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Simplifying the Design of a Self-Compacting Concrete

Simplificando el Diseño de un Hormigón Autocompactante

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TITULARES

- El HAC tiene dos diferencias fundamentales al dosificar respecto a un hormigón convencional (HC).
- Las propiedades básicas del HAC deben cuantificarse, pero los métodos tradicionales no lo hacen.
- Cómo no hay método normalizado para el diseño del HAC muchos desarrollaron sus propios métodos.

HIGHLIGHTS

- SCC has two fundamental differences in designing compared to conventional concrete (CC).
- The basic properties of SCC must be quantified, but traditional methods can´t do it.
- As there is no standardized method for SCC mix design, many have developed their own methods.

RESUMEN

El Hormigón Autocompactante (HAC) se obtiene con el uso de aditivos super fluidificantes otorgando al hormigón las propiedades para que sea colocado por simple vaciado. En estado fresco se caracteriza por una consistencia fluida y una gran resistencia a la segregación, disminuyendo los defectos de compactación. En estado endurecido, el HAC puede alcanzar resistencias mecánicas superiores a un hormigón convencional. Estas propiedades se toman en cuenta en ensayos específicos, no existiendo diseños estandarizados de HAC, sino rangos de aceptabilidad, en este trabajo se simplifica su diseño modificando el método de la ACI 211 para hormigones convencionales, considerando fijos algunos valores. Esto se logró debido a que tras intentos fallidos de hallar el porcentaje de aditivo y otros como el contenido de agregado grueso a través de los datos proveídos por el mini cono y que con ello los hormigones no se obtenían ya que fallaban en dar con los porcentajes deducidos del mini cono y otros métodos reológicos para pastas, por lo que se simplificó el análisis previo con excelentes resultados para la dosis del super plastificante dentro del rango de los fabricantes para diseñar el HAC.

Palabras clave: *Diseño; fluidificante; hormigón autocompactante; simplificación.*

ABSTRACT

Self-Compacting Concrete (SCC) is obtained with the use of super fluidizing additives, giving the concrete the properties so that it can be placed by simple pouring. In its fresh state it is characterized by a fluid consistency and great resistance to segregation, reducing compaction defects. In the hardened state, SCC can achieve higher mechanical strengths than conventional concrete. These properties are taken into account in specific tests, and there are no standardized SCC designs, but acceptability ranges. In this work, its design is simplified by modifying the ACI 211 method for conventional concrete, considering some fixed values. This was achieved due to that after failed attempts by various teams to find the percentage of additive and coarse aggregate through the data provided by the mini-cone and other rheology methodologies for pastes, the analysis was simplified with excellent results for the dosage of the superplasticizer within the range of the manufacturers to design the SCC.

Keywords: *Design, fluidizing, self-compacting concrete, simplification.*

1. INTRODUCTION

SCC has two fundamental differences in terms of the way it is dosed compared to conventional concrete (CC): Firstly, the main objective is to achieve self-compatibility characteristics rather than compliance with a certain resistance. Self-compatibility generally defines the coarse aggregate content, the paste volume, the amount of additive and the water/fine materials ratio.

The strength requirement can be achieved through the appropriate combination of the materials that make up the paste. Secondly, since the amount of materials component of SCC is a greater number of variables and their possible combinations, the shape coefficient should be as high as possible, since the best self-compacting properties without blockages and high creep of concrete are achieved with rounded stones. 3rd or 4th generation superplasticizer additive is used such as Chemical Base: Polycarboxylates.

There are several methods for dosing such as that of Prof. B. L. Karihaloo, the PCA design method mentioned by Linden, B and García-Taengua (23), a two-stage method, that of equivalent mortars and high thermal performance SCC (24). , method of Instruction EHE-08, use of Fuller's parabola, Bolomey formula regarding the granulometry of aggregates and components, tests on pastes and mortars (Okamura and Ozama, 2000) using the Marsh cone, the minicone from Kantro; methods from Kuchi University (Edamatsu et al, 1999), University of Tokyo (Ouchi, 1997/1998); University of Delf (Pelova et al, 1998), University College London (Domone et al, 1999); JSCE Method (Japan Society of Civil Engineers (Getto 2003/2004)); UPC dosage method (Polytechnic University of Catalonia (Gómez et al, 2001)); the EFNARC method and the ACI 2007 method, mentioned by Bermejo Núñez, 2009 (25).

2. MATERIALS AND METHODS

2.1 Work development

The work was developed in three stages, the failed attempts resulting from the results of the Kantro mini-cone and the Marsh cone did not allow the SCC to be designed to comply with the tests that characterize it. The mixture by the proposed design method where no prior tests are carried out on the paste with the additive but rather three initial considerations highlighted in the Design Methodology and which are considered fixed are directly applied, a second stage implemented in the Thesis Consultancies of grade with SCC mixture designs by the modified method, where the problem also arose of the percentage of coarse aggregate to be introduced into the concrete from the results of the mini-cone as well as the dose of the corresponding additive, and a third stage of consolidation in which clarifying conclusions were drawn from previous experiences.

2.2 Design methodology

The dosing methods provide guidelines on how to design concrete mixes using mini-cone pastes, the results of which have not always been able to achieve the self-compactness conditions of SCC. As a result of this, a simplified method was sought that results in a SCC in fewer attempts to achieve the sample (mainly one), which is achieved by meeting the fluidity properties according to the extension tests with the Abrams cone, the box in L, the V-Funnel and the Japanese “J” ring.

With this proposed method, the manufacturer's instructions are followed and according to the results of the tests below, they are in range with the European guidelines that were used. The percentage of water reduction chosen was 5% because the High Effect Water Reducer was used as a superplasticizer, or else the reduction of up to 40% corresponding to this additive, a key issue, would result in a mixture that would not fulfill being HAC. The ACI 211 method used for conventional concretes was also chosen and considerations were made as to whether it would result in the required fluidity range. Preliminary tests were carried out and it was decided to make part of the initial considerations for the design of the mixture, indicating a settlement of 18 cm in the corresponding table of ACI 211 and the percentage of coarse aggregate (maximum size 19.1 mm) 50% of the unit weight or volumetric weight of the Concrete.

The initial data required to dose by this method are the same of Conventional Concrete:

-Granulometry of fine and coarse aggregates.
-Determination of the fineness modulus of the composite fine aggregate.
-Unit mass of dry coarse aggregates. - Dry density of the materials.
-Absorption capacity and humidity of the aggregates (for the work).
-Specifications for the mix design (A/C Ratio, Settlement,
-Maximum size of coarse aggregate and Characteristic strength at 28 days).

3. RESULTS AND DISCUSSION

Data and materials used for one of our dosages:

Table 1: Materials and Characteristics of Engineered Concrete.

Strength	fck	300	Kg/cm²
Maximum Aggregate Size Coarse	TMA	19	mm
Fineness Modulus Fine Aggregate	MF	2,4	--
Cement	Density	3,18	g/cm³
Coarse Aggregate (5ta)	Density	2,72	g/cm³
Fine Aggregate (6ta)	Density	2,69	g/cm³
Sand (fine aggregate)	Density	2,63	g/cm³
Chemical Admixture superplastifyer	Density	1,08	g/cm³
Coarse Aggregate (5ta)	Volumetric Mass	1492	Kg/m³

3.1 Designing

Table 2: Water consumption per m³ of concrete.

Approximate consumption of mixing water and air content depending on the settlement of the truncated cone and the maximum size of the coarse aggregate								
Slump (cm)	Water Consumption (kg/m³) for maximum aggregate size (mm)							
	9,5*	12,5*	19*	25*	38*	50*	75+**	150+**
Concrete without air included								
2,5 5,0	207,0	199,0	190,0	179,0	166,0	154,0	130,0	113,0
7,5 a 10	228,0	216,0	205,0	193,0	181,0	169,0	145,0	124,0
15,0 a 17,5	243,0	228,0	216,0	202,0	190,0	178,0	160,0	---
Approximate amount of air in concrete without air included in percentage	3,0	2,5	2,0	1,5	1,0	0,5	0,3	0,2

The shaded value corresponds to the amount of water (216 kg/m³) for the fixed settlement proposed by the method (Table 2-ACI 211.1), and the maximum size of 19 mm of the coarse aggregate. Due to the dose of the superplasticizer, the water (5%) was reduced to 205 kg/m³.

Table 3: Indicative values of average resistance depending on the characteristic strength. (Media strength: 385 kg/cm²=38,5 MPa).

Code	Design Fck (kg/cm²)	Design Fcm (kg/cm²)
Model	Fck ≤ 500	Fcm=fck + 80
ACI	Fck < 200	Fcm=fck + 70
	200 ≤ Fck ≤ 350	Fcm=fck + 85
	Fck ≥ 350	Fcm=fck + 100

Table 4: Water/cement ratio for a given strength

Correspondence between water/cementitious materials ratio and compressive strength of cc		
Compression strength, 28 days	Water/cement ratio in mass	
	Concrete without air included	Concrete with air incl
420	0,41	-
350	0,48	0,40
280	0,57	0,48
210	0,68	0,59
140	0,82	0,74

Under these conditions and with a relationship between the volume of the dry and compacted coarse aggregate and a volume of 0.5 for a SCC proposed as a fixed value by the researchers, the results of previous tests used values between 0.45 and 0.55, therefore it was chosen for a round value of 0.5 (shaded in Table 5) and with the use of the superplasticizer the HAC was obtained, (1).

(It should be noted that of the 14 Thesis from the FIUNA Library on SCC ref. (9) to (22); nine used 0.5 adopting this criterion, including various cementitious materials and different super plasticizing or super fluidizing).

Table 5: Volume of coarse aggregate per unit weight of concrete

Coarse Aggregate Volume per concrete unit weight (kg/m³)				
Maximum Aggregate Size Coarse (mm)	Volume of dry compacted coarse aggregate per unit volume of concrete for different Fineness Modules of fine aggregate			
	2,40	2,60	2,80	3,00
9,6 (3/8”)	0,50	0,48	0,46	0,44
12,7 (1/2”)	0,59	0,57	0,55	0,53
19,1 (3/4”)	0,66	0,64	0,62	0,60
25,4 (1”)	0,71	0,69	0,67	0,65
38,1 (1 1/2”)	0,75	0,73	0,71	0,69

Table 6: Table derived from the previous ones for this dosage

Wwater	205 kg
Fcm (10 kg/cm²=1 MPa, according to NP 17 058 08**(26)**)	385 kg/cm²
Water/cementicious material ratio	0,44
Volume of dry and compacted coarse aggregate/m³	0,5

Then the following equation was solved:

$$Vw + Vc + Vfa + Vca + Vair + Vaditive = 1000 \text{ liters} \quad (1)$$

Table 7: Dosage result for 1 m³ of SCC (5), at Construction Materials Laboratory.

Material	Brittle 5ta (MS19mm)	Brittle 6ta (MS9,8mn)	Sand	Cement + Adition	Water	Admixture	Fck kg/cm²	F_{28d} kg/cm²
Dry Mass (kg)	746	382	541	467+00	205	7,00 B***(5)	300	385

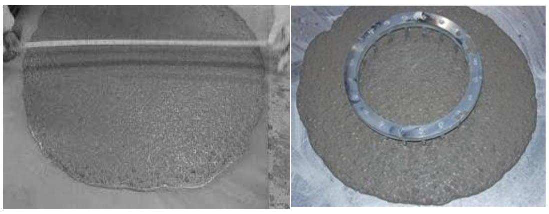
Table 8: Types of chemical additives used (5)

Admixture	Description	Density (kg/dm³)	Recommended dose * (%)
A**	Superfluidifying eter carboxílic class	1,07 a 1,11	0,2 a 0,8
B***	Superplasticizer policarboxilate class	1,07 a 1,09	0,4 a 1,5

The basic properties of SCC (fluidity, resistance to segregation, deformity in state freshness and viscosity) must be quantified, but traditional methods are completely obsolete, and for this new testing alternatives must be proposed. The most accepted for the control and design cycle of the SCC are:

1. The Settlement – Flow Test: Quantify the fluidity of the mass and relate it to the viscosity. The Abrams cone is filled without compacting or crushing, lifting the cone on a moist non-absorbent plate (not waterlogged) and controlling the diametric expansion of the mass and the creep time. The diameter of the discharged mass between 600 mm to 700 mm. The T50 is the time in which the mass reaches 50cm in diameter (between 3s and 5s). The concrete must flow freely without signs of exudation and forming a circular “cake”.

2. Test V – Funnel: Quantifies the deformability of the concrete in the fresh state, which is related to the ability of the concrete to accommodate the geometry of the formwork. It is filled to level without compacting the funnel of indicated dimensions, controlling the discharge time (from 5 s to 12 s). The discharge of the dough must occur continuously, without interruptions.
3. The L-Box Test: It is related to the resistance to segregation of the concrete when crossing the reinforcement zones. The L-shaped box of indicated dimensions is filled until it is level and the gate is raised so that the concrete discharges freely. Its self-leveling capacity in the presence of obstacles, the block on the bars and the creep time are controlled. The following must occur:
- Lock on the bars. No signs of block.
- H2/H1 (Self-leveling) ≥ 0.8
- T20 (Creep time) ≤ 1.5 s. - T40 (Creep time) ≤ 3.5 s.
4. The Japanese Ring or "J Ring". It allows evaluating the capacity of concrete to pass through the reinforcement. It is a type of metal cage built with bars that simulate the presence of armor. The diameter of the reinforcement and the separation between them depends on the requirements of the project. The test is carried out so that the concrete flows through the free spaces between the reinforcement. From the determinations the Extended with "cage" is obtained. These two tests, Extended and J-Ring, allow us to obtain very important conclusions, given that large differences in spread diameters between one test and another can mean that despite being a concrete with sufficient fluidity, as it does not have the capacity to pass between the reinforcements, cannot be considered as a self-compacting concrete. A diameter difference of less than 50mm is recommended, with an optimal value being less than 25mm.



Figures 1 to 4: V-Funnel, L-Box, Settlement-Flow and "J" ring box equipment.

Table 9: Test results (5)

Test	T. V-Funnel	T20	T40	T50	Final Diametre	H2/H1
Settlement-flow	---	---	---	4 s	700 mm	---
V- Funnel	8 s	---	---	---	---	---
L Box	---	1,5 s	3,5 s	---	---	0,8
O Ring	---	---	---	---	650 mm	---

Table 10: Results obtained compared with the European Guidelines

Component	Results Per volumen (liters/m³) **(5)**	Results By weight (kg/m³) **(5)**	European Guidelines
Fines	---	541	380 – 600 kg/m³
Paste	360,66	---	300 – 380 L/m³
Water	205	205	150 – 210 l/m³
Coarse Aggregate	---	746	750 – 1000 kg/m³
Fine Aggregate/mortar	48 %	---	45 – 55 %
Water/fine ratio	1,12	---	0,85 – 1.10

Table 11: Self-compactness type data according to test results (5) and classification (28)

Parameter	Category	Value
d_f	AC2	650 mm a 750 mm
T_{50}		2 s a 5 s
T_v		6 s a 10 s

Class SF2, walls and columns and VS2/VF2 to improve resistance to segregation according to European Guidelines (28).

3.1 Analysis of the results

It should be noted that as there is no standardized method for SCC mix design, many academic institutions, additive manufacturers, ready-mixed concrete manufacturers, pre casters and contractors have developed their own design methods.
Mixing (as with this example it is based on ACI 211.1). Mix designs often use volume as a key factor because of the importance of the need to fill the voids between aggregate grains. Some methods try to define optimal granulometric curves for filling existing voids. Another method is to evaluate and optimize the fluidity and stability of the paste first and then that of the mortar fractions, before introducing the coarse aggregate particles and then the complete SCC mixture is tested. What matters is the ability to prepare the SCC with normal speed with respect to any conventional concrete and this occurs by

passing the corresponding tests according to the indicated ranges of each one. In some case it will require an adjustment and two or three test pastes, although normally with this method the results usually come out directly in the first test, which is very useful in saving time in the design of the mixture. The fixed values mentioned almost guarantee that the concrete is a SCC, this can be seen in the results of the undergraduate theses, where the students lost time with the mini-cone for the design and finally opted for this methodology suggested by the authors, fixing the water reduction, slump and coarse aggregate content in percentage using these fixed values in the ACI 211 method for conventional concretes. The methodology was tested in the Theses according to references and in test papers in master's courses and seminars given. The use of super plasticizing and super fluidizing additives called by some High Range Water Reducers (HRWR) should be used precisely as superplasticizers, since if they are used as HRWR they would be reduced in the order of 20 to 40% of water, however, we use for self-compacting concrete the water reductions are of the order of only 5%, to use it in accordance with what is necessary. Even when replacing part of the cement with additions, the method turns out to be effective for the self-compactness, the result sought in this test, only CCA (rice husk ash) gave resistances lower than the design (fcm). Other results by using this methodology were worked it out by graduating Thesis at FIUNA.

4. CONCLUSIONS

It is feasible to dose self-compacting concrete with this methodology and its main advantage is the savings in time and number of mixes to ensure that the concrete is considered SCC for the resistance that is designed. It is essential to use quality materials, including well-graded and suitable fine aggregates, high-quality cement and specific additives to improve the flowability and workability of SCC. The precise dosage of the components is essential to obtain the desired characteristics in the SCC. It is recommended to carry out previous tests to determine the optimal proportions and adjust the amount of additives necessary to achieve the desired fluidity. During the preparation of SCC, it is important to closely monitor the consistency, workability and strength of the material. When placing SCC, factors such as ambient temperature, humidity and placement time must be taken into account. It is important to coordinate with the construction team to ensure quick and efficient placement of the SCC and avoid segregation or loss of consistency during the process.

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