ANNEX 16

Recommendations for the use of lightweight concrete

Introduction

The specifications and requirements laid down in the articles in this Code refer to the use of normal weight aggregates. It is therefore necessary to establish different or additional recommendations when lightweight aggregates are used to produce structural concretes.

A wide range of densities and mechanical properties may be obtained taking into account that the normal weight aggregate may be replaced by light weight aggregate in a partial manner, replacing only the coarse fraction of the aggregate or total, also replacing the sand by fine lightweight aggregate.

To distinguish lightweight concrete from conventional concrete, a subindicator "l" should be added to the stress-strain parameters of the concrete.

2 Scope

For the purposes of this Annex, structural light concrete (SLC) is defined as closed structure concrete with an apparent density measured under dry conditions up to constant weight is less than 2000 kg/m^3 but greater than 1200 kg/m^3 and containing a certain proportion of natural or artificial light aggregate. Cellular concretes are excluded whether cured in a standard manner or in an autoclave.

It is important to highlight that apparent density (or unit weight) in a fresh state is greater than that of normal aggregate concrete and depends on the light aggregate saturation level and the water content of the mixture.

In the case of light structural concrete, minimum strength is established as 15 or 20 N/mm^2 since maximum strength depends on the type of light aggregate used and the specific design of the mixture. Although applications exist for high strength light concrete, the maximum strength of structural light concrete considered in this Annex is limited to 50 N/mm^2.

3 Supplements to the text of this Code

Recommendations for the use of structural light concrete processed using light aggregates are indicated below with reference to the Titles, Chapters, Articles and Sections in this Code.

TITLE 1. BASIS OF DESIGN

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

TITLE 2. STRUCTURAL ANALYSIS

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

For a non-linear analysis of light concrete structures, a stress-strain diagram shall be adapted based on experimental observations. If no experimental data are available, the diagram in Article 21 may be applied.

In this case, the strain value corresponding to the maximum stress defined in Table A. 16.1 and A.16.2 shall be modified by the following coefficient:

$$\eta_E = \left(\frac{\rho}{2200}\right)^2$$

where p is the apparent dried density of the concrete.

The maximum concrete strain obtained from the equation in Article 21 shall be multiplied by factor *K* depending on the concrete aggregate type and this amounts to:

- 1.1 for concretes with light aggregates and normal aggregate.
- 1.0 for concretes only processed using light aggregates.

In the case of a concrete with light fine aggregate and density of 1,800 kg/m^3, strain corresponding to maximum stress (ε_{cl1}),is defined in Table A.16.1.

TABLE A 16.1

f_{clk} [N/mm^2]	25	30	35	40	45	50
$\varepsilon_{cl,1}$	1.5	1.65	1.8	1.95	2.05	2.2

For a light concrete with normal fine aggregate and density 2,000 kg/m^3, see table TABLE A.16.2

fclk [N/mm]^2	25	30	35	40	45	50
$\varepsilon_{cl,1}$	1.35	1.45	1.6	1.75	1.85	2

The thermal expansion coefficient of concrete with light aggregates depends on the characteristics of the aggregate used in its manufacture with a wide range between $4{\cdot}10^{-6}$ and $14{\cdot}10^{-6}$ °C^{-1}. If no data is present and for structural analysis, an average value of $8{\cdot}10^{-6}$ °C^{-1} may be adopted. In this regard, it is not necessary to consider existing differences between the steel in the reinforcement and the concrete with light aggregate.

TITLE 3. TECHNOLOGICAL CHARACTERISTICS OF MATERIALS

CHAPTER VI MATERIALS

Article 28 Aggregates

28.1 General

There are many different types of light aggregates, both natural and artificial, designed to produce structural light concrete. To determine the light aggregate types used to produce structural concrete, the most reasonable thing is to establish a link with the density ranges laid down in point 1 of this Annex.

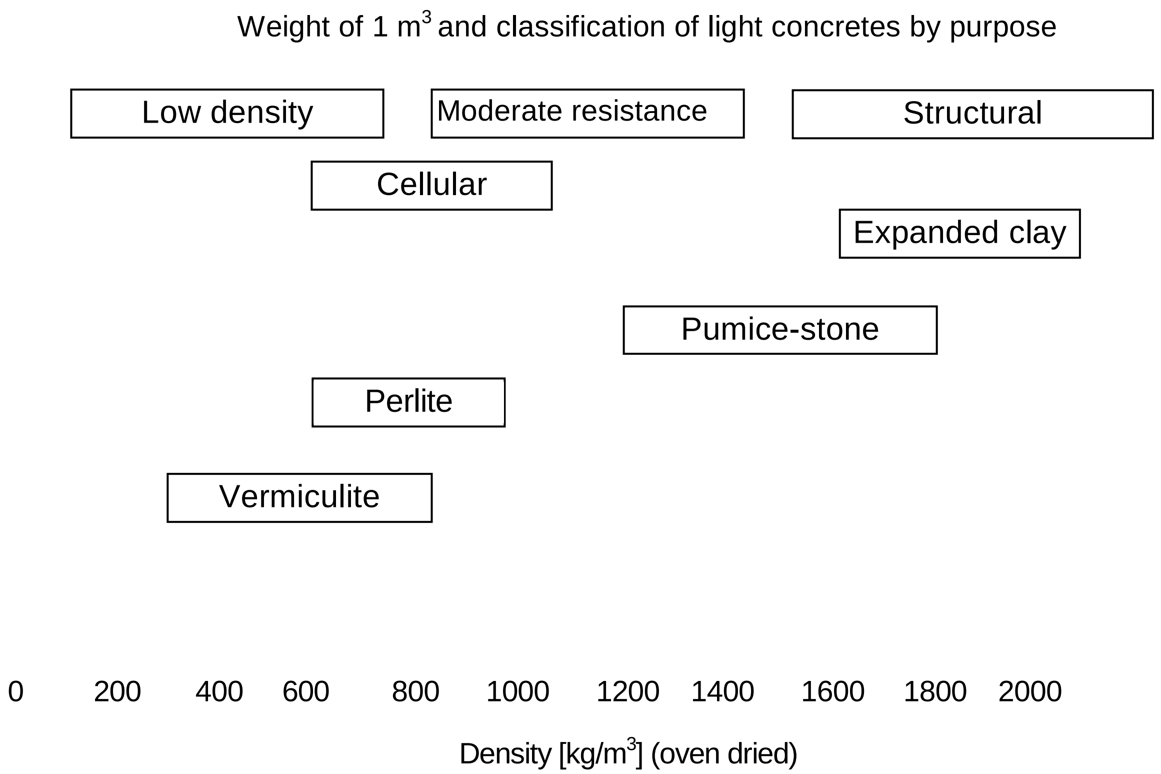

Figure A. 16.1 Density ranges and classification of light weight concretes.

Structural light concretes contain light aggregates that are situated at a high range on the scale and consist of clays, expanded slates or schists, pumice stone or may also take the form of synthetic aggregates, from raw materials such as fly ash.

28.2. Designation of aggregates

When designating aggregates by size, it should be taken into account that granulometric graphs may not be produced by weight for light aggregates. For this reason, it is necessary to change the definition of a maximum size D of an aggregate, and instead of definition of D by weight, it is defined by volume.

28.2. Maximum and minimum aggregate sizes

For the purposes of this Code, the maximum size D of a light aggregate is the minimum sieve size UNE EN 933-2 whereby more than 90% of the volume passes through (% of substandard higher than D 10%) when everything also passes through the double opening screen (% of substandard greater than 2 D equal to 0%). The minimum size of an aggregate is designated as the maximum sieve size UNE EN 933-2 whereby less than 10% by volume passes through (% substandard less than d less than 10%). In *table 28.2*, "% retained by weight" shall be replaced by "% retained by volume" and similarly "% passing through by weight" shall be replaced by "% passing by volume".

28.3. Specifications and tests (this Section has not an equivalent one in this Code).

Density for structural light aggregate is essentially less than 2, which means that the requirement referring to the limitation of particles floating in a fluid of specific weight 2 shall not be applied.

Lightweight aggregates do not display a history of an alkali-aggregate reaction and it will not therefore be necessary to evaluate the product for this type of attack.

28.4. Aggregate particle size grading

With regard to grading analysis, the normal procedure for screening and determining the weight of the retained fraction is insufficient because the difference sized fractions have different densities. If the aggregate is of normal weight and its density does not depend on its size, it is possible to convert weight to volume directly.

The same procedure applied to light aggregates provides incorrect information because the different fractions or sizes possess different densities. This may be taken into account when determining the density of each fraction and if the corresponding volume is calculated. With this proviso, it is possible to consider the same grading limits established for fine aggregates of normal weight.

28.5. Form of coarse aggregate

Because artificial or synthetic aggregates in the approximate shape of a sphere or ellipsoid are used in structural light concrete, the importance of the limits imposed on the shape coefficient and/or slab index shall be reduced.

28.6 Physical-mechanical requirements

Light aggregates are less strong than aggregates of normal weight, both under compression and when subject to the effects of wear by abrasion and crushing. In this situation, the wear resistance of coarse aggregate shall not be evaluated by the Los Angeles methods according to UNE-EN 1097-2, or limitation to the friability of light fine aggregate, evaluated in accordance with a micro-Deval test indicated in UNE 83115 EX.

The absorption capacity of light aggregates is normally high because their lower weight is achieved due to their porous structure. The limitation of water absorption values shall not be applied although ideally they shall be processed in order to present as closed a structure as possible, particularly if absorption is expressed as a % of of the aggregate, because they are less dense.

Since absorption is normally high, to prevent this effect significantly altering the properties of fresh concrete (slump loss, for example), different prior concrete methods or treatments shall be adopted during the concrete production process.

With regard to the frost resistance and structural light concrete, the presence of incorporated air in the concrete helps to reduce deterioration in a similar manner to what occurs with concretes of normal weight. The concrete saturation level (and that of the aggregate) is a crucial factor, as is the appropriate level of strength. Evaluation of the aptitude of aggregates to magnesium sulphate solution treatment cycle in accordance with the method in UNE EN 1367-2 may not be applied, because the low intrinsic strength of light aggregate and its high absorption indicates a remote probability of compliance. In general, the aptitudes of concrete shall be evaluated under freezing and thawing cycles. High strength, inclusion of incorporated air, and a low level of saturation aggregate (and concrete) contribute to significantly improving behaviour.

Article 31 Concretes

31.1 Composition

In structural light concretes, the influence of using light aggregate, mixture proportion, prior saturation level of light aggregate and even the type and variety of light aggregate have a direct influence on the properties of structural light concrete both in a fresh state and in a setting state. For this reason, the composition of concrete and the light aggregate pre-conditioning procedure shall be examined beforehand, without exceptions, to ensure that it is able to produce concretes whose mechanical, rheological and durability characteristics satisfy design needs.

31.4. Minimum strength value

Design strength f_{ck} *(see 39.1)* shall not be less than *15* N/mm^2 in mass concrete, or 25 N/mm^2 in reinforced or prestressed concrete.

31.5. Concrete workability

The principles established in section 31.5 of this Code may be applied without the need for alteration. The characteristics of test methods UNE-EN 12 350-2 nevertheless mean that slump undervalues the aptitude of light concrete to be compacted.

Slump in a tapered cone is due to the strain of concrete under its own weight. The density of light concrete is less than that of conventional concrete and for this reason it offers greater workability for equivalent slumps.

For the same reason, it is not considered prudent to exceed the upper limits for fluid consistency even with the use of superfluidization additives.

TITLE 4. DURABILITY

CHAPTER VII DURABILITY

Article 37 Durability of the concrete and reinforcements

37.2.3. Concrete quality requirements

For equivalent strength levels, structural light concretes possess a mortar matrix that is usually stronger than that corresponding to a concrete of normal weight. For this reason, it is sufficient to indicate that the durability is assured by compliance with stress classes as indicated in table 37.3.2.b. Obviously, requirements relating to the minimum cement content and maximum water/cement ratio shall naturally also be met.

37.2.4. Coverings

Minimum coatings for structural light concrete shall be 5 mm higher than that indicated in point 37.2.4

37.3. Durability of concrete

Structural light concretes processed using light aggregates do not generally display good behaviour to erosion because the light aggregate is usually soft. With the exception of this situation, its behaviour is similar to that of conventional concrete of normal weight.

37.3.1 Proportioning requirements and concrete performance

The following requirements shall be met to achieve appropriate concrete durability:

a) General requirements

- Minimum cement concrete, according to 37.3.2 (see table 37.3.2.a)
- Strength class according to table 37.3.2.b

The accurate determination of the water/cement ratio is not direct because light aggregates are partially presaturated with water and are capable of additional absorption. For this reason, the limit to the water/cement ratio is replaced with the strength class.

a) Additional requirements

It is not prudent to expose structural light concrete to wear by abrasion in a permanent situation. While in the concrete surface the aggregate particles are covered by mortar, light concretes are able to withstand erosion from eventual actions.

37.3.2. Limitations on water and cement content

Depending on the exposure classes to which concrete is subject, defined in accordance with 8.2.2 and 8.2.3, the specifications set out in table 37.3.2.b for the strength class shall be met.

37.3.7. Erosion-resistance of concrete

It is not advisable to use structural light concrete with light aggregate for exposure class E. This does not make structural light concrete able to withstand possible erosion but the wear mechanism is not controlled by the strength of aggregates as is the case with concrete of normal weight.

TITLE 5. DESIGN

CHAPTER VIII Information concerning materials to be used in structures

Article 39 Characteristics of concrete

39.1 Definitions

The mechanical properties of concrete with light aggregates (ultimate strain, longitudinal strain modulus, tensile strength), for the same compressive strength depend to a large extent on the density, being higher as the dry density of light concrete increases.

39.2 Identification of concretes

With regard to the characteristic strength indicated, the same series as for conventional concrete with strength specified in N/mm^2 is used.

HLE - 25, HLE - 30, HLE - 35, HLE - 40, HLE - 45 and HLE - 50

39.3 Characteristic stress-strain diagram of the concrete

For these concretes, it is advisable to use the parabola rectangle or rectangular diagrams given below, which take into account the steady reduction in failure strain when the dry density of light concrete is reduced:

a) Parabola-rectangle diagram:

The same diagram as in the article may be used, changing the ultimate strain in accordance with:

$$\varepsilon_{cu} = 0{,}0035 \cdot \eta_1$$

Where: $\eta_1 = 0{,}40 + 0{,}60 \frac{\rho}{2200}$

b) Rectangular diagram:

The rectangular diagram in the article is applicable, with constant stress

$\sigma_c = \eta(x) f_{cd}$ and height of the compressed block $y = \lambda(x) \cdot h$,, altering ultimate strain as expressed in the above equation and where factor λ for obtaining λ(x) is defined by the equation:

$$\lambda = 0{,}936 \cdot \eta_1 - 0{,}737$$

where:

$$\eta_1 = 0{,}40 + 0{,}60 \frac{\rho}{2200}$$

39.6 Modulus of longitudinal deformation of the concrete

The tangent longitudinal modulus of strain of a concrete with light fine aggregate and density of 1,800 kg/m^3 is defined in Table A. 16.1.

TABLE A 16.1

f_{clk} [N/mm^2]	25	30	35	40	45	50
E_{cli} [kN/mm^2]	22.1	23	23.9	24.7	25.4	26.1

In the case of light concrete with normal fine aggregate and density of 2,000 kg/m^3 the values of the tangent longitudinal modulus of strain are given in Table A. 16.2.

TABLE A 16.2

f_{clk} [N/mm^2]	25	30	35	40	45	50
E_{cli} [kN/mm^2]	27.2	28.4	29.5	30.5	31.4	32.3

CHAPTER IX Carrying capacity of struts, ties and nodes

Article 40 Concrete struts

40.3.4 Confined concrete struts

If no more data are available, the characteristic strength and ultimate elongation of the confined concrete struts may be obtained by means of:

$$f_{clk,c} = f_{clk}\left(1{,}0 + k\alpha\omega_w\right)$$

where

K = 0.66 for light concrete with sand.
K = 0.60 for light concrete with light fine aggregate.

CHAPTER X Calculations relating to ultimate limit states

Article 42 Limit State of failure due to normal forces

42.1.3 Deformation domains

The reduction in ultimate strain in concrete subject to bending shall be taken into account when defining strain domains in accordance with the provisions in this annex.

Article 44. Limit State of Failure due to shear

44.2.3.1 Obtaining V_{u1}

The shear failure force due to oblique compression of the core is obtained as in the article, reduced by a factor υ.

$$\upsilon = 0{,}50\eta_1\left(1-\frac{f_{lck}}{250}\right)$$

42.2.3.2 Obtaining V_{u2}

42.2.3.2.1 Members without shear reinforcement

The shear tensile force in the core is obtained as:

$$V_{u2} = \left[\frac{0{,}18}{\gamma_c}\eta_1\xi(100\rho_1 f_{clv})^{1/3} + 0{,}15\alpha_l\sigma'_{cd}\right]b_0 d$$

with a minimum value of:

$$V_{u2} = \left[0{,}35 f_{lctd} + 0{,}15\alpha_l\sigma'_{cd}\right]b_0 d$$

where $\eta_1 = 0{,}40 + 0{,}60\frac{\rho}{2200}$

44.2.3.2.2 Members with shear reinforcement

The contribution of the concrete to the shear force strength is obtained as:

$$V_{cu} = \left[\frac{0{,}15}{\gamma_C}\eta_1\,\xi\,(100\,\rho_l\,f_{clv})^{1/3} + 0{,}15\alpha_l\,\sigma'_{cd}\right]\beta b_0 d$$

with a minimum value of:

$$V_{u2} = \left[0{,}35 f_{lctd} + 0{,}15\alpha_l\sigma'_{cd}\right]b_0 d$$

where $\eta_1 = 0{,}40 + 0{,}60\frac{\rho}{2200}$

Article 45 Limit State of Failure due to torsion in linear elements

45.2.2.1 Obtaining T_{u1}

The failure torsion force by oblique compression of the core is obtained as in the article, reduced by a factor υ.

$$\upsilon = 0{,}50\eta_1\left(1-\frac{f_{lck}}{250}\right)$$

Article 46. Limit State of Failure due to punching

46.3 Slabs without punching reinforcement

Maximum tensile strength stress in the critical perimeter is obtained as:

$$\tau_{rd} = \frac{0,18}{\gamma_c}\eta_1\xi\left(100\,\rho_\ell\; f_{cv}\right)^{1/3} + 0,1\cdot\sigma'_{cd}$$

with a minimum value of:

$$\tau_{rd} = 0,40\,f_{lctd} + 0,1\cdot\sigma'_{cd}$$

TITLE 6. EXECUTION

Article 69 Construction, reinforcing and assembly processes for reinforcements

69.3 General criteria for structural ironwork processes

69.3.4 Bending

With the aim of avoiding excessive compression and sscratching of SLC in the bar curvature area, folding of the bar to obtain hooks and bends shall be carried out using mandrels of diameter no less than those indicated in Table 66.3 multiplied by [1.5]

The remaining content of this section is applicable to SLC

69.4 Reinforcement of structural ironwork

69.4.1. Distance between bars of passive reinforcements

69.4.1.1 Isolated bars

The maximum diameter of the bar to be used with SLC shall be Φ = 32 mm. The remaining content of this section is applicable to SLC

69.4.1.2. Groups of bars

In SLC, the groups of bars are made up of two bars at most.

69.5 Specific criteria for anchorage and splicing of reinforcements

69.5.1 Anchorage of passive reinforcements

The basic length of SLC corrugated bar anchorage is as indicated in the text multiplied by a factor [$1/\eta_1$],

where $$\eta_1 = 0,40 + 0,60\frac{\rho}{2200}$$

and where ρ is the SLC dry density value ≤ 2000 (kg/m^3)

Article 71 Elaboration and placing of concrete

71.3 Elaboration of concrete

71.3.2. Composition of component materials

In the case of SLC, conducting previous tests with the aim of checking that SLC meets the conditions laid down is the established procedure of accepting the required composition and approving the concrete construction procedure.

The high water absorption levels generally typical of light aggregates in the dry state makes it difficult to predetermine the true water/cement ratio corresponding to the required dose. If the status is saturated, which is not immediately achieved, a process of water transfer to the concrete paste that also alters the required water/cement ratio may arise from the cortex accessible to capillarity effects. In the first case, the workability of SLC will be reduced and in the second case its strength will be reduced.

The complexity of the problem gives rise to different procedures for constructing concrete that evade a standard regulation. The correct result of the planned composition is highly sensitive to small adjustments in the construction procedure. The previous tests are therefore established as a dose and construction procedure validation method, as a unique and indivisible process.

The remaining content of this section is applicable to SLC

71.3.2.3 Aggregates

When working SLC, the aggregates may be composed by weight, volume or in a mixed manner so that the light aggregate is dosed by volume and the rest by weight.

The remaining content of this section is applicable to SLC

71.3.3 Mixing of concrete

Mixing SLC takes longer, in general, than conventional concrete. This increase in mixing time is required for the moistening of the aggregates before adding the cement and blending the mixture after adding additives following the addition of total mixture water. This time is required to prevent rapid absorption of water and additives by the light aggregate removes workability from the concrete mixture and efficacy from the action of its admixtures.

The low density of light aggregate may cause it to float at the beginning of the mixture, depending on the level of water saturation it possesses when it enters the mixing machine, which may determine effective use of the mixing machine.

The remaining content of this section is applicable to SLC

71.4 Transport and supply of concrete

71.4.1 Transport of concrete

If the SLC is transported by pumping the influence of the pump pressure must be considered on the increase in water absorption by light aggregates and also the corresponding decrease when it ceases. In the first case, a loss of workability will arise and in the second case an excess water/cement ratio. In the first example, this will make the concrete difficult to place and, fundamentally, its pumping operation and in the second case, a loss of strength will arise in the affected concrete and also a loss of compactness in internal structures. A change must therefore be made in the dose as a consequence.

The corresponding previous test on SLC after pumping constitutes the concrete validation procedure.

Transport in a concrete mixing truck makes it possible to correct the tendency for a drop in workability that arises in all cases during transport and also the tendency for light aggregates to segregate during the transport of more workable concretes by means of mixing before pouring.

The remaining content of this section is applicable to SLC

71.5 Placing of concrete

71.5.2 Compaction of concrete

Compacting of SLC requires higher vibration energy than that required for normal concrete. As a consequence, compacting is carried out by reducing separation between consecutive vibrator conditions to 70% of that used for normal structural concrete.

The tendency for light aggregate to float grows with excessive vibration.

The surface coating of the face on which the concrete is placed shall be produced by appropriate implements used to press the light aggregate and add it to the mixture so that it is covered by the grouting.