Basic Principles and Requirements of Self Compacting Concrete

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ABSTRACT

Self compacting concrete (SCC), also referred to as self-consolidating concrete, is able to flow and consolidate under its own weight. It is cohesive enough to fill the spaces of almost any size and shape without segregation or bleeding. A SCC, which has excellent deformability and resistance to segregation and can be filled in heavily, reinforced formwork without vibrators. The physical behaviour of the wet concrete extremely flow-able cohesive means that it can be placed without the need for vibration, yet giving a hardened concrete which exhibits excellent results for surface finish, density and strength. The required workability for casting depends on several factors, such as the type of construction, the selected placement and consolidation methods, the shape of formwork, and the congestion nature of the reinforcement. With the increasing use of congested reinforcements in mat foundations and moment-resisting reinforced concrete structures, there is a growing interest in specifying highly flow-able concrete (Okamura, Ozawa, Ouchi 2000). New SCC technology can eliminate the need for vibration, making it possible to reduce labour costs while improving the overall work environment for construction personnel. Faster placement and less finishing time can improve productivity and profitability. Increased flow-ability and consolidation can improve appearance and enhance the durability of the finished element.

Keywords: *self compacting, workability, testing methods*

Introduction

Majority of concrete cast relies on compaction to ensure that adequate strength and durability is achieved. Insufficient compaction will lead to the inclusion of voids that not only leads to a reduction in compressive strength but also strongly influences the natural physical and chemical protection of embedded steel reinforcement afforded by concrete. Concrete is normally compacted manually using vibrators, often operated by untrained labour and the supervision of the process is inherently difficult. Although poorly compacted concrete can be repaired, overall durability is more often than not reduced. From here, the consequences of concrete compaction not only affect the material but also general health, safety and environmental risks including high levels of noise. In addition, recent research work has shown that the perception of full compaction does not actually produce a homogeneous concrete (Gibbs & Zhu 1999).

The concept of self-compacting concrete (SCC) resulted from research into underwater concrete, in situ concrete piling and the filling of other inaccessible areas. Before the advent of super-plasticizers and other admixture, the cost of mixes for those purposes were often expensive with high cement contents required to offset associated high water contents. The development of water-reducing super-plasticizers meant high-workability and high-strength concrete could be achieved without excessive cement contents but excessive segregation and bleeding restricted the use of admixtures to flowing concrete having slumps of between 120 mm and 150 mm. These concretes still required a degree of compaction.

It was recognized that the reducing number of skilled workers in the Japanese construction industry was leading to a reduction in the quality of construction work with subsequent knock-on effects on concrete durability (Skarendahl & Petersson 2000). In the last decade, self-compacting concrete has been developed further, utilizing various materials such as pulverized-fuel ash (PFA), ground granulated blast furnace slag (GGBS) and condensed silica fume (CSF). Structures are now incorporating self-compacting concrete unfeasible and self-compacting concrete is now also well established in a number of countries such as Sweden and USA.

Feature/ benefit analysis would suggest that the following benefits should result in:

i. Increased productivity levels leading to shortened concrete construction time
ii. Lower concrete construction costs
iii. Improved working environment
iv. Improvement in environmental loadings

v. Improved in situ concrete quality in difficult casting condition
vi. Improved surface quality

Non-vibrated concrete is already a common place in the construction industry and is used with acceptable results like in piling and shotcrete applications. Development of SCC has mainly focused on congested civil engineering structures and its acceptance within the market place has primarily grown in solving technically difficult casting conditions.

Basic Principles for SCC

Self-Compacting Concrete (SCC) was first developed in Japan about 10 years ago in order to reach durable concrete structures. Since then, several investigations have been carried out to achieve a rational mix design for a standard concrete, which is comparable to normal vibrated concrete. Self-compacting concrete is defined, so that, no additional inner or outer vibration is necessary for the compaction. SCC is compacting itself alone due to its self-weight and is deaerated almost completely while flowing in the formwork. In structural members with high percentage of reinforcement it fills also completely all voids and gaps. SCC flows like "honey" and has nearly a horizontal concrete level after placing. With regard to its composition, self-compacting concrete consists of the same components as conventionally vibrated normal concrete, which are cement, aggregates, water, additives and admixtures.

However, the high amount of super-plasticizer for reduction of the liquid limit and for better workability, the high powder content as "lubricant" for the coarse aggregates, as well as the use of viscosity-agents to increase the viscosity of the concrete have to be taken into account. In principle, the properties of the fresh and hardened SCC, which depend on the mix design, should not be different from Normal Concrete. One exception is only the consistency. SCC should have a slump flow > 65 cm after pulling the flow cone. Figure 1 shows the basic principles for the production of SCC (Dehn, Klaus & Dirk 2000).

The durability of concrete, it was noted, is directly related to the degree and quality of consolidation efforts, which in turn is related to the skill level of the person operating the consolidation equipment. The apparent difficulty in attracting and retaining skilled workers compounds the problems with durability. (Nakajima, Nakazono & Mori 2002) Unfortunately, many other parts of the world have also experienced the

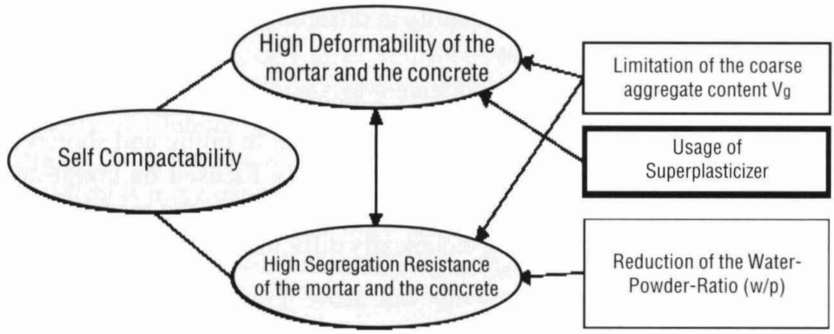

Fig. 1: Basic Principles for the Production of Self-Compacting Concrete

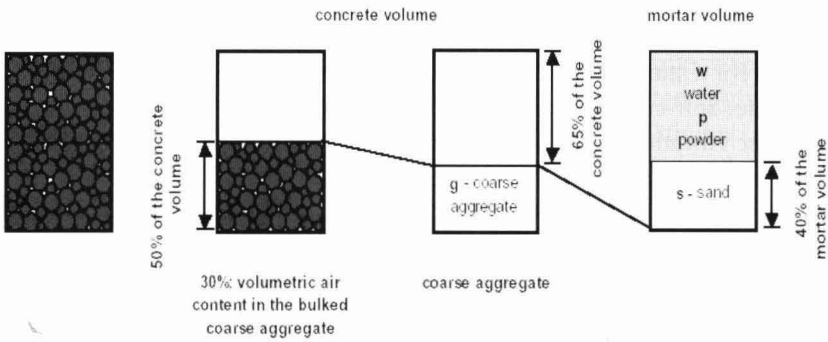

Fig. 2: Determination of the Mix Components for SCC

same problems. As a result, additional research and advancements into SCC technology have since been made, most notably in Europe.

Requirements for SCC

Application Area

SCC differs from conventional concrete, in that its fresh properties are vital in determining whether or not it can be placed satisfactorily. 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 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 (Billberg 2002).

Requirements

SCC can be designed to fulfil the requirements 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. 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 and can be characterized by the following properties:

i. Filling ability (unconfined flow-ability)
The ability of SCC to flow into and fill completely all spaces within the formwork, under its ownweight.
ii. Passing ability (confined flow-ability)
The ability of SCC to flow through tight openings such as spaces between steel reinforcing bars.
iii. Segregation resistance (stability)
The ability of SCC to remain homogeneous in composition during transport and placing.

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

The various aspects of workability need to be carefully controlled to ensure that its ability to be placed remains acceptable.

Test Methods

Many different test methods have been developed in attempt to characterize the properties of SCC. So far no single method or combination of methods has achieved universal approval and most of them have their adherents. Similarly, no single method has been found to characterizes all the relevant workability aspects so each mix design should be tested by more than one test method for the different workability parameters. The test methods to be developed should involve both methods for laboratory tests and site tests.

It is important to appreciate that none of the test methods for SCC has yet been standardized, and the tests described are not yet perfected or definitive. The methods presented here are descriptions rather than fully detailed procedures. They are mainly ad-hoc methods, which have been devised specifically for SCC. Existing rheological test procedures have not been considered here, though the relationship between the results of these tests and the rheological characteristics of the concrete is likely to figure highly in future work, including standardization work.

One principal of the difficulty in devising such tests is that they have to assess three distinct, though related, properties of fresh SCC. No single test so far devised can measure all three properties. There are a number of points which should be taken into account:

i. There is no clear relation between test results and performance on site
ii. There is little precise data; therefore, no clear guidance on compliance limits
iii. Duplicate tests are advised
iv. The test methods and values are stated for maximum aggregate size

Table 1: List of Test Methods for Workability Properties of SCC

	Test	Property
1	Slump-flow by Abrams cone test	Filling Ability
2	T50cm slump spread test	Filling Ability
3	V-funnel test	Filling Ability
4	Orimet test	Filling Ability
5	J-ring test	Passing Ability
6	L-shape box test	Passing Ability
7	U flow test	Passing Ability
8	Fill-box test	Passing Ability
9	V-funnel at T5 minutes	Segregation resistance
10	GTM screen stability test	Segregation resistance

of up to 20 mm; different test values and/or different equipment dimensions may be appropriate for other aggregate sizes

v. Different test values may be appropriate for concrete being placed in vertical and horizontal elements

vi. Similarly, different test values may be appropriate for different reinforcement densities?

For the initial mix design of SCC all three workability parameters need to be assessed to ensure that all aspects are fulfilled. A full-scale test should be used to verify the self-compacting characteristics of the chosen design for a particular application.

Slump Flow Test and T50 cm Slump Spread Test

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of underwater concrete. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete. This is a simple, rapid test procedure, it can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential (Tanigawa, Yonezawa, Izumi & Mitsui 1990). It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the

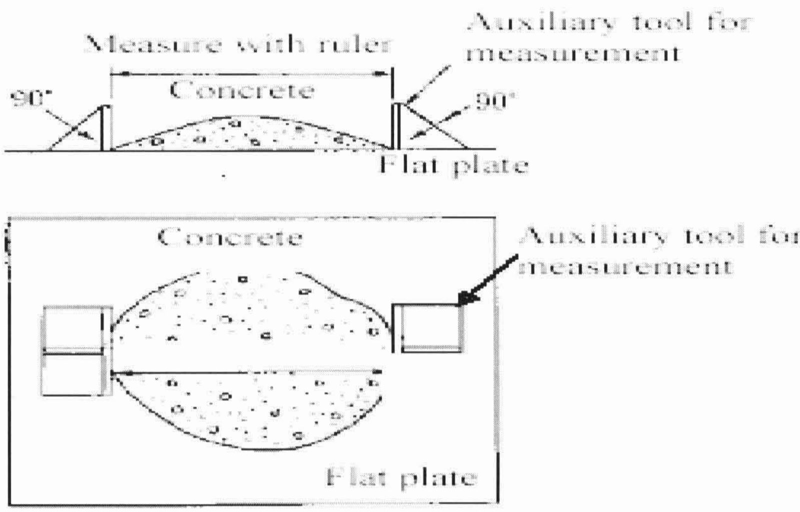

Fig. 3: Slump Flow Test

ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably be used to assess the consistency of supply of ready-mixed concrete to a site from load to load.

The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A value of at least 650 mm is required for SCC. The T50 time is a secondary indication of flow. A lower time indicates greater flow ability.

V Funnel Test and V Funnel Test at T 5 minutes

The equipment consists of a V-shaped funnel, shown in Figure 4. An alternative type of V-funnel, the O funnel, with a circular section is also used in Japan. The described V-funnel test is used to determine the filling ability (flow ability) of the concrete with a maximum aggregate size of 20 mm. (Ozawa, Sakata & Okamura 1995)

Though the test is designed to measure flow ability, the result is affected by concrete properties other than flow. The inverted cone shape will cause any liability of the concrete to block to be reflected in the result – if for example, there is too much coarse aggregate. High flow

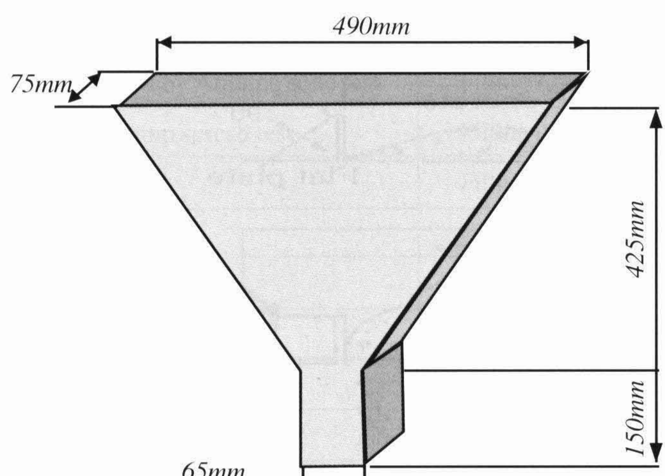

Fig. 4: V-funnel Test Equipment (Rectangular Section) to Determine Flow Time of the Mortar

time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction. While the apparatus is simple, the effect of the angle of the funnel and the wall effect on the flow of concrete are not clear.

This test measures the ease of flow of the concrete; shorter flow times indicate greater flow-ability. For SCC a flow time of 10 seconds is considered appropriate. The inverted cone shape restricts flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking. After 5 minutes of settling, segregation of concrete will show a less continuous flow with an increase in flow time.

L box Test

The test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement (Petersson, Billberg & Van 1996). The apparatus consists of a rectangular-section box in the shape of an 'L', with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted. The vertical section is filled with concrete and then the gate lifted to let the concrete flow. When the flow stopped, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H_2/H_1in the diagram). It indicates the slope of the concrete when at rest. This is an indication passing ability, or the degree to which the passage of concrete through the bars is restricted. The horizontal section of the box can be marked at 200 mm and 400 mm from the gate and the times taken to reach these points measured. These are known as the T_{20} and T_{40} times and are an indication for the filling ability. The sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, three times the maximum aggregate size might be appropriate. The bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete (Domone, Chia 1996).

This is a widely used test, suitable for laboratory, and perhaps site use. It assesses filling and passing ability of SCC, and serious lack of stability (segregation) can be detected visually. Subsequently sawing and inspecting sections of the concrete in the horizontal section may also detect segregation. Unfortunately, there is no agreement on materials, dimensions, or reinforcing bar arrangement, so it is difficult to compare test results. There is no evidence of what effect the wall of the apparatus and the consequent 'wall effect' might have on the concrete flow, but this arrangement does, to some extent, replicate what happens to concrete on site when it is confined within formwork. From the result, if the concrete flows as freely as water, at rest it will be horizontal, so H_2/H_1 = 1. Therefore, the nearer this test value, the 'blocking ratio', is to unity, the better the flow of the concrete.

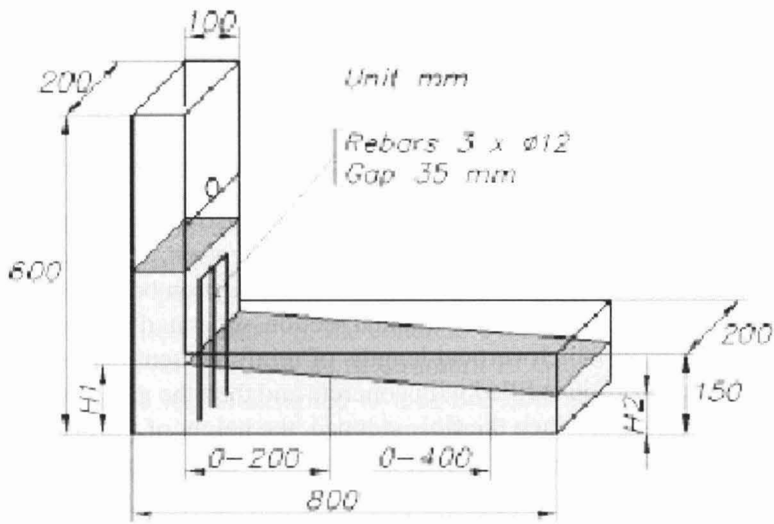

Fig. 5: L-box

U Flow Test

Sometimes, the apparatus is called a "box-shaped" test. The test is used to measure the filling ability of SCC. The apparatus consists of a vessel that is divided by a middle wall into two compartments, shown by R1 and R2 in Figure 6 An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacing of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 litre of concrete then the gate lifted and concrete flows upwards into the other section. The height of the concrete in both sections is measured (Haykawa 1993).

This is a simple test to conduct, but the equipment may be difficult to construct. It provides a good direct assessment of filling ability – this is literally what the concrete has to do – modified by an unmeasured

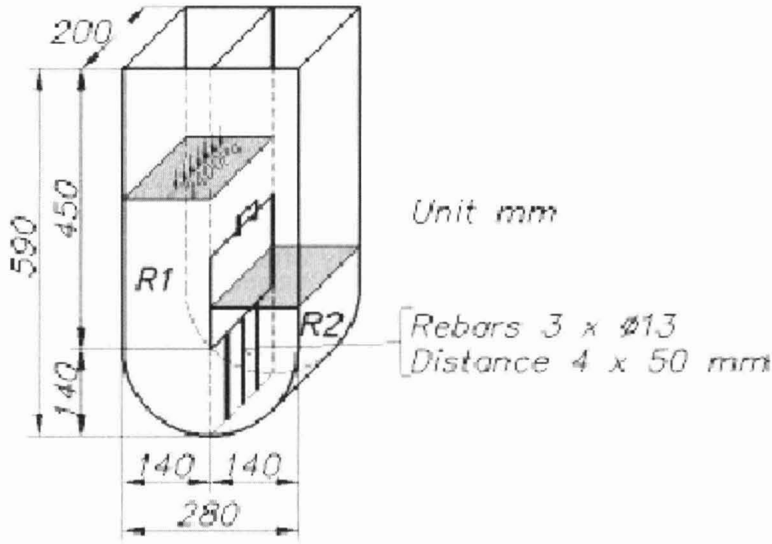

Fig 6: U Flow Test

requirement for passing ability. The 35 mm gap between the sections of reinforcement may be considered too close. The question remains open of what filling height less than 30 cm. is still acceptable (Kuroiwa, Matsuoka, Hayakawa & Shindoh 1993). If the concrete flows as freely as water, at rest it will be horizontal, so $H_1 - H_2 = 0$. Therefore, the nearer this test value, the 'filling height', is to zero, the better the flow and passing ability of the concrete.

J Ring Test

The J Ring test is used to determine the passing ability of the concrete. The equipment consists of a rectangular section (30 mm x 25 mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. The diameter of the ring of vertical bars is 300 mm and the height is 100 mm.

The J Ring bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete. After the test, the difference in height between the concrete inside and that just outside the J Ring is measured. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted.

From the result, it should be appreciated that although these combinations of tests measured the flow and passing ability, the results are not independent. The measured flow is certainly affected by the degree to which the concrete movement is blocked by the reinforcing bars. The extent of blocking is much less affected by the flow characteristics and we can say that clearly the greater the difference in height, the less the passing ability of the concrete. Blocking and/or segregation can be detected visually often more reliably then by calculation.

Fill Box Test

This test is used to measure the filling ability of SCC with maximum aggregate size of 20 mm. The apparatus consists of the container (transparent) with a flat and smooth surface. In the container are 35 obstacles made of PVC with a diameter of 20 mm and the distance centre to centre of 50 mm. At the top side is a filling pipe (diameter 100 mm, height 500 mm) with a funnel (height 100 mm). The container is filled with concrete through the filling pipe and the difference in height between two sides of the container is a measure for the filling ability. If the concrete flows as freely as water, at rest it will be horizontal, so average filling percentage is equal to 100%. Therefore, the nearer this test value, the filling height is to 100%, the better the self compacting characteristic of the concrete.

GTM Screen Stability Test

This test consists of taking a sample of 10 litre concrete allowing it to stand for a period to allow any internal segregation to occur, the pouring half of it on to a 5 mm sieve of 350 mm diameter which stands on a sieve pan on a weight scale. After 2 minutes, the mortar which passed through the sieve weighed and expressed as a percentage of the weight of the original sample on the sieve. Empirical observation suggests that if the percentage of mortar which has passed through the sieve, the segregation ratio is between 5% and 15% of the weight of the sample, the segregation resistance is considered satisfactory. Below 5% the resistance is excessive and likely to affect the surface finish (blow holes likely) while above 15% and above 30%, there is strong likelihood of segregation.

Orimet Test

This test is a method for assessment of highly workable, flowing fresh concrete mixes on construction sites. It is based on the principle of an orifice rheometer that consists of a vertical casting pipe fitted with a changeable inverted cone-shaped orifice at its lower, discharge, end, with a quick-release trap door to close the orifice. Usually the orifice has an 80 mm internal diameter which is appropriate for assessment of concrete mixes of aggregate size not exceeding 20 mm. Operation consists simply of filling the Orimet with concrete than opening the trapdoor and measuring the time taken for light to appear at the bottom of the pipe. This test measures the ease of flow of the concrete, shorter flow times indicate greater flow-ability. For SCC a flow time of 5 seconds or less is considered appropriate. The inverted cone shape at the orifice restricts flow and prolonged flow times may give some indication of the susceptibility of the mix to blocking and/or segregation (Bartos 1998).

Workability Criteria for the Fresh SCC

These requirements are to be fulfilled at the time of placing. Likely changes in workability during transport should be taken into account in production (a measure of the ease by which fresh concrete can be placed and compacted; is a complex combination of aspects of fluidity, cohesiveness, transportability, ability to compact and stickiness). The level of fluidity of SCC is governed chiefly by the dosing of the super plasticizer.

Conclusion

Self-compacting concrete (SCC) has been described as "the most revolutionary development in concrete construction for several decades" (Bartos 1998). Originally developed to offset a growing shortage of skilled labour, it has proved beneficial economically because of a number of factors, including:

i. faster construction
ii. suitable for small and large repair jobs
iii. reduction in site manpower
iv. better surface finishes and less finishing works required especially for slab

v. easier and higher speed of concrete placing
vi. improved durability
vii. thinner concrete sections
viii. reduced noise levels, absence of vibration
ix. safer working environment
x. shorten period of equipment utilization
xi. placing problems caused by heavy reinforcement are reduced?

Originally developed in Japan, SCC technology was made possible by the much earlier development of superplasticisers for concrete. SCC has now been taken up with successfully across Europe, for both sites and precast concrete work. Practical application has been accompanied by much research into the physical and mechanical characteristics of SCC and the wide range of knowledge generated has been sifted and combined in this guideline document. Investigations for establishing a rational mix design method and SCC testing methods have been carried out from the viewpoint of making SCC a standard concrete.

The applications of SCC are summarized below; bridge (anchorage, arch, beam, girder, tower, pier, joint between beam and girder), box culvert, tunnel, dam and concrete products (block, wall and water tank). The factors making up SCC were described in terms of the SCC test results for fresh concrete and mortar are:

i. influence of coarse aggregate depending on spacing size
ii. role of mortar as fluid in flow-ability of fresh concrete
iii. role of mortar as solid particles
iv. influence of coarse aggregate – content, shape and grading.

In order for SCC to be used as a standard concrete rather than a special one, new systems for its design, manufacturing and construction of SCC need to be established with followed the basic principles and basic requirements.

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