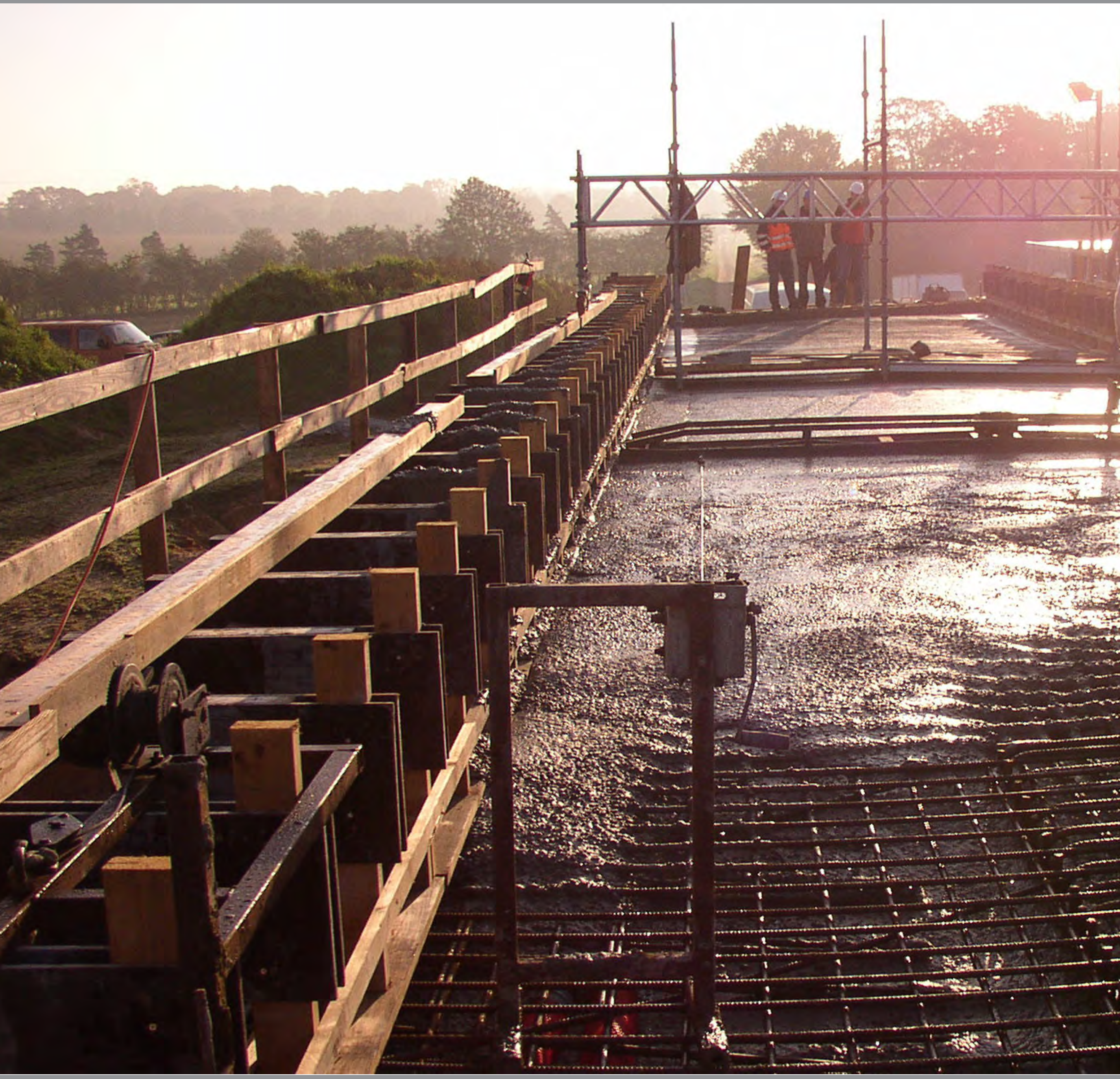
DANISH TECHNOLOGICAL INSTITUTE

Guidelines for Execution of SCC



SCC Consortium

Table of contents

Guidelines for Execution of SCC, May 2008

Publisher: *Danish Technological Institute, Concrete Centre*
Gregersensvej, DK-2630 Taastrup
+45 7220 2226 - concrete.centre@teknologisk.dk

Printing: *Paritas A/S*
ISBN: *87-7756-771-4*

Authors: *Lars Nyholm Thrane, Danish Technological Institute*
Claus Vestergaard Nielsen, Danish Technological Institute
Claus Pade, Danish Technological Institute

Layout: *Thomas Juul Andersen, Danish Technological Institute*

Cover page photo shows the casting of the SCC-Demo Bridge, 17 October 2006

Preface

The SCC Consortium was supported by the Danish Ministry of Science, Technology and Innovation during the period 2003-2007.

One of the most important results of the SCC Consortium's work was the production of two guidelines providing instructions on the composition of SCC and on the job site execution of SCC.

The present "Guidelines for Execution of SCC" is basically an English translation of the Danish guidelines published in 2007. Its main purpose is to contribute to a better understanding between the parties on the construction site regarding the use of SCC.

The contractor who orders concrete and performs the concrete works on the construction site can use the Guidelines to specify the correct flow properties for the concrete with regards to the method of casting, structural type and the form geometry.

The concrete manufacturer can use the Guidelines to correlate the flow properties of the concrete to the different types of applications, thereby, improving his understanding of the contractor's wishes, needs and requirements.

Consulting engineers and job site supervisors will benefit from reading the Guidelines to ensure that the concrete work is performed correctly.

SCC Consortium, May 2008

SCC means Self-Compacting Concrete or Self-Consolidating Concrete. It is defined as a concrete that flows by itself into the formwork and embeds the reinforcement without the use of vibration or any other external mechanical impacts.

However, it is possible to use manual handling such as rake and shovel and to use the gravitational energy from the placement to make it flow into its final position.

SCC Consortium's core partners were:

- *Danish Technological Institute, Concrete Centre (Consortium coordinator)*
- *Aalborg Portland A/S (Cement manufacturer)*
- *Unicon A/S (Ready-mixed concrete manufacturer)*
- *MT Højgaard a/s (Contractor)*
- *Betonelement a/s (Precast concrete manufacturer)*
- *DTU-IMM (Technical University, R&D)*
- *Videometer A/S (Supplier of high-tech equipment)*

www.SCC-Konsortiet.dk/english
www.VoSCC.dk

1. Introduction

SCC is the abbreviated term for Self-Compacting Concrete. The term pertains to the most promising new invention in the concrete industry over the past 20 years. Compared to traditional concrete, SCC does not require vibration during placement and casting. Thus, a number of work operations can be omitted, resulting in an increased productivity and a markedly improved working environment.

The biggest difference between traditional concrete and SCC is the consistency in its fresh state. Figure 1.1 shows traditional slump concrete and SCC. It is clear that the traditional slump measurement does not apply to SCC, and instead the slump flow measurement is the most used parameter to indicate the SCC consistency and workability. However, the so-called plastic viscosity is also needed to fully describe the flow properties of SCC as it is described in the following sections. The other important concrete properties, such as strength, elastic modulus, durability, etc., are by large identical for SCC and traditional concrete.

SCC is expected to contribute to reducing structural damages such as honey combing and incomplete form filling as well as damages to the inner structure of the concrete. However, SCC also has a number of pitfalls that the users should be aware of. The Guidelines may help to avoid these pitfalls.

The flow properties of SCC make it possible to embed dense and complicated reinforcement configurations without the use of vibration. SCC is capable of flowing out into even complicated form work geometries with recesses, openings etc., that would be very difficult or impossible to assess with a poker vibrator. Furthermore, the inner structure of the concrete will not risk being damaged due to the vibration.

Figure 1.1. The slump value of traditional concrete (left) measured as the setting of a 300 mm high concrete cone. The slump flow measurement of a similar SCC test object is shown on the right. The slump value for traditional concrete is typically in the range of 100-200 mm, while the slump flow for SCC is typically 500-700 mm.

One example of a pitfall is the use of SCC with a high slump flow value (say over 700 mm), which provides easy handling and placement of the concrete (with almost self-levelling properties). The inlet for the concrete can be located in one corner of the formwork, and the only parameter determining the filling rate is the concrete supplier's capacity. Such a scenario sounds tempting to a contractor, but it also increases the risk of segregation markedly and an unacceptable layer of paste will typically form on the concrete surface. It is therefore important to choose the right SCC flow properties for the specific task in correct relation to the applied casting technique. The Guidelines help to make these choices, and instructions are also provided for the contractor on how to ensure that the flow properties are as intended when conducting his quality control on the construction site.

To ensure a correct description of the flow properties of SCC a viscosity parameter has been introduced to supplement the slump flow measurement. More about this in the chapter on flow properties.

The Guidelines primarily focus on structures cast on site. However, the principles can naturally be applied to the precast concrete element production. The Guidelines give recommendations for the selection of flow properties based on the specific type of application and based on the selected casting method. There will also be recommendations on how to adjust the casting method if the concrete does not meet the intended flow properties.

Chapter 2 provides a number of general considerations that need to be made when using SCC and the differences compared to traditional concrete are described. Chapter 3 gives a brief introduction to the flow properties of SCC and the background of these. Chapters 4 and 5 provide recommendations for horizontal and vertical castings, respectively.

One important rule-of-thumb for SCC can be stated as: "The farther distance the concrete is able to flow – the less distance it should be allowed to flow." This rule might not make sense at first glance, but it will be explained in the Guidelines.

There are definitions for some important SCC terms in the last part of the Guidelines.

2. SCC compared to traditional concrete

Casting of SCC differs from traditional concrete in a number of ways that mainly associate with the execution and placement. The structural behaviour of the final concrete structure will not be different than that of traditional concrete. As with traditional concrete, the quality and strength are primarily determined using the correct cement content and cement type in combination with the proper water/cement ratio.

Figure 2.1 shows the normal connections between the building owner and his adviser(s) on the one hand, and the contractor and concrete producer on the other hand. The stacked boxes show the traditional responsibilities between the different parties on a construction project. Roughly speaking, compared to traditional concrete, SCC requires more planning of the concrete works and better internal communication between the concrete contractor and the concrete supplier to ensure a successful result.

The building owner and his advisers describe the requirements for a concrete structure in the project material that is prepared. These requirements are most often expressed based on current norms and standards and other relevant specifications such as national surface quality descriptions, road regulations, etc. The requirements for geometry, concrete quality and surfaces are set parameters upon which the concrete contractor must plan his work and choose the concrete.

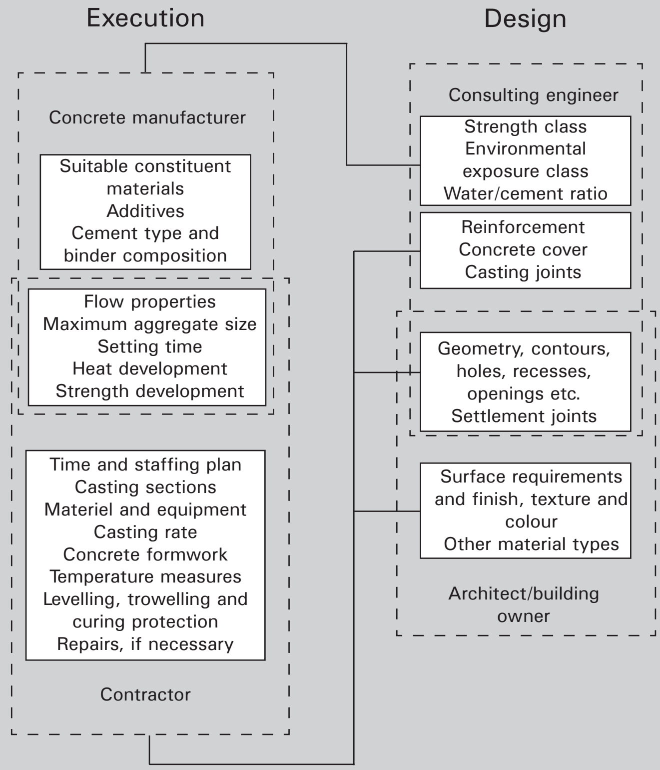


Figure 2.1. Collaboration between the different parties on the concrete work.

Composition of SCC is described in "Guidelines for Mix Design of SCC", May 2008.

The contractor's requirements for the flow properties have great significance for the mix design of the concrete, and there is a greater need for a close dialogue between the concrete manufacturer and the concrete contractor when applying SCC than is the case with traditional concrete. It is therefore important that the contractor and the concrete manufacturer speak the same language when they agree on the flow properties of the SCC for a certain application.

Below are a number of questions that the contractor and the concrete manufacturer can benefit from asking themselves when planning SCC castings.

A review of these questions provides some assurance that the most important SCC aspects have been taken into consideration before the work is commenced. Note that not all questions are relevant for all types of applications.

Contractor

- Is the mould ready and is it made tight enough?
- Has casting method been selected, as well as inlet position(s)?
- Is the formwork designed for hydrostatic pressure?
- Are the embedded parts secured against buoyancy and lifting forces?
- Is the concrete drop height less than 1 m? And only in special cases up to 2 m?
- Do the form geometry and the amount and spacing of the reinforcement give rise to critical issues regarding segregation and/or blocking?
- Have an appropriate slump flow and viscosity class been selected in relation to the intended casting method?
- Has it been verified that the concrete manufacturer is able to supply the requested flow properties?
- Have transport distances and traffic issues been taken into consideration in the casting plan and the planned casting rate?
- Has a decision been made on a backup plant in the event of a breakdown?
- Is vibration equipment needed on the site in the event of unforeseen circumstances? If yes, under what circumstances will vibration be allowed?
- Will a delivery control be conducted at the job site? If yes, what would the quality control and the acceptance limits entail and who will conduct the quality control?
- Have the acceptance limits for the slump flow and viscosity classes, where relevant, been agreed upon in dialogue with the concrete manufacturer?
- Under what circumstances would a concrete batch be discarded on the basis of the job site quality control?
- Are there special requirements for the surface finish? And has the casting technique been adapted to these requirements?
- Are there requirements for air entraining admixtures?

Concrete manufacturer

- Which placement method has been selected?
- Can the required flow properties be supplied with regards to w/c ratio, environmental exposure class, strength class, available constituent materials and transport distances?
- Has it been verified that a backup plant can supply the required flow properties, if needed?
- Have realistic acceptance limits been set for the slump flow and viscosity class at the job site?

2.1 FORMWORK

The requirements for making of the formwork remain the same for SCC. The choice of formwork system depends on the requirements for the finished concrete surfaces, including whether a specific texture or colour have been specified, and depending on the final function of the surface.

The tightness and load bearing capacity of the formwork, and other temporary structures must be designed based on the impacts that are normally calculated for casting of concrete. The weight of SCC is no different than traditional concrete, yet due to its high flow capability, there are some differences that must be taken into consideration when preparing the formwork:

- For SCC slabs on ground cast directly on a subbase of light weight aggregates, a sheet of geotextile must be placed in such a manner that downward seeping of paste into the subbase is avoided. Correspondingly, it should be ensured that insulation materials such as EPS are laid out in a tight formation to avoid paste from seeping downward and subsequent lifting of the insulation material. It is especially important to close the gap between the EPS blocks and a strip foundation for example by using mortar. This is also the case, where the insulation has been manually adjusted around sewage discharges and pipes.

- Generally the requirements for tightness of formwork are higher than for traditional concrete. This is due to risk of seepage of cement paste.

- Embedded pipes and box outs (such as plastic pipes for floor heating systems) must be secured effectively against floating on the concrete. Formwork for doors and windows must also be stiffened against the horizontal forces in the event of asymmetrical SCC form filling. Therefore, it is recommended to fill up around box outs continuously from both sides.

- With a few exceptions, there will be increased formwork pressure for vertical castings due to the hydrostatic pressure from the rather fluid SCC (Figure 2.2). The formwork should therefore normally be designed for increased formwork pressure from the concrete, in particular at the base of the formwork. The form pressure naturally depends to some extent on the selected casting rate, but as pauses are not typically allowed in SCC castings (due to the risk of cold casting joints), the casting rate will typically be three to five times higher than what is traditionally the case for wall and columns.

Even a crack a few millimetres wide is sufficient for SCC paste to seep out of the mould with the risk of honey combing, contamination of adjoining structures, and incomplete form filling.

It is recommended that SCC formwork is always designed for hydrostatic form pressure. Stress measurements exist that demonstrate that SCC flow properties have an effect on the formwork pressure build up. In its fresh state the concrete acts like a fluid until setting begins. The initial creation of an internal structure can reduce the formwork pressure below the hydrostatic level. However, this effect will primarily have an effect at very low casting rates that are typically not relevant for SCC.

Figure 2.2 shows a diagram for calculation of formwork pressures for traditional concrete, depending on the casting rate. Vertical castings with traditional concrete are typically carried out at a casting rate of 1 to 1.5 m per hour, which means that traditional formworks are normally designed for 40-50 kN/m^2. Thus, for wall castings up to 2-2½ m in height, there will only be minor differences between SCC and traditional concrete regarding the formwork pressure. Standard formwork systems normally handle pressures up to twice this level. This means that formwork heights up to approximately 4 m can normally be handled by increasing the dimensions of the bottom formwork stays, while for heights at 5 m or above both special formwork and additional formwork stays will be needed to withstand the formwork pressure.

For SCC the selected casting rate will most often be significantly higher than for traditional concrete, and a 5 m high wall of SCC being cast at 10 m/hour will contain a maximum ½ hour-old concrete at the bottom of the formwork. The formwork pressure in this case follows the hydrostatic pressure development and grows to almost 120 kN/m^2 at a 5 m depth (Figure 2.2).

It is recommended to use a hydrostatic pressure development throughout the height of the formwork when casting SCC. Any deviation from this should be documented with trial castings and stress measurements under realistic casting conditions.

There may be a risk of the hydrostatic pressure resulting in a reduction of the air content at the bottom of a wall as the air void volume is reduced under the compressive load. This can be critical for frost resistant concretes in the aggressive and extra aggressive environmental exposure classes where there are minimum requirements for air content. For a formwork height of 6 m, laboratory tests show that the formwork pressure may cause an air content of approximately 8 % at the top of the wall to be reduced to approximately 3 % at the bottom of the wall. For rather high castings with a minimum requirements for the air content, this should be taken into consideration and the casting rate should remain below approximately 2 m/hour.

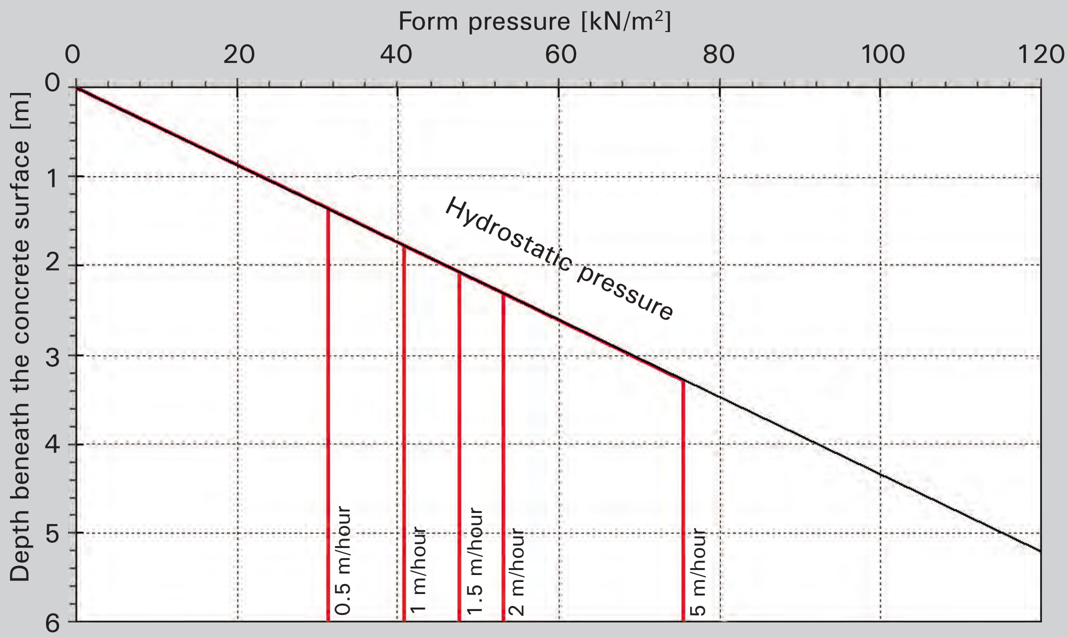


Figure 2.2. The formwork pressure as a function of the casting height and casting rate applicable to traditional concrete with normal density. The listed curves apply to a concrete temperature of 15°C. The diagonal line shows hydrostatic formwork pressure based on a density of 2300 kg/m^3. Refer to the special literature for a more detailed review of the formwork pressure calculations.

Figure 2.3. Preparations of wall formwork with a height of approximately 4 m. Example of recesses and box outs.

2.2 FORM FILLING

The standards for execution of concrete structures normally requires that the concrete is handled, placed and compacted in such a manner that the concrete:

- does not separate,
- creates a uniform and homogenous mass, embedding all the reinforcement and cast-in parts,
- fills the formwork completely, and
- achieves the intended strength, appearance and durability.

These requirements should also apply to SCC. It places certain demands on the flow properties depending upon the selected casting method, as described in the following.

SCC is most often placed in the formwork in one of the following manners (Figure 2.4):

1. Casting from a conveyor belt directly mounted on the concrete truck. Depending upon the dropping height from the belt, the concrete can be placed using a vertical steel pipe. This method requires that the concrete is not too fluid and that the belt angle does not deviate significantly from horizontal.

2. Pumping from above is the most commonly used: (i) For horizontal castings where a bent steel pipe end is typically mounted to the pump hose. The concrete has approximately a free fall of about 1 m (Figure 2.4). (ii) For vertical wall and column castings, the concrete is pumped down into the formwork using a vertically hanging pump hose being guided down between the reinforcement. This method depends strongly on the wall thickness and reinforcement congestion. You can choose to allow the outlet to be placed at a distance above the concrete surface, or possibly immersed just below the concrete surface (Figure 5.4). The pump hose is lifted at the same rate as the concrete surface climbing rate.

3. Pumping SCC from the bottom through a pump inlet connection in the formwork. This is a method that is particularly applied to vertical castings with a difficult geometry and congested reinforcement layout, making it difficult to move the pump hose, or when there is only limited access from above. The method is also used for grouting under a bridge deck, for example, during column replacements. This method can also be applied by placing a pump hose constantly immersed in the concrete from above.

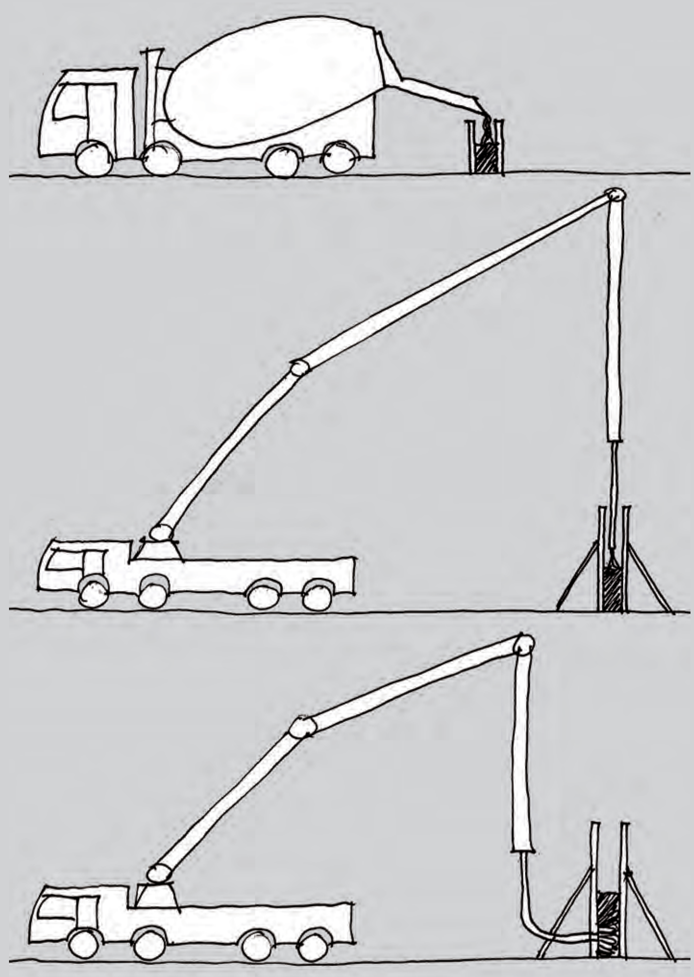


Figure 2.4. Three typical methods for placing SCC.

SCC can be pumped like traditional concrete. However, it requires increased focus on the risks of segregation and blocking through the pump. Smaller pump hoses is often used due to a smaller aggregate size in SCC compared with traditional concrete. In general, it is not recommended to place SCC from a crane bucket on the construction site, as this placing method typically means increased dropping heights, uneven casting rates and difficult control of the form filling. On the other hand, crane buckets are often used at precast factories to place SCC.

As with traditional concrete, the drop height of SCC castings should not be higher than absolutely necessary. A drop height of up to 1 m is generally regarded as acceptable. Dropping heights up to 2 m should only be used in special cases and only when the flow properties have been adjusted to this. Otherwise you risk segregation during casting.

The following describes the advantages and disadvantages related to each individual casting method.

Method	Advantages	Disadvantages
1 Conveyor belt	Easy, simple and cheap method. Good, continuous visual control of the result. Best for simple applications with easy access to the formwork, for example floors, foundations, short columns, etc.	Access conditions for concrete truck are important. Drop heights may become too high. The belt range is often limited. If the slope of the belt is too high, the concrete may get out of control and start segregating. Risk of segregation if the flow properties are not adapted to the conditions. Inflexible in regards to precise placement of the concrete.
2 Casting with pump hose from above	Easy and simple. Good visual control of the concrete surface is often possible. Well suited for practically all types of tasks.	May be difficult to get deep enough down into the vertical formwork. Air voids and surface appearance may depend on the inlet position. Inlet location must be planned taking into account the flow properties and the formwork geometry.
3 Casting by means of pump inlet connections in the formwork	The pumping and concrete do all of the work. Best for complex castings where there is no access to the formwork from above, e.g. top side shuttering.	May be an expensive method. The formwork system must be prepared with connection pieces at the correct locations. Visual monitoring of the result is difficult/impossible. Long flow distances for the concrete increase the risk of dynamic segregation. Requirements to the flow properties are high.

Table 2.1. Choice of placement method depends on the conditions at the construction site, the size of the casting, available equipment, the formwork geometry, surface finishing requirements, the experience of the concrete workers, etc.

Ensure that the SCC has been adjusted to the pump pressure to avoid segregation and blocking through the pump.

If using a soft flexible pumping hose to reduce the effect of free falling, take great caution to prevent the hose from getting blocked or caught during pumping. This may cause a risk of explosion.

Higher dropping heights puts greater demands on the stability of the concrete and requires higher viscosity to prevent dynamic segregation. The risk of trapped air voids is also increased.

Figure 2.5. Pumping SCC for horizontal applications. The pump attendant controls the outlet of the pump hose while a pump operator controls the pump itself and the pump pressure.

Figure 2.6. Examples of form filling with SCC. Top right and bottom right are examples of complete form filling. SCC closes around all boxouts and flows out into all corners. Bottom left shows an example of incomplete form filling with honeycombing and holes below a boxout.

Figure 2.7. Example of complete form filling, where the SCC closes around the L-shaped boxout, flowing into all corners. In this case casting with SCC has saved the planning and execution of access channels for poker vibrators.

2.3 SEGREGATION AND STABILITY

It should be ensured that the concrete does not segregate during casting. In the event of segregation, the concrete develops weak areas without aggregate and a higher risk of shrinkage cracks. There is also a risk that casting joints cannot be created with the required roughness. Segregation is therefore generally unacceptable, and therefore the flow properties of the concrete and the casting technique must be selected correctly as described in the following sections.

Static segregation can be observed, for example, in a wheelbarrow with SCC where the aggregates slowly sink to the bottom. The higher the viscosity, the longer the static segregation will take.

Dynamic segregation may occur, for example, when the drop height is too big. There are no viable methods for measuring the risk of dynamic segregation, and even though SCC is stable with regards to static segregation, that does not mean that dynamic segregation will not occur. Selecting an appropriately high viscosity can reduce the risk of dynamic segregation.

The size of the aggregates also have a great effect on the segregation risk. Thus, there is twice the risk of segregation with D_{max} equal to 16 mm as for 8 mm.

Visual control of SCC during casting is a very important method to register any segregation. Visual control is in most cases the only opportunity to detect segregation and correct either the subsequent SCC deliveries and/or the casting technique being applied.

Figure 2.8 shows an example of segregation during horizontal castings where the planing tool pushes a brim of paste in front of it. Segregation during floor castings typically occurs when the slump flow is too high. Figures 2.9 and 2.10 illustrate various degrees of segregation during vertical wall castings.

Static segregation occurs in stationary SCC where the aggregates are sinking. It is also possible that light aggregates will rise to the surface. Static segregation is closely related to the slump flow value.

Dynamic segregation occurs while the concrete is flowing and is closely related to both the plastic viscosity and the slump flow.

When carrying out the slump flow test, a halo of paste and mortar is sometimes observed around the circumference of the concrete. In this case segregation will certainly occur during casting.

When segregation occurs, that often also means that the air void structure is unstable. That can often be seen as a foamy layer of paste on the concrete surface.

Figure 2.8. Segregation during horizontal floor castings.

Figure 2.9. No segregation (clearly visible aggregates on the surface) – A rough construction joint can be established.

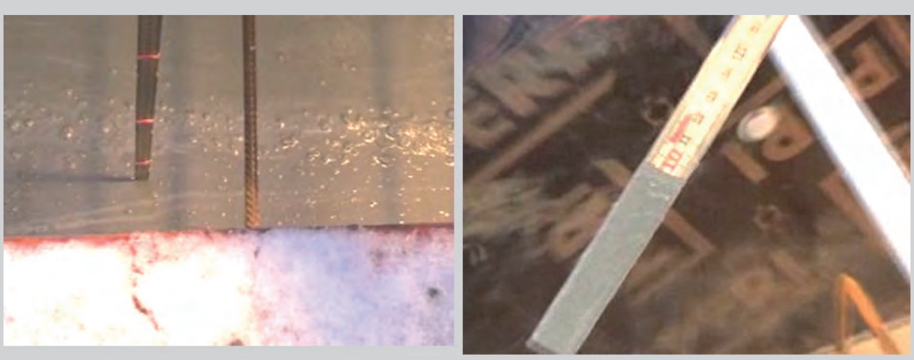


Figure 2.10. Strong segregation (about 10 cm without any aggregates) – A rough construction joint cannot be established without removing a large amount of material.

2.4 BLOCKING

Blocking occurs when the aggregates cannot pass through closely spaced reinforcement or into a complex form geometry with constrictions and changes in direction. Blocking may lead to incomplete form filling, honeycombing, poor embedment of the reinforcement and poor surface finish. Requirements for blocking should be posed on the so-called blocking ratio, i.e. the ratio between the smallest dimension for passage and the maximum aggregate size. Experience has shown the blocking ratio should be at least 2 to prevent blocking (Figures 2.12 and 2.13).

The table below shows the maximum aggregate size for various passages. The smallest passage typically occurs between the reinforcement and the formwork side, equal to the thickness of the concrete cover, which in turn depends upon the environmental exposure class.

The distance between reinforcement bars may, in some cases, be the critical blocking ratio, particularly around boxouts.

A high viscosity may also help to reduce the risk of blocking. The blocking risk can be assessed experimentally by using a so-called L-box or J-ring (Figure 2.11).

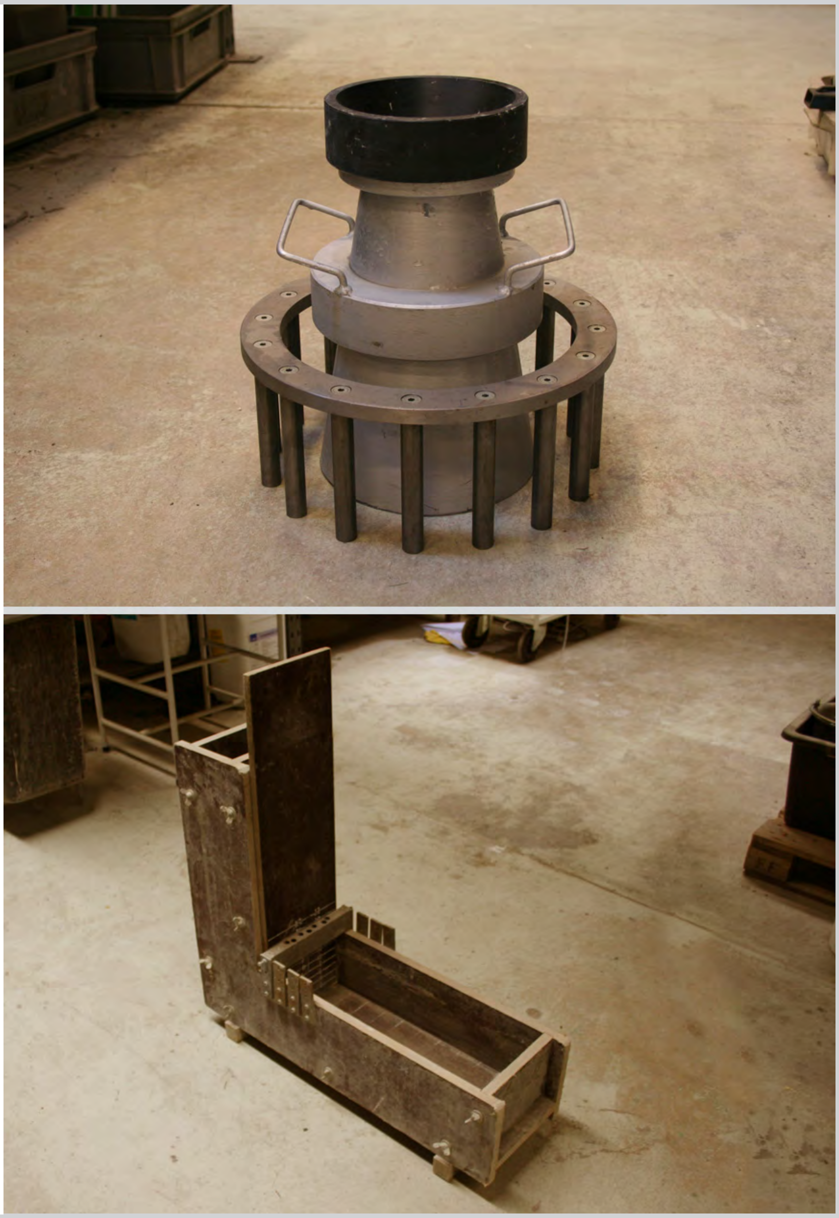


Figure 2.11. Blocking tests. Top: J-ring. Bottom: L-box.

Free passage	Allowable D_{max} for traditional concrete	Allowable D_{max} for SCC
10 mm	8 mm	4 mm
20 mm	15 mm	8 mm
30 mm	25 mm	16 mm
40 mm	32 mm	16 mm
50 mm	32 mm	25 mm

Table 2.2. Selection of D_{max} based on the risk of blocking. Note that increasing D_{max} also increases the risk of segregation.

The blocking ratio for traditional concrete is often set at 1.3, which is normally sufficient when vibration is used to compact the concrete. For SCC the blocking ratio should be at least 2, or preferably even higher.

Figure 2.12. Blocking during SCC castings. Examples of congested reinforcement and accumulation of aggregates behind the reinforcement and honeycombing.

Figure 2.13. Example of no blocking. SCC flows well around the reinforcement without accumulation of aggregates.

2.5 SURFACE FINISH

Generally there is no reason to assume that using SCC results in a lower surface finish quality compared to traditional concrete. However, there are a number of pitfalls when applying in-situ SCC. There is a tendency for air voids to form when the concrete falls freely into the formwork, and when someone walks in the fresh concrete, which happens during horizontal castings. The entrapped air voids may have trouble escaping on its own, particularly at high casting rates and for SCC with a high viscosity. Thus, the combination of the flow properties and casting method is of far greater significance for the surface finish than for traditional concrete.

For concrete that contains air entraining agents, the risk for air voids may be greater than for concrete without such admixtures.

For visible, horizontal soffits (cast against formwork) special consideration must be given to the embedment of reinforcement spacers. This can be ensured by using spacers with a rather small footprint and without small cavities that need to be filled with paste. Figure 2.14 shows an example of a spacer that was not properly embedded in a bridge deck. SCC with a high viscosity increases the risk of visible spacer footprints.

Figure 2.14. Top: Spacer is being embedded by SCC. Bottom and center: Visible tracks and footprints from the spacer in bridge deck soffit.

2.6 EVAPORATION PROTECTION OF CONCRETE SURFACES

Protection of the concrete surface against evaporation during the early curing phase must be established for SCC in the same manner as for traditional concrete. The protection must ensure proper curing of the concrete and prevent plastic shrinkage cracks. The same applies to any early-age temperature measures during and after casting. For SCC, the need to determine the heat development is more urgent than for traditional concrete. This is due to the more extensive use of additives affecting the setting time and the hydration process. The various additives may also behave differently in combination with different types of cement.

For high casting rates of say several hundred square metres of floor per hour note that the protection must follow the same rate, which can be hard to do, particularly under demanding weather conditions. This may lead to a greater risk of plastic shrinkage cracks for large SCC floors compared to traditional castings where the casting rate is often limited. Figure 2.15 shows an example of plastic shrinkage cracks caused from strong wind and lack of protective cover.

*Figure 2.15. Top: Plastic shrinkage of a concrete floor.
Bottom: Application of plastic covering on SCC bridge deck.*

Figure 2.16. Application of curing membrane to an SCC bridge deck as a temporary protection measure, followed by plastic covering as shown in Figure 2.15.

3. Flow properties of SCC

The most important material properties for SCC related to the execution are the flow properties that describe the concrete's ability to flow without external impacts other than the gravitational force and pumping pressure. During casting there will be some manual loading with hand-held tools such as a planer, scraper, shovel, levelling board, etc.

Traditionally the slump flow value is used to describe the SCC flowability, but it has been demonstrated that at least two parameters are required to fully describe the flow properties. Thus, the flow properties for SCC are characterized by the following rheological parameters:

- The yield stress τ_0 describes how far the concrete can flow, i.e. the yield stress is closely related to the slump flow. A high yield stress gives a low slump flow and vice versa.
- The plastic viscosity η_{pl} describes the stickyness of the concrete. A high viscosity gives a sticky SCC that is hard to spread out (flowing very slowly).

There is information about the influence of the constituent materials on the flow properties in "Guidelines Mix Design of SCC", May 2008.

Figure 3.1 presents a diagram that gives an overview of the effect of the two rheological flow parameters on the execution of SCC. Traditional concrete will be placed somewhere outside the top of the diagram, having a very high yield stress.

For example two concretes with identical slump flow, but having low and high viscosity, respectively, are regarded as easy flowing and sticky/tough, respectively by the concrete workers. The two concretes will flow the same distance, but the flow rate will be different.

Let us presume that a casting begins with a low-viscosity SCC that is easy to push around and level. At one point in time a batch of SCC is delivered with high viscosity (assuming that the slump flow remains the same). This may be due to the natural variations in the constituent materials. Now the concrete workers feel that the flowability of the concrete is reduced significantly as it is heavy to level and difficult to spread out (flows slowly). Then they order a "more fluid consistency" from the concrete supplier which in turn increases the slump flow for instance by adding more superplasticizer. Such a measure increases the risk of segregation, which is unacceptable. Instead there is a need to reduce the viscosity without increasing the slump flow at the same time. However, this is hard to do when the viscosity is normally not a control parameter in the daily production on the concrete plant. This example shows why both rheological parameters are necessary to fully describe SCC flowability in the fresh state.

The contractor must understand that the slump flow is typically used as the controlling parameter at the concrete plant, while it is often the viscosity, which the concrete workers experience and refer to. This increases the risk of misunderstandings between the contractor and the concrete supplier.

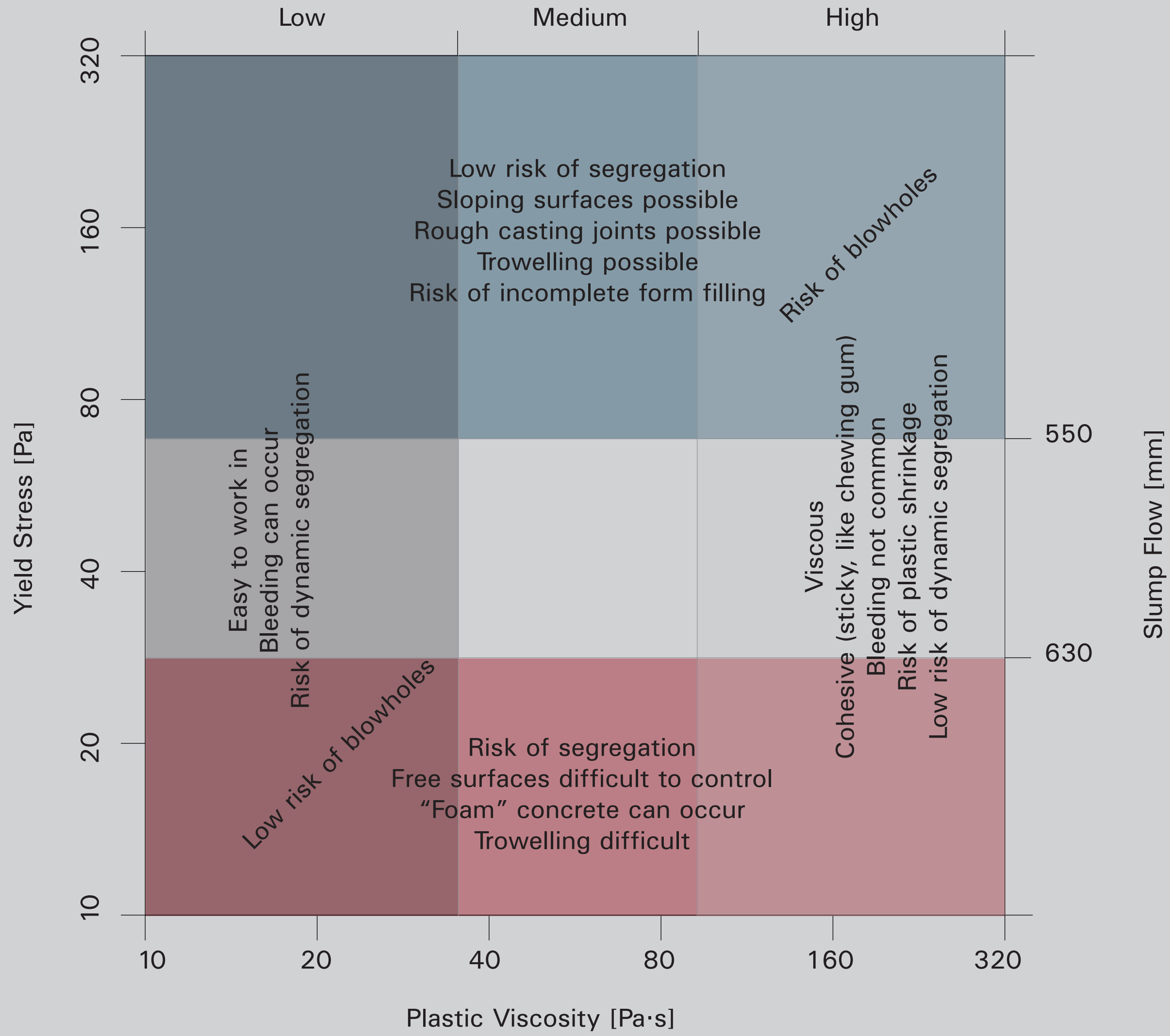


Figure 3.1. Experiences with Danish SCC concretes. Correlation between the flow properties and aspects of execution of SCC. The slump flow is indicated in mm on the right-hand-side vertical axis. The observations are based on measurements with the 4C-Rheometer.

3.1 DETERMINING FLOW PROPERTIES

Rheological parameters can be determined using a rheometer such as the Icelandic BML viscometer or using the 4C-Rheometer system developed at the Danish Technological Institute. The 4C-Rheometer is based on an automated slump flow test where the rheological parameters are determined by analysing the flow curve (spread versus time). The BML viscometer is a "classical" rotational viscometer (concrete is placed between two coaxial cylinders) where the rheological parameters are based on measurement of the resistance on the inner cylinder.

For manual castings, it is recommended to correlate the determination of the slump flow with the time measurement termed t_{500}. A high t_{500} value is equal to low viscosity and vice versa. Figure 3.2 shows the division into three viscosity classes based on the t_{500} values. For most practical purposes, it is sufficient to be able to differentiate between high and low viscosity. However, this division is very much dependent upon the slump flow value, as it is shown in Figure 3.2. This is the division that is used in the following sections that give recommendations for selection of flow properties for different types of SCC applications.

Table 3.1 sums up the significance of the different parameters that are selected for an SCC casting. This information can be used in planning the casting process and for adjustments during casting e.g. the casting rate and the placement of the inlet.

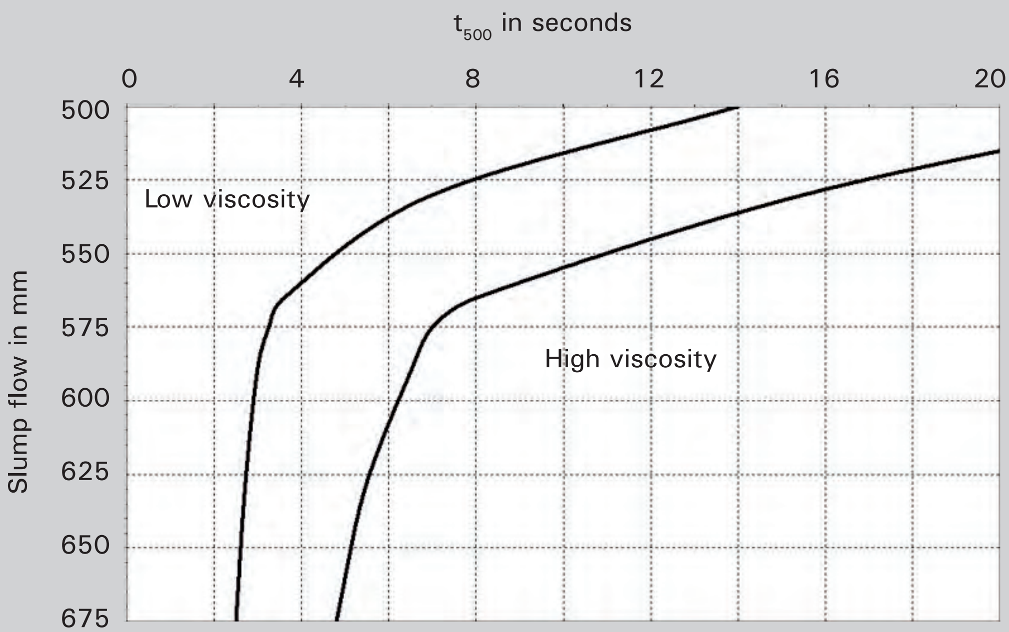


Figure 3.2. Division into low and high viscosity classes as a function of the slump flow. It is presumed that the cone is not inverted and lifted at a rate of approximately 15 cm in 2 seconds.

	Form filling	Segregation	Blocking	Surface finish at mould sides
Success criterion	The formwork is filled completely. The concrete flows out into all corners and encapsulates the reinforcement and embedment parts.	Demixing of aggregate and formation of a paste layer should not occur. A differentiation is made between static and dynamic segregation.	Accumulation of aggregates behind the reinforcement, followed by segregation and honeycombing, should not occur.	The number of air voids at the surface must be as specified.
Yield stress (slump flow)	Has great significance in complex formwork such as close and tightly reinforced formwork where a high slump flow is advantageous. Should be coordinated with the selection of casting technique. Only has slight significance for simple, lightly reinforced formwork. The slump flow determines how far the concrete front flows and the slope of the surface.	Has great significance for both static and dynamic segregation. Low slump flow is advantageous. That allows more inappropriate placements of the inlet, longer concrete fronts and greater drop heights.	Has little significance. A high slump flow flow is advantageous. Can allow a higher slump flow at D_{max} = 8 mm than at 16 mm.	Has great significance. Crucial for whether air voids are allowed to escape. High slump flow is advantageous.
Plastic viscosity	Has little significance on the form filling ability, but great significance for how quickly the concrete front is flowing. High plastic viscosity results in slow concrete propagation and thus a greater control of the concrete front.	Has no significance for static segregation. It just takes longer if the plastic viscosity is high. Has great significance for dynamic segregation. A high plastic viscosity is advantageous. It allows more inappropriate placements of the inlet, longer concrete fronts and higher drop heights.	Has little significance. A high plastic viscosity is advantageous.	Has great significance. Crucial for how quickly air voids will escape. A low plastic viscosity is advantageous.
Inlet placement (horizontal and vertical)	Has slight significance for simple formworks. Typically it will be necessary to fill along the free surface at the end due to the slope of the concrete. Has great significance for complex moulds such as closed and tightly reinforced formworks. To be coordinated with selection of the casting technique technique.	Has great significance as it affects the flow pattern of the concrete and thus the interaction between the paste and aggregate.	Has little significance. Often advantageous to place the inlet in the vicinity of dense reinforcement zones e.g. close to recesses, etc.	Has great significance. Affects the flow between the concrete and formwork sides. Advantageous to have flow along the formwork surface as it “lubricates” the surfaces.
Casting rate	Has no significance.	Has only little significance.	Has little significance. Advantages to increase the flow rate near dense reinforcement zones.	Has significance. Advantageous to apply a low climb rate for wall castings so air voids are able to escape.
Aggregate D_{max}	Has no significance.	Has great significance. Advantageous to have a little D_{max}.	Has great significance. D_{max} must be selected so the blocking ratio does not become critical. The ratio should be higher than approximately 2.	Has no significance.

Table 3.1. Significance of the most important execution and material parameters on an SCC casting. As shown, there are several requirements, each going in their own direction. For example, the consideration for blocking and dynamic segregation will require a high viscosity, while on the other hand, a nice surface finish requires a low viscosity.

3.2 JOB SITE QUALITY CONTROL

As stated in the previous sections, it is important to know the flow properties. It is recommended to control the flow properties of SCC as a part of the delivery control on the job site. The control should include a slump flow measurement where t_{500} is also measured. These are evaluated in comparison to the target slump flow value and the viscosity class.

It is not always sufficient to base the job site quality control solely on the batch report from the manufacturer. More attention is required from the concrete workers as to whether the concrete is well suited for its intended use. It is clear that the extent to which the delivery control is carried out may be adapted according to the complexity of the specific casting and the quality requirements to the final product. It is also clear that the contractor must specify his need for flow properties towards the concrete manufacturer, containing the target slump flow and viscosity class where relevant. It will not be sufficient to order an unspecified SCC from the concrete manufacturer and then presume that the flow properties are right for the specific application.

The contractor should control the flow properties at the construction site as a part of his delivery control. The first couple of batches in particular should be controlled carefully, and then the inspection may include every third batch or so. The quality control forms the basis for adjustments of the casting technique or rejection of batches, if necessary.

Figure 3.3. Automated slump flow measurement applied during job site quality control. To determine the slump flow and viscosity class (4C-Rheometer).

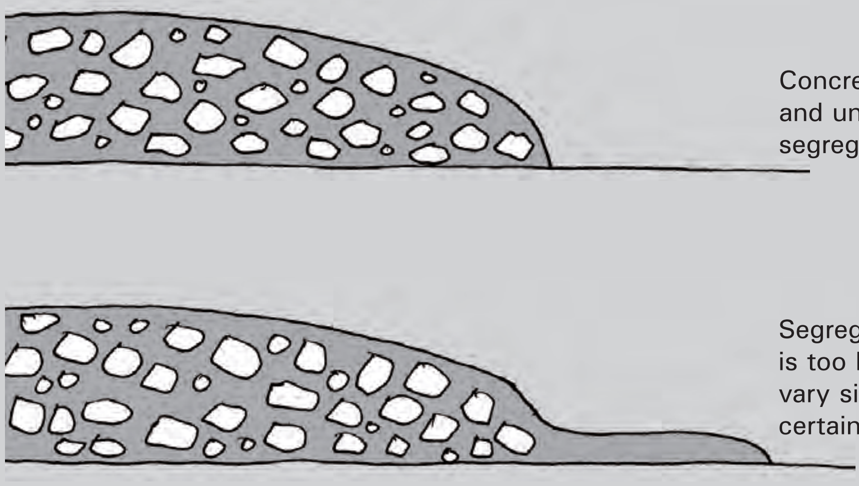
It is important to conduct the quality control corresponding to the final place of use. This typically means after pumping. There may be a difference in the flow properties prior to and after pumping.

4. Horizontal applications

In Denmark, ready-mixed SCC is used to a large extent for horizontal castings of slabs on ground where there most often is a simple form geometry, easy access to the casting area and only a little or no reinforcement. It is also common to deliver fibre reinforced SCC, but this type of concrete is not included in these Guidelines. SCC is well suited for floor castings as vibration equipment can be omitted entirely, and guides do not have to be set up for a vibrating screed.

4.1 SELECTION OF FLOW PROPERTIES

In Denmark, SCC for horizontal castings typically lies within a slump flow range of 500-600 mm, having maximum aggregate size of 16 mm. A slump flow of 500-600 mm may seem relatively low compared to SCC applications outside of Denmark where slump flow values of 700 mm and higher are more often seen. However, a relatively low slump flow value helps ensure that the concrete does not segregate, creating a layer of paste that tends to weaken the surfaces with respect to wear resistance and strength (Figures 2.8 and 4.1). Segregation also causes problems with the subsequent finishing procedures such as trowelling due to a tendency of an extremely inhomogeneous surface quality. Consequently, it is possible to reach a target slab thickness of say 100-150 mm by selecting a suitably low slump flow without loosing control of the moving front of the flowing concrete (Figures 4.3 and 4.4).



Concrete front with a homogenous and uniform concrete distribution. No segregation.

Segregation occurs if the slump flow is too high. The concrete surface will vary significantly with large areas of a certain paste surplus.

Figure 4.1. Illustration of the concrete front during horisontal castings. Bottom: There is a tendency of segregation and poor surface quality, which to a large extent is due to an excessively high slump flow value.

Figure 4.2 sums up how the combination of flow properties affect the execution of horizontal castings. The situations for high and low plastic viscosity respectively are described along the horizontal axis. The influence of the slump flow value, independent of the viscosity, is described along the vertical axis. For example it shows that sloped surfaces put demands on the slump flow value.

Under normal circumstances, it is recommended to use the flow properties for SCC floors corresponding to the upper left area of the diagram (1A) and partially into area 1B. This gives a concrete that is easy to work in and a concrete front that is easy to control. Finally a uniform surface quality is achieved without segregation and foaming. The low viscosity also ensures that encapsulated air voids escape relatively easy.

As an example of flow properties that satisfy these criteria, strive for a target slump flow of 550 mm with tolerances of -50 mm and +30 mm. The maximum value of t_{500} must be between 3-14 seconds, depending upon the slump flow in the range of 500-580 mm. The tolerance range is asymmetrical as it is better to allow for a decrease rather than an increase in relation to the target slump flow value.

There may be SCC with a slump flow value below 500 mm and say all the way down to 450 mm, where t_{500} naturally does not make any sense. There is nothing in this respect that prevents SCC from being used in floors and walls as long as the reinforcement configuration and form geometry is very simple and the viscosity is kept low.

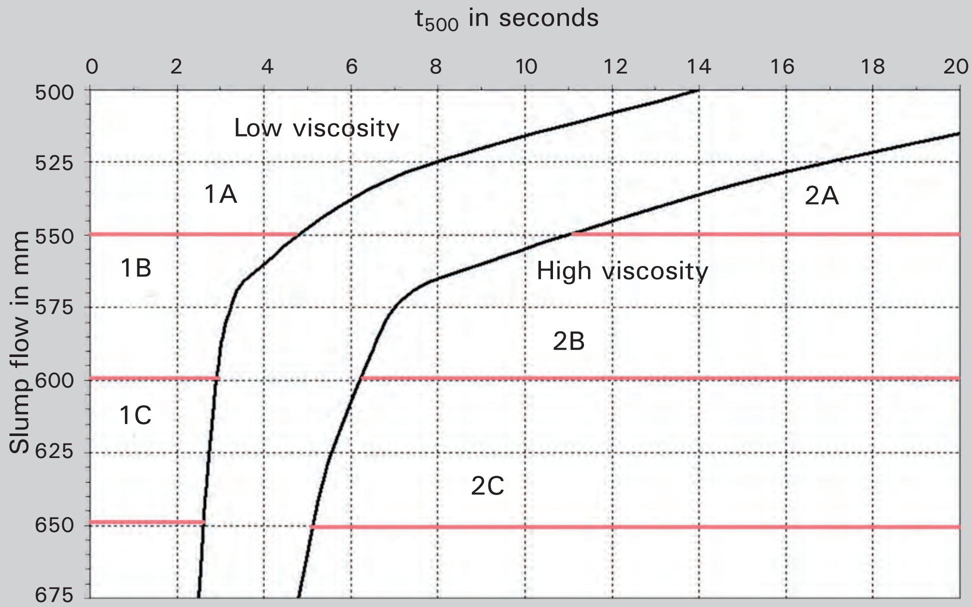
For thicker plates such as base slabs and water tight bottom plates, with two layers of reinforcement, the concrete front may stretch across several meters, and the pump operator will fill the form from above. In such cases there may be a need for more strict requirements for the slump flow value for example, to a maximum of 520 mm to build up the plate thickness without causing the concrete front to become too long at the same time.

There may also be a need to specify a high viscosity to ensure that the concrete front is built up slowly and that the concrete can tolerate a higher drop height through the reinforcement. It is not recommended to build up a thick SCC slab from several concrete layers as it is normal for traditional concrete since this may cause cold casting joints.

As of 2007, the use of SCC in Denmark is slightly less than a third of all manufactured ready-mixed concrete, i.e. just below 1 million m^3 of SCC annually. The majority of this is used for horizontal applications.

The recommendations in this section generally apply to SCC with a maximum aggregate size of 16 mm, being the most frequently used. Using an aggregate size of 8 mm instead will result in higher robustness against segregation and an improved air void stability. However, a smaller D_{max} may give rise to more creep and shrinkage due to a possible higher paste content.

Experience has shown that SCC that requires a low water/cement ratio such as concrete exposed to aggressive environmental exposure classes and will typically result in a rather high viscosity, which should be taking into account when planning the casting process.



Low risk of segregation.
Visible coarse aggregates in the surface.
High air void stability.
Possible to build up a slope (4-5 %).

Limited risk of segregation.
Attention to the concrete front
Building up a small slope (2-3 %) is possible.

Risk of segregation.
Difficult to maintain coarse aggregates in the surface.
The concrete front is difficult to control.
Sloped surfaces not possible.

High risk of segregation.
Paste layer and foamy surface.
Unstable air void structure. Bubbles and foam.
Not suitable for horizontal castings due to variations in the surface quality.

Low viscosity class:

Be careful with drop heights > 1m.
Easy to work in.
Easy to finish.

For area 1A in particular:
Well suited for horisontal castings.

For area 1C in particular:
Easy to plane.

High viscosity class:

Tough and sticky to work in.

For area 2A in particular:
Risk of volcanoes due to entrapped air.
Risk of poor embedment of spacers.
There may be traces of aggregates and air pockets after planing.

For 2C in particular:
High risk of volcanoes and sticky delaminating surface skin due to entrapped air.
May be difficult to plane and trowel.
Suitable for areas with congested reinforcement and complicated geometry and boxouts.

Figure 4.2. The effect of flow properties of the casting of horizontal applications

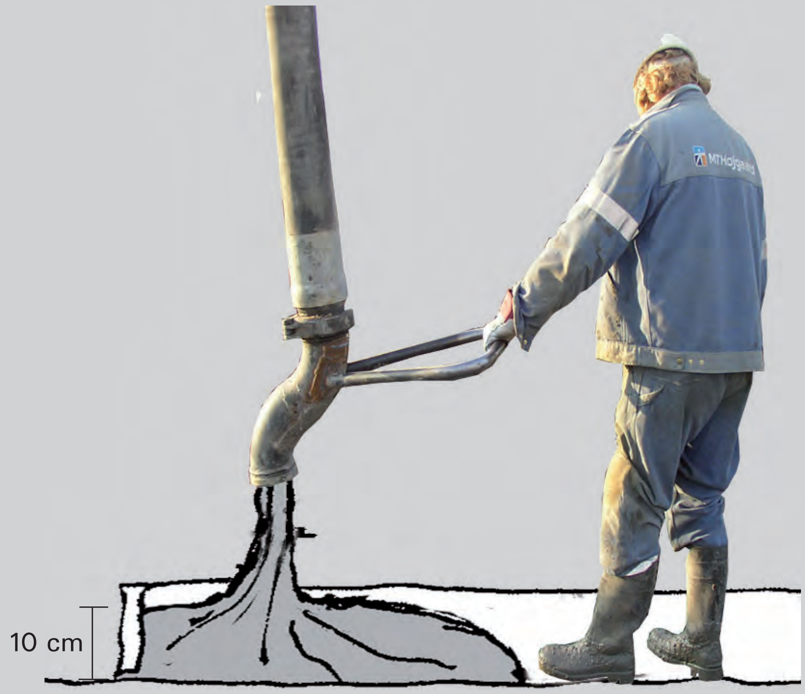


Figure 4.3. Example of floor casting with a low slump flow value of approximately 525 mm. Good control of the concrete front where it is easy to reach the final concrete slab depth (e.g. 100 mm) during a single filling process.

Low risk of segregation for maximum aggregate sizes of both 16 and 8 mm. The concrete is very stable and uniform on the surface after casting, most often also with visible coarse aggregates in the surface. The visible aggregates are submerged just below the surface using a handheld tool shown in Fig. 4.6. Keeping a rather low viscosity ensures that it is easy to submerge the aggregates with this tool.

There is a high air void stability. Thus, the concrete will not foam noticeably. Low viscosity is advantageous for entrapped air voids to escape quickly.

Figure 4.4. Example of floor casting with a high slump flow value of approximately 675 mm. Poor control of the concrete front, flowing a rather long distance from the inlet. It is not possible to achieve a final concrete slab depth (e.g. 100 mm) during a single filling process as the concrete will flow up to 4 m away from the inlet. This contributes significantly to an increased risk of dynamic segregation. It is not possible to cast the concrete floor without having to walk in the concrete.

There is a high risk of segregation. Although it may be tempting to allow the concrete to flow on its own, this should clearly be avoided due to the risk of segregation. It is recommended to move the inlet frequently so that the concrete flows as little distance as possible. This cannot prevent static segregation, but it may help prevent the very visible paste front that typically forms under such casting conditions.

The concrete may bubble and foam a great deal. At high viscosity the air bubbles will rise slowly, while at a low viscosity the surface will appear to "boil".

4.2 NECESSARY CONSIDERATIONS

Once the flow properties have been selected as described in the previous section, it will be possible to achieve a good filling ability where the concrete is homogenous and without honeycombing, paste layers, and blowholes. When casting using a pump (Figure 2.5), the pump operator will most often be located in front of the concrete front, and when selecting an appropriately low slump flow value it prevents the pump operator from having to walk in the fresh concrete. The pump operator ensures an even distribution of concrete by moving the pump hose back and forth across the concrete front. It is not recommended to keep the inlet in the same location for too long at a time as that increases the risk of segregation due to a longer flow distance.

Filling continues until the final surface level is reached, after which the concrete is roughly levelled with scraper and shovel (Figure 4.5). Selecting a low viscosity will make this levelling feel relatively easy. The rough levelling of the concrete is often done with an asphalt scraper, normally by means of laser levelling apparatus. The surface is then slightly excited using the drainpipe to make it appear nice and even. Alternatively a surface planer may be used (Figure 4.6).

The correct time to carry out levelling of the surface is to a large extent a matter of the experience of the concrete crew. It depends a great deal on the weather conditions on the casting site. However, do not begin to carry out levelling as long as the concrete is still bubbling and foamy.

If the concrete does not satisfy the requirements set for the flow properties upon delivery at the job site, the contractor must be aware of the following issues:

1. If the slump flow is too high be cautious regardless of the viscosity (Areas 1C and 2C in Figure 4.2). There is a risk of segregation and areas with non-uniform surface quality. Surface levelling using the drainpipe tool will often be unnecessary due to paste surplus on the surface. A surface planer can be used in its place, if needed. If the slump flow exceeds 650 mm, it should seriously be considered to discard that batch.

2. If the slump flow is acceptable, but the viscosity is too high (Areas 2A and 2B in Figure 4.2), any encapsulated air voids will take longer to rise to the top, and be cautious of doing the surface levelling too early. If the drainpipe tool or surface planer is used too early, there is a risk of getting entrapped air voids just below the surface which may create a weak surface and delamination. For that same reason, avoid walking in the concrete as much as possible as that increases the amount of encapsulated air voids.

Item 1 may be solved by allowing that particular batch of concrete to remain in the concrete truck for a while, after which the slump flow will drop to a desirable level. However, that will also cause the concrete surface to mature unevenly and make it more difficult to perform the surface finishing procedures.

Item 2 may often be relevant for concrete in aggressive environmental exposure classes where experience has shown that a low water/cement ratio often causes relatively high viscosities.

In many cases the surface appearance is satisfactory after levelling with the drainpipe tool. That pertains to slabs that serve as base for further flooring materials or slabs for buildings without any strict surface criteria, i.e. where the surface finish requirements are not high. It may also pertain to slabs that are given a screed layer before final flooring.

A drainpipe levelled surface will not be sufficient if the concrete slab represents the final floor appearance or has to be painted. Firstly the surface structure is too open and rough, secondly the planeness requirements are not necessarily satisfied:

- The surface is typically sealed by trowelling, and SCC places greater demands on this process than traditional concrete. It is initially trimmed with plates mounted on the trowelling machine to level/ screed the surface. Alternatively, it is hand-trimmed, depending on the size of the area.

- Afterwards it is trowelled manually or with a machine. This is done to seal the surface and ensure a tight, strong concrete surface. As with traditional concrete, the waiting time before doing the trowelling should be evaluated on-site and depends on the conditions at the time of the casting. Normally, 3-5 hours pass from the time the casting is done until trowelling can begin.

Machine trowelling puts great demands on the planeness of the floor. In some cases SCC floors have small, local cavities as a result of the drainpipe levelling process. The trimming process using the plates can help to remove these local cavities and improve the evenness, but in certain cases it will not be sufficient to ensure a satisfactory machine trowelling result. If this is the case it may be chosen to grind the floor after the curing process. Such a grinding will typically remove the first couple of mm of the concrete surface and expose the aggregates (Figure 4.7).

Machine trowelling is extra difficult if the floor has been exposed to segregation during casting, for example due to an excessively high slump flow value where local areas of paste layers and delamination are created. Then the trowel machine tends to submerge and damage the surface. It is particularly important for large floor areas that the flow properties are uniform to ensure that trowelling procedure can be done in plausible manner. Conduction of quality control upon delivery of SCC on the job site, as mentioned in Section 3.2, helps to ensure this.

Figure 4.5. Left: Horizontal casting of SCC. Right: SCC is placed using a scraper so that the concrete is redistributed in order to obtain correct slab thickness.

Figure 4.6. Upper right: Curing membrane is sprayed on as soon as the surface is levelled. This should be done as soon as possible after the surface finishing process. Upper left: Visible coarse aggregates in the surface are submerged with a piece of drainpipe mounted on a shaft. Bottom right: The surface is levelled with a surface planer tool. It is not recommended to use the planer when there is a large number of coarse aggregates in the surface as they may leave tracks in the surface. Bottom centre: SCC where segregation has clearly occurred. There are no visible aggregates in the surface or just below it. The surface is also bubbling due to instable air voids. Bottom left: SCC without segregation having visible aggregates in the surface.

Figure 4.7. Upper left: Throwelling of SCC floor slab. Knowing the right time to carry out trowelling is a matter of experience. Particularly for larger floor areas it is important to pay attention to the uniformity of the flow properties of each batch. Otherwise it will cause non-uniform surface quality that makes it difficult to perform trowelling. Upper right: SCC bridge deck surface finished with a final slope 2.5 percent. Bottom left: A surface that has been finished with a surface planer (left) and a drainpipe tool (right). The slump flow is approximately 480 mm and the viscosity is relatively high. The planer leaves visible tracks from aggregates while the drainpipe tool has a difficult time submerging the aggregates. Bottom right: Examples of different surface finish procedures applied on the same floor – trowelled, grinded and a broomed surface.

5. Vertical applications

Ready-mixed SCC is primarily used for horizontal applications, just as most SCC in the pre-cast industry also goes into wall elements cast horisontally. Thus, there is a great unexploited potential for the use of SCC in vertical structures.

The need for planning vertical castings is greater than that for horizontal castings. That is due to the fact that the form geometry and reinforcement play a much larger role for a successful result. It is crucial to make the correct selection of flow properties and casting technique based on the given conditions, partly because it is often difficult to visually follow the concrete while flowing in the formwork, and therefore it is difficult to determine whether there is a need for corrective measures. On the other hand, there is no finishing involved other than the removal of formwork after curing.

Vertical castings include a broad spectrum of structures ranging from lightly reinforced basement walls in rather passive and moderate environmental exposure classes to densely reinforced walls with boxouts and prestressing. There are also slender columns for civil engineering structures and complex structures such as inclined frames with top side shuttering, walls cast against steel sheet piling, tunnel segments and massive anchor blocks.

Formwork geometry, boxouts and amount of reinforcement places demands on the flow properties and the placement of the inlet with regards to the form filling ability and risk of blocking and segregation. Vertical castings with SCC are often done with a pump hose from above as described in Section 2.2. It is important to plan the inlet locations in advance, particularly for long walls and walls with obstacles such as door and window holes and corners. The flow length of the concrete must be limited, which is done with an appropriate location of the inlets. It is generally a good idea to place the inlets near congested reinforcement areas in order to utilize the flow of the concrete to achieve a good form filling and embedment of the reinforcement. Furthermore, the selection of flow properties and the inlet locations should be coordinated, especially if there are special requirements for the surface finish and quality.

The concrete composition must be adapted to the task, including requirements to environmental exposure class, air void content, and selection of maximum aggregate size. The latter should be done under consideration of the blocking risk as described in section 2.4. Finally, the casting rate must be adapted to the form geometry and the logistics for the concrete delivery.

Use of SCC for vertical structures means higher requirements for formwork and shuttering as described in Chapter 2.1.

Maximum aggregate size must be selected out of consideration for the risk of blocking. Note that the aggregate size also has a great effect on the risk of segregation, as described in Section 2.3.

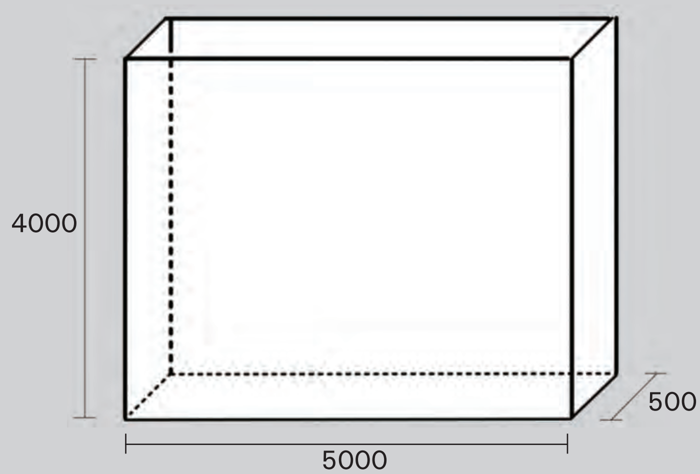


Figure 5.1. A simple lightly reinforced wall with limited length. This type of wall typically takes 5-10 m^3 of concrete, corresponding to a single truck load of concrete. Measures in mm.

In the following three types of wall castings will be discussed. The basis is a simple, lightly reinforced wall with limited length and thus limited flow length of the concrete (Figure 5.1). The concrete cannot flow very far before it reaches the end of the wall. There will typically not be any supply and logistics problems as the entire wall can most often be filled by a single batch of concrete (5-10 m^3).

The second example presumes that the wall length is long (flow lengths larges them 10 m) and that the concrete delivery includes several batches. The long wall may also include corners, making it difficult to follow the concrete flow visually from the inlet location (Figure 5.2).

The last example describes a complex wall geometry with door holes and corners (Figure 5.3).

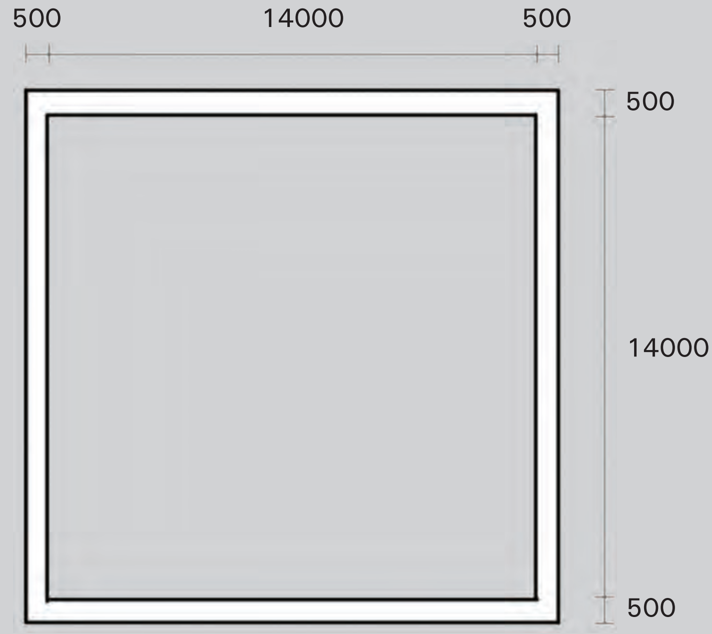


Figure 5.2. A simple, lightly reinforced long wall (horizontal cross-section). The amount of concrete will typically be 50-100 m^3. Measures in mm.

Figure 5.3. A complex wall geometry with congested reinforcement layout and various door holes, boxouts, corners and connecting walls of varying thickness (horizontal cross-section). It may be a casting of 100-150 m^3 of concrete. Measures in mm.

5.1 SELECTION OF FLOW PROPERTIES

The following recommendations are based on SCC with a maximum aggregate size of 16 mm and having an air content of approximately 6% in its fresh state.

Simple wall with a limited length

There are no limitations on the inlet placement for this type of wall. Filling is typically done with pumps from above through the vertically hanging pump hose. One inlet location will be sufficient to obtain complete form filling, yet in the end it will be necessary to top-up along the upper surface of the wall as the concrete will have a slope of 1-10 percent, depending on the slump flow value.

With regards to segregation, it is advantageous to place the inlet just above the concrete surface. The limited flow length also makes it possible to choose the flow properties rather freely, as the risk of dynamic segregation is little. If, on the other hand, the inlet is placed constantly submerged under the concrete surface, it is important to adapt the flow properties accordingly as concrete that is pushed up from the bottom has a greater tendency to segregate. Figure 5.4 shows three different methods of filling the formwork and the significance that the selected method has on how the concrete flows while filling the formwork.

The amount of reinforcement is approximately 100 kg/m³ mainly in the form of mesh reinforcement. Thus, normally there is only a low risk of blocking.

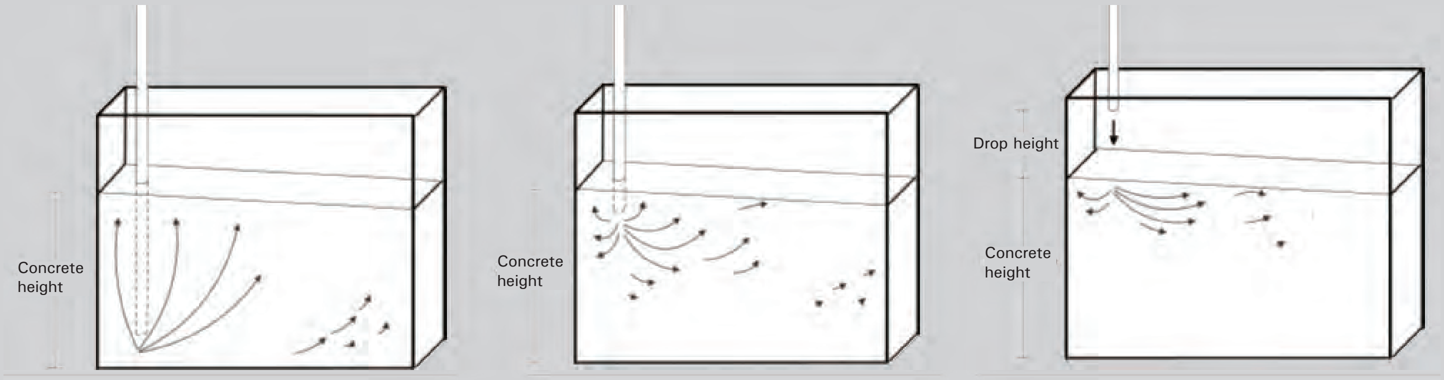


Figure 5.4. Influence of inlet position: Left: Inlet is constantly immersed just above the base of the formwork. Centre: Inlet is immersed just below the concrete surface. Right: Inlet is placed above the concrete surface with a certain drop height).

Figure 5.5 shows the recommended flow properties for the different filling methods. A differentiation is made based on whether or not there are any special requirements to the surface finish of the wall's vertical faces.

No requirements for surface finish means that the inlet location can be freely selected, and it is recommended to place the inlet above the concrete surface (approximately 0.5 m drop height). The horizontal position of the inlet can be kept constant.

If there are requirements to the quality of the surfaces, e.g. in terms of maximum amounts of blowholes and other requirements, it is recommended that the inlet is immersed to a depth depending on the slump flow (yield stress) and plastic viscosity class of the concrete. It is recommended staying within the dark blue area of Figure 5.5 corresponding to a slump flow range of 550 mm to 630 mm.

Simple long wall

It will typically involve delivery of several loads of concrete. The logistics are therefore important, and the planning should take this into account to ensure a continuous casting process without interruptions. In contrast to the short simple wall, it is important to take into consideration the distance between the horizontal inlet positions and the length of the concrete front in order to avoid dynamic segregation and it is quite possible that the inlet has to be moved horizontally at regular intervals. Another reason to move the inlet horizontally is in order to minimize the risk of incomplete form filling due to blocking, e.g. around boxouts and corners. Figure 5.5 can be used as a starting point for selecting a combination of flow properties and vertical inlet position. That is to say, when there is no special requirements for the surface finish, the concrete is allowed to fall freely with the inlet no more than 0.5 m above the surface of the concrete, and in cases where there are surface finish requirements it is recommended to submerge the pump hose during the casting.

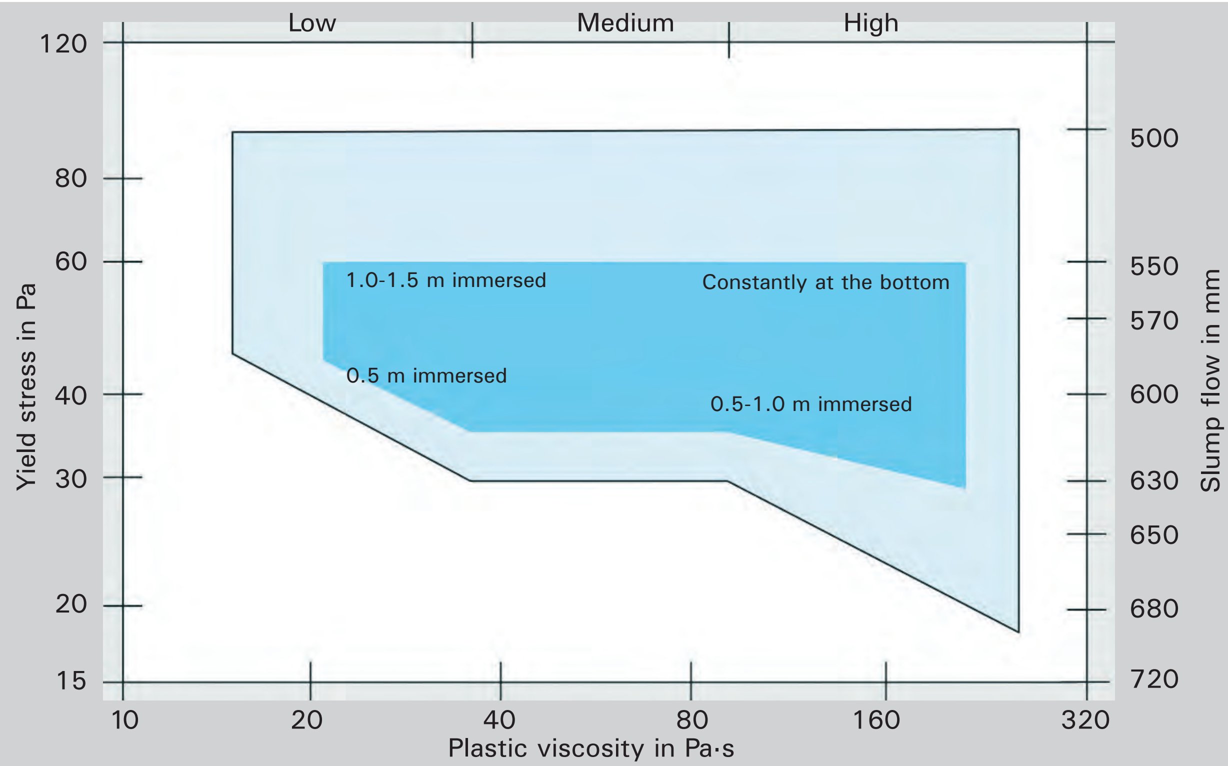


Figure 5.5. Selection of flow properties for casting of a simple, lightly reinforced wall with a limited length. The light blue area applies to walls without any particular surface finish requirements where it is recommended to have the inlet positioned constantly approximately 0.5 m above the surface of the concrete. The narrow dark blue area applies to walls with surface finish requirements. Here the recommendation is to have inlet positioned immersed into the concrete. The viscosity classes correspond to those illustrated in Figure 4.2.

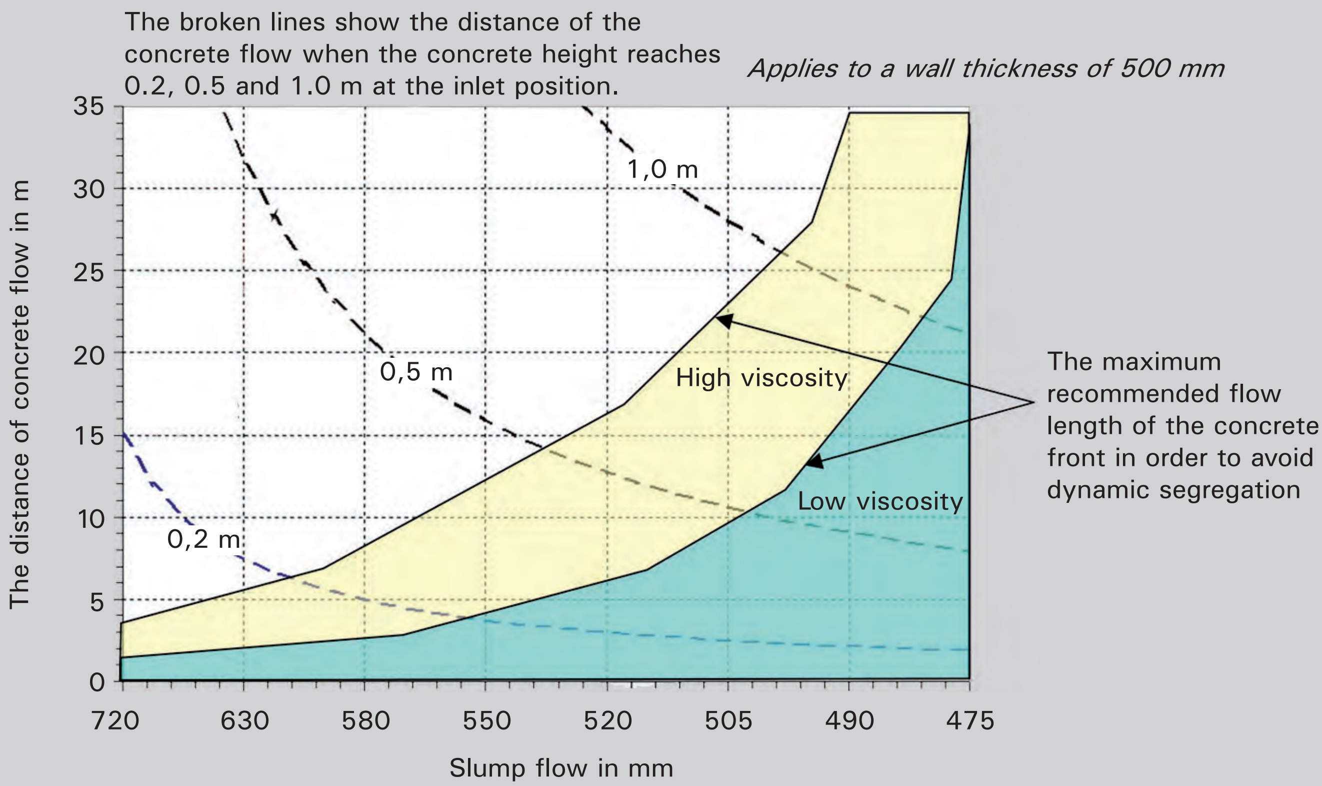


Figure 5.6. The broken lines show how far the concrete front flows from the inlet position and how much the concrete height rises at the inlet position for a given slump flow value. A higher slump flow means longer flow distances. The concrete height at the inlet position can be used to control the length of the concrete front. The recommended maximum concrete flow distance is shown for high and low viscosity classes, respectively.

The horizontal inlet position is adjusted according to the distance of the concrete front from the inlet. The climb rate at the inlet placement can be used as a guide for controlling the concrete front (Figure 5.6). The diagram shows:

- The distance of the flowing concrete front from the inlet position when the concrete height at the inlet rises by 0.2, 0.5 and 1.0 m respectively (broken lines). The flow length only depends on the slump flow value and the wall thickness (diagram shown for 500 mm).

- The recommended maximum distances for the concrete front to flow away from the inlet. It is seen that longer concrete flow distances are allowed for combinations of high plastic viscosity and low slump flow values.

For instance it is seen from Figure 5.6 that for a slump flow of 550 mm the concrete flow distance is allowed up to approximately 12 m at high viscosity class and only approximately 4 m at low viscosity class, corresponding to a height increase at the inlet of 0.4 m and 0.2 m, respectively. Thus, low viscosity results in a need to move the inlet more frequently than with high viscosity.

Figure 5.7 illustrates the principle for controlling the horizontal inlet position casting of a 20 m long wall. Thus, for the formwork shown, two inlet locations will be needed when assuming a slump flow of 550 mm and high viscosity class. If a low viscosity was chosen instead, up to five different inlet locations would have been required.

In general, it is recommended to select a high viscosity class SCC for long flow distances as it will ensure that the concrete front develops at an appropriately slow pace. This again ensures continual control over the casting progress and you are not overrun by the concrete front. Furthermore, in the event of an interruption of the casting the concrete front will just continue its flow very slowly and it is easier to avoid cold casting joints. The disadvantage from using high viscosity class is that it is more difficult to achieve a plausible surface finish.

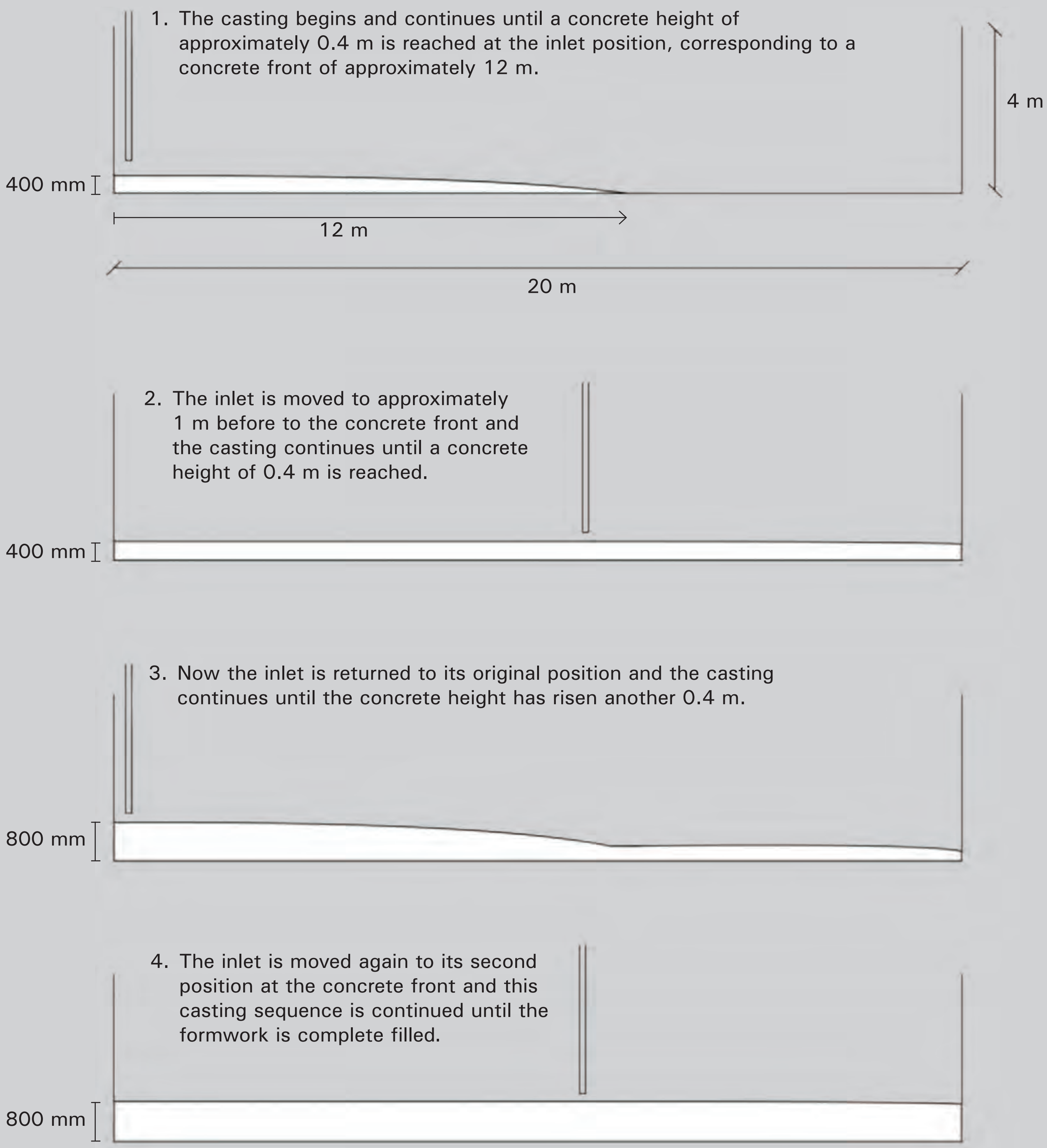
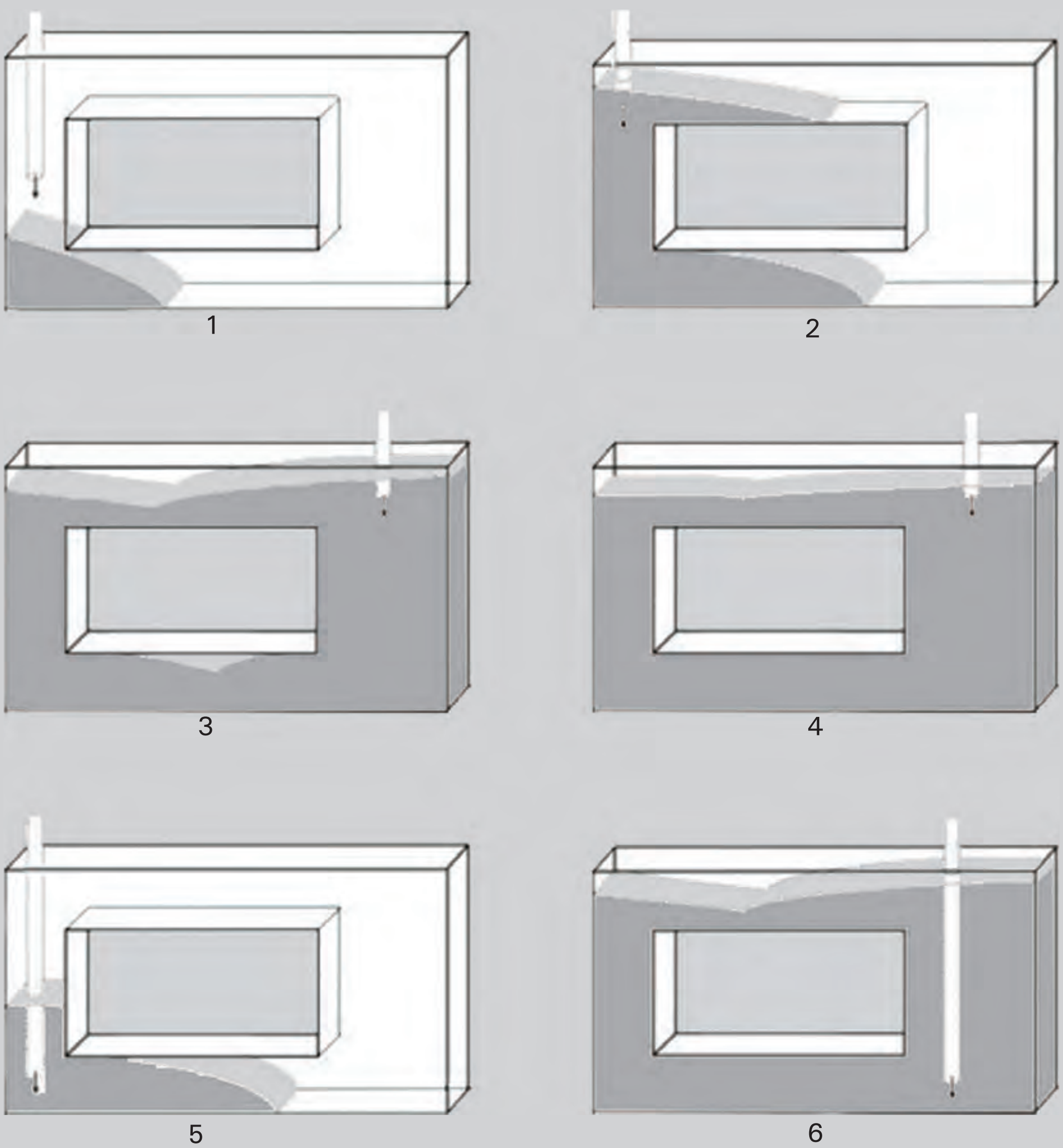


Figure 5.7. Illustration of the principles of Figure 5.6 to control the concrete front in a long wall casting. Wall thickness is 500 mm, length is 20 m and height is 4 m. SCC with a slump flow of 550 mm and a high viscosity class is assumed.

Complicated long wall with holes, boxouts and congested reinforcement

For this type of wall the vertical position of the pump hose will typically be rather limited due to the form geometry and the reinforcement configuration. Thus the concrete may drop freely down into the formwork in many cases. In such cases it could be an advantage to pump the SCC into the formwork through pump inlet connections in the formwork.

Compared to the simple wall it is even more important to consider the choice of flow properties to achieve complete form filling due to the complicated form geometry and reinforcement. Figure 5.8 shows some of the form filling considerations associated with SCC flow near a boxout such as a window hole or an anchor for prestressing. The form filling may have to be done successively on both sides to avoid one-sided hydrostatic pressure.



The inlet is placed right over or just beneath the concrete surface. If the slump flow is too low there is risk of incomplete form filling under the recess (3). With the selected casting technique, there is a need for a higher slump flow to achieve complete form filling under the recess (4).

In this case the inlet is placed just above the bottom of the formwork Compared to the situation above (1-4), there is a lower risk of incomplete form filling using this technique and it is possible to apply a lower slump flow value.

Figure 5.8. Principle sketch for casting SCC near a boxout in a vertical casting.

Figure 5.9 shows recommendations for selection of flow properties with and without surface finish requirements. It presumes that it is only possible to cast with a drop from above and only slightly possible to immerse the inlet beneath the concrete surface. As shown, there are stricter requirements for the flow properties as compared to Figure 5.5 due to the greater risk of incomplete form filling, blocking and segregation. It is therefore recommended to use SCC with high viscosity for complicated vertical castings.

Controlling the length of the concrete front follows the principles described for a simple long wall geometry in the previous section. Correspondingly, Figure 5.10 can be used to plan inlet positions for walls thicknesses of 250 mm and 150 mm, respectively.

It shows that the narrower the formwork, the higher the climb rate will be for the same flow distance of the concrete front. That in turn means that the inclination of the concrete front will be steeper.

For this type of a wall it is recommended to use a relatively high viscosity in part out of consideration for the location of the concrete front, but also due to the increased risk of segregation during the free drop into the formwork and blocking. It can be advantageous to place the inlet near the congested reinforcement zones to utilize the flow of the concrete to achieve a good form filling and embedment of the reinforcement in these areas.

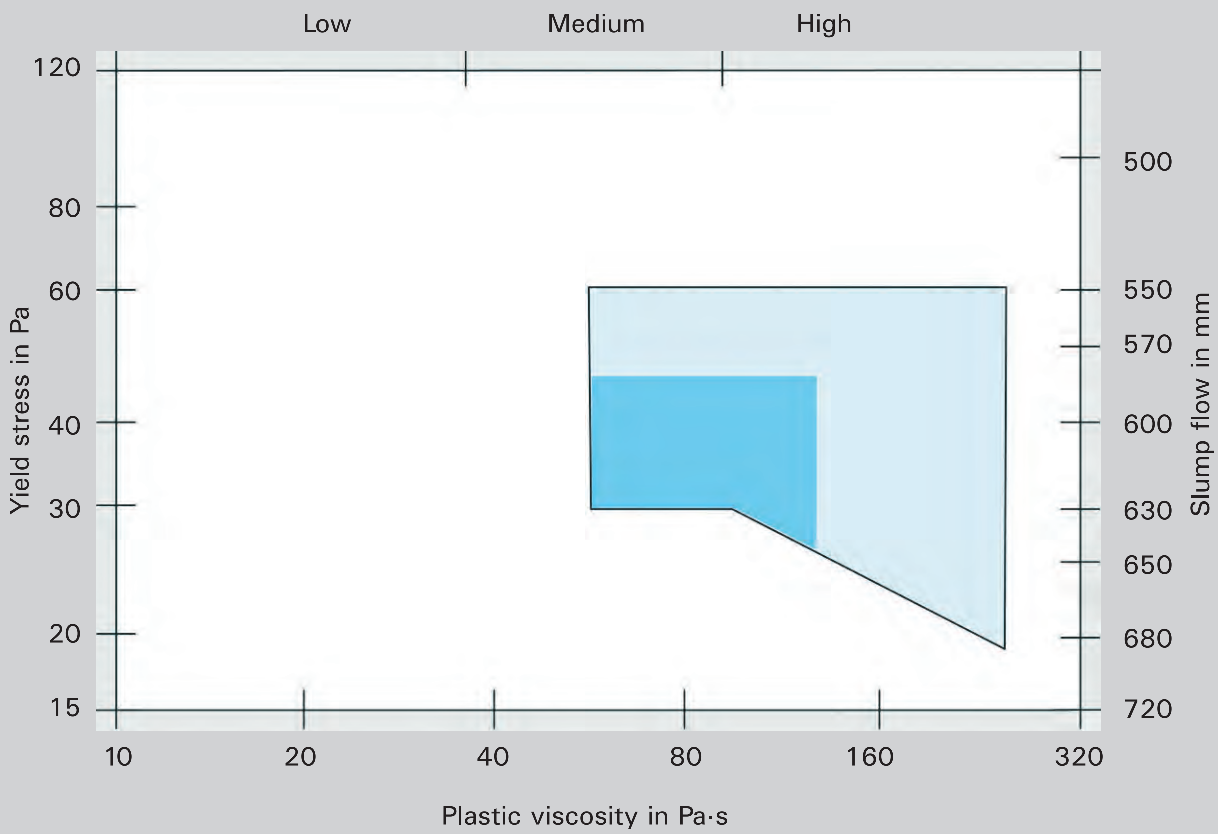
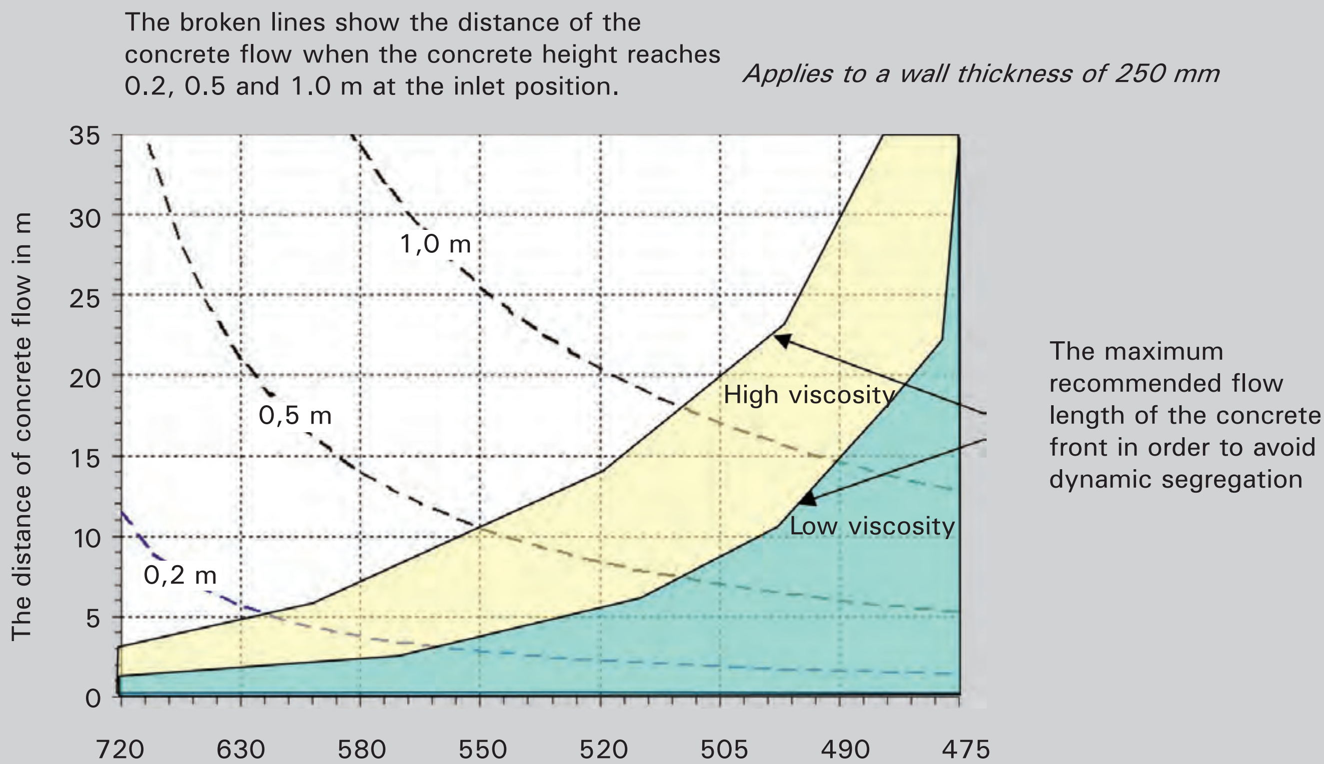


Figure 5.9. Selection of flow properties for casting of complicated wall (Figure 5.3). The light blue areas apply to walls without any particular surface finish requirements. The dark blue area applies to walls with surface requirements. Due to the form geometry and reinforcement layout, it is presumed that it will only be possible to cast with a relatively large drop heights. The viscosity classes correspond to those illustrated in Figure 4.2.



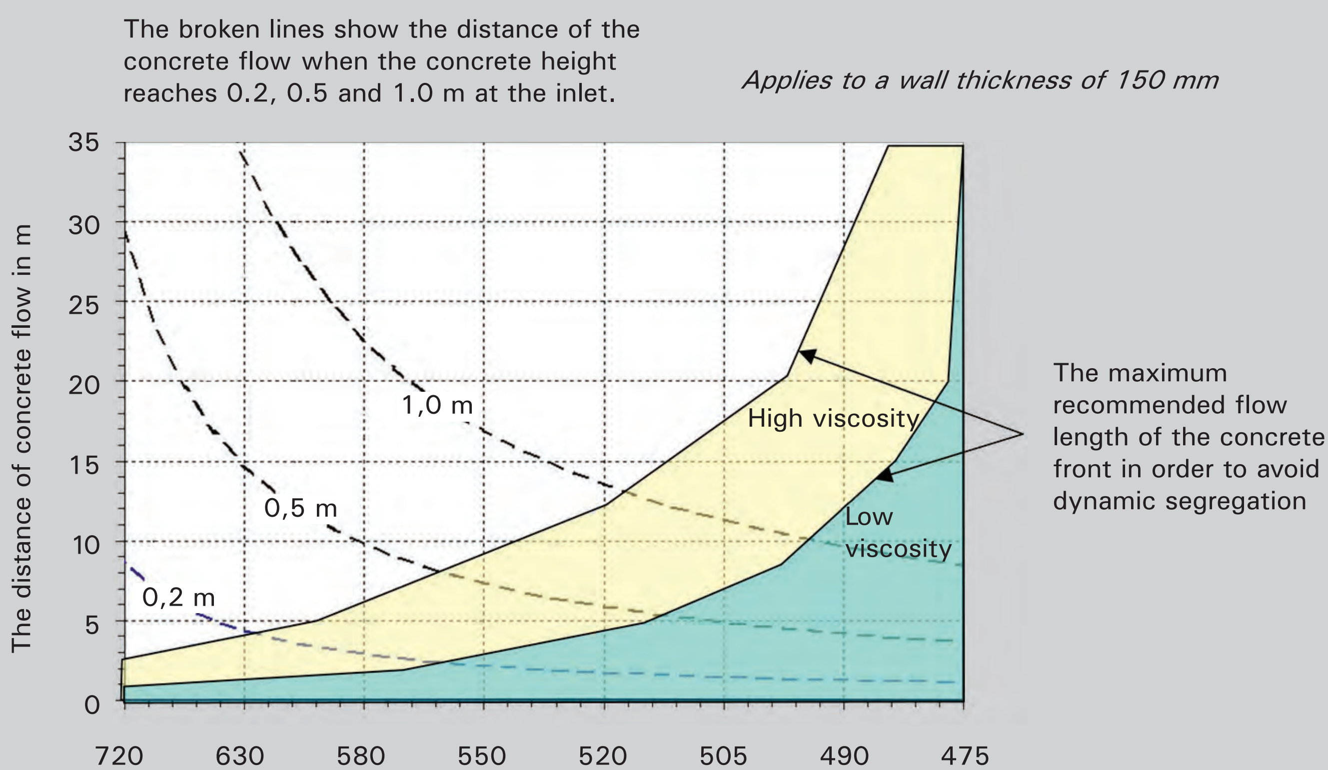


Figure 5.10. Diagrams corresponding to Figure 5.6 for wall thicknesses of 250 and 150 mm.

6. Definitions and terminology

The following terms are used throughout the Guidelines:

Aggregate size, D_{max}	:	States the maximum aggregate size of the mix composition.
Blocking ratio	:	The ratio between the smallest passage distance and the maximum aggregate size. For example the concrete cover thickness divided by D_{max}.
Flow properties	:	Another term for the rheological properties.
Paste	:	Term for the mixture of cement, fly ash, additives and water as well as the fines and filler materials.
Plastic viscosity	:	η_{pl} is the flow property that controls the flow rate. Measured in Pa·s
Rheological properties	:	Parameters for describing SCC flowability, termed yield stress and plastic viscosity.
SCC	:	Abbreviation for Self-Compacting Concrete or Self-Consolidating Concrete. Does not require vibration to flow into a specific formwork, embedding reinforcement and other cast-in parts completely.
Segregation	:	Demixing of the coarse aggregate from the mortar and paste phase.
Slump	:	States the consistency of traditional concrete. Measured as the change in height of a slump cone filled with fresh concrete.
Slump flow	:	Measurement of SCC consistency via the diameter of a fresh concrete sample.
t_{500}	:	Time measurement for SCC viscosity. Stated in seconds.
Traditional concrete	:	The term for plastic slump concrete that requires vibration.
Yield stress	:	τ_0 is the flow property that is related to the slump flow. Measured in Pa.

DANISH
TECHNOLOGICAL
INSTITUTE

SCC Consortium