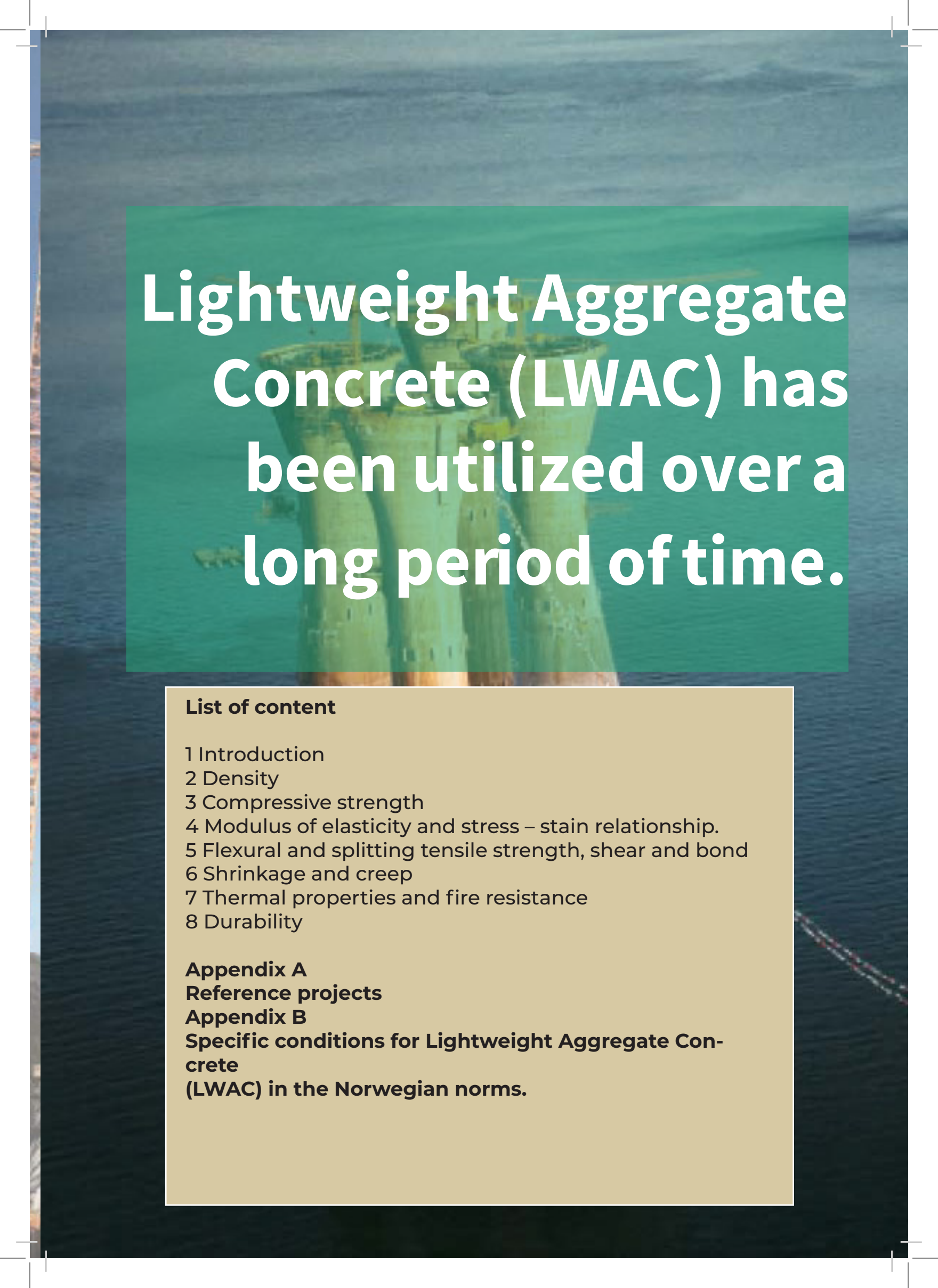


Lightweight Aggregate Concrete – Characteristics of Hardened Concrete





Lightweight Aggregate Concrete (LWAC) has been utilized over a long period of time.

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Appendix A

Reference projects

Appendix B

Specific conditions for Lightweight Aggregate Concrete (LWAC) in the Norwegian norms.

Introduction

Lightweight aggregate concrete (LWAC) is defined as concrete with lower density than normal density concrete (NDC). LWAC has been successfully used for many decades in various constructions where the purpose usually has been to reduce weight.

This guideline will focus on mechanical properties of the hardened concrete and compare the lightweight concrete with the normal density concrete.

NDC is used as a reference since the characteristics are well known by use, experience and through norms.

The guideline will handle several mechanical properties and explain how and why the LWAC is different. Together with this guideline an attachment is added which summarizes the specific text in the national norms that relates to LWAC. Some specific properties, results and experience are not conclusive. The guideline is based on results from the references and general experience. The national norms are definitive for construction and design of structures.

1. Concrete density versus time of drying for Structural Concrete (Holm 1994 – modified)

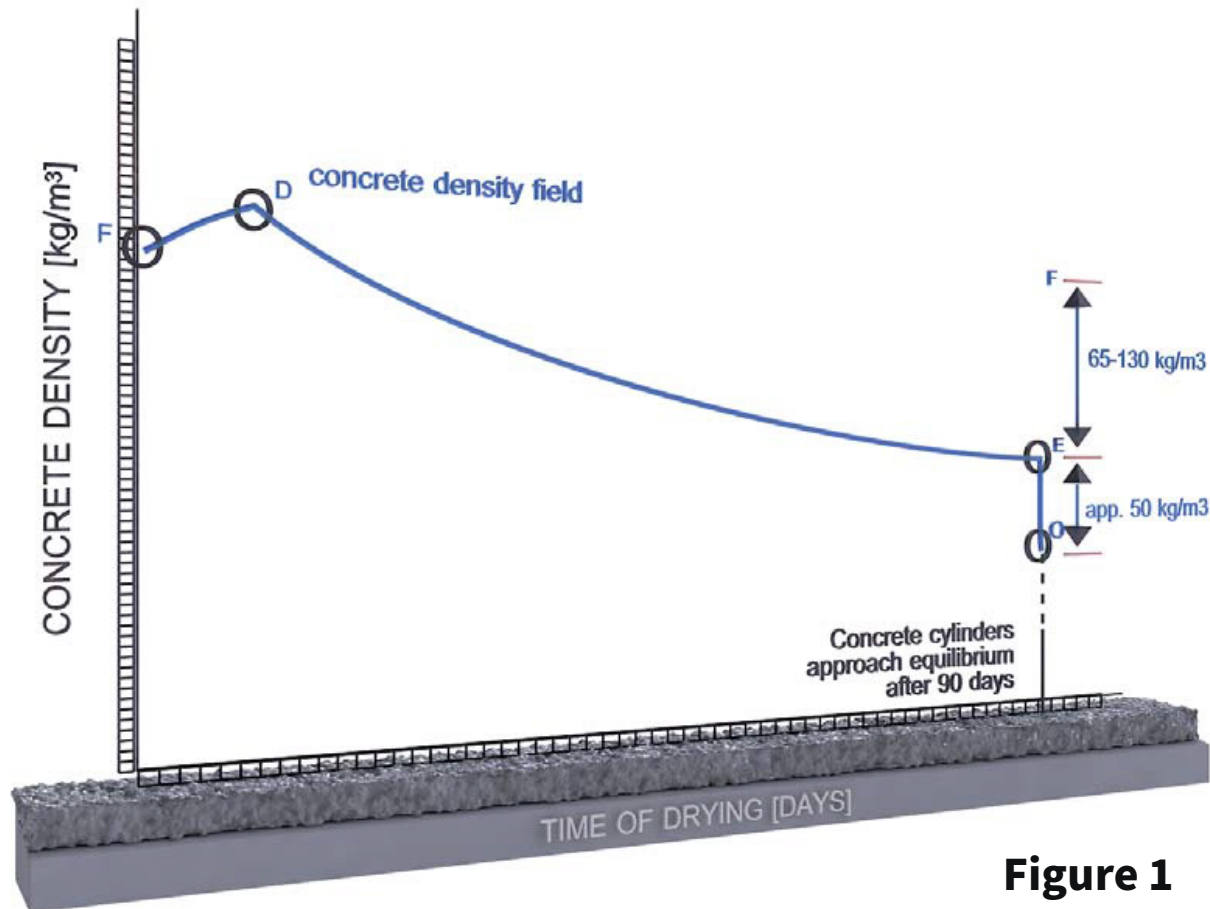


Figure 1

- F Fresh density is measured during manufacturing and is in accordance with the mix design density.
- D Demoulded density is usually 20-50 kg/m³ higher than F.
- E Equilibrium density is dependent on the environment but can range from D to O. American studies conclude that E is 50 kg/m³ higher than O and the ACI 213 concludes that E is 65-130 kg/m³ below F.
- O Oven dry density is used by the norms for calculating other mechanical properties. The Eurolightcon literature defines O to be 100-200 kg/m³ lower than F while The Norwegian guidelines NB 23 recommend using 150 kg/m³.

2. Density

The cardinal reason for using LWAC in structures is the reduced weight achieved by lighter concrete. The fresh and demoulded density of NDC is usually 2300-2400 kg/m³ while LWAC is defined as concrete with dry density < 2000 kg/m³ with an approximately fresh density of 2150 kg/m³.

The norms are limiting and defining the lower accepted density of LWAC. Most mechanical properties of LWAC are related to the density and the compressive strength and it is therefore necessary for the construction norms to limit the use of very light concrete. Such concrete may not comply with the experiences which has formed the regulations in the norms.

The low density of LWAC is usually achieved by using light weight aggregate (LWA) in combination with a normal density binder and sand with high density. Other composition is also possible and not prevented by the norms. To achieve LWAC with low density also fine LWA can replace fine dense sand.

LWA has a porous, partly open structure of pores of different sizes surrounded by solid and strong clay or shale material. Consequently, the LWA will in more or less extend absorb water both during outdoor storage and during mixing and transportation.

The density of a specific LWAC mix may therefore vary in function of the initial moisture level of the LWA and increase during mixing, transportation and placing.

Most of this moisture will later be desorbed to the binder or dry out and the structure will find equilibrium with its environment. Therefore different types of LWAC densities are referred to.

Using and understanding the correct term of density is certainly important if design weight matters. Figure 1 explains the differences of densities measured at different times and can be used as a guide for what density is expected when during service time.

3. Compressive Strength

The other important property of LWAC is the compressive strength which together with the density is used to calculate or estimate the other mechanical properties.

All aggregates have a specific strength ceiling. To stress the aggregate close to the strength limit is not recommended since brittle mechanical properties will occur. From an academic point of view maximum achievable compressive strength is of interest.

Figure 2 estimate maximum achievable compressive strength based on wet, air dry and oven dry density.

In contrast to NDC, LWAC mortar and aggregate has relatively similar strength and stiffness. Dense normal aggregate (NDA) is considerably stiffer than the mortar and takes therefore more of the force and transverse stress and strain in the crucial aggregate - mortar interface zone will initiate micro cracking. After moulding of the LWAC, LWA will absorb mixing water and reduce the w/b-ratio in the interface

zone. During hardening the cement is consuming water and the moist LWA will desorb water to the interface zone resulting in a high degree of hydration and less micro cracks. The micro cracks will therefore first occur at a higher stress level. The ability of the LWA to handle and distribute micro cracks is limited and resulting in a more rapid fracture pattern. The stress – strain diagram for LWAC is therefore more linear and final strain is lower. The relatively low initial LWA strength contributes more to the total strength of the LWAC and limits the maximum strength. The mortar strength is relatively less important and a weak aggregate can in less extent be compensated by a strong mortar.

The development of maximum strength is rapid in LWAC and 90% of the 28d compressive strength is achieved after 7d in a high performance mix. The similar figure for NDC is about 70%. From 28 d to 90d the strength development for LWAC is considerably lower than NDC. This is important to note since the calculation regulations are taking strength growth between 28d and 90d for granted.

Consequently, the norms have limited the maximum strength of LWAC based on density or alternatively demand documentation of late strength growth.

Another issue to note is the relative difference in cylinder and cube compressive strength comparing LWAC with NDC. Norms usually accept the use of cubes for measuring compressive strength. A fixed value is used to calculate the cube strength to cylinder strength which is used in the calculations. For LWAC the cube and cylinder strength are more similar than for NDC. It is therefore recommended to make the documentation with cylinders or determine by tests the specific relationship between them. A higher grade of compressive strength may be achieved by this way.

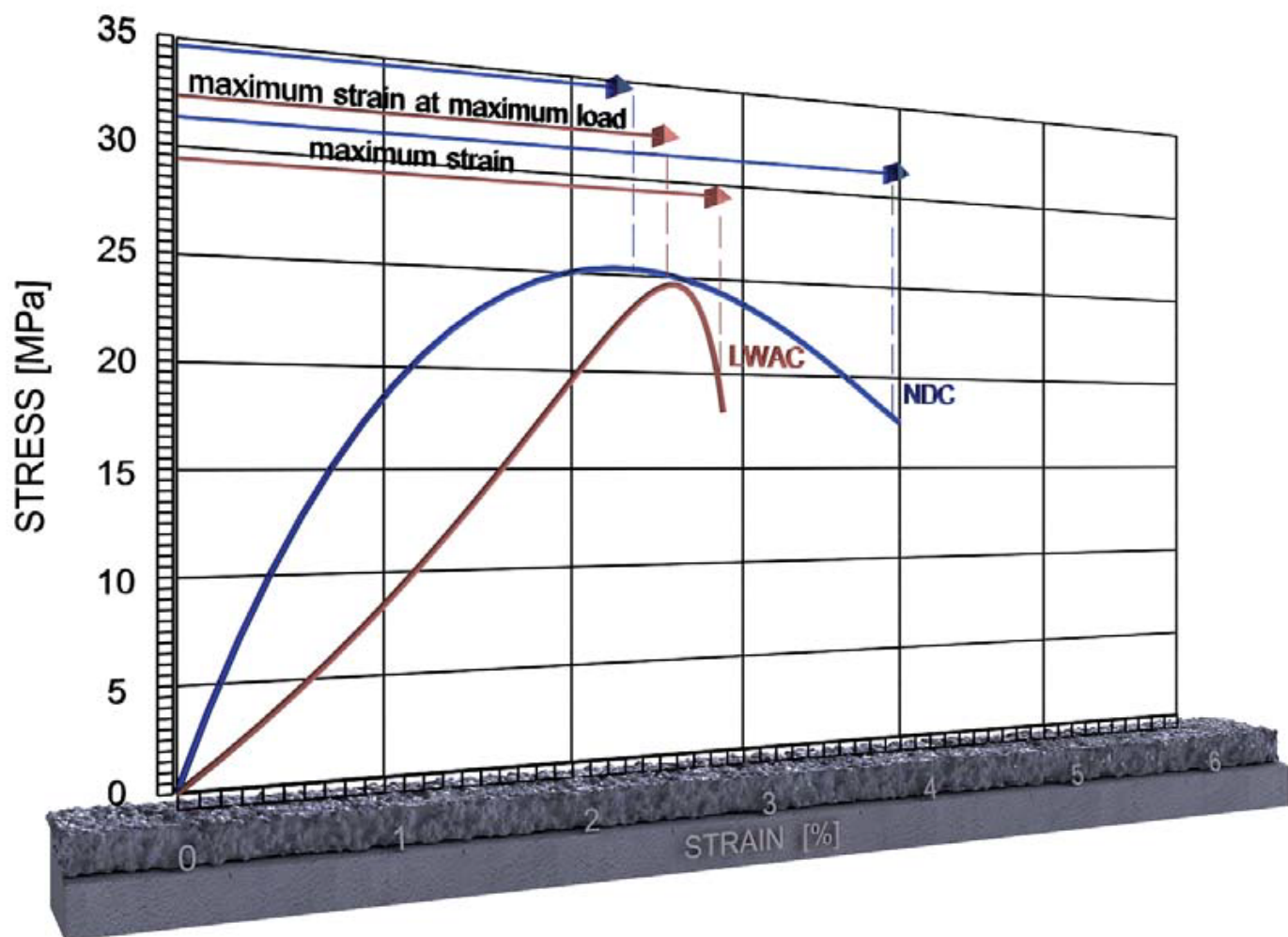


Figure 3.

Schematic figure of stress – strain diagram of LWAC and NDC. The LWAC has a more linear form and manage less maximum strain, but the maximum strain at maximum load is somewhat higher.

4. Modulus of elasticity and stress – strain relationship.

The E-modulus is defined as the stiffness of a material and results from the stress – strain diagram. As for compressive strength, the Emodulus is a function of the individual ingredient moduli, their relative proportion and the bond between the aggregate and the binder.

There seems to be a good correlation between E-modulus and compressive strength and tests indicates no considerable influence of LWA type. Stress-strain relationships for LWAC are generally characterized by a more linear ascending curve, more limited plastic strain and a steeper descending branch, but with a higher maximum strain at maximum load than NDC.

A schematic figure of stress – strain diagram of LWAC and NDC is displayed in Figure 3. The LWAC has a more linear form and manage less maximum strain, but the maximum strain at maximum load is somewhat higher. The linear, brittle behavior is usually enhanced with increasing strength. Comparing LWAC and NDC with similar compressive strength the E-modulus of LWAC is about 20-30% lower. The calculation regulations in the norms use formulas that are close to most measured values.



**Close look at a shear and
bond fracture of a LWAC
beam**

5. Flexural and splitting tensile strength, shear and bond

Traditionally, tensile strength has been defined as a function of compressive strength. The tensile strength is a combination of the LWA strength, binder strength and the interface zone between the LWA and the paste. LWA has considerably less tensile strength than NDA but the binder and the contact zone in LWAC is stronger for comparable concrete.

There are therefore not significant differences in tensile strength. ACI 213 claim LWAC splitting tensile strength to be 75%-100% of NDC with similar compressive strength. In the Eurolightcon project, the tensile strength was claimed to be at 5-15% of compressive strength for LWAC. For lighter and more brittle LWAC the difference may be bigger.

In the norms the tensile strength for LWAC is reduced, but this is an adaptation to be able to calculate shear, bond and reinforcement anchorage. For exact estimation of tensile strength, tests can be performed with actual mix design.

From a shear and bond perspective LWAC behave fundamentally the same way as NDC with similar strength. For high strength LWAC the shear capacity may be predicted by modified tensile strength. For low strength and low density LWAC the shear capacity may be lower than predicted and tests with actual mix should be executed. If necessary, shear and bond capacity can be increased by the addition of polymers.



Test set up for shear test of LWAC lintel.

6. Shrinkage and Creep

Drying shrinkage and autogenous shrinkage is the two main forms of shrinkage. The driving force for both types is removal of water in the paste pore system inducing pore contraction and shrinkage of the concrete. The size of the autogenous shrinkage is directly related to the quantity of cement in the mix. For making a LWAC with same compressive strength as for NDC a larger cement quantity is usually used. At the same time the E-modulus is lower for LWAC.

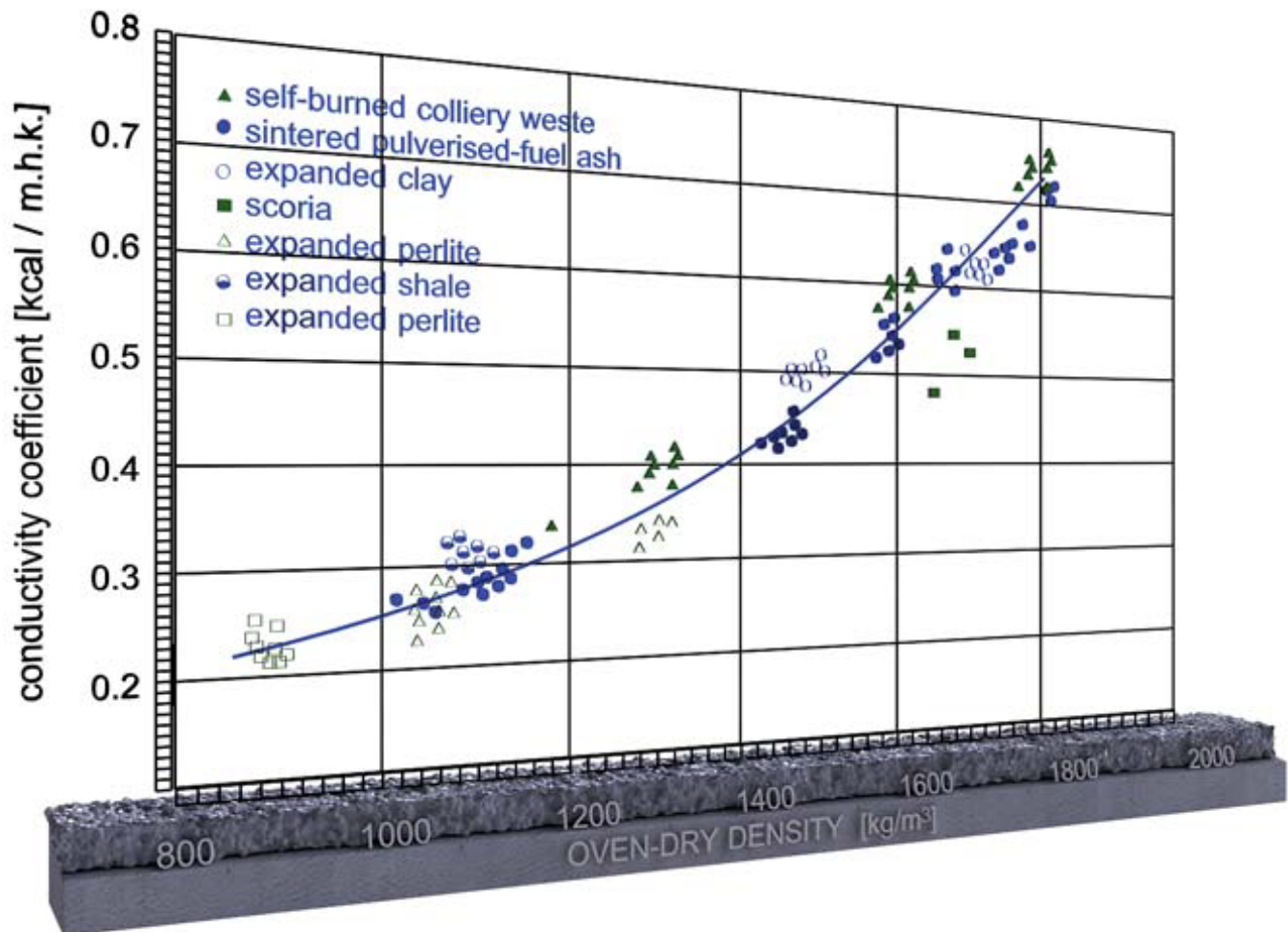
Consequently, the shrinkage for LWAC is expected to be higher but slower.

By the use of presaturated LWA the situation is completely altered. High degree of water absorbed in the pore structure of the LWA will be available to moisture the paste pore structure during consume of paste water. Recent studies and report indicates that the internal curing may eliminate at least early shrinkage completely. The internal curing will also effect and enhance the degree of cement hydration.

In general, shrinkage for LWAC is little documented and the norms usually do not separate LWAC and NDC.

Creep is deformation of the matrix over time due to external force or load. The volume proportion of matrix and aggregate are similar for LWAC and NDC, but the stiffness of LWA is usually lower than NDA.

The creep is therefore expected to be higher for low density LWAC (30% for <math> < 1500 \text{ kg/m}^3 </math>) and more and less similar for denser LWAC >math> > 1800 \text{ kg/m}^3 </math> compared to same strength NDC.



Relationship between thermal conductivity and oven-dry density for lightweight aggregate concrete (based on Lo-Shu, 1980)

7. Thermal properties and fire resistance

Thermal conductivity is considerably lower for LWAC than NDC because of the porous structure of the LWA. LWAC can be used to enhance the insulation of a structure. Conductivity is directly related to the density and moisture level of the concrete - see figure 4.

The specific heat is independent on density and is similar for all concrete = 1 J/kgK, but note that specific heat is defined as energy per weight. Thus a light weight structure has lower specific heat than a dense structure. This is important to consider when planning massive structures which need cooling.

The coefficient for thermal expansion is somewhat lower for LWAC than NDC. In addition the E-modulus is lower and maximum strain at maximum load for LWAC is somewhat higher, results in better resistance for thermal cracking than NDC.

Several factors are involved when characterizing fire resistance of LWAC. In general, LWAC will resist better against a slow cellulose fire but worse against a rapid hydrocarbon fire compared to NDC.

Polypropylene fibers can help fire resistance during hydrocarbon fire.

8. Durability

The main question concerning durability for concrete is corrosion steel reinforcement caused by reduced concrete pH (carbonation) or chloride penetration.

The LWA is porous, partly open and penetration of gas and water is likely to happen. The LWAC usually consist of a dense matrix with low w/b ratio and very high performance interface zone. The permeability of LWAC is dependent on the individual permeability of the three components. In LWAC with low w/b ratio, the paste has a finer pore system than the LWA. This will limit the ability of the aggregate to contribute in the capillary water transport through the concrete.

When the w/b is increased, the capillary resistance in the paste will be reduced, making - in theory - the aggregates able to participate in the water transport. For medium and high strength LWAC the permeability is expected to be better or similar than NDC. For low strength LWAC or very light LWAC a more open concrete can be expected.

Long term studies of various LWAC structures do not indicate that LWAC is more exposed for durability problems than NDC. The norms do not handle LWAC any different than NDC.

The porous LWA will as long the aggregate is dry result in better or similar frost resistance for LWAC as for comparable NDC. The frost resistance is reduced if high degree of water saturation of the LWA occurs. High performance NDC and LWAC can perform very well without air entrainers as long the v/b ratio is low enough and the concrete strength is high enough..

References:

Eurolightcon: LWAC Material Properties: State of the Art: 1998

ACI 213R-03: 2003

NB 23: 1999

Factors controlling properties of LWAC: PhD Thesis: Punkki 1992

GUGGENHEIM MUSEUM - SPAIN

Key data

Gross building area: 28.000 m²

Public opening: October 1997

LWAC volume: 4.800 m³

Light weight concrete LC25:

Compressive strength: 25 MPa

Fresh density: 1700 kg/m³

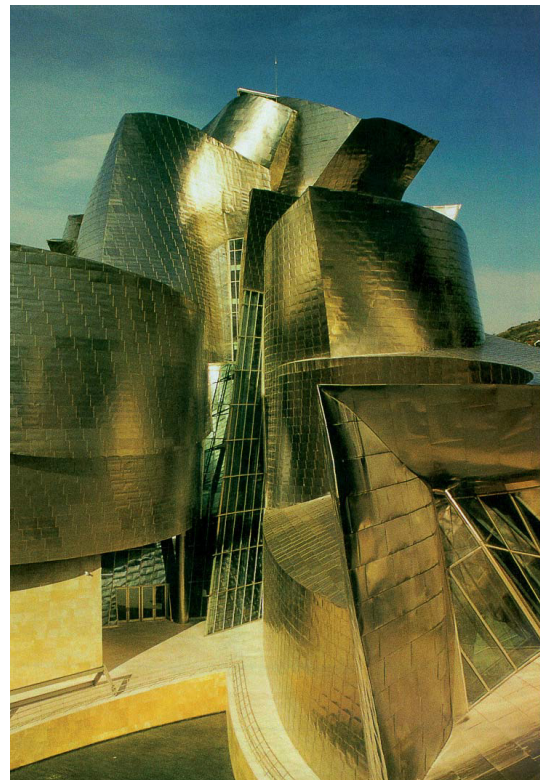
Dry oven density: 1600 kg/m³

Slump 8-10 cm

Light Weight Aggregate: Arlita F-5

Water cement ratio (nominal): 0.60

E-modulus: 18000 Mpa

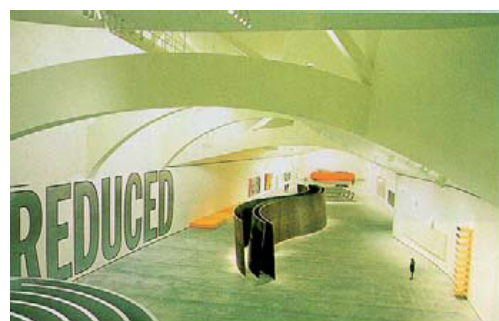


References:

[1]: Javier Lopez Ovejero, Adiros Ligeros S.A: “Arlite Floor Slabs at the Guggenheim Museum in Bilbao, Madrid , Spain, 1997

[2]:Frank O. Gehry: “Guggenheim Museum Bilbao”. The Salomon R. Guggenheim Foundation. New York 1997,1998.

[3]:ECCS No. 91-5: “Architecture Steel”.



Team involved:

Client: Consorcio del Proyecto
Guggenheim Bilbao

Architect: Frank O. Gehry and Associates

Consultant: IDOM/SOM

Contractor: Ferrovial and Lauki

LWA supplier: Aridos Ligeros S.A.



Thermal conductivity is considerably lower for LWAC than NDC because of the porous structure of the LWA. LWAC can be used to enhance the insulation of a structure. Conductivity is directly related to the density and moisture level of the concrete - see figure 4.

Recognised as one of the most representative work of architecture of the late 20th century, the Guggenheim Museum is the masterpiece of one of the foremost American architects of nowadays, Frank O. Gehry.

In order to reduce the weight of the structures due to the special soil conditions, floor slabs was cast using Light Weight Aggregate Concrete (LWAC).

General description

The Guggenheim Museum in Bilbao, Spain provides a unique architectural view using traditional construction materials like steel and glass in combinations with special ones like titanium, Spanish limestone and LWAC.

To design this precious jewel of the Spanish city of Bilbao, the engineers had to solve a tremendous problem, the poor quality of the soil on the shore of the Nervion river, mostly made up of industrial waste accumulated during decades of steel production.

The weight of the gigantic structure of the Museum had to be reduced in every possible way. One of the most important actions taken was the choice of a super light floor slab structure, designed with a zincated steel corrugated plate (galvanized), connected to a concrete slab 60 to 80 mm thick.

The system is light by itself, but the use of expanded clay in the concrete reduced the total weight roughly 30 %. This concrete was used in every single horizontal structure, even the roof, and a total of 4.400 m³ of LC-25 was placed by means of pneumatic pumps.

Construction: To be able to achieve the design density with a compressive strength of 25 MPa, the readymix plant used a mix provided by Aridos Ligeros, consisting of ARLITA F-5, a special lightweight product with a bulk density of 550 kg/m³, particle density of 900 kg/m³ and a size range between 3 and 8 mm.

The concrete was made in the nearby plant of Cavia in Ortuella, transported by truck and placed by pneumatic pumps.

VÆRE TUNNEL - NORWAY



The tunnel is a part of the new highway system from Oslo to the Swedish border and is scheduled to be completed in 2009.

The Være Tunnel was rehabilitated in 2004 with the LWAC slabs and the Road Department is still monitoring the frost values behind the slabs.

A total amount of >120000 m². LWAC slabs need about 27.000 m³ Leca LWA which is contracted by Spenncon and will be supplied from May 2007.

The future is bright for this construction method and it is good reason to expect several new supplies.

Tunnel vaults of light weight concrete

Arch shaped light weight aggregate concrete (LWAC) precast slabs with low density are a considerable challenge from both a constructive and concrete technology point of view. Through several years it has been performed development and full scale testing of physical characteristics of the tunnel concept. Now, another tunnel is under construction.

The reason for using LWAC instead of normal density concrete in tunnel vault is the increased frost insulation with about 4 times. In northern countries frost inside tunnels may lead to ice formation behind the concrete vault and the concrete or loose rock may be pushed out and fall down into the tunnel with severe consequences.

The solution so far has been a combination of normal density concrete slabs and an insulation material. Unfortunately, most insulation materials are combustible and in addition many materials release toxic gases while burning. New fire protection requirements from EC was supported by the Chief Executive in the Road Department and combustible insulation materials are now being phased out. LWAC is not combustible and with an addition of polypropylene fibers the slabs has proven to manage heavy hydrocarbon fire without spalling.

In addition to fire- and frost protection the LWAC slabs must prevent ground water leakage into the tunnel and also support as a mechanical protection between the rough blasted mountain surface and the traffic. A LWAC density of <math><1400 \text{ kg/m}^3</math> with a characteristic compressive strength of >15 MPa was required.

To achieve the requirements at the Være Tunnel, Leca 2-4 mm and 4-10 mm from Leca Rælingen was used together with a high performance cement paste. For such concrete with large volume of LWA, the LWA quality is essential to achieve best possible characteristics.

In addition the LWAC must be workable and fill the form and create smooth surfaces without honeycombs. The result was a concrete density of 1350 kg/m³ and an average compressive strength of almost 20 MPa. The requirements for the surface were satisfied.

SNARØYA CHURCH - NORWAY



Structural features:

The church roof and walls are plate and shell structures without effective stiffeners except for at the boundaries. The walls are founded directly on rock and partly on casted piles to rock. The LWA concrete used in the roof is of higher strength than the LWA concrete used in the walls. This is because the roof slab has relatively long spans and therefore larger local bending moments with less beneficial axial force than the walls.

References:

- [1] Harald Hille, pers. com.
- [2] Østbye/Falk Frederiksen/Espelin: “Snarøya Kapell”, Betongen i dag no. 5. 1968, Norwegian, Oslo, Norway.

Situated close to Oslo, Snarøya Church offers a special architectonic view of a church constructed with the use of light weight aggregate concrete (LWAC). The church was constructed in the sixties.

Key data

General:

Number of seats: 250

Opened: 1968

Costs: NOK 1.25-1.45 mill



LWA concrete walls.

LWAC B-200 with characteristic cube strength 20 MPa and density 1400 kg/m³.

Leca 400 3-10 mm	770 Liters/m ³ .
Sand	630 kg/m ³ .
Cement	420 kg/m ³ .
Density (dry)	1420 kg/m ³ .

LWA concrete roof slab.

LWAC B-250 with characteristic cube strength 25 MPa and density 1600 kg/m³.

Leca 400 3-10 mm	700 Liters/m ³ .
Sand	680 kg/m ³ .
Cement	450 kg/m ³ .
Density (dry)	1550-1650 kg/m ³ .

The reasons for applying LWAC

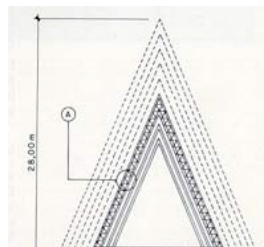
The architect wanted to use concrete as construction material to get a uniform material look on large surfaces combined with relatively large spans. The insulation ability and the low dead weight made the LWAC very suitable for these purposes.

Architectural features:

The church is situated in flat surroundings, but integrated in a local rock crag. The entrance was placed on top of the rock crag, and the high church walls was curved around down to the flat surroundings. All walls consist of parts of curves and straight lines, in the church corners separated by windows in whole height, giving a special light inside the church. The walls are a little inclined.

In addition the LWAC must be workable and fill the form and create smooth surfaces without honeycombs. The result was a concrete density of 1350 kg/m³ and an average compressive strength of almost 20 MPa. The requirements for the surface were satisfied.

POLAR SEA CATHEDRAL - NORWAY



Structural features:

The roof consists of 10 inclined sections, rising from the floor level, with a 2.1m difference between each section. The roof plates were designed to support dead load and wind loads. Snow loads were not taken into account because the roof inclination is more than 60°, actually 67°. The roof plates are stiffened by trusses with chords embedded in the same plates, while the diagonals are architectural details fully expressed. Load tests were carried out in order to control the plate strength by using two half size scale models. The results proved pure tension failures of reinforcement with no sign of bond or shear failures. The real load failure was about 10% higher than the theoretically calculated. The plates were reinforced by two layers of galvanised steel mesh $\bar{E}5c150\text{mm}$ in two directions.

The lightweight structure consists of LWAC with characteristic compression strength at 25 MPa and a density of 1650 kg/m³. The concrete is casted in situ. There have been no durability problems reported by using LWAC in the structure. The code used NS 427 did not contain the use of LWAC, and the project is therefore adjusted to use of normal concrete.

Team involved:

Client: Tromsøysund County

Architect: Jan Inge Hovig

Design: Dr. Ing. A.Aas-Jakobsen AS

Contractor: Ing. F. Selmer A/S

LWA supplier: a.s Norsk Leca

References:

[1] Jan Inge Hovig, "Ishavskatedralen, arkitektens ide", Betongen i dag, no. 5 (Norwegian) 1966

[2] Ivar Vamnes, "Ishavskatedralen, den konstruktive løsning", Betongen i dag, no. 5 (Norwegian) 1966

Situated in the city of Tromsø and surrounded by the Tromsdalstinden mountains, the Polar Sea Cathedral is with its very special architecture been one of the most famous tourist attractions in northern part of Norway. The cathedral was constructed in the mid sixties. The special roof and main structure consist of lightweight concrete.

General description

The building is located in a site close to the Tromsø River and the Tromsø Bridge in the northern part of Norway. Tromsø is characterised with the 3 month long polar night and is known for a lot of snow in the wintertime. The church comprises a main 740- seat nave with a 90-seat chapel in a lower level. The architectural shapes derived from the analysis of the particular site conditions and from the need to keep a constant and uninterrupted relation between interior spaces and landscaping.

The most outstanding building feature is the inclined roof consisting of lightweight concrete sections, which enabled to meet important insulation requirements and to reduce the structure weight. The use of lightweight concrete allowed reducing the structural load about 50% as compared with a conventional rib structure with inner insulation.

It was obtained a high degree of insulation with no thermal bridges, involving considerable cost savings

Key data

Maximum height of church:	28 m
Number of seats:	740 + 90
Number of roof sections:	10
Roof section width:	4.25 m
Roof section thickness:	0.3 m
Construction period:	1964-1965
LWA:	Leca 400, 3-10 mm
Measured density concrete:	1650 kg/m ³
Cement	175 kg

THE TROLL WEST - THE NORTH SEA



Structural features:

The Troll West is a floating platform operating at the North Sea oilfield with the same name 70 km north west of Bergen, Norway. The concrete structure is installed at a water depth between 315-340 metres. Exposed to a harsh marine environment, the design life requirement for the structure is more than 50 years.

To give the construction enough buoyancy, it was planned to install an extra floater unit. Research and studies concluded that use of concrete with lower density would solve the problem. During the construction period, there was developed and utilised a new concrete where natural coarse aggregate was partly replaced by LWA (Light Weight Aggregate). The MND (Modified Normal Density) concrete has a density reduction of about 10%, but still maintain most of the mechanical properties from ND (Normal Density) concrete.

Some key data for the project

Master Plan May. 92
Contract award Jan. 93
Start of construction in dry dock Jun. 93
Tow-out from dry dock Oct. 94
Ready for module mating Feb. 95
Complete installation Nov. 95

Key Data

Water depth 315-340 metres
Concrete floater weight 192 000 tonnes
Concrete, C 75 19 000 m³
Concrete, MND 75 21 000 m³
Reinforcement (ordinary) 17 500 tonnes
Reinforcement (pre-stressed) 3 400 tonnes
Column diameter 29.0 metres
Column spacing (width) 101.5 metres
Total height concrete floater 65 metres
Wall thickness 0,4-0,9 metres
Reinforcement ratio 294-414 kg/m³
Prestressed reinforcement ratio 55-104 kg/m³

Application of high strength LWA concrete for tension leg platforms A large displacement is necessary to achieve the buoyancy required for a floating platform. The hull of the platform has to withstand large hydrostatic pressures. A high strength concrete shell is ideal for such forces.



SAINT-GOBAIN

High strength normal density concrete and high strength light weight aggregate concrete was already utilised in many structures in Norway and the experience with the material was well known. The bottom pontoon slabs and the beginning of shafts were built in dry dock, and then towed out on water for gliding the platform shafts. The Troll West was original planed with HSND concrete. To give the construction enough buoyancy in “out of dock situ”, and to give the structure improved general floating properties an extra floater unit was planed installed. Further studies concluded that use of concrete with lower density had several advantageous properties. During the construction time a new type of concrete where normal coarse aggregate was partly replaced by LWA to reduce the total weight was developed and utilised, the MND concrete. The use of MND concrete was introduced while the structure was under construction.

Therefore only 21000 m3 of total 40000 m3 concrete used was MND. The MND is used in the 4 columns and at the top of the bottom pontoon. The rest of the shaft structure used ND C75 with 3% air. The total reduction of weight is 5200 tons. The same type of concrete is also used in the gravity based (condeep) Troll Gas platform. The MND concrete has a density reduction of about 10%, still maintain most of the mechanical properties from ND concrete. The MND concrete was developed during intensive research and development at SINTEF in 1992-1993 Exposed to a harsh marine environment, the designed lifetime for the structure is more than 50 years. This design life required following demands to the concrete: Chloride diffusion coefficient $D < 30 \text{ mm}^2/\text{year}$, $w/(c+s) < 0.38$ and maximum curing temperature was $< 700\text{C}$.

Concrete mix design

The reduced weight is achieved by replacing some of the natural coarse aggregate with lightweight materials made of expanded clay. The other constituents are the same as used for ND concrete of high strength. The objective of the research project (SINTEF 92-93) was to determine and document the effect on mechanical properties. The results revealed a slightly reduced compressive strength, reduced E-modulus and fracture energy, and slightly increased tensile strength while replacing some of the coarse aggregate by LWA. The density was reduced by 200 kg/m3 by replacing 50% of the natural coarse aggregate with Leca 800. Due to the demands of strength and mechanical properties a.s Norsk Leca developed the Leca 800 for this project. The Leca 800 has a bulk density of 800 kg/m3 for 4-8 and 8-12 mm and gives a concrete with better mechanical properties then the existing Leca 750. The dry particle density is 1450 kg/m3 that is considerably lighter then normal aggregate density at approximately 2600 kg/m3.

Constituents (kg/m³)	
Natural sand 0-5 mm (dry weight)	911
Natural coarse aggregate 5-20 mm dry weight	455
LWA Leca 800 4-12 mm (dry weight)	240
Air-entraining admixture	1
Superplasticizer	7
Cement (High strength Norcem)	420
Silica fume (dry weight)	12
w/(c+s) corrected for water absorption	0.38

The table below shows the requirements and results from the concrete production during the dry dock phase. Both strength and density comply with the requirements.

		req.	mean	st.dev.	charact.
Slump	(mm)	>			
Wet density	(kg/m³)	<			
7 day density	(kg/m³)	<			
7 day strength	(MPa)				
28 day density	(kg/m³)	< 2250 ±30	2220		
28 strength	(MPa)	>75			80
E- Modulus	GPa	32 ±3	31,9		

Strength ratio is between 0.86-0.89. Density of hardened concrete s measured on water stored cubes. The MND concrete had good resistance to chloride diffusion and complied with the demand, but the contractor needed to install water pipelines to reduce the curing temperature.

HIGHWAY BRIDGES

- SPAIN



Structural features:

Lightweight structural concrete has been used in renovation and enlargement in 3 important motorway projects in Spain, namely the A-8 and A-6 motorways.

On the motorway Autovia del Cantábrico (A-8), on the specific part from Barres to Ribadeo, the old bridge “Puente de los Santos” was enlarged to receive another traffic lane in each direction. To be able to execute such a project on an old bridge, Lightweight structural concrete was the obvious solution.

The same situation was the case on the bridge “viaducto Rio San Pedro”, also on A-8, but in between Dueñas and Novellana. On the motorway A-6, the bridge over the river Esla was rehabilitated to be able to receive the new and more intense traffic load.





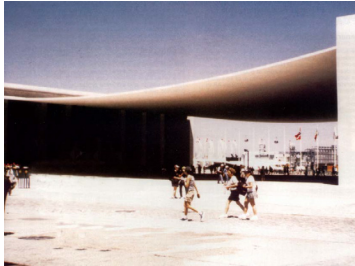
In all 3 of the above mentioned case stories, the main idea by the project engineers was to use the already existing infrastructures. In case of demolition of the old structures and building new bridges, it would have been more expensive and for sure take a lot more time to execute. Using lightweight structural concrete the engineers managed to save both money and time and in a sustainable way utilize already existing infra structures, even though they earlier was designed for different loads and stresses.

In all 3 projects ARLITA F7 was used as the lightweight aggregate. Due to the complexity of the structures, different concrete mix designs were used, with densities from 650kg/m³ to 1.850kg/m³ and respective compressive strength from 2MPa to 60MPa.

Year of the 3 projects: 2008



EXPO'98 PORTUGUESE NATIONAL PAVILION, LISBON, PORTUGAL



The Expo'98-Lisbon International Exposition took place in 1998, focusing on the oceans and their future importance. A number of exceptional structures were made for the event, one of the most spectacular being the Portuguese National Pavilion including the sagged parabolic membrane slab roof cast by means of Light Weight Aggregate Concrete (LWAC). The dimensions of the canopy are 65 m x 50 m, and the slab thickness is 20 cm.

General description

The Portuguese National Pavilion consists of the main 3 storey multipurpose building and the slab canopy, which is described in the following. The pavilion provided conditions for the reception of delegations present at Expo'98. The canopy structure is a 20 centimetre thick parabolic membrane concrete slab hanging from prestressed tendons anchored along the two short sides into slabs placed on top of a reinforced concrete structure of shear walls and stiffeners. LWAC was chosen as material due to low dead weight, so that the horizontal forces in roof and supports could be reduced to a minimum at the same time as appropriate strength and stiffness was maintained. The total weight of the roof was reduced by approximately 430 tons using LWAC. It is the first time that a structure of this type is casted with LWAC in Portugal.



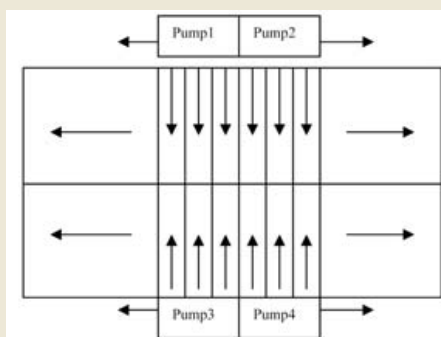
Key data

General data:

Data of execution:	autumn 1997
Type of structure:	Suspended slabs (canopy)
Total length in plan view:	65 m
Total width in plan view:	50 m
Slab thickness:	0.2 m
Sag:	3 m
Longitudinal slope:	0.3 m
Minimum height above floor:	10.0 m
Typical centre distance tendons:	0.6 m

Light weight concrete:

LWAC LC 25	750 m ³
Quoted strength:	LC 25
Achieved strength f _{ck} :	30 MPa
Standard deviation:	2,6 MPa
Quoted maximum density:	1850 kg/m ³
Achieved fresh density onsite:	1835 kg/m ³
Workability (slump):	16 cm



Scheme for Pouring Concrete

Pumping details:	
Presaturation of LWA:	17%
Maximum pumping distance:	60 m
Type of pump:	Piston pump
Pump pressure:	100-150 bar
Production:	80 m ³ /h
Decline of workability:	From 16-8 cm

Mix design:	
Cement:	Portland Type I 42.5 420 kg/m ³
Fly ash:	100 kg/m ³
Silica fume:	MS 610 from MBT 15 kg/m ³
LWA:	Leca 2-4 (1,6-5,5 mm) 234 kg/m ³
Sand:	1,5-2,5 mm 587 kg/m ³
Sand:	0-1,5 mm 251 kg/m ³
Water:	196 kg/m ³
SP:	Rheobuild 561 MBT 6 l/m ³

The mix design gives a theoretical density at 1828 kg/m³. The LWA used are supplied from Leca Portugal, which belong to the Exclay International family. The particle size is from 1,6 mm to 5,5 mm. Bulk density is 500 kg/m³ and particle density is 900 kg/m³.

Concrete development:

In order to provide the adequate weight and resistance for the concrete, Betecna – Betao Pronto developed a special concrete. Several tests were made in order to obtain the best results regarding absorption of water by expanded clay, and the modifications of concrete properties was evaluated carefully.

Construction:

The cast of the roof over more than 3900 m² of falsework started with a central strip 2.5 m wide. It continued with the help of 4 concrete pumps with a production of 80 m³ per hour in accordance with Figure 1. The average delay at working casting joints was no more that 45 minutes in order to get a full continuity in the bottom surface of the slab. The concrete placing took 10 hours and was done in one operation.

Knowing that an error of 1% in the cable force would cause a deviation of 10% of the longitudinal slope of the roof, special emphasis had to be put on the posttensioning procedures.

Structural system:

The sagged roof will induce large horizontal forces at top of the shear wall with stiffeners. Due to the use of LWAC, these forces are minimized. The shear walls insure the force transfer for the horizontal loads from dead-weight, wind and earthquake between the roof and the underground pile foundations. The roof itself is a 20 centimetre thick parabolic membrane LWAC slab. The membrane tension due to sag is compensated by using long posttension cables anchored in support slabs on top of the shear walls.

References:

- [1] A.Segadães Tavares, Rui R. Vieira: "Expo'98 Portuguese National Pavilion. A Large Use of Light Weight Structural Concrete, Lisbon, Portugal [2]: Rui Monteiro: The Portuguese Pavilion – Expo 98, Lisbon, Portugal.

BRIDGE OVER THE RIVER CÁVADO – PORTUGAL



Structural features:

Lightweight structural concrete was used to renovate the deck of the bridge “Ponte de Fão” over Rio Cávado, located in Esposende in the North of Portugal. The bridge was inaugurated in 1892, why it certainly was time for renovation. In 1986 the bridge was classified as a construction of public interest – a monument of steel structure. Lightweight concrete has also been used in other renovation / rehabilitation bridge projects in Portugal.

Bridge over the river Cávado

By using lightweight concrete for renovation of the deck, the old steel structure would not “suffer” for additional loads and the structural / economical aspects would be solved in the best way.

The lightweight concrete developed for this project was a LC30/33, with a density less than 1.700kg/m³.

Volume: more than 400m³ of LC30/33

Year: 2006 / 07

Project: Lisconcebe

Execution: Mota-Engil Engenharia
/ Qualibetão





