PDHonline Course S196 (3 PDH)

Low-Density Concrete Basics

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SPECIFIED DENSITY CONCRETE — A TRANSITION

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SUMMARY

Applications of Specified Density Concrete (SDC) are increasing in the US, Canada and Europe. The use of SDC is driven by engineers' decisions to optimize concrete density to improve structural efficiency (the strength to density ratio), reduce transportation cost, and to enhance the hydration of high cementitious concrete mixtures with very low w/c ratios <.40. Specific projects include bridges, marine structures, precast elements and consumer products with strength ranging from 20-70 Mpa (2900-10150 psi) and densities from 1200 to 2200 kg/m^3 (75 to 138 lb/ft^3). SDC is achieved by customizing the mixture proportion by replacing part of the ordinary Normal Density Aggregates (NDA) (>.2600 kg/m^3, SG >2.60) with either coarse or fine Low Density Aggregates (LDA) (generally <1600 kg/m^3, SG <1.60).

Examples of optimizing the design by using SDC include more structurally efficient members in bridges and buildings, improved buoyancy in marine structures, and reduced transportation costs of consumer products like wallboard, imitation stone, precast element, masonry, etc. SDC is defined as concrete with a range of density less than what is generally associated with Normal Density Concrete (NDC) and greater than the lowest density possible when using all LDA. This paper will focus on the 1800-2200 kg/m^3 (112-137 lb/f^{t3}) density range.

The American Concrete Institute Standard Building Code (ACI 318) provides structural engineers with adequate guidance when designing with structural LDC over the strength range of 20-35 Mpa (2900-5080 psi). ACI 318 precisely defines the differing engineering properties of NDC and LDC including reduced elastic modulus, reduced tensile shear and torsion capacities, increased development length...etc. The increased use of SDC is creating an urgent need for comprehensive, industry wide investigations into the physical properties and engineering characteristics of concretes with strength/density combinations outside of traditional ranges. Future code revisions should include a seamless transition of engineering criteria for concrete properties of all practical achievable strengths with density ranges from 1200-2500 kg/m^3 (75-156 lb/ft^3).

STRUCTURAL EFFICIENCY

There is a paradigm shift taking place in the way engineers design and specify concrete characteristics for structural efficient projects. No longer content to use the suggested "off-the-shelf" concrete mixtures routinely proposed for conventional applications, engineers now require "optimized" concrete performance to satisfy specific needs. These "custom tailored" concretes, often referred to as SDC, have been developed through the combined efforts of design professionals, material suppliers and concrete producers.

The systematic improvement in concretes placed in North American over the past eighty years is shown schematically in Fig. 1. Most increases came as a result of improvements in the cementitious matrix brought about by a new generation of admixtures (e.g. high range water reducers) and the incorporation of high quality pozzolana (silica fume, metakaolin, fly ash...etc.). However, history indicates that the first modern improvement came as a result of the use of LDC in the US lightweight concrete ship building program between 1917 and 1925.

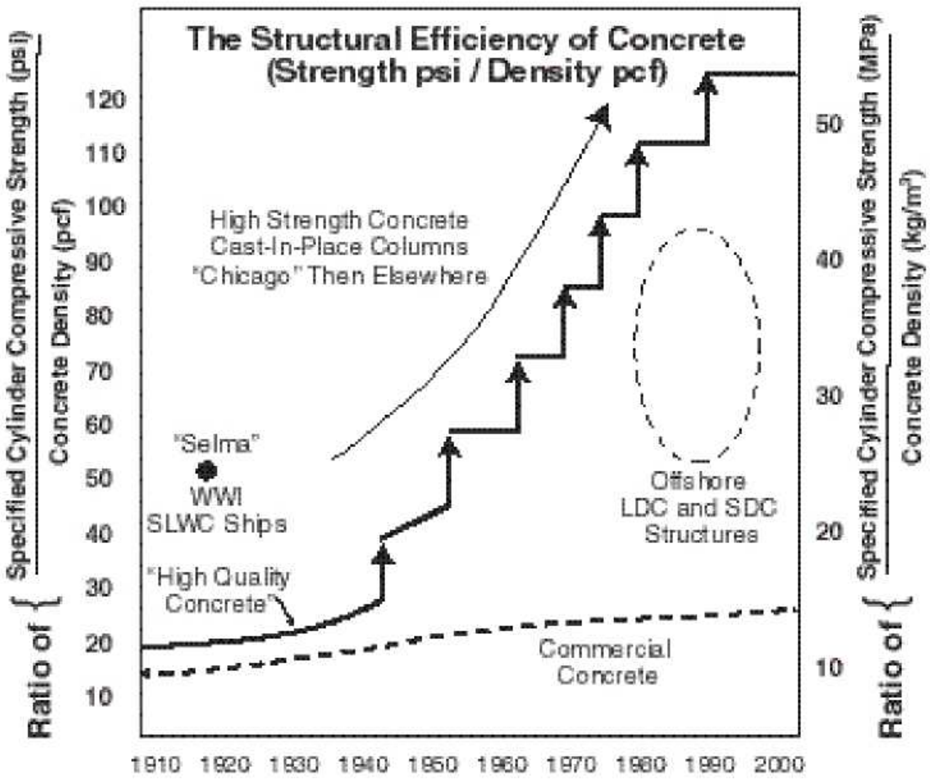

Figure 1. The Structural Efficiency of Concrete
The ratio of specified compressive strength to density (psi/lb ft^3) through the recent history of construction.

MARINE STRUCTURES

Tarsiut Caisson Retained Island - 1981: The first arctic structure using SDC was the Tarsiut Caisson retained island built in Vancouver, Canada and barged to the Canadian Beaufort Sea. Four large prestressed concrete caissons 69 x 15 x 11 m high (226 x 50 x 35 ft) were constructed in a graving dock in Vancouver, towed around Alaska on a submersible barge, and founded on a berm of dredged sand 40 km (25 miles) from shore. The density of the SDC combined with the extremely high concentration of reinforcement was 2,240 kg/m^3 (140 lb/ft^3).

Heidron Floating Platform - 1996: Because of the deep water, 345m (1130 ft), above the Heidron oil fields, a decision was made to construct the first floating platform with High Strength Low Density Concrete (HSSDC). To improve buoyancy, the concept of HSSDC was introduced early in the planning stages. The hull of the floating platform, approximately 70,000 m^3 (91,000 yd^3) is constructed entirely of HSLDC with a maximum density of 2000 kg/m^3 (125 lb/ft^3). Heidron was built in Norway and towed to the North Sea.

Hibernia Oil Platform - 1998: Another significant application of SDC is in the Mobil Oil Hibernia offshore gravity based structure. To improve buoyancy of the largest floating structure built in North America, LDA replaced approximately 50% of the NDA (coarse fraction) in the high strength concrete (HSC) used. The resulting density was 2170 kg/m^3 (135 lb/ft$^{3)}$). Hibernia was built in Newfoundland, Canada, where the structure was floated out of dry dock and towed to a near by deep water harbor area where construction continued. When finished the more than one-million ton structure was towed to the Hibernia North Sea oil field site and set in place on the ocean floor. A comprehensive testing program was reported by Hoff et al. [1].

Bridges: Numerous bridges in North America and Europe have utilized SDC. Examples are the Shelby Creek Bridge, Kentucky, density 2080 kg/m^3 (130 lb/ft^3) [2] as well as numerous long span precast bulb tee bridge girders placed in Ohio and Indiana, 2000-2160 kg/m^3 (125-135 lb/ft^3). A series of major long-span Norwegian prestressed box-girder bridges [3,4], also incorporated HSLDC, for example, the entire bridge span (Boknasundet, 1990), the central part of long main spans (Raftsundet, 1998) and side spans that balanced NDC in main spans, (Sandhornia,1989). The Raftsundet Bridge, located north of the Arctic Circle in Norway, is of box girder construction utilizing HSLDC for 220M (721 ft) of the main span length of 298m (1023 ft). At the time of construction this bridge was the longest span bridge of this type in the world.

REDUCED TRANSPORTATION COST

The concept of specified density concrete is not new. Almost 20 years ago a precast manufacturer evaluated the trade-offs between the physical properties and the transportation costs. Mixes included a typically used limestone “control” concrete paralleled by other mixtures in which 25, 50, 75 and 100% of the ND limestone coarse aggregate was replaced by an equal absolute volume of an LDA. This resulted in 5,11, 15 and 21 percent reductions in density respectively. Results of the testing programs are shown in Table 1 and Fig. 2. Figure 3 demonstrates that for the particular LDA and limestone tested, these replacement levels had little effect on early or 28 day compressive strengths.

Because of weight limits on roads, this precast producer developed the lower density SDC mixtures that reduced the weights of members allowing an increased number of precast elements per truck. By adjusting the density of the concrete, precasters are able to maximize the number of concrete elements on a truck without exceeding highway load limits. This reduces the number of truck loads which lowers project cost. Opportunities for increased trucking efficiency are greater when transporting smaller concrete products (e.g. hollow core plank, wallboard, precast steps, imitation stone...etc.).

Table 1. Physical Properties of Concrete Mixtures

Limestone Coarse Aggregate replaced by varying percentages of structural Low Density Aggregate. Concrete manufactured and tested at U.S. East Coast Prestressed Plant to optimize structural efficiency and reduce transportation costs .

Mixture Number		1	2	3	4	5	M
Coarse Aggregate		Limestone	.75S, .25L	.5S, .5L	.25S, .75L	LDA	NONE
Target Equilibrium Density	kg/m^3 (lb /ft^3)	2300 (143)	2160 (135)	2050 (128)	1920 (120)	1800 (112)	2000 (125)
Physical Properties @ 18-24 Hrs.							
Compressive Strength	MPa (ksi)	24 (3.50)	26 (3.75)	29 (4.27)	28 (4.10)	26 (3.80)	34 (4.88)
Elastic Modulus (Test)	GPa (ksi x 10^3)	24 (3.42)	23 (3.30)	23 (3.27)	20 (2.97)	18 (2.67)	23 (3.38)
Elastic Modulus (Calc. ACI 318)	GPa (ksi x 10^3)	26 (3.70)	24 (3.49)	20 (2.89)	17 (2.42)	15 (2.17)	17 (2.48)
E (Test) / E (Calc. ACI 318)		1.08	1.06	0.88	0.81	0.81	0.73
Physical Properties @ 29 Days							
Compressive Strength	MPa (ksi)	39 (5.60)	41 (5.89)	41 (5.91)	41 (5.95)	42 (6.12)	47 (6.85)
Elastic Modulus (Test)	GPa (ksi x 10^3)	30 (4.28)	28 (4.09)	26 (3.81)	24 (3.53)	22 (3.25)	27 (3.96)
Elastic Modulus (Calc. ACI 318)	GPa (ksi x 10^3)	31 (4.49)	28 (4.10)	29 (4.17)	22 (3.13)	20 (2.92)	31 (4.50)
E (Test) / E (Calc. ACI 318)		1 .05	1.00	1.09	0.89	0.90	1.14
Tensile Split Strength @ 29 Days MPa (ksi)		4.0 (580)	4.2 (615)	3.7 (531)	3.4 (492)	3.4 (498)	3.5 (504)

NOTE:
1. All concrete mixtures contain 446 kg/m^3 (752 pcy) Cement, 706 kg/m^3 (1190 pcy) Natural Sand.
2. All concrete mixtures, Air 3.5 ±0.5%, Slump 100 mm (4")
3. Mortar Mixture "M" contains 716 kg/m^3 (1208 pcy) Cement, 1050 kg/m^3 (1770 pcy) Natural Sand, Air 5.5%, Slump 140 mm (5.5")
4. All strength and modulus tests conducted on 152 x 304 mm (6" x 12") cylinders.

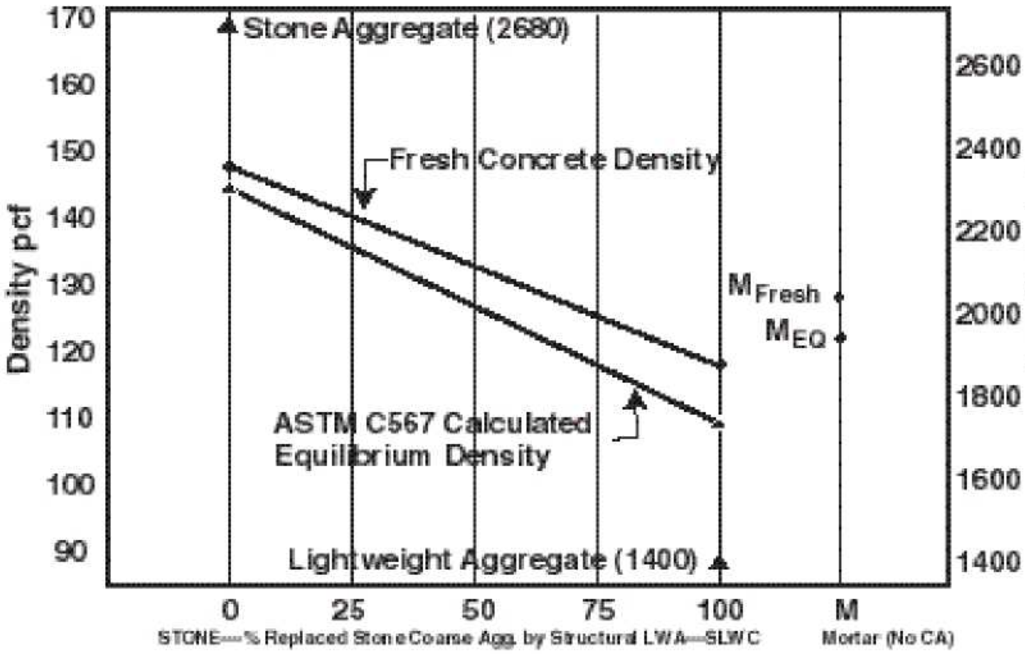

Figure 2. Fresh and ASTM C567 Calculated Equilibrium Concrete Density with varying replacement of limestone coarse aggregate with LDA

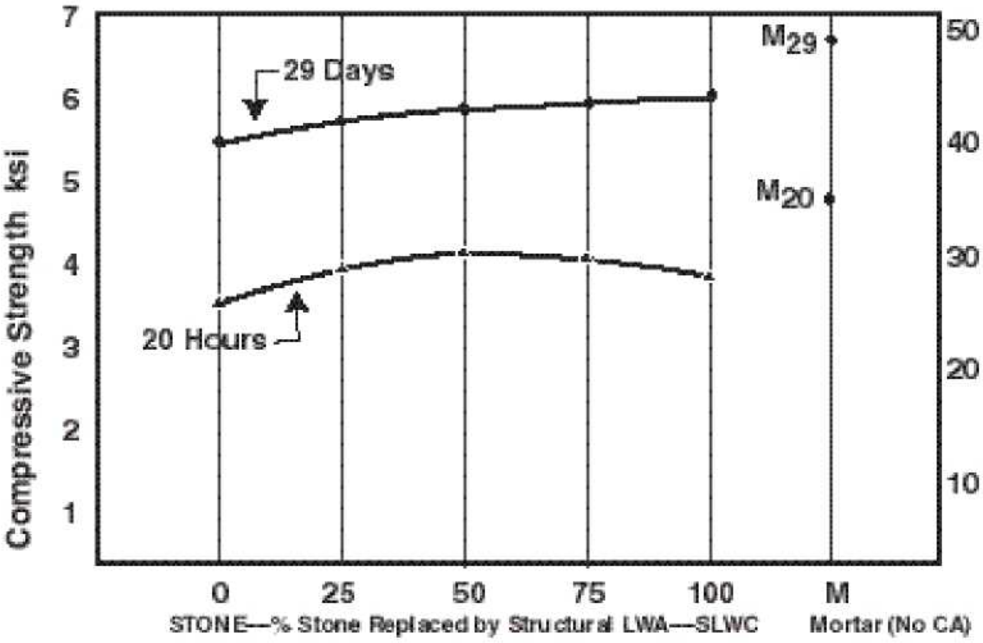

Figure 3. Compressive Strength 152Ø x 304 mm (6" x 12") Cylinders with varying replacements of Limestone Coarse Aggregate with LDA

Concretes containing LDA have lower modulus of elasticity at both early and later ages. Since exact modulus data at release (18 hrs. □) is crucial to strand location, camber and deflection control, it is essential to determine the properties directly from the proposed concrete mixture. It is also important to realize that even with NDA's at the same density, the modulus of elasticity can vary considerably. Table 1 reveals that for the "control" limestone NDC, the tested elastic modulus correlated with the computed value using the ACI 318 formula $Ec=33w^{1.5}\sqrt{Fc}$. For LDC at earlier ages and with compressive strengths over 35 MPa (5080 psi), the ACI formula clearly over estimates the value of the elastic modulus.

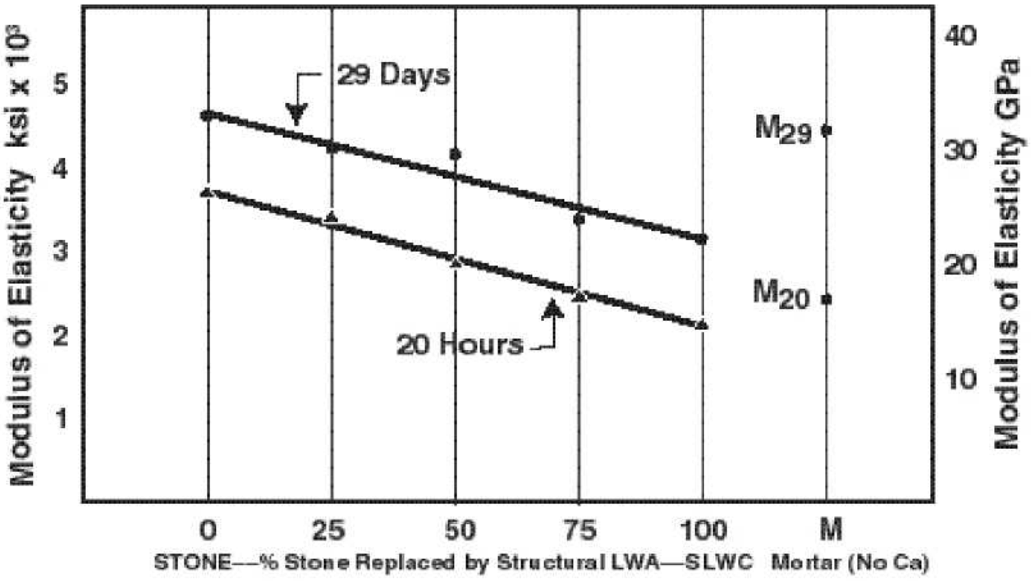

Figure 4. Modulus of Elasticity 152 x 304 mm (6" x 12") Cylinders with varying replacements of limestone NDA with LDA