORM SYSTEM

• All commonly used form materials are suitable for SCC. For surface quality of SCC, wood is better than plywood, and plywood is better than steel. More pores seem to form on the surface when the form skin is colder than the SCC. During cold weather placement of SCC, it may be necessary to insulate the formwork to maintain temperature and normal setting time. SCC is more sensitive to temperature during the hardening process than the conventional vibrated concrete.
• Due to the cohesiveness of SCC, the formwork does not need to be tighter than that for conventional vibrated concrete.
• Higher form pressures than normal were not observed even at high rate of concrete placement. However, it is recommended that the formwork be designed for hydrostatic pressure, unless testing has shown otherwise.

SURFACE FINISHING AND CURING

• Finishing and curing of SCC can follow the good practices of superplasticized high performance concrete. Surface of SCC should be roughly leveled to the specified dimensions, and the final finishing applied as necessary before the concrete hardens.
• SCC tends to dry faster than conventional vibrated concrete, because there is little or no bleeding water at the surface. SCC should be cured as soon as practicable after placement to prevent surface shrinkage cracking.

COLD JOINT

• When placing a new layer of SCC on old SCC, the bond between the old and new SCC is equal to or better than in the case of conventional vibrated concrete. Normal vibration will not destroy the concrete, such as in the case of placing conventional vibrated concrete on fresh SCC. This may be necessary when the surface slope is greater than practicable for SCC.

2. REQUIREMENTS FOR SELF-COMPACTING CONCRETE

2.1. Application area

SCC may be used in pre-cast applications or for concrete placed on site. It can be manufactured in a site batching plant or in a ready mix concrete plant and delivered to site by truck. It can then be placed either by pumping or pouring into horizontal or vertical structures. In designing the mix, the size and the form of the structure, the dimension and density of reinforcement and cover should be taken in consideration. These aspects will all influence the specific requirements for the SCC.

Due to the flowing characteristics of SCC it may be difficult to cast to a fall unless contained in a form.

SCC has made it possible to cast concrete structures of a quality that was not possible with the existing concrete technology.[12]

2.2. Requirements

SCC can be designed to fulfil the requirements of EN 206 regarding density, strength development, final strength and durability. Due to the high content of powder, SCC may show more plastic shrinkage or creep than ordinary concrete mixes. These aspects should therefore be considered during designing and specifying SCC.

Current knowledge of these aspects is limited and this is an area requiring further research. Special care should also be taken to begin curing the concrete as early as possible.

The workability of SCC is higher than the highest class of consistence described within EN 206 and can be characterised by the following properties:

Filling ability

Passing ability

Segregation resistance

A concrete mix can only be classified as Self-compacting Concrete if the requirements for all three characteristics are fulfilled.

3. Case studies

3.1. Case studies

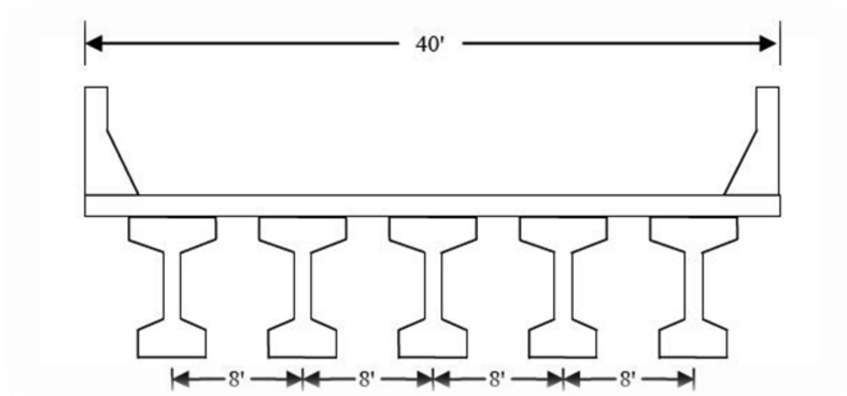
In 1996, a large consortium was formed by European countries to develop SCC for practical application. As a result, a large number of SCC bridges, walls, and tunnel linings have been constructed in Europe (Ouchi et al., 2003). In 2000, approximately 10 years after the development of SCC, the amount of SCC used in structures including bridge girders, walls, bridge towers and tunnels. By 2001, SCC had been used in 19 highway bridges in Sweden due to improved labor conditions (Persson,2001).Various typical SCC large projects from different countries are presented and discussed as follows: [6]

3.1.1. Bridge Girders Project and High Strength SCC:

Because of the favorable properties that SCC exhibits, the Federal Highway Administration and the precast concrete industry have been promoting the research and development of SCC for structural applications in bridges. If SCC is properly specified and used, it has the potential to yield more economical and higher quality prestressed concrete products than conventional concrete. To take advantage of this new technology, there was a need to study production feasibility and structural performance of prestressed SCC bridge girders made with aggregates. Proportioning, behavior, and properties of SCC are highly dependent on the coarse aggregates physical properties. Two types of aggregates, crushed limestone and quartzite, are frequently used in preparing concrete for bridges.

A hypothetical two lanes bridge was considered for the girder design. The girders are assumed to have a span of 40 feet and a center-to-center spacing of eight feet. A schematic cross sectional view of the hypothetical bridge is shown in below Figure1.

Figure1- Schematic Cross Section of the Hypothetical Bridge



The present laboratory tests show the behavior of SCC is similar to or better than conventional concrete of the same strength.
The material cost of SCC is approximately 26% more than that of conventional concrete. However, the enhanced finished quality and the production efficiency of SCC girders make SCC an attractive choice among concrete producers. This may result in better finished product at no additional cost to the client.
The high cost of replacing and/or upgrading the deficient bridges has prompted engineers to investigate the feasibility of constructing new bridges using innovative materials that possess enhanced engineering properties.
High strength concrete was used to reduce structure loading and column size. Many requirements for high strength concrete mixture are as follows:

1. Mean elastic modulus of 39 GPa at 28 days.
2. Mean compressive strength of 90 MPa. Target 108 MPa at 28 days.
3. Pumpable to a height of 320 meter without blocking, segregation or dewatering in a single stage.
4. Fully self-compacting under its own weight(minimal compaction is acceptable).

Critical Solution

a) Pump to a height 320 m- need to use of special PC-based super plasticizer to adjust the flowability over the working period in order to compensate flow lost during pumping.
b) Maintaining concrete temperatures below of 25 degree of centigrade target was difficult to achieve during the summer months.
c) Minimize air-entraining effect in concrete under extreme high pressure during pumping-super plasticizer was especially formulated to meet this requirement.
d) To achieve the specified elastic modulus-volcanic rock was used as the coarse aggregate.

Observation:
It was observed that precast, prestressed T-girders by SCC manufactured in the PC factory showed good cost performance if some conditions are satisfied. However, in many cases, SCC in Japan is still regarded as special concrete because of its cost performance and difficulty of quality control, although it is apparent that SCC offers many advantages to PC factory or cast-in-place concrete. Therefore, for

advanced expansion of SCC, it is significant to establish a new system that evaluates other values, such as life-cycle-cost and environmental issues.

3.1.2 Sewer Tunnel Project

The challenge with Tunnel project was how to fill the slot between the covers of the formwork with concrete and ensure complete filling and good surface finish. The previous practice was the use of normal slump concrete (150 mm) with vibration; however, large numbers of shallow trapped air pockets were found on the concrete surface after demdeling.

1. Due to inside casting and the limited access to the tunnel (only three manholes available for the whole length of the sewer line), it was very difficult to get the concrete to the form. Highly flowable concrete had to be pumped up to 600 m to the tunnel through manholes.
2. The shrinkage is to be less than 0.03%.
3. Very high flow was necessary for the narrow spaces within the formwork to create concrete with no voids, bubbles and aggregate pockets.
4. The early strength development to allow stripping of formwork by 12 – 14 hours because of a two shift/day production schedule.

To meet these stringent requirements, the SSC mix was designed with a low water/cement to reduce shrinkage as well as with a shrinkage-reducing admixture. Examples of Tunnels are shown in below Figures 2, 3:

Figure2 - Tunnel picture in Los Angeles, USA

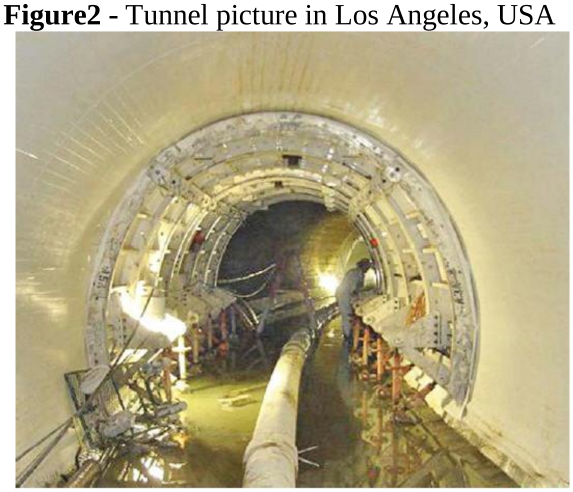
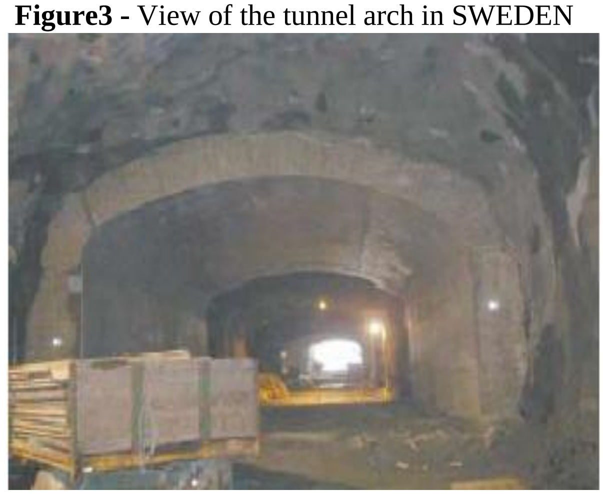


Figure3 - View of the tunnel arch in SWEDEN



4. Conclusions

Self-Compacting Concrete has optimized performance characteristics the durable reliable concrete structure can be achieved through lower water to cementitious ratio and use of larger amount of mineral fillers. New mix-proportion designed new test method of workability for SCC were developed extensive experiences and theoretical analysis indicate that the existing structural design and analysis method for normal concrete are applicable to SCC.
Relevant techniques should be developed and rational training and qualification system for engineers should be established to promote the rapid diffusion of the techniques for the production of Self Compacting Concrete. In summary, there is a need for research to investigate both short-term and long-term performance of SCC girders fabricated with locally available materials and to check the accuracy and applicability of available test procedures,

design tools, and material models before Mn/DOT can confidently allow the use of SCC for bridge girders in the State of Minnesota.

5. Summary:

1. The elimination of vibrating equipment improves the environment protection near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration.
2. SCC is favorably suitable especially in highly reinforced concrete members like bridge decks or abutments, tunnel linings or tubing segments, where it is difficult to vibrate the concrete, or even for normal engineering structures.
3. The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction. Based on these facts it can be concluded that SCC will have a bright future.
4. SCC can be design by combining it with other type of admixtures or materials, to meet different types of engineering requirements and produce not only highflow, but also high performance and durable concrete.

5• Production of SCC requires more experience and care than the conventional vibrated concrete. The plant personnel would need training and experience to successfully produce and handle SCC. In the beginning, it may be necessary to carry out more tests than usual to learn how to handle SCC and gain the experience.

6• Before any SCC is produced at the plant and used at the job site, the mix must be properly designed and tested to assure compliance with the project specifications. The ingredients and the equipment used in developing the mix and testing should be the same ingredients and equipment to be used in the final mix for the project.

7• Admixtures for the SCC may be added at the plant or at the site. There is cost benefit in adding the admixtures at the site. Conventional ready-mix concrete can be bought at a lower cost than the cost of SCC bought from a ready-mix supplier.

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