ANNEX 17

Recommendations for the use of self-compacting concrete

1 Scope

For the purposes of this Annex, self-compacting concrete is a concrete that is compacted by the action of its own weight as a consequence of a studied composition and the use of specific superplasticization admixtures, without the need for vibration energy or any other compacting method. It does not display segregation, coarse aggregate blocking, bleeding or grout exudation.

Self-compacting concrete adds to the properties that conventional concrete in any of strength classes, the properties of self-compactability described above.

The specifications laid down in the articles of this Code are guaranteed by experience on conventional concretes, whose workability is measured through the slump in the Abrams cone in accordance with UNE-EN 12350-2. This Annex lays down recommendations for appropriate use of such concrete that, due to its compactability, possesses properties in the fresh state that give it a workability that may not be evaluated by slump in the Abrams cone.

It is the responsibility of the Design Author or, if appropriate, the Project Management to specify the most appropriate type of self-compacting concrete in each case.

2 Supplements to the text of this Code

Recommendations for use of self-compacting concrete are indicated below with reference to the Titles, Chapters, Articles and Sections of this Code.

TITLE 1. BASIS OF DESIGN

The bases laid down in this article of the Code are applicable.

TITLE 2. STRUCTURAL ANALYSIS

CHAPTER 5 Structural analysis

The principles and methods of calculation established in this article are applicable.

For any long-term analysis and also loss or difference deflections calculations, the values and evolution of the modulus of elasticity, flow rate and shrinkage may differ from conventional compacting concretes.

If experimental tests are not available to provide rheological parameters of this concrete, they may be available by consulting specialised texts.

TITLE 3. TECHNICAL CHARACTERISTICS OF MATERIALS

CHAPTER 6 Materials

The component materials used in self-compacting concretes are the same as used in conventional compacting concretes in accordance with the requirements laid down in the current UNE 83001, and Title 3 of this Code, also including other specified below, that shall meet the standard quality requirements applied. It is particularly important that self-compacting concrete should be manufactured with the greatest possible regularity. This means

that the initial selection and inspection of materials are very important as is the previous validation of any dosage.

Self-compacting concrete should preferably be manufactured using appropriate cements for this purpose depending on the type and quantity of admixtures they contain or otherwise with common cement type CEM I, concrete admixtures meeting the regulation (Article 30 of this Code) and using, where required, an appropriate inert filler as an aggregate to correct the granule size of finer diameter sands that pass through a 0.063 mm screen.

One way or the other, a sufficient quantity of fines (particles passing through a 0.125 mm screen) shall be achieved to obtain the property of self-compactability. The total quantity of fines less than 0.125 mm supplied by the cement, the concrete admixtures and the aggregates required to manufacture self-compacting concrete is in the order of 23% by weight of the concrete mass. This may be determined, when necessary, with greater accuracy by means of the corresponding characteristic tests.

As in conventional compacting concrete, other components such as water recycled from concrete plants, pigments, shrinkage reducing admixtures based on glycol or fibres may be used in self-compacting concrete when necessary, applying the same limitations and specifications as for conventional concrete.

Article 26 Cements

Cements conforming to the current specific regulations shall be used. When cements are used for specific special applications in self-compacting concrete that include in their composition a quantity of additional admixtures destined exclusively to provide the self-compacting concrete the necessary amount of fine particles (particles that pass through a 0.125 mm screen), the minimum quantities of the above mentioned cements to be used shall be such that after deducing the amount of complementary admixtures they contain, they meet the requirements laid down in Article 37.3.2 of this Code. The quantity of complementary admixtures shall not be considered in the calculation of the water/cement ratio or the maximum cement quantity. Both the maximum water/cement ratio value and the maximum cement quantity shall comply with the specifications laid down in the Articles of this Code.

Article 28 Aggregates

The maximum size of aggregates for the self-compacting concrete defined in accordance with Article 28.3 of this Code shall be limited to 25 mm. It is advisable to use maximum sizes between 12 mm and 20 mm, depending on the reinforcement layout.

Fillers are aggregates whose large proportion passes through a 0.063 screen and are obtained by treating the source materials from which they proceed.

Appropriate fillers are those that come from the same materials as the aggregates that conform to the specifications laid down in Article 28 of this Code.

In accordance with Standard UNE EN 12620, the granule size of a filler shall be defined in the following table (Table A17. 1)

Table A17.1. Filler granule size

Sieve size (mm)	Percentage passing through by weight
2	100
0'125	85 to 100
0'063	70 to 100

The initial designation tests, the factory production control and certification of the above mentioned control for the filler in question are established in Standard UNE EN 12620.

It is advisable in exclusive case of self-compacting concrete, that the quantity obtained by adding the fine aggregate particle content passing through a UNE 0.063 screen and the lime addition, if appropriate, of the cement should not be greater than 250 kg/m^3 of self-compacting concrete,.

For the filler storage, methods similar to those used for cement shall be used. Waterproof recipients or silos shall be used to protect the filler against humidity and contamination.

The water requirement of inert fines that pass through a UNE 0.063 screen shall be compensated by the use of appropriate superplasticization admixtures that guarantee fulfilment of the water/cement ratios specified in Article 37.3.2 of this Code, thus guaranteeing durability.

Article 29 Admixtures

The use of a superplasticization admixture is a fundamental requirement in self-compacting concrete and it may sometime be advisable to use a viscosity modulating admixture that minimizes the effect of changes in humidity content, fine content or granule size distribution to ensure that the self-compacting concrete is less sensitive to small changes in the quality of raw materials and proportions, regarding the self-compactability property.

It should be used after finding out its compatibility with cement and additions, checking effective maintenance of rheological properties over time specified by installation of the self-compacting concrete and the corresponding mechanical properties by carrying out previous tests.

The superplasticization admixtures shall meet the Standard UNE EN 934-2.

The viscosity modulating admixtures shall help achieve appropriate mixtures, minimizing the effects of changes in humidity content, fine content or granule size distribution.

The viscosity modulating admixtures should conform to the general requirements laid down in Table 1 of UNE EN 934-2.

Article 30 Additions

The use of additions not covered by Article 30 of this Code is not considered.

Article 31 Concretes

As its definition suggests, self-compacting concrete displays three basic intrinsic properties:

- Fluidity or ability to flow without external aid and fill the formwork
- Resistance to blocking or ability to pass between the bars of the reinforcement
- Dynamic and static ability and resistance to segregation that allows it to achieve a final uniform distribution of the aggregate throughout the mass.

31.1. Composition

The components of self-compacting concrete are the same as those of conventional structural concrete although their proportions may differ, as self-compacting concrete is characterized by a lower coarse aggregate content, higher mineral fines content and a lower maximum aggregate size in general.

31.3 Mechanical characteristics

Compressive strength value is an essential reference for self-compacting concrete.

Development of compressive resistance through time may be considered equivalent to that of conventional compacting concrete. As already mentioned, however, the possibility of a delay in the gain of initial strength due to the higher dose of admixtures used shall be taken into account.

The same considerations as applied to compressive strength may be applied to tensile strength. The relationship between both strengths proposed by article 39.1 of this Code may be applied, as it can be for flexural strength.

31.5 Concrete workability

The workability of self-compacting concrete may not be characterised by the methods described in article 31.5 of this Code for conventional concrete. This self-compactability is characterised through specific test methods that make it possible to evaluate the material performance in terms:

- of fluidity by means of flow test according to UNE 83361 or flow test in a V funnel according to UNE 83364.
- block resistance by means of a flow test with a J ring in accordance with UNE 83362 and by means of L box test according to UNE 83363.
- and resistance to segregation.

Although no standard tests are available to evaluate the resistance to segregation, this characteristic may be checked from the behaviour of the material in the flow tests and V funnel. In the flow test, a uniform distribution of coarse aggregates should be observed and not type of segregation or exudation in the perimeter of the final test cake.

Table A17.2 displays the acceptable ranges that self-compacting parameters should conform to, in any case, according to the different test methods. These requirements shall be met simultaneously for all specified tests. The design Author or, if appropriate, the Project Management may define a more specific self-compactability level by means of the categories defined in section 39.2 of this Annex depending on the work characteristics.

Table A17.2 General requirements for self-compactability

Test	**Parameter measured**	**Permissible range**
Flow	$\mathbf{T_{50}}$	$T_{50} \leq 8$ sec
	$\mathbf{d_f}$	550 mm $\leq d_f \leq$ 850 mm
V funnel	$\mathbf{T_V}$	4 sec $\leq T_V \leq$ 20 sec
L box	$\mathbf{C_{bL}}$	$0.75 \leq C_{bL} \leq 1{,}00$
Flow with J ring	$\mathbf{d_{Jf}}$	$\geq d_f$-50 mm

Self-compacting concretes shall maintain their self-compactability characteristics over a time period, referred to as “open time” that is sufficient for their correct installation based on design operating and environmental needs. The characterisation test mentioned above may be used to determine the open time, comparing the result of various repetitions of the same tests carried out consecutively in the same sample.

TITLE 4. DURABILITY

CHAPTER 7I Durability

Article 37 Durability of concrete and reinforcements

37.3 Durability of concrete

As a consequence of the absence of vibrations and the habitual use of additions and fillers in self-compacting concrete, the paste-aggregate interface is usually denser than in conventional concrete. As a consequence, together with the greater general compactability of the granular structure, it is usually observed a reduction in the speed of entrance of most corrosive agents.

The absence of vibration shall lead in turn to an external coating layer of concrete of higher density that is therefore less permeable.

However, the maximum a/c ratio and minimum cement content required laid down in point 37.3.2 of this Code for the relevant exposure class shall be respected in any case.

The behaviour of self-compacting concrete under freezing and thawing cycles may be considered equivalent to that of conventional compacting concrete, the same precautions and specifications laid down in point 37.3.2 in this Code for conventional concrete shall be considered.

Due to the denser microstructure of self-compacting concrete, the risk of explosive spalling may be higher for this material. For self-compacting concrete, however, when the additional of silicate fume is not significant, the fire resistance may be assumed to be the same as set out in Annex 7 of this Code for conventional concrete of the same strength class or high strength concretes where the above mentioned addition is significant.

TITLE 5. DESIGN

CHAPTER 8 Materials data for the design

Article 39. Characteristics of concrete

While the properties of self-compacting concrete in the fresh state differ to a large extent from those of conventional compacting concrete, its behaviour in terms of strength, durability and other performance parameters in a set state may be considered similar to those of conventional concrete of the same w/c ratio and produced using the same component materials. The properties of self-compacting concrete in a set state referred to in the following section shall be evaluated using the same test procedures used for conventional compacting concrete.

Regarding its behaviour at an early age, some changes may arise in properties such as shrinkage and/or setting times as a consequence of the higher doses of fines and admixtures are generally used.

In applications where the modulus of elasticity, shrinkage due to drying and flow rate may be critical factors and the paste or coarse aggregate content varies essentially from that normally used, these properties shall be analysed by means of specific tests.

In general, the differences from conventional concrete are sufficiently small to ensure that self-compacting concrete may be used in the formulation given in the articles of this Code. Particularly, the same active and passive reinforcement anchorage length may be used, the same criteria to specify minimum concrete strength and the same construction joint processes.

39.1 Definitions

Self-compacting concrete may be subject to the equations proposed in 39.1 of this Code, which connect compressive strength with tensile strength and with flexural strength.

39.2 Identification of concretes

The designation of self-compacting concrete is similar to that of conventional compacting concretes according to Article 39.2 of this Code. All that needs to be done is to use the code AC (e.g. HA-35/AC/20/IIIa) in accordance to the equation given below as indicator C of consistency.

T-R/AC/TM/A

Alternatively, self-compactability may be defined by a combination of the classes corresponding to flow (AC-E), viscosity (AC-V) and block resistance (AC-RB) in accordance of the following equation.

T-R/(AC-E+AC-V+AC-RB)/TM/A

where T, M, TM and A refer to the same as defined in section 39.2 of this Code and y AC-E, AC-V and AC-RB represent the corresponding classes in accordance with tables A17.3, A17.4 and A17.5.

Table A17.3 Flow classes

Class	Criterion, according to UNE 83361
AC-E1	550 mm ≤ d_f ≤ 650 mm
AC-E2	650 mm<d_f≤750 mm
AC-E3	750 mm < d_f ≤ 850 mm (*)

Table A17.4 Viscosity classes

Class	Criterion for flow test, according to UNE 83.361	Alternative criterion for V funnel test according to UNE 83364
AC-V1	2'5 sec < T_{50} ≤ 8 sec	10 sec ≤ T_v ≤ 20 sec
AC-V2	2 sec < T_{50} < 8 sec	6 sec ≤ T_v ≤ 10 sec
AC-V3	T_{50} ≤ 2 sec (*)	4 sec ≤ T_v ≤ 6 sec (*)

Table A17.5 Blocking resistance classes

Class	Characteristic requirement	Criterion by J ring test, according to UNE 83362 (*)	Criterion for L box test, according to UNE 83363
AC-RB1	Required when the maximum aggregate size is greater than 20 mm or the thickness of the holes through which the concrete passes is between 80 and 100 mm	$d_{Jf} \geq d_f$-50 mm, with a ring of 12 bars	$\geq$ 0.80, with 2 bars
AC-RB2	Required when the maximum aggregate size is less or equal to 20 mm or the thickness of the holes through which the concrete passes is between 60 and 80 mm	$d_{Jf} \geq$ df.50 mm, with a ring of 20 bars	$\geq$ 0.80, with 3 bars

(*) where: d_f represents the flow in the test according to UNE 83361 and
D_{Jf}, represents the flow in the J ring test according to UNE 83362

If the concrete must pass through areas with thicknesses less than 60 mm, the behaviour shall be assessed experimentally by designing components that make it possible to evaluate specific block resistance in this specific case.

In general, self-compactability class AC-E1 shall be considered as the most appropriate for most structural elements that are normally constructed. Particularly, its use is recommended in the following cases:

- structures that are not strongly reinforced,
- structures where the filling of the formwork is simple, the concrete may pass through wide holes and the pouring holes do not require it to be horizontally displaced in long distances inside the formwork.
- structural elements where the non-formwork surface is slightly separated from the horizontal.

The self-compactability class AC-E3 is recommended in the following cases:

- Structures that are strongly reinforced,
- Structures where the filling of the formwork is very difficult, the concrete may pass through very small holes and the concrete pouring holes require very long horizontal displacement inside the formwork.
- Horizontal structural component where it is very important to achieve concrete self-levelling.
- Very high, very slender and very strongly reinforced structural elements.

39.6. Modulus of longitudinal deformation of the concrete

As self-compacting concrete contain a higher volume of paste than conventional compacting concrete and given that the paste modulus of elasticity is lower than that of aggregates. A slightly lower strain modulus may be obtained (between 7% and 15%) in the case of self-compacting concrete.

In the absence of experimental data, the strain modulus may be calculated using the equation in the articles of this Code for conventional compacting concrete. When detailed knowledge of the longitudinal strain modulus is required, as for example in certain structures with an advance construction process where strain monitoring is critical, experimental determination of the above mentioned value may be used like in conventional concrete.

39.7. Shrinkage of concrete

In general, the equation in Article 39.7 of this Code is applicable. However, due to the composition of self-compacting concrete, higher shrinkage may occur, which shall be considered as indicated below.

As self-compacting concrete has a higher quantity of fines in its composition and a high resistance to segregation, the material exudes practically no water during installation. Although this aspect is theoretically positive, in practice the effect may be negative because exudation water very often compensates for water that evaporates in the fresh state and consequently prevents cracking due to plastic shrinkage.

In this way, due to the low water/binding agent ratio generally considered, the curing of self-compacting concrete is particularly important, more in structures with high surface/volume ratios.

In self-compacting concrete, a combination of factors is more likely to arise than in conventional compacting concrete, leading to significant endogenous shrinkage; a higher cement content and the use of finer cement (leading to higher heat of hydration), a higher quantity of fine material in general and low water/fines ratio.

The use of fly ashes and/or lime filler may contribute to the reduction of endogenous shrinkage.

If the endogenous shrinkage of material is a significant parameter for the function of the structure, it shall be evaluated for the mixture in question throughout a time period of at least 3 months through laboratory tests on samples sealed immediately after taking out of the mould.

As occurs in conventional compacting concrete, a high cement content will lead to a higher heat of hydration, consequent expansion and subsequent thermal heat shrinkage, which may be critical as far as cracking is concerned in medium or large mass components. The same precautions shall be taken as for conventional compacting concrete.

If the shrinkage due to drying of the material is a significant parameter for the function of the structure, it shall be evaluated for the mixture in question over a time period of at least 6 months through laboratory tests on samples exposed to a controlled atmosphere.

39.8. Creep in concrete

The formula given in Article 39.8 of this Code may be used in general. The flow behaviour of self-compacting concrete may be considered equivalent to that of conventional compacting concrete of the same a/c ratio. Although slightly higher strain may arise for the same strength level, if air drying is allowed, this difference may disappear due to the higher refinement of the self-compacting pour structure.

In applications where flow rate may be a critical factor, this property shall be taken into account during the dosage process and checked by means of specific laboratory tests on samples exposed to a controlled atmosphere.

CHAPTER 10 Calculations relating to Ultimate Limit States

Article 44. Limit State of Failure due to shear

Although no differences worth to be considered have been detected in the calculation process, due to the lower coarse aggregate content and the lower maximum size in general, self-compacting concretes display a smoother crack structure than that of conventional contracting concretes of the same strength. This slightly reduces the resistant component of the assembly. In any case, the corresponding calculation may be carried out using the formula in the articles set out in this Code for conventional compacting concrete.

TITLE 7. CONSTRUCTION

Article 68. Processes prior to placing of reinforcements

68.2. Falsework and underpinning

When using self-compacting concrete, it shall be taken into account that the static pressure law exercised by the concrete may be hydrostatic when calculating falsework, formwork and moulds.

68.3. Formwork and moulds

Although the self-compacting concrete does not increase the loss of grout through the formwork joints, it is desirable to ensure that the formwork is properly watertight, as when using conventional compacting concrete.

Article 69 Construction, reinforcing and assembly processes for reinforcements

69.5. Specific criteria for anchorage and splicing of reinforcements

In average terms, the adherence between the reinforcement bars and the concrete is higher for self-compacting concrete than for comparable conventional concrete. Therefore the standard adherence stress still can be considered.

Article 70. Positioning and tensioning processes for the active reinforcements

70.2. Processes prior to the tensioning of active reinforcements

70.2.3. Bonding of active reinforcements to concrete

The prestressing reinforcement anchorage length may be calculated using the formula given in point 70.2.3 of this Code. Nevertheless constructing prestressed components using self-compacting concretes of a strength class lower than that used for construction with conventional concrete, is not allowed.

Article 71 Manufacture and placing of concrete

71.2 Installations for the manufacture of the concrete

In the self-compacting concrete manufacturing process, special care should be taken over the following aspects:

Self-compacting concrete should be prepared in a plant that belongs or not to the construction site.

The humidity of aggregates shall be accurately calculated during storage and before mixing of concrete components to prevent unexpected variations that affect the workability of the concrete.

The admixtures may be incorporated in the plant or construction site. Due to the special characteristics of this concrete, it is nevertheless advisable to combine both situations under the control of the concrete manufacturer.

Transport shall be carried out by means of a mobile mixer or cement truck.

71.3 Manufacture of concrete

71.3.1 Supply and storage of component materials

71.3.1.1 Aggregates

If using a filler, the characteristics shall be determined in accordance with UNE EN 121620.

71.3.2 Dosage of component materials

When dosing a self-compacting concrete, the corresponding needs relating to the design shall be considered, as follows:

structural needs spacing between reinforcement bars, element sizes, architectural complexity of the formwork, visible faces, design peculiarities that may affect concrete flows such as thickness changes, bulges, etc.

operational needs:: filling procedure (pump, tank, channel, etc.), filling speed and duration, characteristics of the formwork, visibility of concrete during filling, distance where flow must arrive, drop height, accessibility of the cement truck, positioning of pumping equipment, etc.

environmental: climate and temperature of the atmosphere at the time of filling, temperature of the material, transport duration, any critical traffic situations, etc.

performance: environmental exposure class, characteristic strength and other design requirements.

As general characteristics, in a self-compacting concrete the total fine content (particle size < 0.125 mm), i.e. cement, additions and fillers, shall be in the range from 450 to 600 kg/m^3 (180 to 240 litres/m^3). The cement content is in a range of 250 to 500 kg/m^3. Paste volume (water, cement, active mineral additions, fillers and admixtures) are normally above 350 litres/m^3.

Water and cement content limitations are specified in accordance with the exposure conditions defined in the articles of this Code, in accordance with Article 37.3.2.

Taking into account that the paste is mostly responsible for giving the aggregate fluidity and movement, it is logical to think about continuous granulometry and over and above the spacing conditions between bars, a maximum aggregate size no greater than 25 mm. The coarse aggregate volume is lower in self-compacting concrete than in conventional compacting concrete, generally not exceeding 50% of total aggregates.

If more than one admixture is used, it is important to note the compatibility between them.

Once self-compacting requirements have been achieved (see point 31.5 of this Annex), it is essential for dosing to be tested in a situation of industrial supply to the construction site.

71.5. Placing of concrete

71.5.1. Pouring and positioning of concrete.

When the self-compacting concrete is laid by means of pumping, the corresponding pressure increase shall be taken into account.

When using self-compacting concrete, a maximum pouring distance of 10 m from the point where the concrete is poured is recommended.

The improved coatings of visible surfaces and lower air occlusion is achieved when the concrete is laid as close as possible to the base of the formwork. That is the reason why it is recommendable to initiate concrete pouring by placing the hose as close as possible when pumping.

71.5.2. Compaction of concrete

Due to the condition of self-compactability, it is not generally necessary to subject the concrete to a compacting process.

71.5.3. Placing of concrete in special climatic conditions

71.5.3.2. Concreting in hot weather

Measures shall be adopted to reduce the risk of drying out during the various stages of manufacture, transport, installation and curing during the first few hours.

71.6 Curing of concrete

It is advisable to carry out effective curing that prevents surface drying and the effects of plastic shrinkage as self-compacting concrete may be more vulnerable than conventional compacting concrete.

TITLE 8 CONTROL

CHAPTER 14 General bases for the control

Article 86. Control of the concrete

The principles and methods established in this article are applicable.

The self-compacting concrete acceptance conditions with regard to the properties of self-compactability that characterise this specific concrete shall be established on the basis of the result of the test referred to in point 86.3.2 of this Annex and that specifications given under point 31.5 of the Annex.

86.3.1. Tests on the workability of the concrete

The workability of self-compacting concrete is not measured by means of consistency as for a conventional compacting concrete, but by means of the property of self-compactability whose specifications are laid down in point 31.5 of this Annex.

When using self-compacting concrete, the self-compactability properties must be checked in each and every one of the cement trucks or supply units by means of a single flow test in accordance with UNE 83361, for each cement truck or supply unit in the case of mass or reinforced concrete, with reinforcements that do not obstruct the passage of concrete or by means of a single flow test and another with a J ring, in accordance with UNE 83363, in the case of a densely reinforced or prestressed concrete.

Remaining tests for characterisation of self-compactability laid down in point 31.5 of this Annex by means of the V funnel and L box methods according to UNE 83364 and 83363, respectively, shall only be carried out in the concrete production plant as previous tests to adjust dosage and characteristic tests.

86.3.2. Tests on the strength of the concrete

These tests shall be carried out in the same way as in conventional compacting concrete but with a modification to UNE 83301 whereby the tests shall be manufactured by simple pouring, once only, without any type of compacting. Only surface finishing with a trowel shall be permitted.

86.4. Inspection prior to supply

In any case it is advisable to carry out prior tests systematically to optimise the dosing to be used in self-compacting concretes, paying particular attention to the characteristics of self-compactability.

A 22 Prior and characteristic tests of the concrete

A.22.2 Characteristic tests of the strength

The calculation principles and methods established in the Annex 22 of this Code are applicable.