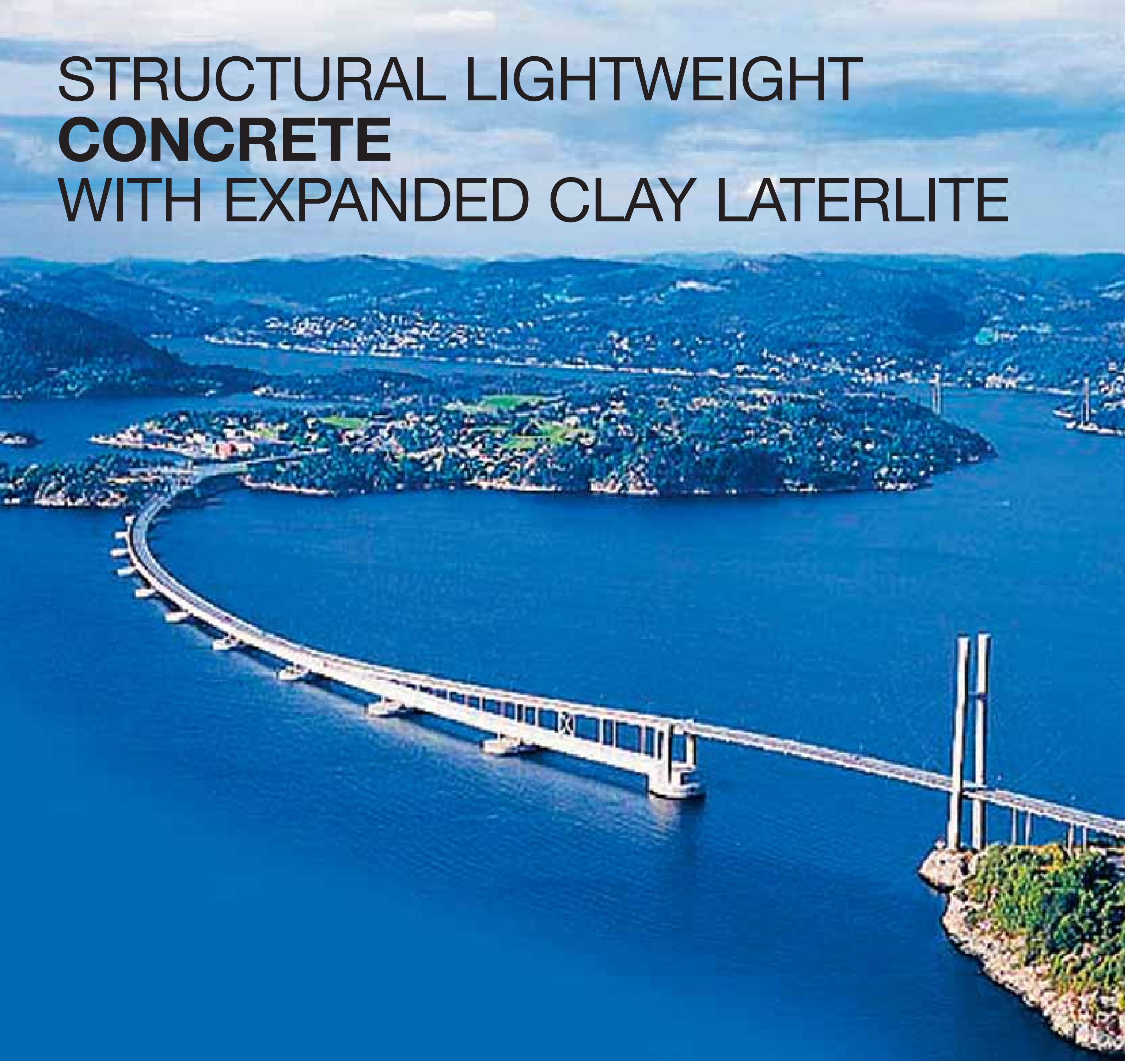
STRUCTURAL LIGHTWEIGHT **CONCRETE** WITH EXPANDED CLAY LATERLITE



Leca

soluzioni leggere e isolanti

CONTENTS

FOREWORD

This publication is intended as a work tool for all those who need further information on structural lightweight concrete prepared with expanded clay. The use of structural lightweight concrete is strongly expanding and the interest in its features is spreading also as concerns ordinary construction works.
Hence, we want to summarize the features, the applications, the performances, the standards and the packaging and laying modalities. This publication is especially meant for those who calculate, control and use structural lightweight concrete prepared with expanded clay, indicating the legislations and the standards currently in force, but also to those who produce, package and lay the product.

NOTE:
Starting from 01/01/2002 there has been an integration of the activities in the sector of expanded clay and lightweight premixed materials between Laterlite and Buzzi Unicem. The new Laterlite company operates with the brands Leca, Ares and Termolite. Hence wherever the text speaks about Leca, Leca Strutturale or Leca Terrecotte it is possible to replace it with Termolite (T4), Termolite (T6), and Termolite (T8) respectively. As concerns the Ares product it is always best to first contact Laterlite Technical Assistance.

II edition
Updated May 2007 - © Laterlite

For updates that should become effective during the year, please visit the site www.leca.it

For further information contact Laterlite Technical Assistance (tel. 02 48011962).

Cover:
NordHordland Bridge
1991-1994 Bergen - Norway
Structural lightweight concrete
density: approx. 1900 kg/m^3
resistance approx. 55 N/mm^2

INTRODUCTION

1. INTRODUCTION: STRUCTURAL LIGHTWEIGHT CONCRETE

The Italian legislation currently in force concerning concrete sets forth that “structural lightweight concrete“ can be defined as a **concrete aggregate with closed structure obtained replacing in whole or in part the ordinary aggregate with an artificial lightweight aggregate, formed by expanded clay or schists.** The possibility of creating lighter structures such as beams, piles and floors, cast on site or prefabricated, is feasible by replacing the larger parts of the traditional “natural” aggregate (gravel or stones) with an “artificial” aggregate, made up of expanded clay granules or schists. **No other,** natural or artifical, **lightweight inert material** such as polystyrene, volcanic rocks, pumice or other are admitted.
The concrete must have the following features:

- **a mass** at 28 days between **1,400 and 2,000 kg/m^3** [1]
- **characteristic compressive strength R_{ck}** (at 28 days) not lower than **15 N/mm^2**.

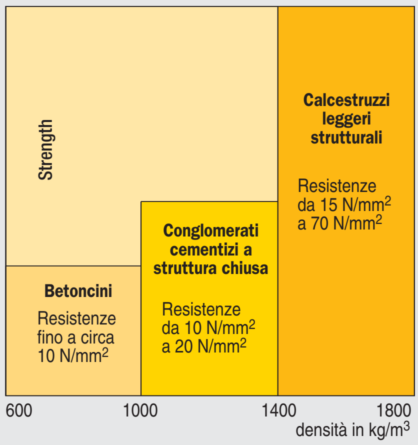
The requirements on mass and resistance, in addition to the type of aggregate used to make the mixture lighter, at the moment are the limitations used for creating a concrete that may be defined both “lightweight” and “structural”.
Expanded clay is a lightweight aggregate produced industrially whose features may be modified to optimize the performance of the aggregate with very different uses.
It is possible to obtain:

- **lightweight insulating grout with open structure:** concrete aggregates with open structure and density between 600 and 1000 kg/m^3;
- **concrete aggregates with closed structure:** with density between 1000 and 1400 kg/m^3;
- **structural lightweight concrete:** caggregates made with a granulation curve such as to form a closed structure, with density between 1400 and 2000 kg/m^3.

The closed structure of the aggregate is obtained by integrating the fine part of the material with traditional aggregate and particularly with natural sand. Furthermore, by changing the density of expanded clay and the replacement percentage of the ordinary aggregate, it is possible to obtain concrete with variable densities between the limits indicated, with strength levels starting from **15 N/mm^2 up to 70 N/mm^2**.
The traditional Exclay, besides being used to prepare grout for insulating layers and slopes, can also be used to prepare structural concrete with density 1500 ÷ 1600 Kg/m^3 and strength up to 25 N/mm^2.
Tougher expanded clay is used to obtain higher strength levels (see par. 3.1).
A concrete with a density of **1600 kg/m^3** mixed with **Exclay Structural**, enables to reach, **on the work site**, a characteristic compressive strength R_{ck} (28 days) of **30 N/mm^2**.
This concrete can be made directly on site, mixed in concrete mixing plants or at the prefabrication plant. **Pre-mixed concrete in bags (Exclay CLS1400, Exclay CLS 1400Ri and Exclay CLS 1600)** are also available and are mostly used for smaller interventions, generally in restoration work.
Being among one of the lightest in the range (with a density of 1400 ÷ 1600 Kg/m^3) they are practical and safe for building reinforcement toppings in the restoration of floors and in all those applications that call for a structural casting without over-loading the existing structures.

Structural concrete with Exclay

Diagram showing the trends of the strength level according to the density for the various lightweight aggregates.



(1) The mass of the aggregate according to the procedures indicated in the UNI 7548 - Part 2nd standard (June 1976.

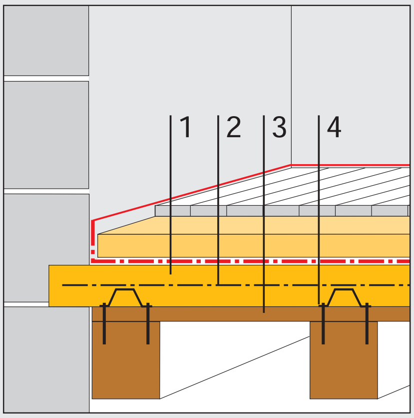
2. APPLICATIONS OF STRUCTURAL LIGHTWEIGHT CONCRETE

The use of lightweight structural concrete has a wide and interesting bibliography ranging from off-shore structures to bridges or large building roofs, but besides being an excellent solution in complex situations it is also a plus in many other cases, closer to the designing and construction activities.

2.1 RESTORATION OF FLOORS

In the restoration of wood, corrugated sheet, I-beam and tile floors which calls for a structural concrete to consolidate the floor without overloading the existing structure too much.

Wood floors



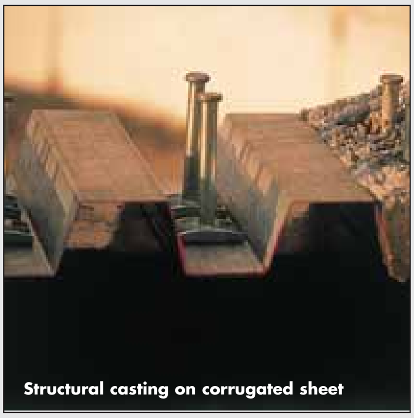
Caption of drawings of page. 4 - 5
1 Exclay Structural Concrete.
2 Weldmesh or metal grid.
3 Existing floor or structure to reinforce.
4 Continuous or dotted metal connectors for slab acting compositely with the structure.

Consolidation: connection to stakes

Consolidation: continuous connection

Structural restoration of wood floors - Alessandro Manzoni house, Milan

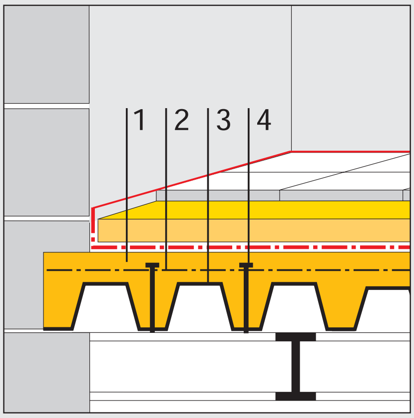
Restoration of the heads of wood beams



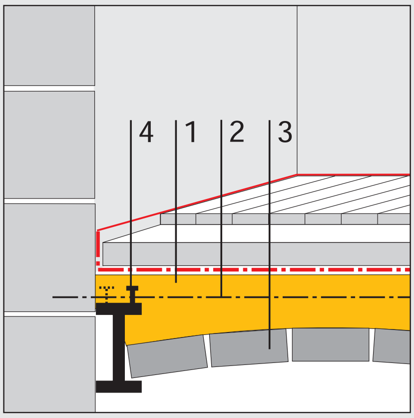
Structural casting on corrugated sheet

Consolidation: resin stake method

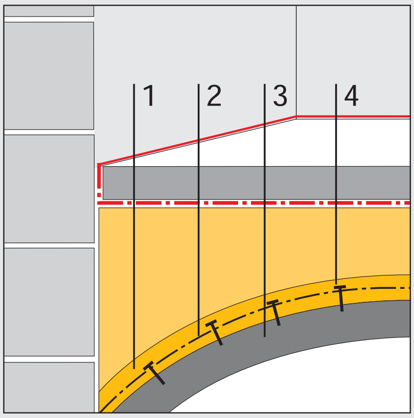
Corrugated sheet floors



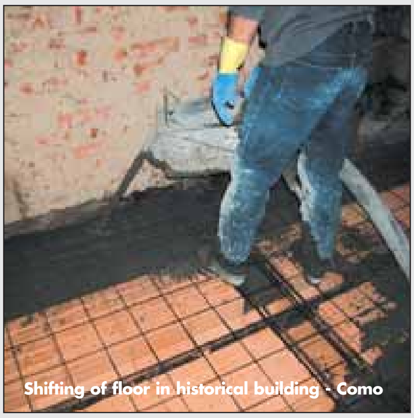
I-beam and tile floors

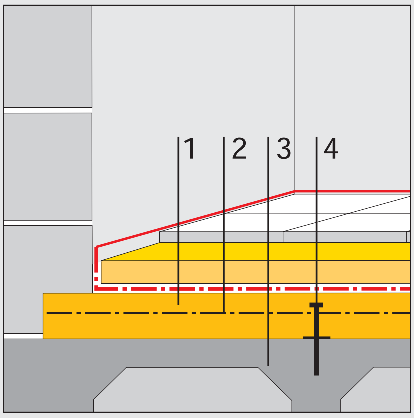


Restoration of vaults



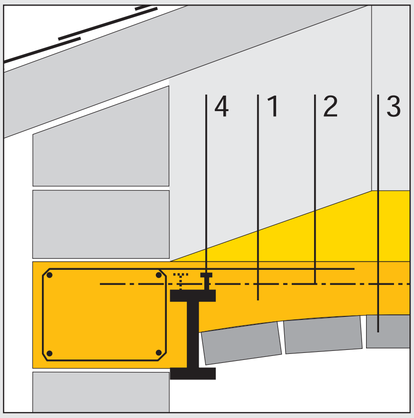
Restoration of tile and cement floors





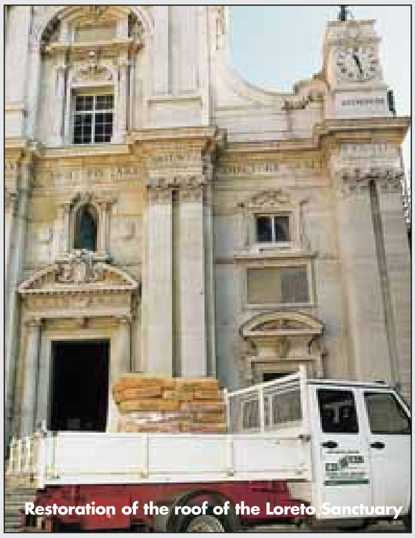
2.2 RESTORATIONS IN GENERAL

Restorations, besides for floors, for all other types of casting (piles, bearing walls, beams, slabs, stairs, structures on shelves, etc.) that have to be lightened up not to weigh on pre-existing structures and foundations.



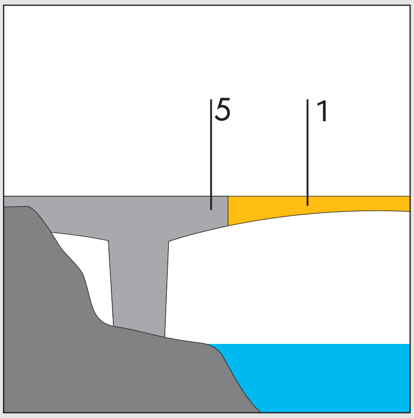
1 Exclay Structural Concrete.
2 Weldmesh or metal grid.
3 Existing floor or structure to reinforce.
4 Continuous or dotted metal connectors for slab acting compositely with the structure.


Restoration of the Vigevano Castle


Restoration of the roof of the Loreto Sanctuary

2.3 STRUCTURAL CASTING

Structures in which the load is the main component of the operating loads (bridges with a long bay, concrete roof tiles, large pre-fabricated panels, floors with large clear spans, pedestrian platforms etc...). In these cases, in fact, the use of a lightweight concrete enables the creation of thinner structures with lower sections, hence less concrete and frames. The final result is aesthetically more pleasant besides being more convenient.



1 Exclay Structural Concrete.
5 Traditional concrete.


Polifunctional tower- Padua

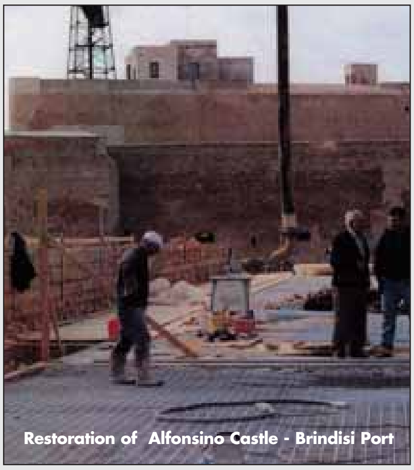

BMW building – Munich

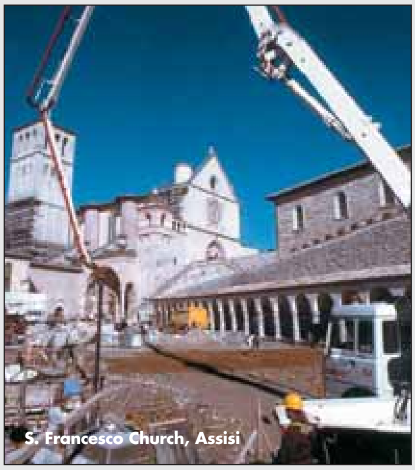

Stolmen Bridge – Norway

(Photo courtesy of Bergens Tidende, photographer: Jan M. Lillebø)

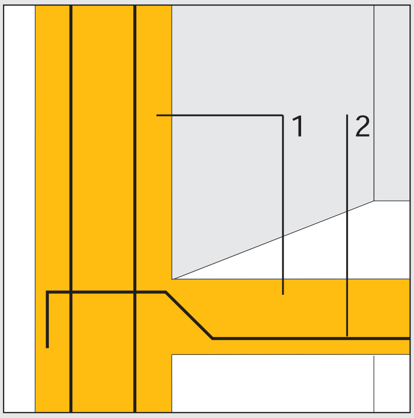
2.4 COSTRUCTIONS IN SEISMIC AREAS

The action of the earthquake is proportional to the mass of the structures involved: in **constructions in seismic areas** lightening a structure means reducing the stress on the outer walls especially in restoration works.


Restoration of Alfonsino Castle - Brindisi Port


S. Francesco Church, Assisi

1 Exclay Structural Concrete.
2 Weldmesh or metal grid.



2.5 PREFABRICATED STRUCTURES

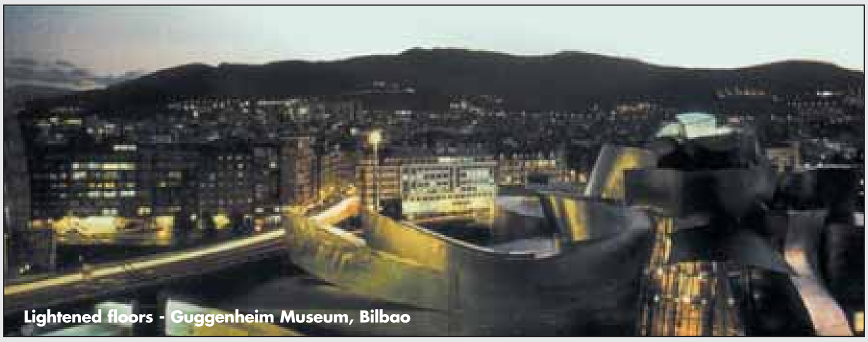
In prefabricated structures to the beneficial post-tensioning effect, lightness (especially in concrete roof tiles) and thermal and sound isolation (panels and barriers) we must add the big advantage of convenient transport.


Panels of an industrial unit - Forlì


Concrete roof tiles - Boffalora Ticino

2.6 STRUCTURES IN GENERAL

Structures laid on soils with poor carrying capacity. In these cases, load reduction helps save on foundation costs or, weight being equal, create bigger structures.


Lightened floors - Guggenheim Museum, Bilbao

Structures where a lightweight concrete, with thermal isolation (thermal conductivity equal to less than 1/3 compared to an ordinary concrete) and resistance to fire (REI) properties, are both **technically necessary and economically advantageous** (1/3 of the weight less compared to an ordinary concrete).


Nations bank - Charlotte, North Carolina


Floating boxed structure - Genoa

Clay, the natural raw material used for the production of Exclay (above).
The rotating furnace for baking the clay (below).

3.1 THE PRODUCTIVE CYCLE

Expanded clay is a natural aggregate (ANAB certificate – June 2002) obtained by burning particular types of clay in rotating furnaces. After excavation, the clay is left for long periods outside so time, weather and climatic conditions can perform a first natural "pre-preparation" phase. In the second industrial phase, mills crush the clay into very fine particles and prepare it for the furnace. The raw clay is put inside a rotating furnace and burned at increasingly high temperatures. Due to the combined action of gases that develop inside and to the rotating movement it expands, into an almost fluid phase, and forms small round granules. Research, technology and experience allow us to control the level of expansion which optimizes the quality of the final product. The hot material is then extracted from the furnace and sent through a "fluid bed" made of air flows, which besides cooling down the expanded clay also causes the oxidation and then the clinkering of the outer shell.
The final product acquires its main feature: an inner core with air-filled cavities that assures lightness, intrinsically bound to a hard outer shell that assures resistance.
By acting on the temperatures, on the rotation and other parameters, it is possible to control, within certain limits, the density and the granulation curve of the final product.

3.2 EXPANDED CLAY LATERLITE, EXPANDED CLAY LATERLITE STRUCTURAL AND EXPANDED CLAY LATERLITE TERRECOTTE

Concrete is a non-homogeneous material made up of cement paste and aggregates. Its compressive strength depends on the strength of its components. In traditional concrete the aggregates (if of good quality) have higher levels of resistance compared to those of cement paste. In this type of concrete, the quality of the cement paste determines the compressive strength. By observing the break line of a sample of traditional concrete we can clearly see how the fracture lines pass through the paste "sliding" over the aggregates without affecting them. In concrete with lightweight aggregates, the aggregate is the part with less resistance. By breaking a sample of lightweight concrete it is possible to see that the break affects the grains of the aggregate. Hence, Laterlite produces specific lightweight aggregates (Exclay Structural and Exclay Terrecotte) with a compressive strength level close to that of cement paste. With these aggregates it is possible to produce lightweight concrete that, with cement quantity being equal, reach the strength levels of traditional concrete.

Lightweight expanded clay aggregates can be divided into the following groups:

Exclay: widely used in the construction sector both loose and as aggregate for grout and concrete. It is produced with low density granules and is especially used for thermal insulation and to make foundations lighter. Exclay is used to produce structural concrete with densities up to 1500 ÷1600 Kg/m^3 and strength levels up to 25 N/mm^2.

Exclay Structural and Exclay Terrecotte: produced with production cycles and special clays, they are characterized by a lower expansion level compared to traditional Exclay, with a less expanded inner porous core and an outer, thicker and more resistant, clinkerized structure. The different structure of the granules confers a higher specific weight to Exclay Structural and Exclay Terrecotte and a considerably higher compressive strength of the granules (see table below). The higher compressive strength of the granules enables the creation of aggregates with features comparable to those of traditional concrete. The non-spherical shape, combined with a rough surface assures effective adhesion with the cement paste, hence excellent performances, in the case of reinforced concrete, in terms of iron/concrete adherence. This is why they are particularly indicated as aggregates for lightweight structural concrete with compressive strength from 25 to 70 N/mm^2.

EXCLAY

Grain size	0 - 2	2 - 3	3 - 8
Density Kg/m³ circa	700	480	380
Compressive strength (UNI EN 13055-1) N/mm²	4.5	2.5	1.5
Thermal conductivity λ W/mK	0.12	0.10	0.09
Reaction to fire	Euroclass A1 (Incombustible)		

EXCLAY STRUCTURAL

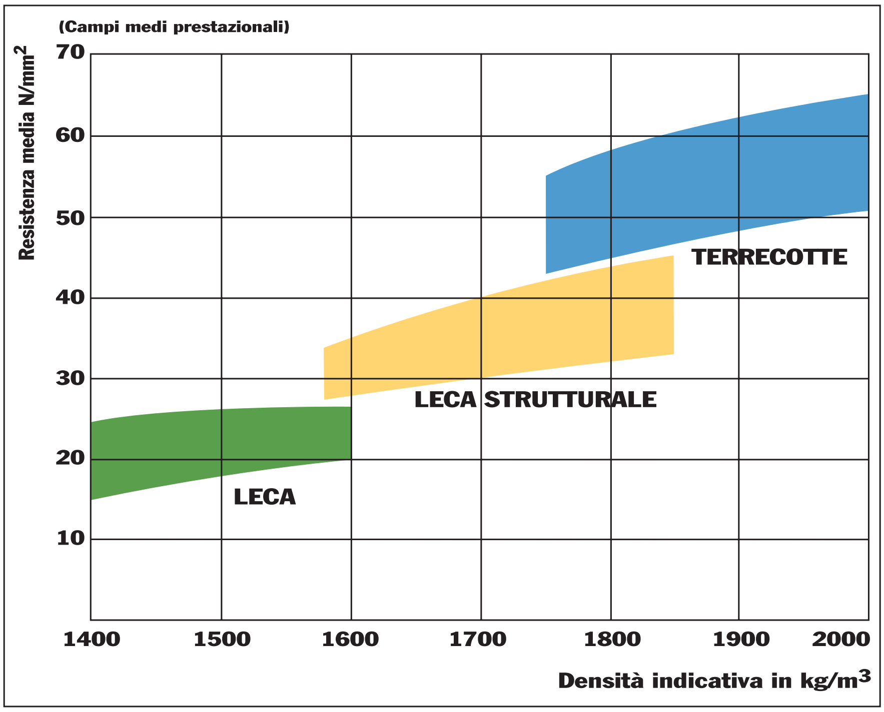
Grain size	0 - 5	5 - 15	0 - 15
Density Kg/m³ circa	800	650	730
Compressive strength (UNI EN 13055-1) N/mm²	10.0	4.5	6.0
Thermal conductivity λ W/mK	0.12	0.12	0.13
Reaction to fire	Euroclass A1 (Incombustible)		

EXCLAY TERRECOTTE

Grain size	0 - 6	6 - 12	0 - 12
Density Kg/m³ circa	950	800	900
Compressive strength (UNI EN 13055-1) N/mm²	12.0	7.0	7.5
Reaction to fire	Euroclass A1 (Incombustible)		

"Grain size" does not refer to the diameter of Exclay grains expressed in mm but it is a commercial item.
The above mentioned density and strenght are average values calculated on the yearly production controls of every production unit, with a ± 15% tolerance as established by the UNI Standard.
For more detailed and updated information request the product sheet of every production unit or visit www.laterlite.net.

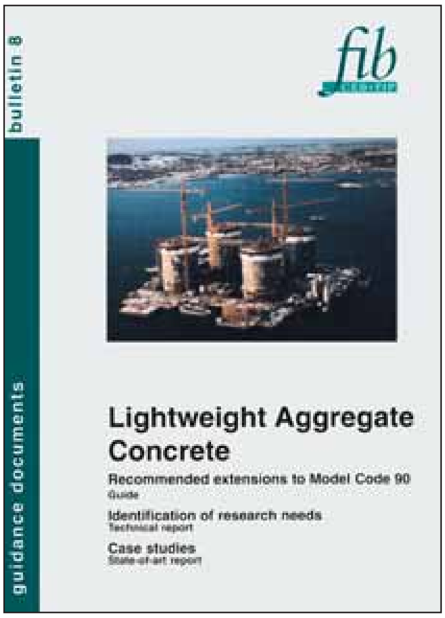
AVERAGE PERFORMANCE LEVELS OF CONCRETE WITH EXCLAY, EXCLAY STRUCTURAL AND EXCLAY TERRECOTTE

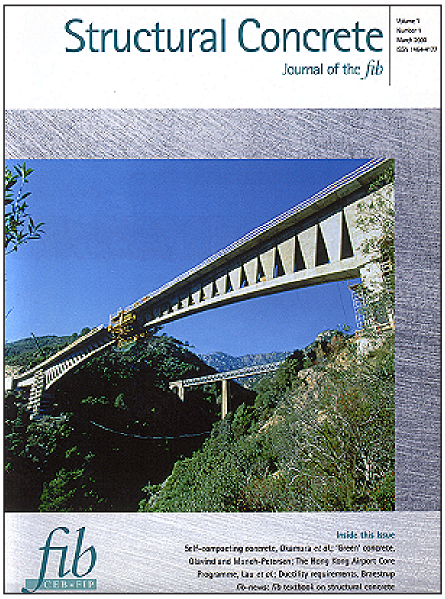


Burning at 1200 °C and the expansion process.

Exclay granule (above) and Exclay Structural (below): The porous structure of the material that forms the granule is closed in a hard and resistant shell.

The "pile" of Exclay in the factory.





4. THE STANDARDS

For many years now Italian legislation has thoroughly and clearly dealt with the issue of structural lightweight concrete.
Let's see which regulations are used today at both international and national level, which are the calculation procedures used and the particularities of lightweight expanded clay concrete.

4.1 INTERNATIONAL TECHNICAL STANDARDS

First it might be appropriate to refer to the international standards that include both calculation codes and specific technical regulations for the application of structural lightweight concrete.
The ample literature and regulations available provide evidence of how thorough international experimentation is and how widespread the use of these materials is also for large projects.
In international literature lightweight structural concrete is called **"Structural Lightweight Aggregate Concrete"**, generally referred to as "LWAC".

The most important standards that deal with structural lightweight concrete are published by international bodies and/or research organizations such as: CEN - European Standards Body (ENV, prEN and EN standards, www.cennorm.be), FIB - International Federation for Structural Concrete/fedèration internationale du bèton (created after the merger between CEB and FIP, bulletins and Model Codes, www.fib.epfl.ch), American Concrete Institute (guide ACI, www.aci-int.org).
Also the national technical regulations of many countries deal with this type of material such as: DIN (Germany - www.din.de), BS (UK - www.bsi-global.com), ASTM (United States - www.astm.org), NS (Norway - www.standard.no), NEN (Holland - www.nni.nl) and more.

Among all these we will use information taken from the following:

- **UNI ENV 1992-1-4:1995** Eurocode 2: Design of concrete structures - Part 1-5: General rules - Lightweight aggregate concrete with closed structure. It is a general base for designing buildings and civil engineering works using reinforced and prestressed concrete, and with closed structure produced with Lightweight aggregates, as established by ENV 206.
- **UNI ENV 1992-1-1:1993** Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings. It is a general base for designing buildings and civil engineering works using ordinary reinforced and prestressed concrete produced with standard mass aggregates.
- **ACI 211.2-91**: Standard Practice for selecting proportions for Structural Lightweight Concrete, 1991;
- **ACI 213R-87**: Guide for structural Lightweight Aggregate Concrete, 1987;
- **ACI SP-136**: Structural Lightweight Aggregate Concrete Performace, 1992.

4.2 NATIONAL STANDARDS

IIn Italy we must refer to the Decree of January 9, 1996 of the Ministry for Public Works(1) "Technical regulations for the calculation, execution and testing of reinforced, normal, pre-stressed concrete structures and metal structures" hereinafter referred to as "Technical Standards of 1996"(2).
These standards refer to the calculation and testing with the semiprobabilistic method of ultimate limit state and also allow for the application of the experimental European regulations "Eurocode 2 - Design of concrete structures, parte 1-1, General rules and rules for buildings", with certain particular modifications and integrations.

As concerns the calculation with the admissible tension method, the Decree of January 9, 1996 refers back to Decree of February 14 1992(3), with the same content.

(1) Published in the Official Gazette of February 5, 1996 and hereinafter indicated as "Technical Standards of 1996".

(2) The updated version of the technical "Standards for buildings" will be issued in 2008 by the Ministry of Infrastructures.

(3)Published in the Official Gazette no. 65 of March 18, 1992 and hereinafter indicated as "Technical Standards of 1992".

(4) Notice no. 252 AA.GG./S.T.C , published in the Official Gazette of November 26, 1996 and hereinafter indicated as "Notice '96".

(5) Notice no. 37406/STC of 24.06.1993, published in the Official Gazette of August 16, 1993 and hereinafter indicated as "Notice '93".

The obligation to design structures in compliance with these regulations and relating technical standards is laid down by Law no. 1086 of February 5, 1971.

Both decrees clearly speak about concrete with “ordinary” aggregates, but the Notice of the Ministry of public works of October 15, 199[4] (hereinafter referred to as “Notice ‘96”) gives detailed information, modifications and integrations to the above decrees for concrete aggregates made with lightweight expanded clay aggregates. As concerns the calculation with the admissible tension method, reference is made to the same Notice of the Ministry of Public Works of 24.06.1993[5] (hereinafter referred to as “Notice ‘93”).

The requirements contained in these documents are based on experiences gained during the 70’s and 80’s and are conservative compared to the performances which can be obtained with the new expanded clay materials (Exclay Structural and Exclay Terrecotte), specifically studied to obtain the technical features of the current high performance lightweight structural concrete.

Expanded clay concrete aggregate can be used both in normal reinfrocements and in pre-compression reinforcements, with calculation modalities and rules that are similar to those of ordinary concrete.

Notice ‘96 also recalls some UNI standards (www.unicei.it) specific for lightweight concrete aggregates such as:

UNI 7548 - 1 - Lightweight concrete - Definition and classification

UNI 7548 - 2 - Lightweight concrete - Determination of mass

UNI 13055 - 1 - Lightweight aggregates for concret, mortar or injection mortar.

GAZZETTA UFFICIALE

DELLA REPUBBLICA ITALIANA

MINISTERO DEI LAVORI PUBBLICI

DECRETO MINISTERIALE 9 gennaio 1996.

Norme tecniche per il calcolo, l'esecuzione ed il collaudo delle strutture in cemento armato, normale e precompresso e per le strutture metalliche.

DECRETO MINISTERIALE 16 gennaio 1996.

Norme tecniche relative ai «Criteri generali per la verifica di sicurezza delle costruzioni e dei carichi e sovraccarichi».

DECRETO MINISTERIALE 16 gennaio 1996.

Norme tecniche per le costruzioni in zone sismiche.

GAZZETTA UFFICIALE

DELLA REPUBBLICA ITALIANA

MINISTERO DEI LAVORI PUBBLICI

Istruzioni per l'applicazione delle «Norme tecniche per il calcolo, l'esecuzione ed il collaudo delle opere in cemento armato normale e precompresso e per le strutture metalliche» di cui al decreto ministeriale 9 gennaio 1996.

Excerpt of "Notice '96"

… E. Concrete aggregate structures with normal or pre-stressed reinforcements made with artificial lightweight aggregates.

The works and elements in cement made with artificial lightweight aggregates as defined in E.1 and with ordinary and/or pre-stressed reinforcements, follow the regulations of ordinary concrete (Technical Standards Part 1 and relating annexes), modified by the following standards.

E.1 Structural lightweight concrete

Structural lightweight concrete is a concrete aggregate with a closed structure obtained by replacing in whole or in part the ordinary aggregate with an artificial lightweight aggregate formed by expanded clay or schists.

E.2.2 Features of the granules

… for expanded clay granules…: surface with mainly a closed structure without granulation fractions obtained through crushing after burning.

The average mass of the granules is the ratio between the mass of the dried material and its volume, limited by the surface of the granules themselves. The value of the mass of the granule can be determined using the procedures indicated in standard UNI EN 13055-1.

The mass of a pile of lightweight aggregate (weight of a pile) is the mass of a unit of the aggregate, including the air-filled cavities of the granules and between the granules in the calculation. The value can be determined with the procedures indicated in standard UNI EN 13055-1.

For expanded clay aggregates, approximately, the average mass of the granules can be calculated by multiplying the mass of a pile by 1.7.

5. SPECIFICATIONS OF LIGHTWEIGHT AGGREGATE

As concerns ordinary aggregates, the Technical Specifications of '96 give indications on the freezing and compressive features of the aggregates, the lack of organic substances or other "pollutants", in addition to the maximum size of the aggregate. Notice '96 thoroughly deals with the definition of the features of lightweight aggregate.

However, in any case, only lightweight expanded clay aggregates or schists can be used.

This aggregate in fact has particular features, which necessarily affect the preparation of the concrete and that allow for the calculation of its density and strength.

5.1. THE MASS OF THE AGGREGATE

Since we are dealing with "lightweight" aggregate, the first definition refers to the mass of the aggregate.

The following values are determined:

- **the mass of the granules (ratio between the mass of a dry granule and its volume), since it can be modified through the same production process (higher or lower expansion**);
- **the mass of a pile of aggregate, the typical mass of a pile of aggregate**.

Notice '96 suggests to calculate the average mass of the granules by multiplying by 1.7 the mass of a pile of granules. More specifically, the mass values to take into account during the preparation of the mixture are indicated in the table.

Expanded clay	average mass of granules (kg/m³)	average mass of a pile (kg/m³)	Coeff.
Exclay 3-8	685	380	1.80
Exclay Structural 0-5	1,665	800	1.85
Exclay Structural 5-15	1,260	650	1.80
Exclay Structural 0-15	1,390	730	1.80
Exclay Terrecotte 0-6	1,760	950	1.85
Exclay Terrecotte 6-12	1,400	800	1.75
Exclay Terrecotte 0-12	1,620	900	1.80

"Grain size" does not refer to the diameter of Exclay grains expressed in mm but it is a commercial item.
The above mentioned density and strenght are average values calculated on the yearly production controls of every production unit, with a ± 15% tolerance as established by the UNI Standard.
For more detailed and updated information request the product sheet of every production unit or visit www.laterlite.net.

Laboratory: procedures for the calculation of the mass.

5.2 THE SOAKING PARAMETER

The lightweight aggregate can absorb water, and this is an important feature because it affects the workability of the mixture.
Periodically, in the productive units, tests are carried out to monitor the soaking parameter of the various typologies of expanded clay and check the absorption limits, to assess compliance with the standards. The average figures are indicated in the table:

Expanded clay	mass of a pile (kg/m³)	absorption at 30 minutes	at 1 day
Excaly 3-8	380	**12%**	18%
Excaly Structural 0-3	800	**4%**	7%
Excaly Structural 3-15	650	**6%**	9%
Excaly Structural 0-15	730	**5%**	7%
Excaly Terrecotte 0-6	950	**4%**	6%
Excaly Terrecotte 6-12	800	**5%**	7%
Excaly Terrecotte 0-12	900	**4%**	6%

"Grain size" does not refer to the diameter of Exclay grains expressed in mm but it is a commercial item.
The above mentioned density and strenght are average values calculated on the yearly production controls of every production unit, with a ± 15% tolerance as established by the UNI Standard.
For more detailed and updated information request the product sheet of every production unit or visit www.laterlite.net.

5.3 COMPRESSIVE STRENGTH OF GRANULES

To univocally identify the resistance of expanded clay granules we refer to UNI 7549/7 which defines in Kg/cm² the value of the "compressive strength of granules". This value is indicated as the pressure needed to exercise a preset deformation onto a rated sample of lightweight aggregate.
The crushing resistance values of granules for the different types of Exclay are indicated in the table.

Expanded clay	compressive strength of granules [N/mm²]
Excaly 3-8	1.5
Excaly Structural 0-5	1.0
Excaly Structural 5-15	4.5
Excaly Structural 0-15	6.0
Excaly Terrecotte 0-6	12.0
Excaly Terrecotte 6-12	7.0
Excaly Terrecotte 0-12	7.5

"Grain size" does not refer to the diameter of Exclay grains expressed in mm but it is a commercial item.
The above mentioned density and strenght are average values calculated on the yearly production controls of every production unit, with a ± 15% tolerance as established by the UNI Standard.
For more detailed and updated information request the product sheet of every production unit or visit www.laterlite.net.

The crushing resistance of the aggregate affects the compressive strength of the structural lightweight concrete: by determining the choice of lightweight aggregates, it is possible to obtain concrete with high R_{ck} levels.

The soaking parameter of the lightweight aggregate is defined in Notice 96 as the quantity of water that the lightweight aggregate can absorb, in specific conditions, expressed in percentage value of its mass. Its value must be determined using the procedure indicated in standard UNI EN 13055-1.
IThe soaking parameter determined after 30 min. must be lower than 10% for aggregates in a pile with mass higher than 500 kg/m³, and 15% for aggregates in a pile with mass no higher than 500 kg/m³.

Laboratory: control of technical features.

Notice '96 establishes that the water absorbed is considered equal to the absorption in weight at 30 min. measured according to UNI EN 13055-1. If there is no direct determination, this absorption can be considered equal to 10% of the weight of the lightweight aggregate present in the mixture. The correct quantity of water is the result of the sum of the effective water and absorbed water, minus the water contained in the natural sand and, conventionally, 40% of the water contained as balancing humidity with the environment of the lightweight aggregate. This content must be determined each time before making the mixture.

6.1 BINDER

The performance features of a lightweight concrete may be strongly affected by the type of lightweight aggregate that forms it, but generally, as happens with traditional concrete, the quality of the cement paste counts very much. All the technical and the technological specifications that make up the correct proportioning of the type and quantity of cement in traditional concrete must be taken into account also in the packaging of structural lightweight concrete. The choice between the various types of cement according to their properties, the link between resistance and the water/cement ratio, the quantity of water according to the maximum dimension of the coarse aggregate and the use of admixtures, are the most important factors of the mix design also in the case of lightweight concrete.

6.2 AGGREGATES

According to the definition of structural lightweight concrete contained in the "Technical Standards '96", the traditional aggregate can be totally or partially replaced with expanded clay. To assure the right granulation curves with optimal absorption of the aggregates, it is preferable to integrate the curve of the lightweight aggregate (Exclay, Exclay Structural and Exclay Terrecotte) with fine traditional aggregate. Adding fine sand (0-3 or 0-4), natural or from crushing, closes the granulation absorption (which as regards expanded clay for concrete is generally poor in fine parts) and enables the production of closed structure compact, resistant and long-lasting concrete.
The correct proportioning between the quantity of sand and that of the Exclay aggregate also helps calibrate the density of the concrete, which is more variable in relation to the traditional 2200 - 2400 Kg/m^3 of ordinary concrete.
The packaging of lightweight structural concrete may also include the introduction of extra minerals, anchored or not with the binder. Silica fume fly ash, loose ashes, limestone and other fillers are suggested to increase the rheology of the mixture especially for lightweight concrete to be pumped and self-compacting lightweight concrete (SCC technology - Self Compacting Concrete).

6.3 WATER

Lightweight aggregate besides having its own humidity content in balanced conditions with the environment, may also absorb a certain quantity of water during the mixing phases. It is necessary to take into account both aspects in the determination of the quantity of water needed in the mixture, besides the humidity contained in the traditional aggregate.
Basically, to the quantity of water needed to work the mixture it is necessary to add the water absorbed by the lightweight aggregates and subtract the water corresponding to the humidity content of the aggregates (light and normal) during the mixture.
We define:
- **effective water: contained in the cement paste, it affects the workability and resistance of the lightweight concrete. By increasing the quantity of effective water, with the maximum size of coarse aggregate being equal, it is possible to obtain concrete that is easier to work and, with the quantity of cement being equal, lower strength values. Of course also vice versa (see diagram on the page to the side**);
- **absorbed water by the lightweight aggregate in the time between the mixing and the laying operations**.

The elementary relations indicated in the diagram on the side may be modified by adding the right water reducing additives to the mixture (fluidifiers, superfluidifiers, etc…).

Below is some information on the content of humidity of a pile of expanded clay in certain typical situations expressed as percentage of the weight of a dry pile of material:

Condition of the material	Excaly	Excaly Structural	Exclay Terrecotte
Dry	0-2%	0-1%	0-1%
Humid	2-8%	1-4%	1-3%
Wet	8-15%	4-7%	3-7%
Saturated	>15%	> 7%	> 7%

Experimental results performed by Laterlite at the Enco laboratories. They demonstrated that the conditions of saturation with a dry surface (s.s.a.), necessary for the calculation of the content of effective water for the balancing of the mixture, are reached with a humidity level of approx. 7% for Exclay Structural and Exclay Terrecotte.

Qualitative trend of the workability and strength as the quantity of effective water varies in the mixture.

Effective water	Workability (Dmax being equal)	Strength (Cement being equal)
↑	↓	↑
↑	↑	↓

6.4 AIR

The trapped air helps make the concrete easier to work and contributes to its freezing resistance. However, it decreases its compressive strength. If there is too much air, the mass of the fresh concrete will be lower than the expected value. The test that is generally performed when the concrete is cast to determine the quantity of trapped air in the cement paste, generally requires the use of a porosimeter. This instrument, forcing measurable quantities of air in a fresh concrete sample, quantifies the residual empty cavities. This type of test is not important for structural lightweight concrete with expanded clay. The air under pressure in fact fills the microcavities contained in the expanded clay thus affecting the final result.

According to Notice '96 the trapped air is measured through the residual empty cavities settling of the mixture and has a volume that can be considered between 2.5% and 3.5% of the volume on average of the settled concrete. The quantity of trapped air can be increased through aerating admixtures (see UNI EN 934-2), however never exceeding 7% of the volume of settled concrete.

6.5 MIXTURES

The use of the most common admixtures available on the pre-mixed and pre-fabricated concrete market sets no chemical-physical or technological limitations for structural lightweight concrete. Fluidifying, super-fluidifying, aerating, accelerants, anti-freeze and all the other chemical products for concrete can be put into the mix design according to the quantities indicated by the manufacturer. The most important manufacturers of admixtures offer specific products for the use of lightweight concrete.
As for traditional aggregates it is always advisable to run a trial test to control the effectiveness of the "admixture quantity – effect on the mixture".
When making the mixture we suggest adding admixtures at the end of the mixture to prevent the aggregate from absorbing them.

7. RHEOLOGY PROPERTIES

One of the features the designer considers when choosing the right concrete for the construction work is certainly workability. The type of structure to build, the level and type of reinforcement, the quality of the labor, the distance of the building site from the production center, the start-up conditions and curing, are all features that affect the preparation of the concrete "upstream" and that call for a precise indication of the consistency class.

7.1 WORKABILITY

The consistency of structural lightweight concrete can be determined with the same classes (from S1 to S5) of traditional concrete (UNI 9418). Sometimes though, especially for densities lower than 1800 Kg/m^3 the concrete might slump to a certain amount due to gravity (Abrams cone slump test.

This phenomenon is explained by the fact that the slump test uses the weight of the sample to assess its "gravity" settling force. In lightweight concrete, the different weight of the concrete compared to traditional concrete affects the reliability of the tests. Hence, the workability of a concrete is often assessed using the expansion test which assesses the increase (percentage or absolute) in diameter of a section of concrete subjected to 15 blows on the plate it is set on. The table shows the classification according to UNI 9417.

Expansion test according to UNI 9417 % (starting diameter 35 mm)				
FA1	FA2	FA3	FA4	FA5
< 40	42-62	64-82	84-100	>100
3 mm (starting diameter 20 mm)				
FB1	FB2	FB3	FB4	FB5
<340	350-410	420-480	490-550	>560

The FA series refers to a percentage increase of the diameter of the laboratory starting sample. The FB series, referred to the test on site, indicates the absolute value in mm of the diameter of the sample at the end of the test.

7.2 SEGREGATION

The segregation phenomenon could take place in ordinary concrete when the ingredients have not been measured correctly in the preparation of the mixture. At the fresh state, the coarse aggregate tends to deposit on the bottom and the fine part (cement and fine aggregates) tend to move up to the surface. In these cases, besides not obtaining a homogeneous material there could also be important and harmful bleeding effects (flowing of water and fine parts towards the surface) and "dusting" of the surface of the hardened casting. In structural lightweight concrete, when the quantities are not right, there is always a segregation that makes the expanded clay aggregate "float" because it has less mass than the fine parts. In both cases, segregation problems can be avoided by correctly dosing the elements that make up the mixture (especially water). For situations which call for larger quantities of water (for example pumping) this phenomenon can be avoided by using proper thinning admixtures.

7.3 VIBRATION

To obtain the right mechanical and durability performances it is necessary to compact the concrete by removing the excess air. As for ordinary concrete, also lightweight concrete is compacted through vibration.

The lightweight concrete vibration operation, if performed using immersion vibrators, must be done very carefully making sure that not too much pressure is put in the same point of the mixture because the low mass of the concrete entails a lower spreading of the vibration. A homogenous action over the entire section will limit the risk of segregation. Where available (generally in prefabrication) we suggest using vibrating boxes that are able to compact concrete in a more uniform way.

8. THE PERFORMANCES OF HARDENED CONCRETE

The properties of structural lightweight concrete are affected by their composition, density and type of lightweight aggregate used. Some mechanical properties can be linked, through experimental correlations, to the density of the hardened concrete; others are implied from the values used for ordinary concrete, adapting them with appropriate corrective parameters. As usual, the relations useful to the determination of the properties of concrete can be used when more specific and accurate information is not available.
Below are the indications given by Notice '96, the most updated information of specific scientific literature and the figures relating to the experimental campaigns on expanded clay concrete.
The most recent experimental figures (obtained for example at ENCO laboratories in 2000 - 2001) using the new expanded clay mixtures (Exclay Structural and Exclay Terrecotte) with accurate mix designs, yield for certain performances, better results compared to the indications contained in the Ministerial notices.

According to Notice '96 concrete mass is the one measured at 28 days of curing determined according to standard UNI 7548/2. This standard offers three different testing procedures: reference, alternative or indicative. According to this procedure the mass at 28 days may be obtained by subtracting the value of 80 Kg/m³ from the value of the mass of fresh concrete. In the assessment of the weight of the concrete structure, the project developer must also take into account the weight of the frame (100 Kg/m³ iif there are no specific indications).

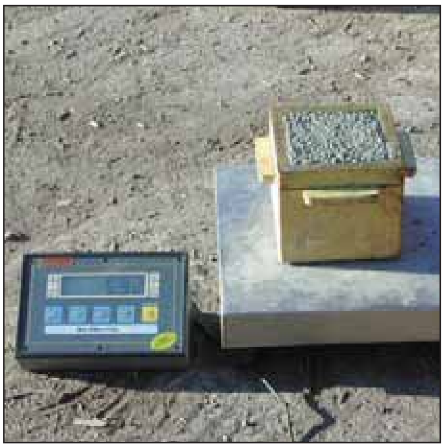
8.1 MASS

Standard UNI ENV 1992-1-4 and UNI ENV 1992-1-1 dentify the density classes for lightweight concrete, as indicated in the table below (consistent with standard EN 206-1):

Density Classes	1.0	1.2	1.4	1.6	1.8	2.0
Dry density ρ (kg/m³)	801-1,000	1.001-1,200	1,201-1,400	1,401-1,600	1,601-1,800	1,801-2,000
Density Cls (design) (kg/m³) reinforced concrete	1,050 1,150	1,250 1,350	1,450 1,550	1,650 1,750	1,850 1,950	2,050 2,150

The table shows the experimental figures of the mass of certain structural lightweight concretes with expanded clay prepared for specific testing campaigns.

Measurement of a mass of fresh concrete.



Laterlite experimental campaign: structural lightweight concrete

Concrete	Aggregate	Mass vol. Fresh [Kg/m³]	Relative. mass [Kg/m³]	Mass vol. 28days (reinforced) [Kg/m³]
CLS "A"	Exclay	1,650	1,570	1,670
CLS "B"	Termolite T6	1,720	1,640	1,740
CLS "C"	Exclay STR	1,750	1,670	1,770
CLS "D"	Termolite T6	1,760	1,680	1,780
CLS "E"	Termolite T6	1,800	1,720	1,820
CLS "F"	Exclay STR	1,850	1,770	1,870
CLS "G"	Exclay TC	1,950	1,870	1,970
Exclay CLS 1400	Pre-mixed	1,480	1,400	1,500
Exclay CLS 1600	Pre-mixed	1,680	1,600	1,700

where CLS "C" and CLS "G" are mixtures prepared for research at ENCO (2000), CLS "B", CLS "D" and CLS "E" Smae research (1989), CLS "A" and CLS "F" Laterlite experimentation, Exclay CLS 1400 and Exclay CLS 1600 are pre-mixed products. The mixing recipes for this concrete are indicated in chapter 12.

Characteristic compressive strength is defined as for ordinary concrete according to the criteria in Attachment 2 of the Technical Regulations '96. The rules applied to ordinary aggregates are used to determine the R_{ck} and a preliminary qualification test before beginning the construction must be performed.

The table shows, in a qualitative way, the various possibilities available for making structural lightweight concrete with expanded clay aggregates. Exclay is excellent for the preparation of structural concrete that calls for lightness and good isolation levels. Exclay Structural and Exclay Terrecotte are ideal for lightweight concrete mixtures with high and very high performances to be used, besides in concrete mixing plants, also in the prefabrication sector.

8.2. CHARACTERISTIC COMPRESSIVE STRENGTH

As stated, expanded clay lightweight concrete reach compressive strength values similar to ordinary aggregate concretes between 15 and 70 N/mm^2.

The UNI ENV 1992-1-4 standard and the following UNI ENV 1992-1-1 identify the strength classes for lightweight concrete as indicated in the table below:

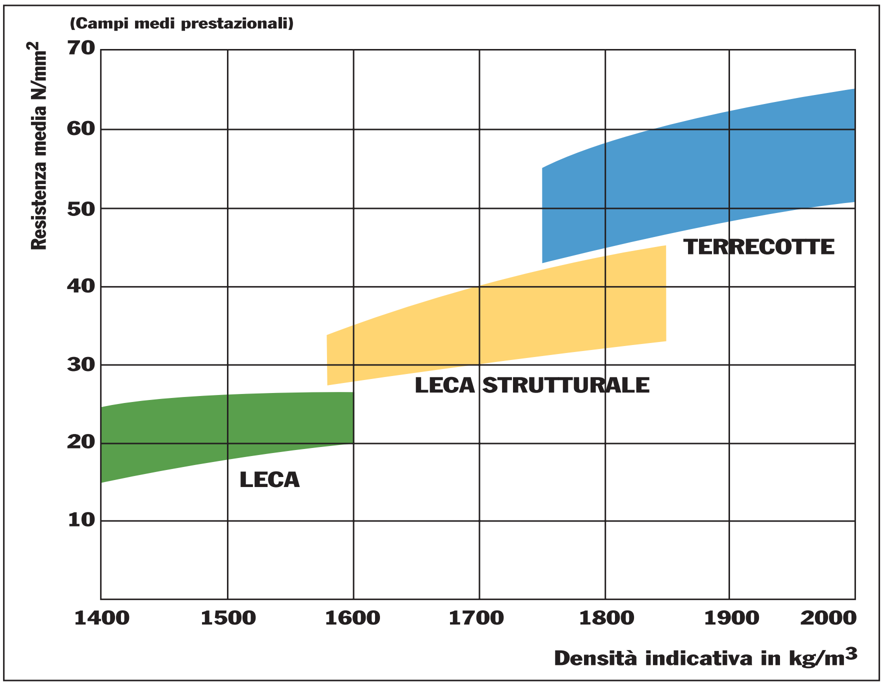
Strength class	12	16	20	25	30	35	40	45	50	55
f_{lck} (MPa)	12	16	20	25	30	35	40	45	50	55
f_{lcm} (MPa)	20	24	28	33	38	43	48	53	58	63

where:
- f_{lck} is the characteristic cylindrical compressive strength at 28 days for lightweight concrete
- f_{lcm} is the average cylindrical compressive strength

Strength levels higher than 50 MPa are not really used in Italy as per Notice '96 which limits, as concerns the calculation of the structures, the R_{ck} value to 50 N/mm^2. However other standards (such as UNI ENV 1992-1-1) foresee use up to R_{ck} 80 N/mm^2.

To change the mechanical strength of structural lightweight concrete it is possible to work on the quantity and type of cement, the water/cement ratio and other factors that normally affect the traditional aggregate, but also the type of expanded clay used. Characteristic compressive strength, which is determined as for heavy concrete, increases gradually using Exclay, Exclay Structural or Exclay Terrecotte (basically choosing materials with higher density and crushing resistance levels).
Further indications on compressive strength values of expanded clay concrete, referred to the mass of hardened concrete, can be seen in this table. The advantage of structural lightweight concrete is evident: limited masses reach very high strength levels.

AVERAGE PERFORMANCE LEVELS OF CONCRETE WITH EXCLAY, EXCLAY STRUCTURAL AND EXCLAY TERRECOTTE



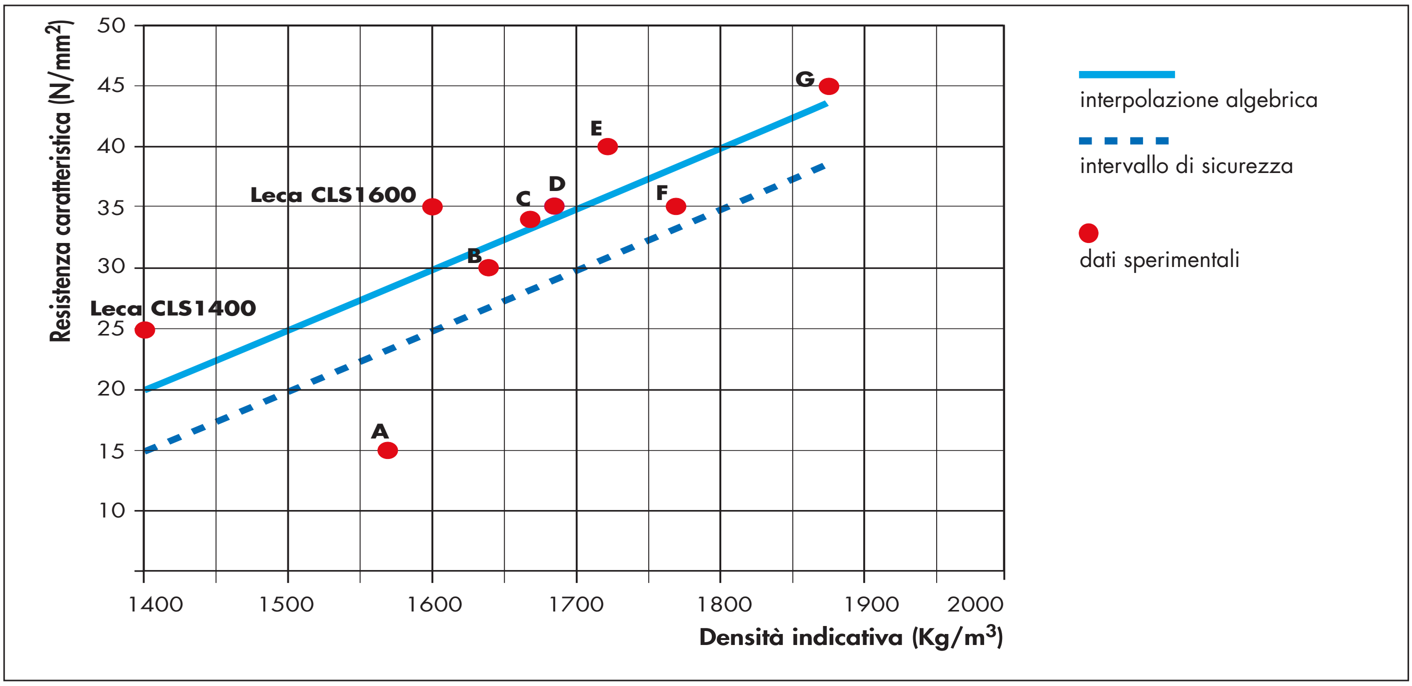
The experimental results, obtained from a specific testing campaign (see page 17) are indicated in the table and the following diagram.

Concrete	Aggregate	Relative mass [Kg/m³]	Strength [N/mm²]
CLS “A”	Exclay	1,570	15
CLS “B”	Termolite T6	1,640	30
CLS “C”	Exclay STR	1,670	34
CLS “D”	Termolite T6	1,680	35
CLS “E”	Termolite T6	1,720	40
CLS “F”	Exclay STR	1,770	35
CLS “G”	Exclay TC	1,870	45
Exclay CLS 1400	Pre-mixed	1,400	25
Exclay CLS 1600	Pre-mixed	1,600	35

The points in the diagram are the experimental results obtained for laboratory pre-mixed concrete (the mix-designs are indicated in chapter 12), basically in optimal conditions and the continuous line represents the algebraical interpolation. The dotted line indicates the safety margin (approx. 5 N/mm²), which should be referred to practically for a structural lightweight concrete prepared with the same recipe on site or in a concrete mixing plant.

The curves take into account the various types of Exclay aggregates and qualitatively describe the trend of the resistances.
The extreme values are reached by concrete “A” and “G”. The former, prepared with ordinary Exclay, represents the structural lightweight concrete that is generally requested for ordinary building projects. The latter, with Exclay Terrecotte, is an aggregate with very high performances ideal for the prefabrication sector.
Basically the mixtures prepared with Exclay Structural and Exclay Terrecotte always reach very high strength levels.

EXPERIMENTAL CAMPAIGN: INTERPOLATION OF RESULTS



According to Notice '96 tensile strength must be verified before starting the construction works and must be determined through simple tensile experimental tests, according to the UNI standard.
After checking the average tensile strength fctm on at least 6 prismatic or cylindrical samples, the typical values corresponding to 5% and 95% can be equal to: f_{ctk} (5%) = 0,7 f_{ctm} and f_{ctk} (95%) = 1,3 fctm, as for ordinary concrete. If tensile strength is determined using indirect tensile strength or bending tensile strength tests, the value of the simple tensile strength can be implied by using appropriate correlation parameters.

According to Notice '96, also for lightweight concrete, the average bending tensile strength will be equal to: $f_{cfm} = 1{,}2\ f_{ctm}$

8.3 TENSILE AND BENDING STRENGTH

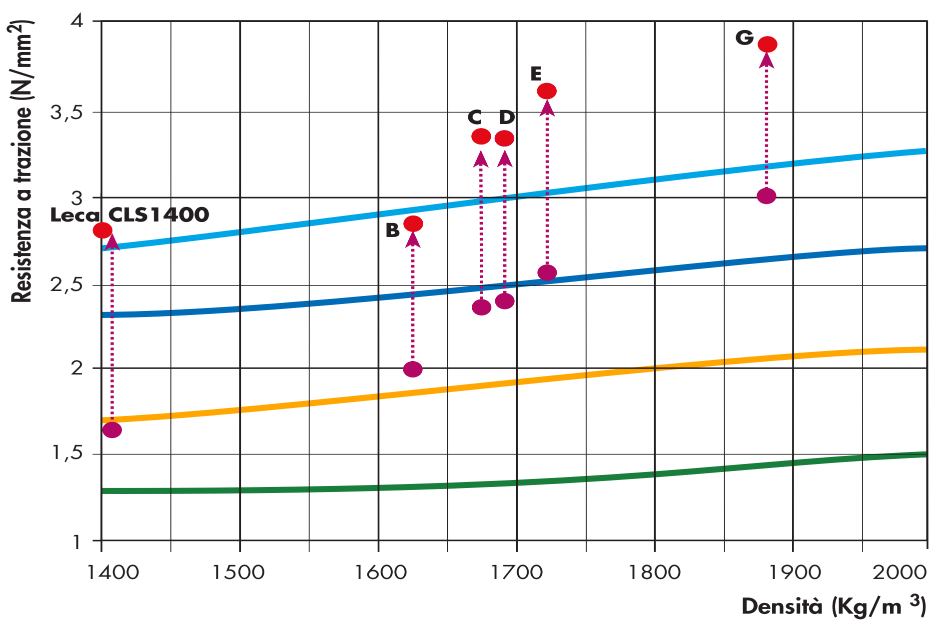
As an indication for the design, various standards offer relations that are based on the tensile strength of ordinary concrete, modified with the application of corrective factors, according to the density of lightweight concret. According to UNI ENV 1992-1-4 and UNI ENV 1992-1-1 Itensile strength (f_{lctm}) can be obtained by the reference values for ordinary concrete, multiplying them for the ratio:

$$\eta 1 = 0.4 + 0.6\rho/2200$$

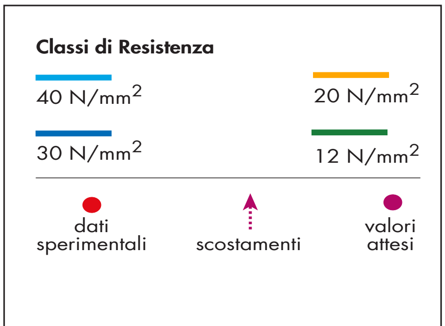
where ρ is the upper limit of oven dry density of the various density classes of lightweight concrete indicated in the table Density Classes on page 17. Hence, for the various strength classes of lightweight concrete:

	density	strenght classes								
f_{lck} (MPa)		12	16	20	25	30	35	40	45	50
f_{ctm} (MPa)	ordinary	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1
f_{lctm} (MPa)	1.400	1.3	1.5	1.7	2.0	2.3	2.5			
f_{lctm} (MPa)	1.600	1.3	1.6	1.8	2.2	2.4	2.7	2.9		
f_{lctm} (MPa)	1.800	1.4	1.7	2.0	2.3	2.6	2.9	3.1	3.4	
f_{lctm} (MPa)	2.000	1.5	1.8	2.1	2.5	2.7	3.0	3.3	3.6	3.9

As concerns expanded clay concretes the experimentation carried out (see page 17) gave the values indicated in the diagram.



In the diagram it is possible to compare the positioning of the indirect experimental tensile strength values related to structural lightweight concrete (whose recipes are indicated on page 29) compared to the average values according to UNI ENV 1992 (according to the strength classes). It is possible to see how the values resulting from UNI ENV are "safety values" compared to the experimental tests which also used the new specific expanded clays Exclay Structural and Exclay Terrecotte.
The dotted arrows indicate the shifting values of the individual concretes compared to the value expected by the UNI ENV 1992.



According to Notice '96, also for lightweight concrete the value of bending tensile strength shall be equal to:

$$f_{cfm} = 1{,}2\ f_{ctm}$$

8.4 ELASTIC MODULUS

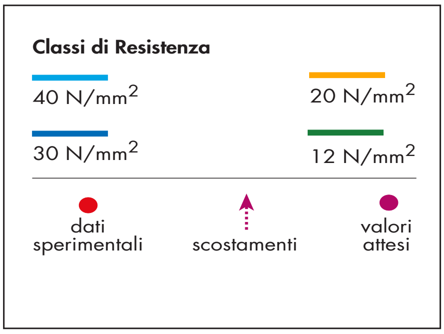
As regards the rigidity of structural lightweight concrete, during the design phase it is possible to use the Eurocode as reference: according to UNI ENV 1992-1-4 and UNI ENV 1992-1-1 (and other standards) the average value of the secant modulus can be calculated by the relations referred to ordinary concrete, multiplying these values by the corrective parameters according to the density of the concrete, strength classes being equal.
Particularly, UNI ENV 1992-1-4 sets the following parameter: $\eta_E = (\rho/2200)^2$
where ρ is the upper limit of oven dry density of the various density classes of lightweight concrete indicated in the table Density Classes on page 17. Hence the values:

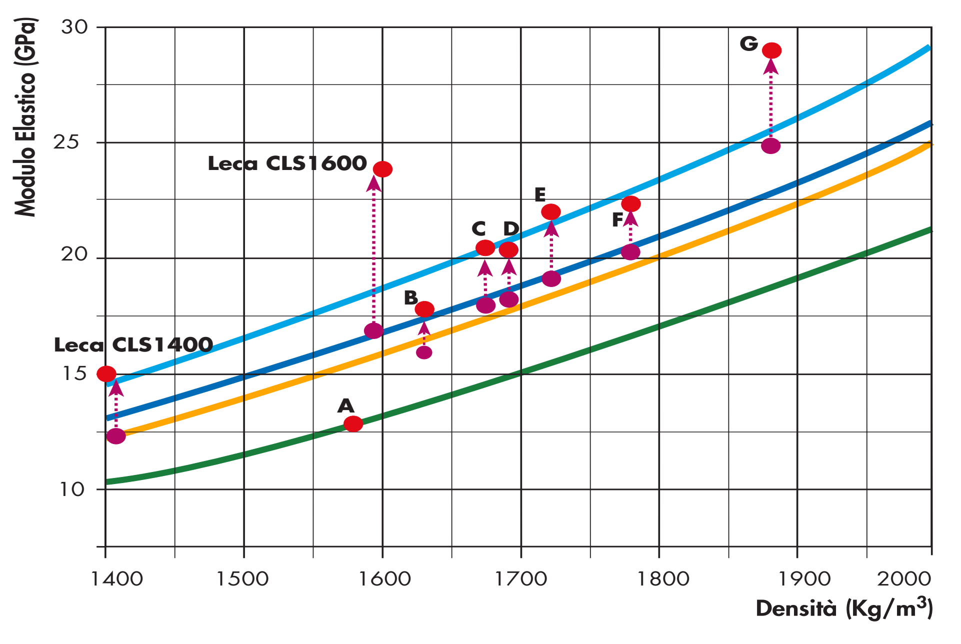
	density									
f_{lck} (MPa)		12	16	20	25	30	35	40	45	50
E_{cm} (GPa)	ordinary	27	29	30	31	32	34	35	36	37
E_{lcm} (GPa)	1.400	11	12	12	13	13	14	-	-	-
E_{lcm} (GPa)	1.600	14	15	16	16	17	18	19	-	-
E_{lcm} (GPa)	1.800	18	19	20	21	21	23	23	24	-
E_{lcm} (GPa)	2.000	22	24	25	26	26	28	29	30	31

IThe lower elastic modulus, even though it calls for more attention due to the elastic deformation phenomena, also offers some advantages:
• in seismic areas, lower elastic modulus values reduce the transmission of dynamic vibrations whereas the lower density of the concrete reduces the entity of earthquake vibrations that as known, are proportional to the masses moved;
• the risk of load concentrations due to mistaken casting decreases thus allowing for a good redistribution of the loads;
• if the importance of the load (for example in bridges, panels or roof tiles) allows for a more favorable dimensioning of the section if the project is made with lightweight concrete. In this case the influence of the minor load is predominant on that of the minor elastic modulus, hence the arrows will be smaller.
As concerns expanded clay concrete the experimentation carried out (see page 17) gave the following values:

The compressive elastic modulus must be assessed, according to Notice '96, through direct experimentation before the beginning of the construction work and must be carried out in compliance with UNI 6556 (March 1976), and is given by the average value on at least 3 prismatic or cylindrical samples.

Viaduct in Marghera (VE)





In the diagram, it is possible to compare the positioning of the experimental data related to structural lightweight concrete (recipes on page 29) compared to the rigidity values indicated in UNI ENV 1992 (iaccording to the strength class). It is possible to see how the values resulting from UNI ENV are "safety values" compared to the experimental tests which also used the new specific expanded clays Exclay Structural and Exclay Terrecotte.
The dotted arrows indicate the shifting values of the individual concretes compared to the value expected by the UNI ENV 1992.

Notice '96 sets forth that the thermal expansion ratio could be equal to:

$\lambda = 8 \times 10^{-6}\ °C^{-1}$

Notice '96 gives the possibility to refer to the rules in point 2.1.6. Part I of the technical regulations for ordinary concrete, multiplying the final shrinkage values ε_{cs} (t_{8}, t_{o}) by the ratio: $\eta_1 = 1.5$

According to Notice '96 the admissible values of the final viscosity ratio $\varphi (t_\infty, t_o)$ can be calculated using the rules in section 2.1.7, Part 1, of the technical regulations for ordinary concrete, multiplying the values $\varphi (t_\infty, t_o)$ by the ratio:

$\eta_2=(\rho/2400)^2$

where ρ is the mass of the lightweight concrete expressed in kg/m³.

8.5 POISSON'S RATIO

Notice '96 did not indicate any modifications to the values used for ordinary concrete (n ranging between 0 and 0.2), also confirmed by UNI ENV 1992-1-4 and UNI ENV 1992-1-1.
Value $\nu = 0$ is used in case of deflection and value $\nu = 0{,}2$ if there is no deflection.

8.6 THERMAL EXPANSION

The value of $\lambda = 8 \times 10\text{-}6$ °C-1, generally confirmed also by UNI ENV 1992-1-4 and UNI ENV 1992-1-1 is approx. 20% lower than the one generally used for ordinary concrete ($\lambda = 10 \times 10^{-6}\ °C^{-1}$).

8.7 SHRINKAGE

UNI ENV 1992-1-4 and UNI ENV 1992-1-1 use similar criteria (1) to the one used in Notice '96.
For expanded clay concrete the experimentation carried out (see page 17) yielded the values indicated in the following table (in μm/m):

	3days	7days	14days	21days	28days	60days	90days
CLS C	60	227	320	407	460	520	640
CLS G	100	150	190	300	340	390	499

Shrinkage essentially depends on the quantity of cement and water in the mixture. In structural lightweight concrete it decreases as the mass of the aggregate and the crushing strength of the light aggregate increase. Concrete prepared with Exclay Structural and Exclay Terrecotte have, cement content being equal, lower shrinkage levels compared to structural concrete prepared with lighter aggregates.

8.8 VISCOSITY

The viscosity of concrete, defined also fluage or creep, is the deformation in relation to time in permanent load conditions and must be summed to the initial deformation and shrinkage effect. This effect, in certain cases, can be favorable because it reduces the stress due to shrinkage, thermal expansion, stress in hyper-static structures, thus reducing the risk of cracking. It is known that, since fluage derives from the deformation of the cement paste, it increases as the quantity of cement that holds together the mixture increases. Hence, concretes with a good granulation curve of the aggregate call for lower cement doses, hence entail lower fluage values.
Fluage depends not only on the quantity but also the quality of cement. It decreases as porosity decreases and as strength increases.

For expanded clay concrete the experimentation carried out (see page 29) yielded the values indicated in the following table (in μm/m):

	3days	7days	14days	21days	28days	60days	90days
CLS C	210	330	420	550	650	875	940
CLS G	133	178	210	260	338	490	575

The fluage of structural lightweight concrete decreases as the rigidity of the aggregate increases and hence of the crushing strength of the aggregate: concrete prepared with Exclay Structural and Exclay Terrecotte have lower fluage levels compared to structural concrete prepared with lighter aggregates.

(1) UNI ENV 1992-1-4 uses an "η_4" parameter equal to 1.5 for strength classes up to 16 and equal to 1.2 for higher strength classes; UNI ENV 1992-1-1 uses the same corrective parameters to apply to values valid for ordinary concrete, even though these are determined in a different way.

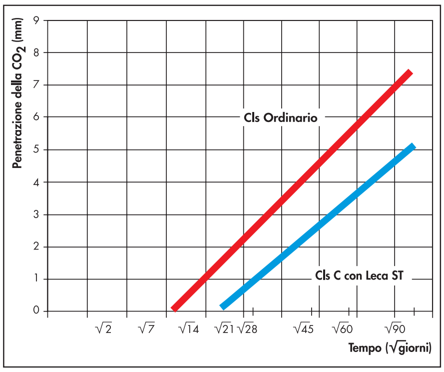
8.9 DURABILITY

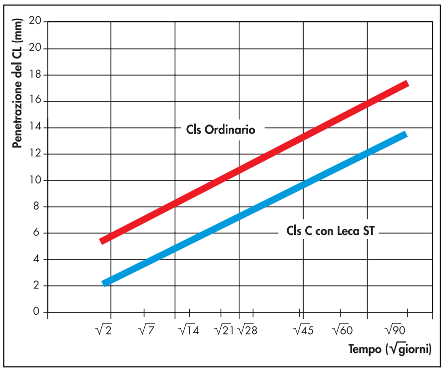
Notice '96 does not give any specifications for lightweight concrete. Standard UNI ENV 1992-1-4 fonly gives qualitative suggestions on durability (cover reinforcement). The latest UNI ENV 1992-1-1 gives lightweight concrete the same exposure classes of ordinary concrete, even though it indicates (in a conservative way) a 5 mm increase in cover.

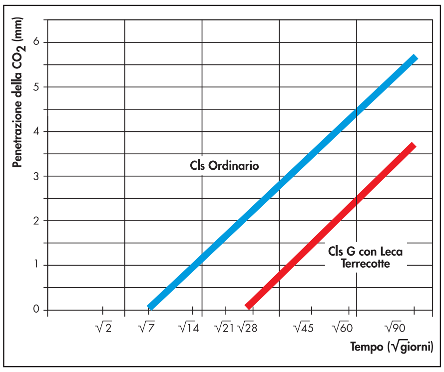
At the end of the testing campaign, which was held at the ENCO laboratories on structural lightweight concrete with Exclay Structural and Exclay Terrecotte, the penetration results of CO_2 and chloride in the lightweight concrete were particularly positive compared to those for an ordinary concrete with equal mechanical strength, with identical cement quantity and water/cement ratio as shown in the diagram on the side (the complete report on the ENCO 2000 research is available at the Laterlite Technical Assistance office).

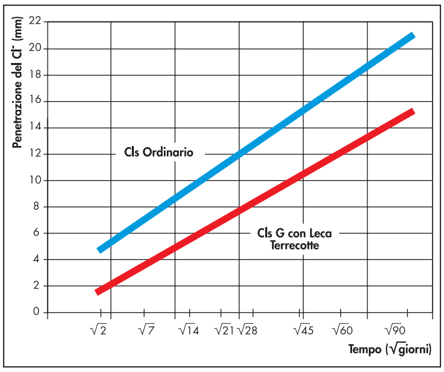
Heidrun tension leg platform - North Sea

Road bridge in Isernia





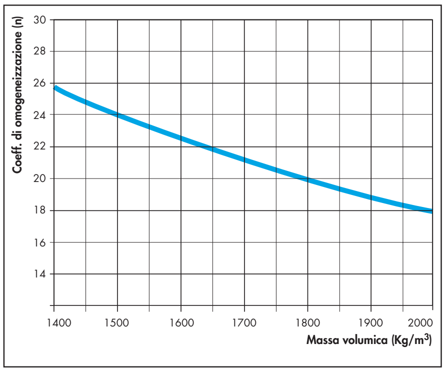




Penetretion of CO_2 and chlorides in lightweight concrete prepared with Exclay Structural and Exclay Terrecotte compared to those calculated for an ordinary concrete with the same mechanical strength, the same cement quantity and water/cement ratio.

Notice '96 allows for a wide use of lightweight concrete with characteristic compressive strength values between 15 N/mm² and 40 N/mm², the upper limit can be brought up to 50 N/mm², with a higher accuracy in the calculation and control of the aggregate.
All the calculation rules and codes generally used for ordinary concrete are used, but with the modifications indicated below.
It is possible to use both the admissible tension method and the semiprobabilistic method of ultimate limit

Conventional homogenization ratio n according to the mass.



The complete report on the ENCO 2000 research is available at the Laterlite Technical Assistance office with the figures of the iron-concrete adherence tests (pull out).

[(1)] Notice no. 37406/STC of 24.06.1993, published on the Official gazette of August 16, 1993.

9.1 THE ADMISSIBLE TENSION METHODS

IThe admissible tension methods for ordinary concrete refer to the Technical Regulations of 1992 and similarly, for structural lightweight concrete, to the corresponding Notice '93 [(1)].
The regulations for lightweight concrete are simple and limited since the calculation method is the same as the one used for ordinary concrete construction works.
The normal compressive strength on the aggregate ($\bar{\sigma}_c$ e $\bar{\bar{\sigma}}_c$) is considered equal to that defined for ordinary concrete, with some specifications:

$$\bar{\sigma}_c = 6 + \frac{R_{ck} - 15}{4} \quad (N/mm^2)$$

For slab beams and pillars subject to bending or pressure-bending and
$\bar{\bar{\sigma}}_c = 0{,}7\ [1 - 0{,}03\ (25 - s)]\ \bar{\sigma}_c$ or $\bar{\bar{\sigma}}_c = 0{,}7\ \bar{\sigma}_c$
for pillars calculated at simple compression, valid the former for s<25 cm and the latter for s≥25 cm, where s is equal to the minimum dimension of the section.

The only modifications refer to:

- the conventional homogenization ratio, which for this type of concrete must be equal to: $n=36.000/\rho$ where ρ is the mass of the concrete expressed in kg/m³.

In the case of structural lightweight concrete, the ratio "n" can vary between the values n=25 for concrete mass equal to 1450 kg/m³ and n=18 for concrete mass equal to 2000 kg/m³, values higher than those used for concrete with ordinary aggregates (n=15).
The homogenization ratio takes into account both the elastic modulus of the aggregate and the frame and the deformations differed in time and the attention used in the sizing of the sections: hence there is no immediate correspondence (inverse) between the elastic modulus of ordinary concrete and lightweight concrete and the relating homogenization ratios.

- the values of the admissible tangential pressure, $\bar{\tau}_{co}$, $\bar{\tau}_{c1}$, $\bar{\tau}_b$ which must be reduced by multiplying them by the ratio $\eta_3 = 0.8$

The indication on the reduction of the value of the admissible tangential pressures is, if there is no specific evidence, common to various standards that take into account the lower adherence of iron-concrete for lightweight aggregate concrete compared to ordinary concrete with the same strength.
The value of admissible tangential pressures can always be subtracted from the compressive strength value with the following relations:

$$\bar{\tau}_{co} = 0{,}8\ (0{,}4 + \frac{R_{ck} - 15}{75}) \quad (N/mm^2)$$

$$\bar{\tau}_{c1} = 0{,}8\ (1{,}4 + \frac{R_{ck} - 15}{35}) \quad (N/mm^2)$$

$$\bar{\tau}_b = 3\ \bar{\tau}_{co} \quad (N/mm^2)$$

where $\bar{\tau}_{co}$ is the value of tangential pressure for which the control of the shear reinforcement or tensile stress reinforcement is not requested, $\bar{\tau}_{c1}$ is the tangential pressure that must not be exceeded only due to the shearing, $\bar{\tau}_b$ is the adherence pressure between bars and the aggregate in case of uniform distribution. The complete report on the ENCO 2000 research is available at the Laterlite Technical Assistance office with the figures of the iron-concrete adherence tests (pull out).

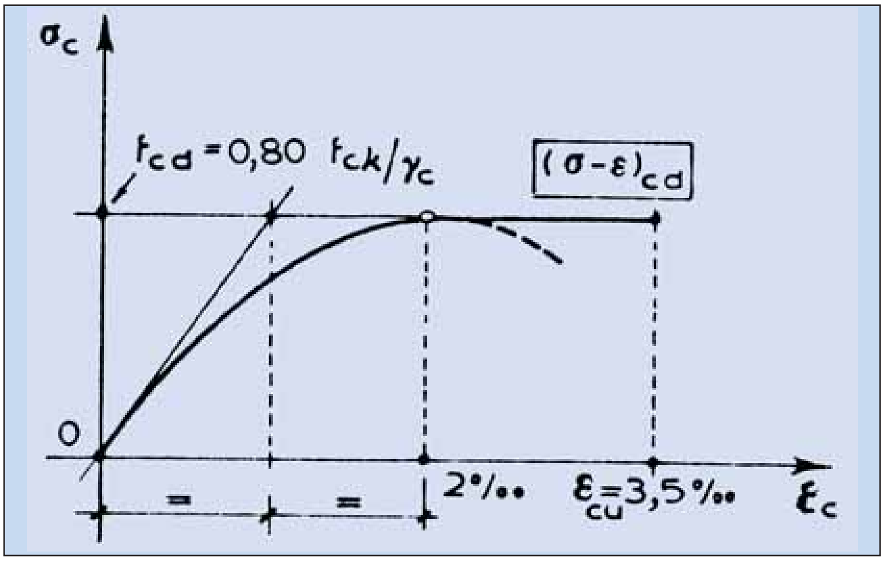
9.2 THE SEMIPROBABILISTIC METHOD OF ULTIMATE LIMIT STATE

Controls must be performed both as regards the ultimate operating limit state and the ultimate limit state.
Also as regards the control of the structures with the method of the finished elements the differences compared to ordinary concrete refer basically to the $\sigma-\varepsilon$ link for normal strengths and the rules for shearing strengths.

9.2.1 Controls of the ultimate limit state

9.2.1.1 Stress that causes normal tension

In the controls of the ultimate limit state for normal stress or simple bending and/or pressure-bending stress, the use of the stress-deformation parabola-rectangle or "stress block" diagram is allowed for lightweight concrete, but with a more conservative measure.



9.2.1.2 Shearing stress

Also for lightweight concrete we make a distinction between the case in which elements without transversal frames resistant to shearing are admitted (slabs, plates, etc.) and the case in which the elements are shear-resistant.
In the first case, the control foresees that the aggregate has no oblique cracks under the shearing stress status so that the lowered arch and chain operating pattern are observed.
Consequently, the most important factor is the tensile strength f_{ctm} of the aggregate.
Also in this case, the standard proves a bit more conservative towards lightweight concrete not allowing for the benefit of ratio r = (1.6-h) ≥1 which is considered equal to 1 for any value of the maximum height of the section.
In the second case, with shearing-resistant elements, it is necessary to assess the capacity of the compressed connecting rods of the ideal trestle to absorb stress, exactly as for normal aggregates.
Also in this case, the expression is a bit more conservative for lightweight concrete, admitting a compressive value about 33% lower compared to ordinary concrete.

9.2.2. Control of the ultimate operating limit state

The operating strength limits already laid down for ordinary concrete are valid also for lightweight concrete, but with a change in the conventional homogenization ratio n which is considered equal to:
$n = 36{,}000/\rho$
where ρ is the mass of the concrete expressed in kg/m^3.

According to Notice '96 the parabola rectangle diagram is always defined by a second degree parabola arch and a line segment.
The x-coordinate values of the end of the parabola (ε = 2 ‰) and of the line (ε = 3,5 ‰) remain unchanged. Then maximum y-coordinate of the diagram is modified which is 0.80 f_{cd} = 0,80 f_{ck}/γ_c (for ordinary concrete it is 0.85 f_{cd}).
Even for lightweight aggregate concretes the relation f_{ck} = 0,83 R_{ck} is true. This relation links cylindrical strength f_{ck} with cubic strength R_{ck}.
In case of uniform compression distribution (stress block) a rectangular diagram extended to 3/4 of the compressed area can be used also for lightweight concrete, with constant strength equal to:
- *0,80 f_{cd} for compressed area with constant or decreasing width towards the neutral axis (for ordinary concrete is 0.85 f_{cd});*
- *0,75 f_{cd} for compressed area with increasing width towards the neutral axis (for ordinary concrete is 0.8 f_{cd}).*

Again in this case it is clear how the standard has a very cautious attitude, but basically lightweight concrete is treated just as ordinary concrete.

According to Notice '96 the aggregate must be controlled by cautiously setting ratio r = 1 for all maximum "d" heights of the section. Hence the following condition must be assessed:

$V_{sdu} \leq 0{,}25\, f_{ctd} \bullet 1\, (1 + 50\, \rho_l)\, b_w \bullet d \bullet \delta$

where f_{ctd} is the design tensile strength of the concrete ($f_{ctd} = f_{ctk}/1{,}6 = 0{,}7\, f_{ctm}/1{,}6$) and the other symbols have the meaning indicated in the Technical Regulations.

For elements with cross sectional reinforcement the calculation must be:
$V_d \leq 0{,}20\, f_{cd}\, b_w\, d$
where f_{cd} is the compressive strength of the concrete, b_w is the width of the membrane resistant to shearing and d is the maximum height of the section.

INDICATIONS FOR THE CALCULATION

As concerns lightweight concrete Notice ’96 indicates an 80% reduction of the l/h ratio, hence:

Limit conditions	*l/h (trad. concrete)*	*l/h (light.concrete)*
Cantilever	*7*	*5.6*
Beams and plates simply leaning	*20*	*16*
Continuous beams, anchored plates	*25*	*20.8*

and for bearing beams partition walls:

Limit conditions	*cls trad.*	*cls legg.*
Leaning beams	*l / h ≤ 120 / l*	*l / h ≤ 96 / l*
Continuous beams	*l / h ≤ 150 / l*	*l / h ≤ 120 / l*

9.2.2.1 Cracking ultimate limit state

This type of control is generally done when it is necessary to verify the protection of the frames against the exposure to an aggressive environment or there are special design requirements for the structural element.
Without going too much into the calculation details, for which Notice ’96 does not give any specific indication on lightweight concrete, it is important to stress that as regards controls it is important to take into account the different homogenization ratio n and the tensile strength of the specific concrete.

9.2.2.2 Deformation limit state

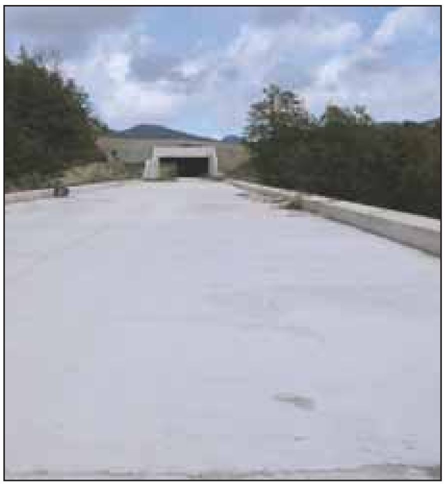
This control is generally not necessary in ordinary civil applications, however a more cautious attitude is foreseen for controls resulting from the higher intrinsic deformation degree of the material itself.
The Technical Regulations ‘96 allow for, in the case of rectangular section beams and plates, under precise calculation conditions, the omission of the control of the deformation limit state providing the l/h ratio being observed. (l=luce, h=altezza totale della sezione) indicated on the side. The same criteria holds true also for lightweight concrete, but with more cautious ratios.

9.2.3 Slender elements

Notice ’96 sets a slenderness limit for lightweight concrete pillars which is:
$l = l_o / i < 70$
where l is the slenderness ratio in the considered direction, l_o is the relating length of free deflection and i is the inertia radius of the aggregate section.

Prefabricated structures - Calgary stadium

Scraping of road surface - Isernia



9.3 CONSTRUCTION DIRECTIVES

The specific construction directives for lightweight concrete laid down in Notice ’96 are limited and basically all focused on a careful evaluation of the steel/concrete adherence:

• the allowed ordinary frames are rods with enhanced adherence or weld-mesh.
• the diameter of the rods must not exceed 20 mm.
• in pre-stressed structures, with adherent frame, the diameter of the strands must not exceed 3/8 of an inch.
• as concerns the anchoring of the rods, the directives indicated in the technical regulations for normal concrete are valid, increasing the anchoring and overlapping length by at least 25%.

Bearing structure of multi-floor building - Brescia

PREPARATION SUGGESTIONS

10. PREPARATION SUGGESTIONS

When the concrete is being prepared, the expanded clay aggregate is used in the same way as a traditional aggregate, using the standard equipment found on construction sites or concrete mixing plants.

10.1 PRE-MIXED CONCRETE IN BAGS

Premixed structural lightweight concrete offers the guarantee of a safe, controlled and certified product in addition to the convenient handling and use of the product on site. It is necessary to carefully follow the indications on the quantity of water to put into the mixture indicated on the technical sheets and the bags themselves to assure the proper performances.

10.2 PREMIXED CONCRETE

The aggregate should be measured in volume. If it is measured in weight pay attention to the density of the material and its humidity conditions to avoid making mistakes in the composition of the mixture.
The lightweight aggregate is delivered on dumpers, pumped in silos or bagged in Big-Bags of 1.5-2 m^3. When placing the order, it is possible to ask that the density and the humidity of the material be indicated on the transport documents to simplify the preparation of the mixture. Of course these values can vary according to the time and the stocking modalities and must be re-checked if the casting operation does not immediately follow the delivery of the aggregate. The material must not necessarily be stocked in a silo, but it can also be stocked in a hopper or store yard.
The weight of expanded clay varies according to the type (Exclay, Exclay Structural or Exclay Terrecotte), the granulation and humidity. Exclay Structural or Exclay Terrecotte is used for concretes with characteristic strength values over 25 N/mm^2 These materials can be considered with saturated dry surface (s.s.a.) when the humidity is at least 7%.
After verifying the humidity conditions of the aggregates (lightweight and not) and after correcting the quantities, the suggested order for adding the components foresees loading all the lightweight aggregate (Exclay, Exclay Structural or Exclay Terrecotte) with 2/3 of the water.
After mixing for a few minutes, add the other aggregates and the binder, the rest of the water and then the admixtures.

Vehicle passages for the Milan Fairground

From Notice'96:
We suggest testing the mixer to verify the suitability of the mixture for the foreseen preparation. In normal conditions, we suggest introducing the components of the mixture in the mixer in the following order:
- coarse aggregate
- 2/3 of total water foreseen
and, after about 30"/ 60"
- fine aggregate and cement,
- 1/3 of water with admixtures is applicable.
The mixing time, calculated after all the components have been added must be at least 1 minute, even though we suggest a bit more time.

Laying and compacting
The castings must be performed within layers with limited thickness to enable the complete vibration of the mixture and avoid segregation.

CASTING SUGGESTIONS

11.1 TRADITIONAL CASTING

Traditional casting operations (with gutter or bucket) of premixed and pre-packed Exclay concrete do not require any special attention other than the good practice methods for traditional concrete. Premixed Exclay CLS 1400, particularly, can be laid using pneumatic pumps (for foundations). Compacting with vibrators calls for special attention: especially for concrete casting with a density lower than 1600 Kg/m^3 it is good practice not to insist too much with the needle in the same point. A light and distributed movement on the entire section will prevent the risk of segregation. Where available (especially in the prefabrication sector) vibrating boxes are preferable because they assure a uniform compacting of the material.

11.2 CASTING WITH CONCRETE PUMPS

IDuring the design and execution phase of lightweight concrete, unlike what happens for traditional concrete, special care must be used to make pumping operations easier. The modalities for laying the concrete affects the preparation.

Due to the absorption capacity of lightweight aggregate during the pumping phases, a part of the mixing water may be absorbed. The final mixture may be poor in water (burned) or can even get blocked inside the pump. An increase in the quantity of water might make the operation easier but would inevitably decrease the resistance of the mixture, thus increasing bleeding. Therefore during pumping, the lightweight aggregate should be able to flow smoothly. This can be achieved in two ways: through pre-wetting of the lightweight aggregate and by using the SCC technology (as described below).

11.2.1 Pumping through pre-wetting

Pre-wetting the expanded clay is necessary before preparing the mixture, if it is very dry and in any case if it is far from the s.s.a conditions (dry surface saturation). It is procedure absolutely recommended for pumping very light structural concrete (density between 1400 and 1600 Kg/m^3) especially for those prepared with Exclay 3-8. Practically, for small quantities it is enough to soak Exclay in the concrete mixer the night before the preparation. If the quantity of concrete to prepare increases, keep Exclay wet during stocking using irrigators. The aim of these operations is to give clay enough absorption water so that no water is taken in during the pumping phase.

11.2.2 Pumping with SCC technology [1]

Modern concrete self-compacting techniques are used to increase the fluidity of the mixture and prevent the lightweight aggregate to start floating (SCC - self compacting concrete).

By adding the appropriate fluidifying admixtures and enhancing the granulation curve with fine parts (addition of minerals like loose ashes, silica fume fly ash etc…), it is possible to prepare concrete with high fluidity levels that can settle alone in the boxes. The SCC design besides enabling the pumping of structural expended clay concrete in any humidity condition, also enables to reduce or avoid compacting of the casting thus enhancing the performances of the concrete in terms of resistance, rigidity and durability. Specific hyper-fluidifying admixtures are added to give high rheology to the mixture reducing the risk of segregation.

[1] This technique especially refers to lightweight structural concrete with density levels higher than 1600 Kg/m^3 and prepared with Exclay Structural and Exclay Terrecotte which have absorption margins lower than normal Exclay expanded clay.

EXAMPLES OF MIX DESIGN

12. PERFORMANCES

Below is a table that summarizes the performance levels of structural lightweight concrete used in the experimental campaigns carried out by Laterlite (together with ENCO and other laboratories) indicated in this document.

The designer can use these values as a reference for the expected performances of concrete made with lightweight aggregates and mixtures similar to those indicated in chapter 13. The designer will add the corrective factors according to the type of works, construction features, quality of the labor force and all the other factors deemed necessary.

Summary table of performances

Concrete	Aggregate [Kg/m³]	Fresh mass vol. [Kg/m³]	Ref. mass [Kg/m³]	Characteristic strenght [N/mm²]	Tensile strenght [N/mm²]	Elastic modulus [N/mm²]	Shrinkage (28days) [µm/m]	Fluage (28days) [µm/m]
CLS A	Exclay	1,650	1,570	15	-	13,000	-	-
CLS B	Termolite T6	1,720	1,640	30	2.9	18,100	-	-
CLS C	Exclay STR	1,750	1,670	34	3.3	20,400	460	650
CLS D	Termolite T6	1,760	1,680	35	3.3	20,200	-	-
CLS E	Termolite T6	1,800	1,720	40	3.7	21,600	-	-
CLS F	Exclay STR	1,850	1,770	35	-	22,000	-	-
CLS G	Exclay TC	1,950	1,870	45	3.9	28,500	340	338
Exclay CLS 1400	Pre-mixed	1,480	1,400	25	2.8	15,000	-	-
Exclay CLS 1600	Pre-mixed	1,680	1,600	35	-	23,000	-	-

13. EXAMPLES OF MIX DESIGN

Below are the mixture recipes for the structural lightweight concrete used in the experimental campaigns.

These mix designs are useful references to make preliminary mixtures that the know-how and experience of the technicians will enhance and optimize according to the requests and specific situations.

It is possible to request the visit of a Laterlite technician to the site or the concrete mixing plant to perform a pumping test.

Recipe	CLS 1	CLS 2
Cement [kg/m³]	420	480
Loose ashes [kg/m³]	80	-
Exclay Str 0-15 [kg/m³]	560	580
Sand 0-3 [kg/m³]	480	490
Superfluidifier [kg/m³]	5.0	5.8
Thinner [kg/m³]	1,3	1.4
Water [kg/m³]	200	192
A/C	0.4	0.4

Mix design: mixtures for pumpable concrete (SCC technology) with reference mass of **1600 kg/m³** and R_{ck} of **35 N/mm²**.

Mix design: mixtures of Laterlite experimental campaigns

Recipe	CLS A	CLS B	CLS C	CLS D	CLS E	CLS F	CLS G (cem. 52,5)
Cement [kg/m³]	400	330	400	395	490	400	425
Exclay 3-8 [kg/m³]	270	-	-	-	-	-	-
Exclay Str 0-15 [kg/m³]	-	-	590	-	-	-	-
Termolite T6 3-8 [kg/m³]	-	370	-	335	300	480	-
Termolite T6 8-12 [kg/m³]	-	145	-	130	115	-	-
Exclay TC 0-6 [kg/m³]	-	-	-	-	-	-	395
Exclay TC 6-12 [kg/m³]	-	-	-	-	-	-	285
Sand 0-4 [kg/m³]	760	675	600	690	680	780	600
Admixtures [kg/m³]	4.5	1.65	4.95	1.58	1.96	6.0	6.34
Water [kg/m³]	180	181	160	190	196	180	205
A/C	0.45	0.55	0.4	0.48	0.4	0.45	0.51

SPECIFICATIONS

14.1 PREMIXED LIGHTWEIGHT CONCRETE

Exclay premixed lightweight concrete CLS 1400 (1400 Ri)
Exclay structural lightweight concrete CLS 1400 (or Exclay CLS 1400 Ri) premixed in bags with special expanded clay, natural aggregates, Portland cement and admixtures.
Dry density of concrete at 28 days approx. 1400 kg/m^3. Average compressive strength at 28 days (at 7 days for Exclay CLS 1400Ri) determined on prepared cubes on job site 25 N/mm^2.
Preparation and casting according to manufacturer’s instructions.

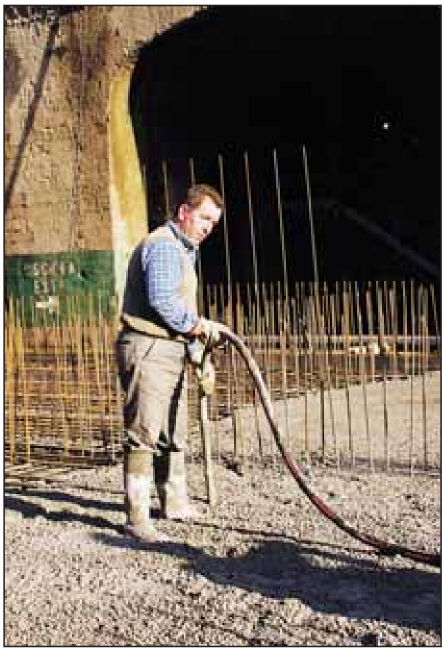
Exclay premixed lightweight concrete CLS 1600
Exclay structural concrete CLS 1600 premixed in bags with special expanded clay, natural aggregates, Portland cement and admixtures.
Dry density of concrete at 28 days approx. 1600 kg/m^3. verage compressive strength at 28 days determined on prepared cubes on job site 35 N/mm^2.
Preparation and casting according to manufacturer’s instructions.

14.2 PREMIXED LIGHTWEIGHT CONCRETE

Premixed lightweight and insulating concrete
Structural lightweight concrete made up of Exclay expanded clay, natural aggregates, cement … and admixtures. Reference density at 28 days. … (from 1400 to 1600 kg/m^3). Average compressive strength at 28 days determined on prepared cubes on job site… (from 15 to 25 N/mm^2).

High resistance structural lightweight concrete
Structural lightweight concrete made up of Exclay Structural expanded clay, natural aggregates, cement … and admixtures. Reference density at 28 days. … (from 1550 up to 1850 kg/m^3). Average compressive strength at 28 days determined on prepared cubes on job site… (from 20 to 45N/mm^2).

Very high resistance structural lightweight concrete
Structural lightweight concrete made up of Exclay Terrecotte expanded clay, natural aggregates, cement … and admixtures. Reference density at 28 days. … (from 1750 up to 2000 kg/m^3). Average compressive strength at 28 days determined on prepared cubes on job site… (from 40 to 65 N/mm^2).



Church “Tenda della Riunione” - Porto San Giorgio (AP) - Designer Prof. Eng. Michele Mele

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soluzioni leggere e isolanti

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