DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

CECW-EWS

Circular
No. 1110-2-6055

30 August 2002

EXPIRES 30 SEPTEMBER 2004
Engineering and Design
CONSTRUCTION CONSIDERATIONS FOR LOW-DENSITY CONCRETE

1. Purpose. This circular provides interim guidance on construction and economic considerations with regard to the use of low-density concrete (in contrast to normal-density concrete).

2. Applicability. This circular applies to USACE Commands having responsibility for design of Civil Works projects.

3. Distribution Statement. Approved for public release; distribution is unlimited.

4. References.

a. American Concrete Institute (ACI), *Manual of Concrete Practice* (ACI, PO Box 9094, Farmington Hills, MI 48333)

(1) ACI 211.2, Standard Practice for Selecting Proportions for Structural Lightweight Concrete

(2) ACI 213, Guide for Structural Lightweight Aggregate Concrete

(3) ACI 318, Building Code Requirements for Structural Concrete

b. American Society for Testing and Materials (ASTM), *Standard Specifications* and *Test Methods* (ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959)

(1) ASTM C 33, Concrete Aggregates

(2) ASTM C 94, Ready-Mixed Concrete

(3) ASTM C 150, Portland Cement

(4) ASTM C 173, Air Content of Freshly Mixed Concrete by the Volumetric Method

(5) ASTM C 231, Air Content of Freshly Mixed Concrete by the Pressure Method

(6) ASTM C 330, Lightweight Aggregates for Structural Concrete

(7) ASTM C 567, Density of Structural Lightweight Concrete

(8) ASTM C 595, Blended Hydraulic Cements

(9) ASTM C 618, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a

Mineral Admixture in Concrete

(10) ASTM C 989, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

(11) ASTM C 1157, Hydraulic Cement

(12) ASTM C 1240, Silica Fume for Use as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout

c. Headquarters, Department of the Army, 2001, Engineer Manual 1110-2-2000, "Standard Practice for Concrete for Civil Works Structures"

d. Holm, T. A., and Bremner, T. W., 2000, "State-of-the-art report on high-strength, high-durability structural low-density concrete for application in severe marine environments," ERDC/SL TR-00-3, U.S. Army Engineer Research and Development Center, Vicksburg, MS (http://libweb.wes.army.mil/uhtbin/hyperion/SL-TR-00-3.pdf)

e. Neville, A. M., 1996, *Properties of Concrete*, 4th ed., Pearson Education Limited, Essex, England

5. Terminology and Abbreviations.

a. Normal-density concrete (NDC) is made from traditional materials. Densities are typically about 2,240 to 2,400 kg/m^3 (140 to 150 lb/ft^3). The term "normal-weight concrete" is also used; however, with changes toward use of SI units and attendant nomenclature, "normal-density concrete" is now the preferred term.

b. Normal-density aggregate (NDA) is obtained from traditional sources (e.g., quarried or from natural deposits) and is covered by ASTM C 33. Specific gravities typically vary from about 2.5 to 2.8. This material is also called "normal-weight aggregate."

c. Low-density concrete (LDC) is made with low-density, structural-grade aggregates. Densities typically range from about 1,760 to 2,000 kg/m^3 (110 to 125 lb/ft^3). The density is controlled primarily by the properties of the low-density aggregate, although there are other factors, including the density of the other constituent materials and the air content. This material is also called "light-weight concrete."

d. Low-density structural-grade aggregate (LDA) typically has specific gravities in the range of 1.3 to 1.7, although specifications are based on loose bulk density, as covered by ASTM C 330. This material is also called "light-weight aggregate." Low-density aggregates are primarily manufactured products, made by high-temperature processing of clay, shale, fly ash, slag, or slate, although natural products (such as pumice, scoria, and tuff) do exist.

e. Low-density high-strength concrete is LDC that has a 28-day compressive strength greater than 35 MPa (5,070 psi). This strength level is not a specification requirement in any standard guidance, but rather a practical demarcation.

f. Specified-density concrete is that in which normal-density coarse aggregates have been partially replaced with low-density, structural-grade coarse aggregate.

6. Background. In general, concrete construction using LDC is quite similar to that using NDC. However, some constructibility considerations differ. These differences must be given due attention in order to maximize the quality of the concrete and avoid problems during construction. The cost of LDA is higher than NDA. However, in some cases, cost savings can be realized in other areas that will help mitigate the extra expense of the LDA. A cost analysis must be made on a project-by-project basis to determine whether LDC is economically advantageous. A discussion of pertinent issues related to mixing, placing, curing, pumping, laboratory and field control, and the economics of LDC, are presented in the following paragraphs.

7. Mixing.

a. Mix proportioning. LDC follows the same proportioning techniques used for NDC. The following paragraphs and Table 1 highlight some special considerations when developing mixture proportions. Structural-grade LDC can be successfully proportioned using the weight method or the volumetric method prescribed in ACI 211.2. For LDA, use the "as-is" specific gravity anticipated prior to use in the proportioning calculations.

b. Coarse aggregate.

(1) Adsorbed moisture. Like normal-density aggregate, LDA may have moisture on the surface, which is referred to as adsorbed or "free water." This water affects the water-cementitious materials ratios (w/(c+m)) of both NDC and LDC, and must be accurately measured and accounted for in batch water determinations.

(2) Absorbed moisture. Due to their porous structure, LDA can absorb a significant amount of water. Absorption in saturated LDA aggregates can reach as high as 25 percent by weight of dry aggregates. Generally, NDA can only reach absorption less than 2 percent. Unsaturated, air-dried LDA can pull between 59 and 71 kg/m^3 (100-120 lb/yd^3) of water from concrete, based on its level of saturation (Neville 1996). LDAs that are well below a saturated state can result in significant slump reduction in the concrete. To minimize fluctuations in consistency, LDA should be saturated with water prior to being used in concrete.

(a) Concrete batch plants can achieve adequate saturation through continual spraying of the aggregate for several days prior to being used in the concrete. Methods should be checked for proper sprinkler dispersion to effectively saturate the entire stockpile. If normal placement techniques are used, aggregates at their 1-day immersion content will not severely reduce slump. (See paragraph 7b(2)(b) for definition of 1-day immersion moisture content.) This level will not be achieved as quickly using a sprinkler system.

(b) The reference to "saturated" LDA is somewhat of a misnomer and must be used with care. LDA will never become fully saturated under atmospheric pressure, regardless of the length of time it is sprinkled or immersed in shallow water. It will, however, reach a state of saturation whereby little additional absorption will occur under atmospheric conditions. This state of saturation can be reached by immersion in water for approximately 24 hours, or by thorough sprinkling for approximately 1 week. Once LDAs have been saturated in this manner, minimal additional water will be drawn from a concrete mixture into the LDA particles. Therefore, slump loss during transport and placing will be reduced. Thorough saturation is especially important if the concrete is to be pumped. The pressure exerted by the pump onto the concrete will force additional water into the LDA particles. The degree to which the LDA was saturated prior to being introduced into the concrete will affect the amount of additional water that is forced into the particles during pumping. Poorly saturated LDA will result in an unacceptably high amount of water intake during pumping, which results in high slump loss. Consultation with the LDA supplier for proper saturation procedures is advised, especially when the LDC is to be pumped.

(c) The majority of water in LDA is held within the porous structure. Therefore, it will not be immediately available for chemical interaction as mix water. However, as the concrete cures, this moisture is pulled from the pores and promotes internal curing.

Table 1 - Basic Mixture Proportion Criteria for Structural Low- and Normal-Density Concrete Exposed to a Marine Environment (Source: Holm and Bremner 2000, Table 15)

Mixture Criteria	NDC	LDC	Comments
Cementitious materials (cement, fly ash, silica fume) kg/cu m (lb/cu yd)	335-445 (560-750)	360-445 (610-750)	For equal strengths, LDC may require an additional 25-80 kg/ cu m (15-50 lb/cu yd) of cement
Water-cementitious materials ratios (w/(c+m)) or minimum compressive	<0.40	34.5 MPa (>5,000 psi)	ACI 318 requirements
Nominal size of coarse aggregate, mm (in.)	4.75-25.0 (No. 4 - 1 in.)	4.75-19.0 4.75-12.5 (No. 4 - ¾-in.) (No. 4 - ½-in.)	Check with local LDA producers
Coarse aggregate absolute volume	≈35%	≈35%	Influence of coarse aggregate on workability, other factors similar
Water **absorbed** in coarse aggregate	Generally <1%	5 to 20%	Water absorbed by coarse aggregate must be accurately determined for control of strength and density
Water **adsorbed** on coarse aggregate	**Adsorbed** water affects w/(c+m) of both LDC and NDC and must be accurately measured and accounted for in w/(c+m) determination.		
Admixtures and other cementitious materials: Water-reducing admixtures High-range WRAs Retarding admixtures Fly ash Silica fume Other pozzolans GGBFS[1] Air-entraining admixture	Admixture and pozzolans or slag influence the properties of the mortar fraction of the concrete. The many advantages and construction benefits obtained through their use in NDC are essentially paralleled in LDC, and their incorporation in structural concrete enclosed to a marine environment is strongly recommended. A LDC is air entrained whether or not it is to be exposed to freezing and thawing.	(See NDC)	(See NDC)

[1] Ground granulated blast-furnace slag.

(3) Aggregate size/gradation. The maximum size of LDA is generally smaller than that used in NDC due to manufacturing limitations. Maximum sizes of some LDA are further limited due to lower strengths of the aggregate particles as they increase in size. The rough, porous surface and angular shape can reduce the workability and slump of LDC. Well-graded aggregate is required for workable mixes.

c. Fine aggregate. Although low-density fine aggregate can be used, typical practice in North America is to use normal-density sand for the fine aggregate fraction. Use the same quality criteria as used for NDC.

d. Admixtures. Use of admixtures will provide the same results in LDC as will be found in NDC.

e. Cementitious materials. There are no significant differences between the cementitious materials used for LDC and NDC. The contribution pozzolans make in reducing the generation of heat can be especially beneficial in LDC. The lower thermal conductivity inherent to LDC can result in higher peak temperatures relative to a comparable NDC mixture. If a structural element cast with LDC is sufficiently large, the higher temperatures can lead to thermally induced cracking. Using pozzolans to comprise a portion of the total cementitious material can serve to moderate the temperature rise due to hydration of the cementitious materials. Cementitious materials commonly used in LDC include:

(1) Portland cement as specified by ASTM C 150 or ASTM C 1157.

(2) Blended hydraulic cements as specified by ASTM C 595, provided the fly ash or natural pozzolan comprises a minimum of 15 percent, by mass, of the total cementitious materials. Blended hydraulic cement meeting the requirements of ASTM C 595 Type I (PM) should not be specified because of the possibility that it could contain less than this minimum amount of fly ash or natural pozzolan (HQUSACE (1994) par 4-3b(7).

(3) Pozzolans, such as fly ash and natural pozzolan, classified and specified by ASTM C 618.

(4) Ground granulated blast-furnace slag as specified by ASTM C 989.

(5) Silica fume as specified by ASTM C 1240.

(6) Metokaolin, classified as a natural pozzolan, and specified by ASTM C 618.

f. Truck mixers. Although the use of truck mixers is common practice in some areas of the country, this is generally not the best choice for mixing large volumes of LDC. Mixing efficiency can vary greatly between trucks and is difficult to control. However, if truck mixers are used, the charging and loading of a truck mixer follows the same general practice that is used for stationary mixers. Due to lower units weight, additional LDC can be transported in truck mixers without exceeding the axle load limits or state legal limits. However, volumes of LDC should not exceed the rated drum capacity. Additionally, do not exceed 63 percent of the drum volume when used as a mixer, or 80 percent of the drum volume when used as an agitator in accordance with ASTM C 94.

8. Placing. With proper proportioning, structural LDC can be delivered and placed using the same equipment and procedures as NDC. Preventing segregation of the coarse aggregate from

the mortar paste is still a primary concern. While NDA will settle out of the mortar paste, LDA will rise to the top.

a. Workability. Workable mixtures include a minimum amount of water. Slump requirements for LDC placed without pumping is the same as NDC. Well-proportioned LDC can typically be placed and screeded with less physical effort than that required for comparable NDC.

b. Consolidation and finishing. While vibration is required for consolidation in the forms, excessive vibration will segregate the heavier mortar fraction to the bottom and cause an excessive amount of LDA to rise to the surface. The lack of adequate mortar at the surface will degrade finishing. As such, excessive vibration should be avoided.

9. Curing. Curing operations similar to those used for NDC should begin as soon as possible after finishing. Do not apply membrane-curing compounds until bleeding has stopped. The high absorption in LDA provides an internal source of moisture for curing. This internal moisture is transferred to the mortar fraction as evaporation takes place. In effect, there is a continuous moisture balance essential for extended continuous hydration. This does not replace proper curing practices, which provide moisture to the LDC surface to enhance hydration or, in the case of curing compounds, to minimize the loss of moisture from the surface.

10. Pumping. LDC has been pumped successfully to several 60-story buildings. One example was the 60-floor Nations Bank Project I, in Charlotte, NC, where Mixture 2 (detailed in Table 2) was pumped 250 m (830 ft). Previous pumping of LDC has demonstrated a need for several additional requirements.

a. High pressure due to pumping causes the LDA to absorb part of the mixing water. Therefore, LDA moisture content must be raised to its 24-hour immersion level and beyond. Adequate presoaking will significantly reduce the amount of moisture the LDA absorbs from the mortar fraction. This will result in lowering slump loss during pumping. Consult with the aggregate supplier for minimum levels of aggregate absorption.

b. LDC should have a minimum slump of 75 mm (3 in.) prior to the addition of water-reducing admixtures. LDC that starts with a slump less than 75 mm (3 in.) will be difficult to pump, regardless of the high slump gained after the water-reducing admixtures are added. ACI 213.3R includes the following recommendations for the pumping system:

(1) Use the largest pumpline possible with a minimum of 125 mm (5 in.).

(2) Prior to pumping, ensure that all lines are clean, the same size, and "buttered" with grout at the start.

(3) Avoid rapid size reduction from the pump to the line.

(4) Reduce operating pressures by limiting the rate of placement and number of bends, using steel lines and as short a run of rubber lines as possible, and ensuring that all lines are firmly braced and tightly joined with adequate gaskets.

11. Laboratory and Field Control. Changes in LDA moisture content, grading, or particle density, as well as usual job site variations in entrained air, suggest frequent checks of the fresh concrete to facilitate adjustments necessary for consistent concrete characteristics.

Table 2 - Mixture Proportions and Physical Properties for Concretes Pumped on Nations Bank Project, Charlotte, NC, 1991
(Source: Holm and Bremner 2000, Table 17)

Parameter	Mixture 1		Mixture 2[1]		Mixture 3	
Mixture proportions						
Cement, Type III, kg/m^3 (lb/yd^3)	250	(550)	295	(650)	341	(750)
Fly ash, kg/m^3 (lb/yd^3)	64	(140)	64	(140)	64	(140)
LDA 20 mm to #5, kg/m^3 (lb/yd^3)	409	(900)	409	(900)	409	(900)
Sand, kg/m^3 (lb/yd^3)	623	(1,370)	585	(1,287)	547	(1,203)
Water, L/m^3 (gal/yd^3)	134	(35.5)	138	(36.5)	141	(37.2)
WRA, L/m^3 (fl oz/yd^3)	0.78	(27.6)	0.90	(31.6)	1.01	(35.6)
HRWRA, L/m^3 (fl oz/yd^3)	1.56	(55.2)	2.31	(81.4)	2.27	(80.1)
Fresh concrete properties						
Initial slump, mm (in.)	63	(2-1/2)	51	(2)	57	(2-1/4)
Slump after HRWRA, mm (in.)	140	(5-1/8)	191	(7-1/2)	171	(6-3/4)
Unit weight, kg/m^3 (lb/ft^3)	2.5	--	2.5	--	2.3	--
	1,887	(117.8)	1,890	(118.0)	1,890	(118.0)
Compressive strength, MPa (psi)						
4 days	29.6	(4,290)	35.2	(5,110)	39.4	(5,710)
7 days	33.6	(4,870)	39.9	(5,790)	44.4	(6,440)
28 days (avg.)	43.2	(6,270)	47.0	(6,810)	51.4	(7,450)
Splitting tensile strength, MPa (psi)	3.59	(520)	3.72	(540)	3.90	(565)

[1] Mixture selected and used on project.

a. The Corps' general policy for mixing and placing concrete is that no additional water should be added to the mixture after the concrete is batched. Exceptions can be made in extreme circumstances where a known amount of water can be intentionally withheld at the batch plant and that amount added to a truck mixer at the jobsite. This practice is sometimes employed to mitigate severe slump loss problems in long haul or hot weather placements. Care is exercised to ensure that the specified maximum water-cementitious materials ratio is not exceeded. However, when mixing and placing LDC, the need to add water at the placement site is more common due the tendency for LDA particles to continue to absorb water after being introduced into the mixer. While good saturation in the stockpile will minimize this extra absorption, it will usually not prevent any extra absorption. The extra water absorbed into the LDA aggregate particles during mixing and transport takes away from the mixing water that provides slump, as well as from the water-cementitious materials ratio water that controls the strength of the LDC. Therefore, it can be permissible to add water to a LDC at the job site in a quantity determined to replace that absorbed by the LDA particles during mixing and transport. So long as the amount of water added at the placement site does not exceed that absorbed by the LDA during mixing and transport, the quality of the concrete will not be decreased. Standardized field tests for slump, unit weight on unhardened concrete, and air content should be employed to verify conformance of field concretes with mixtures developed in the laboratory and the project specifications. The combination of these tests can be used to estimate the amount of water available to be added to the LDC to replace that absorbed by the LDA. For example, jobsite tests that show specified air content, but low slump and high unhardened unit weight, are evidence that the water content is low in the batch being tested. Sufficient water to bring the slump back within the range of the specification could likely be added and thoroughly mixed in without being detrimental to the overall quality of the LDC.

b. ASTM C 567 describes procedures for calculating the in-service, equilibrium density of structural LDC. In general, when variations in fresh density exceed ±3 percent, an adjustment in batch weights may be required to restore specified concrete properties. To avoid adverse effects on durability, strength, and workability, air content should not vary more than ±2.0 percent from specified values. Air content *cannot* be measured in LDC using the ASTM C 231, Pressure Method. The proper test method for measuring air content in LDC is ASTM C 173, Volumetric Method.

12. Economic Considerations.

a. Increased costs. LDA's typically consist of expanded shale, clay, or slate. The raw materials are quarried, then processed through a kiln with temperatures around 1,200 °C (2,160 °F). The fuel and other plant expenses are realized in higher costs for the LDA as compared to NDA. The location of the nearest LDA supplier and the associated shipping costs can also be a significant factor in the overall cost. Transportation costs of the LDA alone can make the use of LDC unfeasible in some locations.

b. Possible economic benefits. Each project has it's own unique characteristics. Therefore, the costs of using LDC versus the benefits of using LDC must be evaluated on a project-by-project basis. Two areas where benefits could be realized are as follows:

(1) Reduced dead load. In some structures, the reduced dead load achieved by the use of LDC can result in smaller supporting structural members or reduced foundation requirements.

(2) Marine applications. Marine structures are often cast in a graving dock and then floated to their final location. A structure constructed with LDC will have lower draft requirements as compared to an identical structure constructed with NDC. This factor can be prominent in inland waterways.

c. Cost/benefit analysis. Various other factors can also play a role in the overall cost of using LDC. The designer must properly weigh the extra costs associated with using LDC against the benefits of using LDC on each project. Proper analysis will help determine whether savings in design, construction, and ultimate performance outweigh the higher initial costs of LDC.

13. Action Required. This EC should be used as interim guidance pending publication of the final EM. Any comments regarding improvements or clarification during this interim period should be submitted to HQUSACE (CECW-EWS), Washington, DC 20314-1000.

FOR THE COMMANDER:

DWIGHT A. BERANEK, P.E.
Chief, Engineering and Construction Division
Directorate of Civil Works