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Review paper

SELF-COMPACTING CONCRETE AND ITS APPLICATION IN CONTEMPORARY ARCHITECTURAL PRACTISE

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In majority of the most modern architectural designs realised in the past 10-20 years, concrete having features in fresh and hardened state as well as making, placing and curing techniques that are defined in detail was used. Quite frequently concrete which was self-compacting in fresh state was used. In order to get acquainted with this material and with possibilities of its application this paper presents various buildings in which it was used. The definition of self-compacting concrete is given and advantages of its application are underlined. Next, features of fresh SCC, test methods are described in detail and classifications especially defined for this material are proposed.

Key words: architectural concrete, self–compacting concrete, flowability, viscosity, passing ability.

INTRODUCTION

Building conditions for contemporary architectural buildings set new, various requirements regarding construction methods of reinforced concrete buildings. Meeting those criteria led to development of concrete with specifically defined properties in fresh state. An idea of **self-compacting concrete** (SCC), a material that flows, that is placed into formwork and that is compacted under the influence of self-weight only, without vibration and additional processing emerged. Realisation of self-compacting as the key feature of fresh concrete enabled at the same time application of technologically higher-quality material with improvement of economic building conditions.

The main advantages of application of self-compacting concrete on site are as follows:

- No vibration of fresh concrete is necessary during placement into forms.
- Placement of concrete is easier.
- Faster and more efficient placement of fresh concrete is achieved. Total concreting time is reduced.
- Noise level on construction site is reduced. Thus the number of working hours on the construction site can be increased and the night shift in urban zones is enabled.
- Energy consumption is reduced.
- Required number of workers on construction site is reduced.
- Safer and healthier working environment is obtained.

Upon self-compacting concrete hardening in structures:

- High quality of placed concrete is achieved, regardless the skill of the workers.
- Good bond between concrete and reinforcement is obtained, even in congested reinforcement.
- High quality of concrete surface finish is obtained with no need for subsequent repair.
- With a better final appearance of concrete surface, smooth wall surfaces and flat floor surfaces that need no further finishing are obtained.
- Improved durability of structures is achieved.
- Maintenance costs are reduced.

EXAMPLES OF STRUCTURES BUILT OF SELF-COMPACTING CONCRETE

Earliest research in design of self-compacting concrete mixes began in the mid-eighties in the twentieth century in Japan. The main drive for this research were the endangered durability of reinforced concrete structures, need for easier and high-quality fresh concrete placement and lack of skilled labour force. In 1986, Okamura, Kochi University, Japan, was the first to propose concrete that would be placed under the influence of self-weight only. The new technology was possible owing to the development of concrete superplasticisers which had been developed during the previous decades.

After an extremely successful initial application in actual structures in Japan, the application of self-compacting concrete began in the entire world. Presently it is a very eagerly used material both in construction sites and in

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production of precast members. Extensive testing of physical and mechanical properties of SCC was carried out during the past decade. This was followed by economic analyses which confirmed the rationality of SCC application. Practical application was extended from large infrastructure buildings (bridges, tanks, retaining walls, tunnels, etc.) onto architectural buildings also. SCC appears here as a structural material in load-bearing members but at the same time it also appears frequently as architectural concrete. Architectural concrete was defined by the American Concrete Institute as "concrete which will be permanently exposed to view and which therefore requires special care in selection of the concrete materials, forming, placing and finishing to obtain the desired architectural appearance". Several characteristic examples are shown below.

Burj Dubai

The Burj Dubai structure represents the state-of-the-art in super high-rise buildings. During its construction the most recent accomplishments in all fields have been united, including concrete production technology. Several different concrete mixes were used in this project. It was necessary to place 230000m^3 of fresh concrete. That is the quantity that was built-in into tower, podium and office annex excluding foundations. The designed concretes were obtained using Portland cement combined with silica fume, fly ash or ground slag. As a result, different materials having high density and high final strength were obtained (concrete C50 was built-in into floor structures and C60 and C80 into vertical load-bearing members).

The structure has sufficient rigidity, toughness and high load-bearing capacity. In course of construction of the building the concrete was pumped to higher and higher heights so it was necessary to provide extraordinary flowing ability of concrete through pipes. A world record was achieved: on November 8, 2007 highest vertical concrete pumping for buildings, 601m, was performed. Everything in this fantastic project was carefully planned. Thus concrete was poured usually at night to enable work at lower temperatures and higher humidity. Concrete was additionally cooled by adding a part of water in the form of ice. Total height, 818 m, was reached on January 17, 2009 (http://www.burjdubai.com/)

Arlanda Airport Control Tower, Stockholm, Sweden

This tower was designed by Wingårdh Arkitektkontor AB. The total height of the tower is 83 m. The structure of the pillar consists of two shafts having different dimensions which is emphasised by two-colour design. There are several eccentrically placed circular floor structures at the top. Facade walls are parts of a cone. The tower was completed and opened in 2001. Today it represents a symbol of Stockholm.

During the construction stage, the inner formwork was being climbed by a crane while the outer scaffolding and formwork were self-climbing. SCC was used in order to achieve the concreting speed of a standard floor height h=3.27m in a 4 day climbing cycle of formwork and to ensue high-quality concrete placing without vibration. The decreased noise level during concrete placing enabled concreting during the night shift.

National Museum of 21st Century Arts (MAXXI) in Rome, Italy

MAXXI was designed by Zaha Hadid. In 1998 she won the international competition out of 273 candidates. The museum building covers a surface of 30,000 m^2 in Flaminio District on a site originally occupied by a car factory and army barracks built in the 19th century. The building is characteristic for its winding exhibition space formed of reinforced concrete walls with glass roof. These structures look more like bridges since they only have walls at the sides and a floor structure while the roof is of glass on steel girders. On its winding path the structure comes across large spans, irregular supports and long overhangs. In some places the walls are 14m high. Reinforced concrete wall surfaces are visible and they require a perfect surface finish. In order to

Figure 1: Burj Dubai, May 2009.

Figure 2: Arlanda Airport Control Tower, view,

(http://en.wikipedia.org/wiki/File:Arlanda_Flightower.jpg)

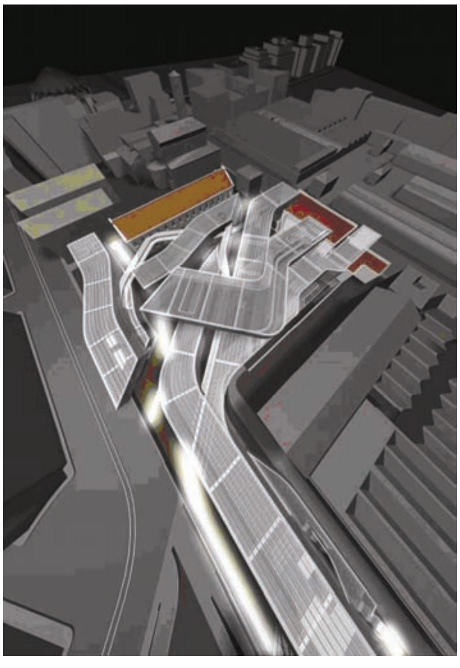

Figure 3: National Museum of 21st Century Arts in Rome, Italy, model

(http://www.maxxi.parc.beniculturali.it/english/museo.htm)

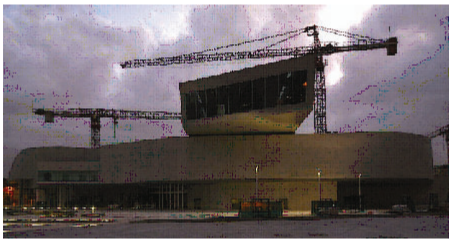

Figure 4: Entrance of the MAXXI under construction (http://www.maxxi.parc.beniculturali.it/english/museo.htm)

meet all these high requirements the contractor for the concrete structure decided to use self-compacting concrete. The concrete was cast along the entire lengths of the walls to avoid construction joints. This amounted up to 70 meters in length and 9 m in height in some members. The concrete was mixed and made on the construction site. Concreting lasted even up to 18 hours. To avoid segregation, the height from which the fresh concrete was poured was limited to maximum 15cm. Application of powdered limestone and epoxy-resin additives provided perfectly smooth surface finish of concrete walls. To prevent development of excessive heat in fresh concrete, concreting was performed only when the temperature was below 25º, i.e. practically from November to April.

Ušće Shopping Center

The Ušće Shopping Center was designed by a company from Belgrade, "ARCVS", while Italian company "Chapman Taylor", whose architect Gerardo Sanella designed the interior decoration and facade views, joined in 2008. The building was built since mid-2007. As many as 5000 people worked on the construction of the building at a particular same moment. Upon opening on March 31, 2009, Belgrade gained the largest Shopping centre in the region with 130,000 m^2 in area.

Figure 5: Ušće Shopping Center

Within the structural design, concrete MB40. was specified for foundations, floor structures, columns, etc.. To shorten the construction periods and to obtain high-quality visible part of the structure, the decision was made immediately before the beginning of the construction works that the fresh concrete to be used will be self-compacting in some parts of the construction..

Peripheral walls of underground structures were built with SCC. Used fresh concrete reached flowability class SF3 (SF = 850mm, see Table 1) Hardened concrete was MB 40 . Columns of underground floors were also made with SCC. Flowability of fresh concrete was SF = 900mm, and class of hardened concrete was MB60. Concrete in foudation slabs was SCC, with flowability of fresh concrete SF = 900mm. Hardened concrete was MB40. Foundation slab thickness of 30cm provided complete watertight concrete.

These are only some of the most recent and most modern architectural buildings in which SCC was used. It is expected that the implementation of SCC in the future be more frequent and wider.

Basics in technology of self-compacting concretes are described in the following sections.

DEFINING THE PROPERTIES OF FRESH SELF-COMPACTING CONCRETE

Behaviour and usability of fresh self-compacting concrete can be defined with four key properties of fresh concrete mix:

- Slump-flow - flowability is a property of fresh concrete mix to flow and fully fill complex formwork under action of self-weight only. This is the first, essential property, and therefore it is always (e.g. with every new batch on construction site) necessary to perform the slump flow test.
- Viscosity is the resistance of the fresh concrete to flow once it has already started to flow. We can also speak of density of concrete as a fluid. Through terms of time we can gain an insight into rate of movement of fresh concrete mass. Low-viscosity concrete will have large initial flow and then it will stop. High-viscosity concrete will flow slowly but it will continue to move in a longer period of time. The reciprocal of viscosity is called fluidity. Fluidity can be defined as flowability in a certain period of time.
- Passing ability is a property of fresh concrete mix to find its way through congested reinforcement assemblies or small openings between reinforcing bars. When defining the necessary SCC passing ability, geometry, reinforcement quantity and arrangement, maximum aggregate grain size and previously adopted slump-flow and viscosity are taken into account.
- The dimension of the smallest opening (limit opening) through which the SCC must continually pass is defined. Testing of this property must be especially emphasised since in a large number of structures the reinforcing bars are spaced at a sufficient distance thus enabling SCC to bypass them without any problem and to fill the space between them.
- Segregation resistance – stability is a feature of maintaining constant content of all components in the mix during transport and placing, without segregation of coarser aggregate grains or water bleeding. If the stability of the mix is not sufficient, two types of segregation occur, in respect of time and place of occurrence:

1) *External segregation* occurs during transport or placing concrete into formwork. It is manifested by visible cement slurry bleeding in the first wave of concrete and by piling of coarser aggregate grains in front of obstacles or near the location where the concrete is placed into the structure.

2) *Internal segregation* occurs after the concrete has been placed into forms, before cement starts setting. Coarser aggregate grains settle in the lower layers of concrete section and cement slurry bleeds on the surface. Internal segregation has the worst influence in high elements (columns, walls). In thin plates this phenomenon gives weak surface finish and causes cracks.

Segregation resistance becomes a very significant parameter in self-compacting concretes with higher slump–flow classes or in placing which can be favourable for segregation (when placing concrete from a larger height or along longer flow path). Only in these cases it is necessary to define the segregation resistance class.

CHOICE OF MATERIALS

The following are the key steps in choosing materials for self-compacting concrete mixes:

Defining the type of aggregate, maximum grain size and grading curve. Maximum aggregate grain size is limited to 8 – 20 mm. Decreasing maximum grain size results in lower local stresses in cement paste, influences improvement of concrete workability without vibration and prevents segregation of coarse grains. In normal strengths, natural, river aggregate is used. With its smooth surfaces it contributes to better flowability and workability. Only in cases where high classes of hardened concrete are required, crushed aggregate can also be applied. Aggregate grading curve is usually continuous, with maximum quantity of fine aggregate.

Adopting mineral additions: Mineral additions are inorganic materials that are added to concrete. They are classified into two groups:

- Inert: Fillers which include powdered limestone, and pigments
- Pozzolanic or latent hydraulic additions: those are ground granulated blast furnace slag (GGBFS), fly ash (FA), silica fume (SF), synthetic silica and natural pozzolana.

The following are the most important properties of mineral additions: High level of fineness, high pozzolanic activity and compatibility with other ingredients of the mix. Moistened fine particles of mineral additions "lubricate" like spheres the cement grains thus reducing friction in fresh concrete mix. They give the concrete better workability and higher cohesion and impermeability. Water bleeding from fresh concrete mix is significantly reduced.

Adopting the type and quantity of hydraulic binder: As a rule, the mixture for SCC is designed with a large quantity of cement. Expected cement quantities are 350–500 kg/m^3. If reduction of hydration heat is desired when designing the mixture, cements with low hydration heat should be applied, a part of the cement mass should be replaced by puzzolana or special measures for reducing temperature of the fresh concrete mix should be provided. If high final strengths are desired, it is considered that it is absolutely necessary to use silica fume in addition to cement. Application of silica fume should be limited to 20–25% of cement mass. If additional quantities of filler are required, powdered limestone can be used. Thus 2 types of fine particles are added and a best package is achieved. Powdered limestone is an inert filler and silica fume can be considered to be both a filler and a latent hydraulic binder at the same time.

During the recent years microfine cements (for example, Mikrodur®, Nanodur®, Dyckerhoff products, Germany) have appeared on the market (Strunge J.and Deuse T., 2008). These are new types of cement having finer grain size and different order of magnitude of size of individual particles. Dense packing in cement rock is enabled by combining cement, microfine cement, finely ground blast furnace slag and synthetic silica. In a carefully developed production process, Portland cement clinker and blast furnace slag are separately ground to a desired fineness. Next, the components are joined in accordance with individual requirements in a special process. The final product has a guaranteed constant "granulometric composition" of fine, reactive particles instead of uniform "coarse" ordinary cement grains.

Adopting the water/powder ratio, with simultaneous application of chemical admixtures. Self-compacting concrete is much more sensitive to water content than ordinary concretes. The specified water quantity must be sufficient for chemical reaction with all hydraulic binders. Larger quantity of cement requires a larger quantity of water in a fresh mix. Further increasement of water quantity is necessary to increase the workability of fresh concrete but we usually remain at water quantity 150 – 210 l/m^3. The final water/powder ratio (by volume) is 0.85 – 1.10. The required flowability and other properties of fresh concrete are achieved by wide application of chemical admixtures.

Admixtures are materials which are added to concrete in very small quantities (compared to the cement mass) before or during mixing in order to achieve certain properties of fresh or hardened concrete. Specific admixtures have been developed for self-compacting concrete:

- **high range water reducing admixtures - HRWRA** Application of HRWRA provides fluidity of fresh concrete and reduces the required water quantity.
- **Viscosity modifying admixtures-VMA** increase the cohesion of fresh concrete and can replace a part of mineral additions. They have the effect of cement paste densifying and keeping fine particles within the matrix.
- **Special admixtures for SCC – combined HRWRA + VMA**: The majority of admixture manufacturers produce special admixtures for SCC which include both HRWRA and VMA within them. By application of these special admixtures, possible incompatibility in application of separate admixtures is avoided and desired viscosity of fluid mix is obtained.

CONCRETE MIX DESIGN

In SCC mix design, required quantity of individual concrete components is defined. In addition, it is necessary to achieve the following:

- The paste carries the aggregate grains. Therefore the paste volume has to be greater than the volume of voids between the aggregate grains. Each individual aggregate grain has to be fully coated and lubricated by a layer of paste. Thus the fluidity is increased and the friction between aggregate grains is reduced.
- Fluidity and viscosity of the paste have to be controlled and balanced by the choice and ratio of cement and admixtures. Limitation of water/powder ratio and application of chemical admixtures gives best results in obtaining required properties of concrete in fresh state.
- In order to control concrete shrinkage and temperature during the hydration process significant quantities of mineral additions and fillers are applied. At the same time, mineral additions increase the final strength of concrete.
- The coarse aggregate grains must be fully surrounded by mortar. This reduces coarse aggregate interlock when the concrete passes through narrow openings in forms or gaps between reinforcement. The quantity of coarse aggregate in SCC is always reduced.

As a result, concretes having the following in comparison to vibrated concretes are obtained:

- Lower coarse aggregate content with limited nominal maximum grain up to 20 mm,
- Greater total quantity of fines, lower than 0.125 mm (cement, active and inert mineral additions and finest aggregate particles),
- Increased paste content,
- Lower water/powder ratio,
- Increased quantity of superplasticisers or hiperplasticisers (HRWRA),
- Included application of viscosity modifying admixture (VMA).

In order to obtain the required properties of concrete in fresh and hardened state it is necessary to define the mix design method (procedure). The best known is the Method of mix design by Okamura, in 6 steps. The properties of concrete mix thus specified must be confirmed by laboratory testing in each step and corrected if necessary.

TEST METHODS

Behaviour of fresh, self-compacting concrete is not included in current codes for concrete structures. The existing methods used for testing ordinary (vibrated) concretes in fresh state are not suitable for SCC testing either. Therefore it is necessary to define the methods for fresh concrete properties testing and to give a relation between the set conditions at the moment of concrete placing and specified material properties.

Test methods are in the development and standardisation stage. Some of the most frequently used methods, (Specifications and Guidelines for Self-Compacting Concrete, 2002), properties that can be checked by a specific method, as well as recommended concrete classification, if it exists (The European Guidelines for Self-Compacting Concrete, 2005) are presented here.

Slump flow test and T_{500} time test

Slump flow gives an assessment of horizontal free spread (flow) of self-compacting concrete without obstacles. The method was developed in Japan from the well-known Abram's cone slump method.

Equipment: Metal cone 300 mm high, base 200 mm in diameter, top opening 100 mm in diameter. A rigid square plate measuring 700 - 1000 mm, with a marked centre of the cone and a circle 500 mm in diameter.

Procedure and basic measuring values: The cone is placed on the board, filled with concrete and then raised. Instead of measuring the settlement of concrete in the cone, the diameter of concrete circle SF = d is measured when the fresh concrete mass stops flowing. Slump flow is calculated as the average value of two measured diameters perpendicular to each other:

$SF = (d_m + d_r)/2$

This is a fast, simple method which is most frequently used both in laboratories and in construction sites. It gives a good assessment of deformability (flowability of fresh concrete) and can give visual information on stability. It does not give any information on passing ability of fresh concrete.

It is necessary and obligatory to define the slump flow class, SF, as the basic characteristic of fresh concrete mix, in the concrete design. Three classes are proposed and the mark is derived as an acronym from the name of the test in the English language:

Figure 6: Filling the Abram's cone

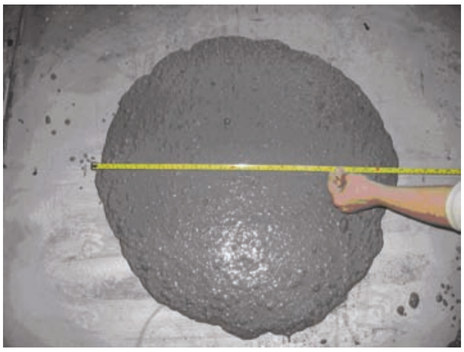

Figure 7: Resulting concrete spread 670 mm (class SF2)

Table 1: Proposed classification and criteria for SCC slump flow testing

Concrete class	Slump flow (mm) specified	Confirmation of required spread criterion
SF1	550 – 650	520mm ≤ d_m ≤ 700mm
SF2	660 – 750	640mm ≤ d_m ≤ 800mm
SF3	760 – 850	740mm ≤ d_m ≤ 900mm
Stated value of spread concrete diameter	d_m	$d_m \pm 80$ mm

Application of concrete according to the introduced classes:

SF1 can be applied in:

- Slightly or non-reinforced concrete structures that are cast from the top with free spread from the delivery point (for example, floor structure slabs),
- Pumped concretes,
- Sections of structures that are sufficiently small to prevent larger horizontal flow (piles and some sections of foundations).

SF2 can be applied in majority of normal structures (walls and columns).

SF3 is usually applied in concrete with maximal aggregate grain size less than 16 mm, in elements with congested reinforcement, in structures with complex shapes of forms, if the forms are filled from below. SF3 class gives better surface finish than SF2 when the fresh concrete is placed normally vertically but the risks of segregation are higher.

In special cases self-compacting concretes with flow diameter greater than 850 mm can be required but then special care should be taken of control of all forms of segregation. In that case maximum grain of coarse aggregate should be less than 12 mm.

In case time required to reach the spread concrete diameter of 500 mm is measured, viscosity of the fresh mix can also be controlled. The planned classification is given in table 2.

V-funnel test and V-funnel test at $T_{5minutes}$

This method was developed by a Japanese team of researchers: (Haykawa M., 1993) and (Okamura H. and Ouchi M., 2003). The method is simple so it can be applied both in a construction site and in a laboratory.

Testing imitates flow of concrete during placing thus giving a good insight into viscosity and deformability of fresh concrete. Information on stability of the mix (segregation resistance) can also be obtained. The test is related to concrete with maximum aggregate size 20 mm. The basic value measured is time required for the concrete to flow through the funnel.

Equipment: Metal funnel, shown in the figure. The funnel width is constant and is always 75 mm. The top section is 450 mm high, the top opening is 515 mm long (the inclination of the funnel top part sides must be 2:1). The bottom, narrow part of the funnel is always 150 mm high and the size of the bottom opening with a movable bottom is 65/75mm. The funnel holder must provide stability and vertical position of the funnel during filling and emptying.

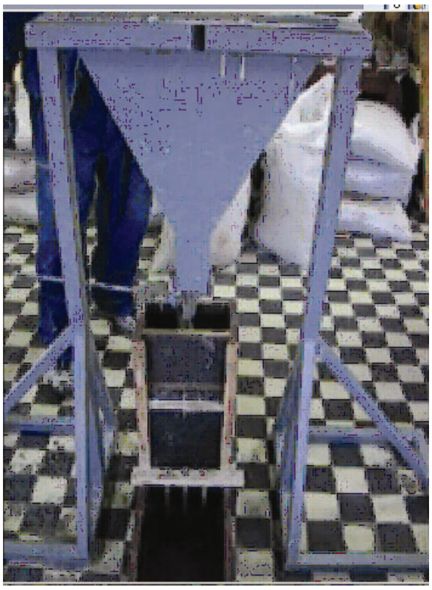

Figure 8: V–funnel test (Okrajnov–Bajić R., 2009)

Table 2: Proposed SCC classes with parallel criteria for respecting methods

Concrete class	**T_{500} (s) , specified time of concrete flow to d_m= 500 mm,**	**Corresponding time of V-funnel emptying t_v (s)**	**Confirmation of required criterion (for emptying time of V-funnel (s))**
VS1 / VF1	$t \leq 2$	$t \leq 8$	$t \leq 10$
VS2 / VF2	$2 < t$	$8 < t \leq 25$	$7 < t \leq 27$
Target time for V-funnel emptying			$t - 3 \leq t \leq t + 3$

Measuring Procedure: The funnel is moistened and placed on a flat, stable base; a container is placed under the funnel. The funnel is filled with concrete using a scoop, without compaction. The movable bottom of the funnel is opened after 10 s and free flow of fresh concrete under gravity action is enabled.

Basic measure: The time from the moment of opening the movable bottom to the moment when light at the bottom appears is measured.

If viscosity is described as time required for the V-funnel to be emptied (time needed for fresh concrete to flow out so that light can be seen at the bottom), two classes are used: VS1/VF1 and VS2/VF2. The proposed classification of self-compacting concretes by viscosity was introduced in 2005 in European Guidelines for Self-compacting Concrete. It is described in the following table and it gives parallel criteria for the time for the concrete to flow out of the V-funnel and concrete flow time to diameter 500 mm, $\mathbf{T}_{500}$ (method described in previous chapter).

VS1 / VF1 has excellent filling ability even with congested reinforcement and in complicated forms. It gives best surface finish. Coarse grain segregation and cement mortar bleeding must be specially controlled in these mixes.

VS2 / VF2 is a class with no upper limit. It is logical that the density of fresh concrete increases and that the formwork pressure decreases with increase with time. (appearance of tixotropic effects). Segregation resistance is improved. Possible negative effect is lower quality of surface finish (appearance of blow holes). More sensitive to stoppages in delivery of fresh concrete.

Viscosity testing is required in special cases. It is very useful information in concrete mix design. As additional information $\mathbf{T}_{500}$ can confirm constant concrete quality from one to the next batch during slump testing.

L-box test method

This method, based on Japanese designs for underwater reinforced concrete structures, was described later (Petersson Ö. Et al. (1996). It is used as a primary method in testing passing ability of concrete through congested reinforcement (The European Guidelines for SCC, 2005).

Equipment: "L" shaped box made of rigid non-absorbing material is used. The longer side is placed horizontally on a rigid base. There is a moveable vertical gate at the connection between the two sections; immediately behind it there are vertical obstacles (usually one row of vertical rebars 3 Ø12 with a gap of 41 mm or 2 Ø12 with a gap of 59 mm). The dimensions of the box are defined [(6)] with tolerance ±1mm.

The basic dimensions which are measured are: $\mathbf{H}_1$ – height of concrete in the vertical section (immediately behind the moveable gate) and $\mathbf{H}_2$ – height of concrete at the end of the horizontal section of the L-box.

Procedure and basic measurement: The inside surfaces of the L-box are moistened and surplus water is removed. The gate is closed. The vertical section of the box is filled with concrete without compacting. The filled box is left to stand for 1 minute. The concrete is observed for appearance of segregation. The moveable gate is lifted and the concrete is allowed to flow freely through the vertical grid and to fill the horizontal section of the box. When the fresh concrete stops flowing, measure $\mathbf{H}_1$, the height of concrete in the vertical part (immediately behind the moveable gate), and $\mathbf{H}_2$, the height of concrete at the end of the horizontal part of the L-box. Both heights are calculated in three points, by subtracting the height between the edge of the concrete and the top of the box from the maximal height of the box. The passing ability (the ratio of concrete heights at the end and at the beginning of the L-box) is calculated and it gives an estimate of the passing ability of fresh concrete.

PA = H2 / H1.

The passing ability should be within the limits $0,8 \leq H_2 / H_1 \leq 1,0$, regardless whether L-box with 2 or 3 vertical rebars is used. If the blocking ratio is closer to 1.0, the passing ability of fresh concrete mix through the reinforcement cage and formwork filling are better.

The proposed classes for passing ability PA (The European Guidelines for SCC, 2005) occur depending on the size of the gaps between the rebars. Thus the following criteria are adopted:

- In case of thin slabs with clear distance

Table 3: Introduced classes and criteria for use in L-box testing

Concrete class	**Passing ability**	**Confirmation of the required criterion (for passing ability PA)**
PA1	$0.8 \leq PA$ with obstacle with 2 rebars	$0.75 \leq PA$
PA2	$0.8 \leq PA$ with obstacle with 3 rebars	$0.75 \leq PA$
specially defined passing ability of L-box		not less than 0.05 below specified value of PA

between rebars greater than 80 mm and for other structures with clear distance between 2 rebars greater than 100 mm, it is not necessary to test the passing ability;

- **PA 1**: in architectural buildings and vertical structural members having clear distance 80-100 mm between 2 reinforcing bars, L-box with 2 vertical rebars is used;

- **PA 2**: In heavily reinforced members of engineering structures having clear distance 60-80 mm between 2 rebars, passing ability is tested in an L-box with 3 vertical rebars.

- In complex structures having clear distance between 2 reinforcing bars less than 60 mm, the passing ability of the concrete shall be tested separately for the specific maximal aggregate grain and the specified arrangement and distance between the reinforcing bars.

In case of segregation, obvious blocking of coarse aggregate behind the vertical rebars can be detected visually. At the same time, the flow of the concrete in the horizontal section of the L-box is seriously slowed down.

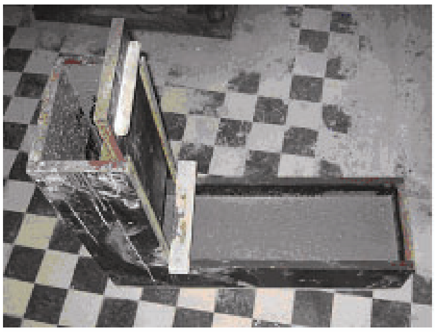

Figure 9: L-box

Figure 10: L-box

Testing using this method is shown in *Figures 9 and 10* (Okrajnov–Bajić R., 2009)

Summary of test methods: The number of methods proposed for standard SCC testing is large. It was expected that 1 test which would comprise testing of all properties of fresh concrete will be defined, but that proved to be an impossible requirement. Work conditions on construction sites require more simple and robust equipment (slump flow and T_{500}), while some of the proposed test methods have been used since the beginning of SCC making and thus there is abundance of data. However they are used in laboratory conditions (L-box, V-funnel, U-box). Segregation testing is performed by relatively new and unknown methods.

The following are shown as basic methods (The European Guidelines for SCC, 2005):

- Slump flow + T_{500},
- V-funnel – alternatively T_{500}
- L-box
- Sieve segregation resistance test. It is not presented here since it is relatively rarely specified.

CONCLUSION

Contemporary architectural buildings set new, high technological requirements. Concrete which appears in all contemporary architectural buildings adapts to these new building conditions. Thus, today we can speak of self-compacting concrete which is transported by pumps to heights even up to 600 m, about concrete which can be continually placed into congested reinforcement and which can be allowed to flow and can be placed into forms under the action of self-weight only, without vibration. Self-compacting concrete appeared as a response to increased conditions of reinforced concrete buildings durability and high-quality smooth surface of architectural concrete. As a material, it seeks new standards in production and control. These standards connect fresh concrete properties and possible application fields.

References

Haykawa M. (1993) "DEVELOPMENT AND APPLOCATION OF SUPER WORKABLE CONCRETE", RILEM Workshop on 'Special Concretes – Workability and Mixing' edited by prof. P.J.M. Bartos, (Paisley) 183-190

Okamura H. and Ouchi M. (2003) "SELF–COMPACTING CONCRETE", Journal of advanced Concrete Tehnology, Vol.1, No. 1 pp. 5–15

Okrajnov–Bajić R. (2009): HIGH STRENGTH SELF-COMPACTING CONCRETE WITH DISTINCT PRINCIPAL TENSILE STRESSES, doctoral dissertation, Faculty of Civil Engineering, University of Belgrade

Petersson Ö. et al. (1996): a "MODEL FOR SELF–COMPACTING CONCRETE", Proceedings of International RILEM Conference on 'Production Methods and Workability of Concrete', Paisley, pp.483–490

Strunge J. and Deuse T. (2008) "SPECIAL CEMENTS FOR ULTRA HIGH PERFORMANCE CONCRETE", Proceedings of the Second International Symposium on Ultra High Performance Concrete, Kassel, Germany, march 05–07, pp. 61– 68

Other resources

"SPECIFICATION AND GUIDELINES FOR SELF–COMPACTING CONCRETE", EFNARC, Farnham, UK, February2002, http://www.efnarc.org/pdf/SandGforSCC.PDF

"THE EUROPEAN GUIDELINES FOR SELF–COMPACTING CONCRETE", BIBM, CEMBUREAU, ERMCO, EFCA, EFNARC, May 2005 http://www.efnarc.org/pdf/SCCGuidelinesMay2005.pdf

http://www.burjdubai.com/

http://en.wikipedia.org/wiki/File:Arlanda_Flightower.jpg

http://www.maxxi.parc.beniculturali.it/english/museo.htm