Guide for Cast-in-Place Low-Density Cellular Concrete

Reported by ACI Committee 523

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This guide provides information on the materials, properties, design, proper handling, and applications of cast-in-place low-density cellular concretes having oven-dry densities of 50 lb/ft^3 (800 kg/m^3) or less. Roof deck systems and geotechnical applications often incorporate these low-density cellular concretes.

Keywords: cellular concrete; engineered fill; foaming agent; geotechnical fill; insulating concrete; insulating concrete roof decks; low-density cellular concrete; low-density controlled low-strength material (LD-CLSM); preformed foam.

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ACI 523.1R-06 supersedes ACI 523.1R-92 and became effective August 15, 2006.

CHAPTER 1—GENERAL

1.1—Definition of cellular concrete

Low-density cellular concrete (Fig. 1.1) is defined as concrete made with hydraulic cement, water, and preformed foam to form a hardened material having an oven-dry density of 50 lb/ft^3 (800 kg/m^3) or less. These mixtures may include aggregate and other material components including, but not limited to, fly ash and chemical admixtures.

This guide provides data and techniques pertaining to the properties and applications of cast-in-place low-density cellular concrete. Common applications of cast-in-place low-density cellular concrete are on roof decks and geotechnical applications. On roof decks, the material provides roofing base, thermal insulation, and drainage slope for flat-roofed industrial and commercial buildings (Fig. 1.2).

In geotechnical applications, the material is applied in thick sections of cellular concrete with low compressive strengths (Fig. 1.3) for the replacement of poor soils, fills for abandoned structures (pipelines), and cellular concrete fills designed, mixed, and placed to meet specific job conditions and functional requirements.

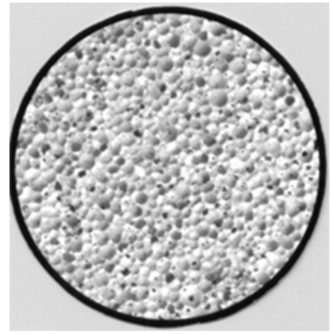

Fig. 1.1—Typical cell structure of cellular concrete.

Fig. 1.2—Roof deck application (click on picture to view video).

Fig. 1.3—Geotechnical application (click on picture to view video).

1.2—Definition of low-density, controlled low-strength material (LD-CLSM)

Controlled low-strength material (CLSM) is a cementitious material that is in a flowable state at the time of placement, and that has a specified compressive strength of 1200 psi (8.3 MPa) or less at the age of 28 days. This material is discussed further in ACI 229R. Low-density CLSM (LD-CLSM) meets this definition, and has a cast density that is controllable from 20 to 50 lb/ft^3 (320 to 800 kg/m^3). The quantity of preformed foam in the mixture determines the mixture's final density.

CHAPTER 2—MATERIALS

The basic materials in low-density cellular concrete are cement, water, and preformed foam. Because the main ingredient by volume of a low-density cellular concrete mixture is preformed foam, it is critical that all admixtures be compatible with the preformed foam within the specific mixture. Trial mixture tests are needed to determine compatibility and the resulting physical properties. Low-density cellular concrete mixtures may also include supplementary cementitious materials.

2.1—Cement

The cement should meet the requirements of ASTM C 150 (portland cement), C 595 (blended cement), or C 1157 (hydraulic cement). Blended cements include cement containing combinations of portland cement, pozzolans, slag, other hydraulic cement, or some combination of these. Blended cement may result in lower rates of early strength development and should be tested for specific applications. High-early-strength (Type III or HE) cement produces cellular concrete with higher rates of early strength development.

2.2—Water

Mixing water for concrete should be clean and free from detrimental amounts of oils, acids, alkalis, salts, organic materials, or other substances deleterious to concrete or reinforcement. Any nonpotable water should be tested for hardness, pH, suspended solids, total salt content, and other characteristics that might affect the preformed foam, the setting time, and the strength of the low-density cellular concrete.

2.3—Preformed foam

Preformed foam is created by diluting a liquid foam concentrate with water in predetermined proportions (Fig. 2.1) and passing this mixture through a foam generator. Meter the preformed foam directly into the cement-water slurry at the job site (Fig. 2.2). The density of the preformed foam is typically between 2.5 and 4.0 lb/ft^3 (40 and 65 kg/m^3).

The foam concentrate should have a chemical composition capable of producing and maintaining stable air cells within the concrete mixture. The air cells should be able to resist the physical and chemical forces imposed during mixing, pumping, placing, and setting of the cellular concrete. If the cellular (air-cell) structure is not stable, it may break down under these forces, resulting in an increased concrete density. Most common proprietary formulations of foam concentrates contain protein hydrozylates or synthetic surfactants. ASTM C 796 provides a standard method for laboratory measurement of the performance of a foaming chemical to be used in producing foam (air cells) for making cellular concrete. ASTM C 869 is a standard specification that covers foaming agents specifically formulated for making preformed foam for use in the production of cellular concrete. This specification provides the means for evaluating the performance of a specific foaming agent. Further information concerning these formulations and the procedures for using them is available from foam manufacturers.

2.4—Aggregates

Low-density cellular concrete may include lightweight aggregates such as vermiculite or perlite meeting the requirements of ASTM C 332 Group 1 to lower the slump to achieve steeper roof slopes, and to maintain moisture in dry climates. Wilson (1981) provides additional information on the use of lightweight aggregates used in cellular concrete. Any proposed aggregates should be tested for physical properties, pumpability, and compatibility in trial mixtures.

2.5—Admixtures

2.5.1 *Chemical admixtures*—Chemical admixtures, such as water-reducing admixtures and set accelerators, are used with cellular concretes. Water-reducing admixtures can improve compressive strength for special mixtures or applications. Hot water, high-early-strength (Type III or HE) cement, and chemical accelerators can be used singly or in combination

Fig. 2.1—Diluting foam concentrate in water (click on picture to view video).

Fig. 2.2—Metering preformed foam into cement-water slurry (click on picture to view video).

to accelerate setting. Accelerators containing chloride ions should not be used in cellular concrete placed in contact with steel. Chemical admixtures should conform to ASTM C 494 and be used at dosages recommended by the manufacturer or determined by trial mixtures.

Not all chemical admixtures are compatible for use in foamed cellular concrete. Individual manufacturers of foam concentrate should be contacted for information about the compatibility of specific admixtures with their foam concentrates, and trial batches should be used to determine the resulting mixture characteristics.

2.5.2 *Supplementary cementitious materials*—In the production of cellular concrete, supplementary cementitious materials such as fly ash, silica fume, high reactivity metakaolin, or ground-granulated blast-furnace slag (slag cement) are included to reduce bleeding and segregation and to increase strength. Trial batches should be used to confirm the compatibility of the selected foam concentrate with other admixtures, and to help determine the proper admixture dosages and resulting physical properties. Various mineral admixtures may differ considerably in composition, fineness, and other properties. The user should review major fly ash properties—loss on ignition (LOI), cementing activity, and

Fig. 2.3—Typical fiber types.

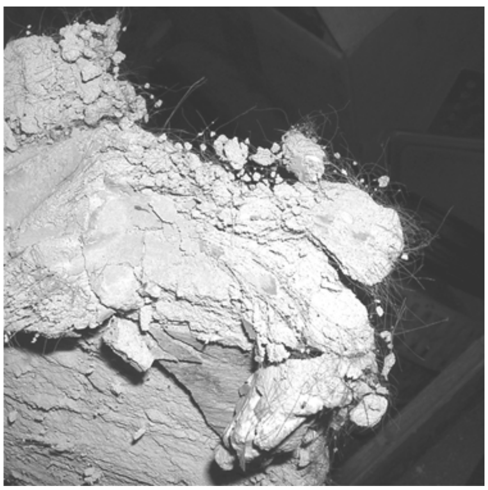

Fig. 2.4—Fibers in cellular concrete.

water demand of the fly ash—before including fly ash in a low-density cellular concrete mixture. The first of these properties (LOI) is addressed in ASTM C 618. A fly ash with a high LOI (carbon content) may adversely affect the preformed foam by causing an increase in density and loss of yield. If cementing activity is low, the concrete may set too slowly, resulting in a lower strength and a higher density. High water demand may require that the water-cementitious material ratio (*w*/*cm)* be adjusted to achieve the desired strength.

2.6—Nonstandard materials

Special cements, supplementary cementitious materials, and aggregates may be included as nonstandard materials. Some mine-fill applications may use local materials as aggregates or fillers in low-density cellular concrete to extend the mixture when transportation of materials to remote areas is difficult. The user should pretest nonstandard mixtures for proper development of the desired fill properties.

2.7—Fiber reinforcement

Low-density cellular concrete may include commercially available fibers, such as nylon, polypropylene, polyester, and alkali-resistant glass, as reinforcing materials (Fig. 2.3). The choice of fiber type depends on performance requirements. Cellular concrete's flexural and tensile strength,

Fig. 3.1—Measuring as-cast density (click on picture to view video).

impact resistance, fatigue limit, energy absorption, and spalling resistance can be enhanced through the use of fibers that are known to be sufficiently durable under the expected service conditions. Zollo and Hays (1998) address the material and engineering properties of fiber-reinforced cellular concrete. Fibers can also help control plastic shrinkage cracking (Fig. 2.4).

CHAPTER 3—PHYSICAL PROPERTIES

3.1—As-cast density

The as-cast density at the point of placement should be determined by calculating the density of samples using a container of known volume and empty weight, as prescribed in applicable sections of ASTM C 796 (Fig. 3.1). Monitoring the as-cast density of the cellular concrete is an important job-site quality-assurance tool for controlling the uniformity and density of the mixture at the point of placement. Procedures for sampling and testing hardened insulating cellular concrete are given in ASTM C 513.

3.2—Oven-dry density

Oven-dry density, evaluated using ASTM C 796 and C 495, determines the unit weight used to define low-density cellular concrete, which by definition has a maximum oven-dry density of 50 lb/ft^3 (800 kg/m^3).

3.3—Compressive strength

The relationship between compressive strength and as-cast density is an important indicator of the quality of cellular concrete (Kearsley and Wainwright 2002b). The compressive strength of cellular concrete should be evaluated in accordance with ASTM C 796 and C 495. Compressive strength specimens should not be oven-dried. When it is necessary to determine oven-dry density, it is necessary to make companion specimens for this test in addition to those specimens for compressive strength testing. The user should relate compressive strength to the oven-dry density of cellular concrete as indicated in Table 3.1. Table 3.1 is a guideline only, based on Type I cement, no cement substitution, and using local materials. The user should test specific local materials to determine these properties.

For geotechnical applications, the cast density of the material is usually the most significant property and is more important than bearing capacity (unconfined compressive

Table 3.1—Possible ranges of compressive strength and modulus of elasticity versus oven-dry density for cellular concrete in roof deck applications

Oven-dry density		Usual range of compressive strength at 28 days		Modulus of elasticity	
lb/ft^3	kg/m^3	psi	MPa	10^3 psi	GPa
20 to 25	320 to 400	70 to 125	0.48 to 0.86	30 to 52	0.21 to 0.36
25 to 30	400 to 480	125 to 225	0.86 to 1.55	52 to 89	0.36 to 0.61
30 to 35	480 to 560	225 to 350	1.55 to 2.41	89 to 135	0.61 to 0.93
35 to 40	560 to 640	350 to 450	2.41 to 3.10	135 to 183	0.93 to 1.26
40 to 50	640 to 800	450 to 750	3.10 to 5.17	183 to 320	1.26 to 2.21

Table 3.2—Physical properties for geotechnical (Engineered Fill 2001)

Maximum cast density		Minimum compressive strength		Bearing capacity	
lb/ft^3	kg/m^3	lb/in.^{2}	MPa	ton/ft^2	MPa
24	385	10	0.07	0.7	0.07
30	480	40	0.28	2.9	0.28
36	575	80	0.55	5.8	0.56
42	675	120	0.83	8.6	0.82
50	800	160	1.10	11.5	1.10

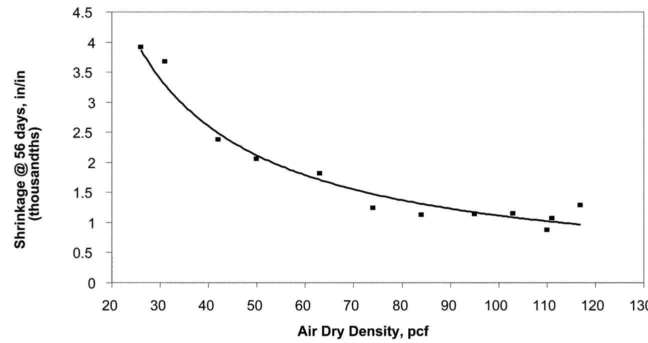

Fig. 3.2—Drying shrinkage versus air-dry shrinkage (1 in. = 25.4 mm; 1 lb/ft^3 = 16.0 kg/m^3).

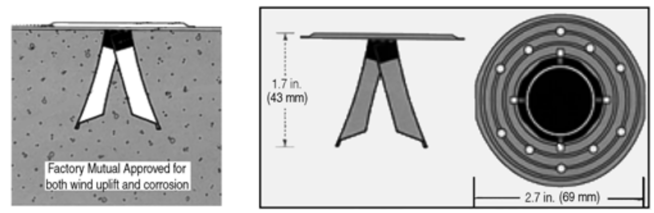

Fig. 3.3—Typical base-sheet nail.

strength). As a result, these densities and compressive strengths are lower than those for roof deck applications (Table 3.2). If standard materials are used, the density of the low-density cellular concrete has properties that fall within ranges specified by the manufacturer of the foam concentrate. If nonstandard materials are used, special test batches may be required to confirm specific properties. To define the general relationship between cast density and compressive strength for specific applications, one manufacturer has divided the cast density into convenient ranges.

Because the need for controlled low-density fill is usually the main reason for using low-density cellular concrete, compressive strengths and ultimate bearing capacities require only minimum values. For specialized low-density cellular concrete geotechnical applications, other physical properties may be required.

Cellular concrete with a compressive strength below 70 psi (0.48 MPa) has proven satisfactory for special applications such as pipe and wall insulation, tunnel and mine fills, energy absorption or shock mitigation, and backfills in sewer and highway construction per ACI SP-29 (ACI Committees 213 and 523 1971).

3.4—Drying shrinkage

Drying shrinkage is not usually critical in cellular concrete used for roof deck insulation or geotechnical applications. The reason for this is that when cellular concrete is used to insulate roof decks, it is not considered to contribute structurally; and when it is used in geotechnical applications, any shrinkage cracking that it might undergo does not significantly reduce bearing capacity. Drying shrinkage is typically 0.30 to 0.60% after 6 months at 50% relative humidity and 73 °F (23 °C), and increases with decreasing density. Some of the effects of drying shrinkage can be mitigated by adding fibers to the mixture (Section 2.7). Figure 3.2 relates drying shrinkage at 56 days to the air-dry density of cellular concrete (ASTM C 157).

3.5—Thermal expansion

The coefficient of thermal expansion for cellular concrete varies directly with density, and is typically 5.0 to 7.0 × 10^{-6} per °F (9.0 to 12.6 × 10^{-6} per °C) as evaluated using a linear thermal expansion test with strain gauges. The designer should consider thermal expansion in applications with significant variation in placing temperatures, operating temperatures, or both. These conditions could occur in applications such as roof decks, power plants, ovens, and steam lines.

3.6—Walkability

Walkability, a term developed to describe the ability of low-density concrete to sustain normal construction foot traffic without damage, is best judged by examining surface distress. Walkability improves with increased density. When heavy construction traffic is expected (such as from wheelbarrows, scaffolds, material storage, or pathways), the surface of the roof deck should be protected with wooden boards or by a similar method.

3.7—Mechanical attachment

For roof deck applications, the roofing base sheet should be mechanically attached to the low-density cellular concrete roof deck using specifically designed nails or screws (Fig. 3.3). Fastening within 2 to 7 days of concrete placement is possible if the fastener can be installed without shattering or spalling the cellular concrete and if an installed fastener has a minimum specified withdrawal resistance of 40 lb (180 N), which is consistent with required wind-uplift resistance and typical nailing patterns (such as three rows,

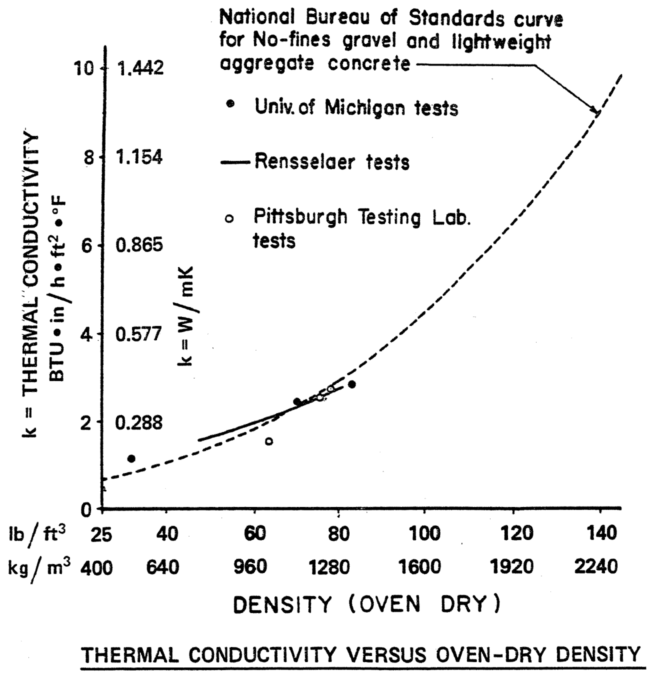

Fig. 3.4—Thermal conductivity versus oven-dry density (National Bureau of Standards 1955).

uniformly spaced over the width of each base sheet, and using a nail spacing of 7-1/2 in. [190 mm] in each row). Because no consensus standard exists, nailing patterns are generally qualified by product- and pattern-specific testing, and are published in evaluation-service reports (ANSI/SPRI FX-1-2001 2001).

3.8—Thermal conductivity

The thermal conductivity of cellular concrete should be measured using the guarded hot plate (ASTM C 177) or the heat flow meter (ASTM C 518) methods. A full-scale assembly is measured by a hot box apparatus (ASTM C 1363). Table 3.3 lists typical thermal conductivity values. These values follow the curve of Fig. 3.4, originally produced by the National Bureau of Standards (1955).

3.9—Fire resistance

The fire resistance of cellular concrete in a building system is determined by a fire test, during which the cellular concrete element must support its design load, remain within the temperature increase specified by the test standard, and withstand the transmission of flame or hot gasses per ASTM E 119. Information on the demonstrated fire resistance of slabs with cellular concrete and charts for estimating the fire resistance of various two-course roofs is available (Abrams and Gustaferro 1969; Gustaferro et al. 1970).

Fire-resistance tests have been conducted on wall, floor, and roof assemblies of cellular concrete cast over concrete (precast or cast-in-place), galvanized steel, and wood substrates. Some of these assemblies contain expanded polystyrene insulation board sandwiched within the cellular concrete. Recognized laboratories, such as Underwriters Laboratories, Inc., publish construction details for the tested assemblies, including fire ratings in hours evaluated using ASTM E 119.

Table 3.3—Typical thermal conductivity values for oven-dry cellular concrete

Oven-dry density		Thermal conductivity, K	
lb/ft^3	kg/m^3	BTU × in. (h × ft^2 × °F)	$w/(m \times K)$
20	320	0.75	0.11
30	480	0.91	0.13
40	640	1.11	0.16
50	800	1.36	0.20

3.10—Permeability

Generally, low-density cellular concrete has a low coefficient of permeability k that is constant throughout the lower-density ranges (Kearsley and Wainwright 2001a). The coefficient of permeability is inversely related to the effective confining pressure on the sample. Because low-density cellular concrete is a rigid material rather than a yielding soil, its permeability is measured using a modified triaxial-type test including a confining pressure to prevent direct passage of water (short-circuiting) along the interface between the specimen and the confining membrane. A constant head should be maintained during the test. Reported values range from 1×10^{-4} to 1×10^{-5} mm/s (4×10^{-6} to 4×10^{-7} in./s) (ASTM D 2434).

3.11—Freezing-and-thawing resistance

Freezing-and-thawing resistance of low-density cellular concrete is evaluated using Procedure B (rapid freezing and thawing) of ASTM C 666, with a modified cycling protocol involving a longer thawing period. This modification is necessary because the insulating properties of low-density cellular concrete prevent rapid lowering and raising of the temperatures at the interior of the specimen, and thus prevent completion of a freezing-and-thawing cycle in the originally prescribed maximum 4-hour time period.* Low-density cellular concrete intended for exterior exposure should have a relative dynamic modulus of elasticity E at least 70% of its original value after 120 cycles when tested according to Procedure B of the modified ASTM C 666. Because the freezing-and-thawing resistance of low-density cellular concrete increases with increasing density, cellular concrete within 2 to 3 ft (0.6 to 1 m) of a surface subjected to cycles of freezing and thawing while exposed to water must have a density of at least 36 lb/ft^3 (575 kg/m^3). MacDonald et al. (2004) provide an evaluation of the freezing-and-thawing performance and testing of cellular concrete.

CHAPTER 4—PROPORTIONING AND TESTING

4.1—Proportioning

Guidance for mixture proportioning is generally available from the manufacturer of foam concentrates. The mixture proportion specifies the range of proportions of the various ingredients needed to attain the desired physical properties (density and compressive strength). The user should test mixture proportions when nonstandard materials or special applications are involved.

*Personal correspondence from E. L. Bidwell, University of Illinois, to Elastizell Corp. of America, and report, "Freeze Thaw Testing of Low Density," *Elastizell Lightweight Concrete*, Apr. 2, 1975.

4.2—Ingredient compatibility

Each ingredient that does not meet standard specifications for mixture compatibility should have the cellular concrete physical properties checked in actual mixtures according to ASTM C 796 and C 869. Cements may have significant strength variations within standard specification limits. Mill reports and test batches are useful for reviewing the product differences between cement and fly ash sources. Kearsley and Wainwright (2002a) demonstrate how to optimize fly ash content for strength.

4.3—Cast density

Measuring the cast density at the point of placement is the simplest and most convenient test for monitoring the quality of the placed material. Cylinder specimens for compressive strength tests, usually measuring 3 x 6 in. (76 x 150 mm), should be cast at the same time that periodic density tests are performed. These samples should be covered and stored in a protected area for at least 24 hours before they are transported to the testing laboratory for testing in accordance with ASTM C 796.

4.4—Physical properties

For standard mixtures made from standard materials, cast density determines the physical properties of the cellular concrete. It is not necessary to repeat the specialized tests of materials for each project. These specialized tests include permeability and freezing-and-thawing resistance; they may require up to 3 months to complete. Strength and density determinations are often sufficient. If unique applications or nonstandard materials are used, special tests may be required. A special test is one related to the performance of the material in the specialized application. Legatski (1994) provides a detailed review of testing the properties of cellular concrete.

CHAPTER 5—BATCHING, MIXING, PLACING, FINISHING, AND CURING

5.1—Storage of materials

All materials should be stored in a manner to prevent deterioration and contamination by foreign matter.

5.2—Batching

Materials for low-density cellular concrete are typically proportioned and batched on site, directly into a specialized mixer. The cement, fly ash, and other dry materials are weighed on a calibrated scale, and the mixing water is metered. The preformed foam is metered into the mixture through a calibrated nozzle. The accuracy of each batching device is critical to the final mixture density and its subsequent reproducibility. Each batching device (scales, water meter, foam-generating nozzle) should be calibrated before starting a project, and during a project if there is a reason to believe it is necessary.

5.3—Mixing

Mechanically mixing cellular concrete produces a uniform distribution of materials with a suitable consistency at the specified as-cast density. Excessive mixing should be avoided, as it may cause changes in density and consistency.

In batch mixing, the mixer should be charged with mixture water and dry ingredients, followed by special admixtures and the preformed foam. The as-cast density should be monitored at the point of placement every 30 to 60 minutes based on consistency of results. Allowance should be made for any density changes that result from placing methods or conditions, such as pumping distances and extreme weather conditions. Ingredients should be added in the proper proportions and sequence during continuous mixing operations. This is necessary to ensure reasonable uniformity and achieve the required as-cast density at the point of placement.

Standard concrete mixing equipment is normally not acceptable for low-density cellular concrete mixtures because the action of the mixer does not combine the ingredients with the correct speed and mixing action. A high-speed paddle mixer is preferable because it properly combines the ingredients and blends the preformed foam rapidly and efficiently to produce a uniformly consistent low-density cellular concrete mixture. Other mixers and processes that produce uniform mixtures include high-shear mixers.

5.4—Placing

Cellular concrete should be placed by a progressive-cavity pump or a peristaltic pump. The pump hose should be large enough in diameter (usually 2 to 2.5 in. [51 to 64 mm]) to ensure uniform delivery of cellular concrete at the point of placement without damage to the structure or substrate. Low-density cellular concrete can be pumped over long distances (over 1500 ft [460 m]). This is a major advantage for low-density cellular concrete over other materials and placing methods, and is important on large, congested projects with difficult access.

5.5—Finishing

For roof deck applications, cellular concrete should be finished to the slope and thickness specified on the project drawings. A minimum slope for proper roof drainage is 2% (equivalent to 1/4 in./ft [21 mm/m]). It is possible to place this material on steeper slopes. The cellular concrete surface is usually finished with a darby or screeded to the specified slope (Fig. 5.1). The surface should be smooth and free from ridges, projections, and depressions that might adversely affect the roofing membrane.

For geotechnical applications, lift thicknesses ranging from 2 to 4 ft (0.6 to 1.2 m) are typical. The lift thickness is job-specific and related to the project layout and casting procedure. A greater lift thickness is acceptable for specific job conditions. The heat of hydration developed within the mass, the material density, the cement content, and the ambient temperature also influence the lift thickness. Thinner castings reduce the heat buildup from hydration of the cement. It is desirable to cast material in a formed area within 1 or 2 hours to permit an undisturbed setting. In general, low-density cellular concrete should be cast to final grade with a tolerance of 0.1 ft (0.03 m). It is not necessary to scarify intermediate lift surfaces. A darby finish is acceptable for the final lift.

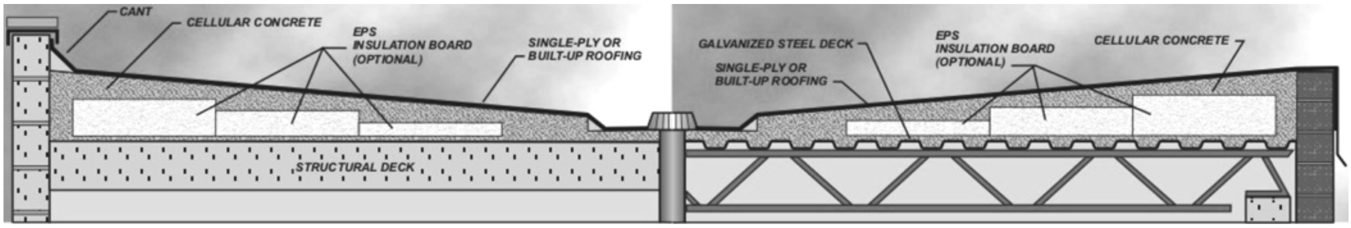

Fig. 5.1—Typical roof deck cross sections.

5.6—Curing

Water curing or use of a curing compound is advisable for roof deck applications when rapid drying is anticipated. Curing compounds should be compatible with the final roofing system. Traffic should not be permitted on freshly placed cellular concrete roof decks until adequate walkability (Section 3.6) is demonstrated. Check with the manufacturer of foaming agent for specific recommendations to ensure compatibility with subsequent roofing membrane material.

5.7—Placement in cold weather conditions

When ambient temperatures below 32 °F (0 °C) are predicted within 8 hours after placement, special precautions should be taken, including the use of Type III (high early-strength) cement or Type I cement with heated mixing water to increase the initial internal temperature of the concrete and accelerate the setting time. Because of the relatively high cement content and insulation properties of cellular concrete, these precautions are usually adequate. Cellular concrete should not be mixed or placed during freezing weather, rain, or snow, or when standing water, snow, or ice is present on the deck. The foaming agent manufacturer should be consulted for specific cold weather placement recommendations.

5.8—Placement in hot weather conditions

When expecting ambient temperatures above 100 °F (38 °C) during casting, the following special precautions should be considered:

- Casting before dawn will avoid the heat of the day;
- Vermiculite or perlite aggregate may be used as an additive to maintain moisture in the mixture;
- Fiber reinforcement may be incorporated in the mixture to minimize plastic-shrinkage cracking;
- The roof deck may be moist-cured by fogging after casting; and
- The roofing membrane may be installed as soon as the moisture content is deemed acceptable for the roofing application. The installation may begin as soon as 2 days after casting.

The foaming agent manufacturer should be consulted for specific hot weather application recommendations.

CHAPTER 6—DESIGN CONSIDERATIONS FOR ROOF DECKS

6.1—Form systems

A common application of cellular concrete is as insulation for concrete roof deck fills. The cellular concrete is cast over the structural deck system of the building. Typical deck types include corrugated or fluted steel, structural concrete, and wood.

6.1.1 *Steel*—Casting cellular concrete against permanent, uncoated structural metal formwork is not good concrete construction practice. Steel embedded in cellular concrete should be protected from corrosion in a manner consistent with its service environment (refer to ACI 222R).

Corrugated or fluted steel deck should be galvanized, coated, or both to meet the requirements of ASTM A 653. Steel decks are designed for gravity loads by selecting an appropriate steel gauge and deck profile, depending on the load and the span. The deck should be attached to the framing by welds or mechanical fasteners according to the deck manufacturer's recommendations and as required to resist the specified loadings, as determined by the designer with due consideration to diaphragm strength, uplift, and other structural design requirements. The steel sheets should be vented, with bottom slots having an open area of at least 0.5% of the plan area (Fig. 6.1). Side-lap embossments improve bond, which is important under seismic loading and wind uplift.

6.1.2 *Structural concrete*—A structural concrete base for cellular concrete (Fig. 6.2), whether cast-in-place or precast, may require venting for moisture relief that can be achieved with unsealed joints between precast structural concrete elements or by venting (refer to Fig. 6.3).

6.1.3 *Wood*—Cellular concrete is cast over structural wood roof decks to produce the proper slope for drainage and for thermal insulation (Fig. 6.4). A waterproof membrane, such as an asphalt-saturated felt, should be securely fastened to the wooden deck with the edges sealed before the cellular concrete fill is placed.

6.2—Roofing readiness

A roof membrane can generally be installed 2 to 5 days after a cellular concrete roof deck has been cast if the moisture content is deemed to be acceptable for roofing membrane application. The surface hardness of the cellular concrete should be adequate to withstand foot traffic and other light roofing operations without damage. The screeded surface of the cellular concrete should be smooth and free from ridges or depressions that would adversely affect the integrity of the roofing membrane. Ridges should be scraped flat. Roofing base sheets are commonly attached to the roof deck by nailing. The roofing membrane is commonly attached to the base sheet by mopping or torch-heating. Other roofing-attachment systems should be compatible with

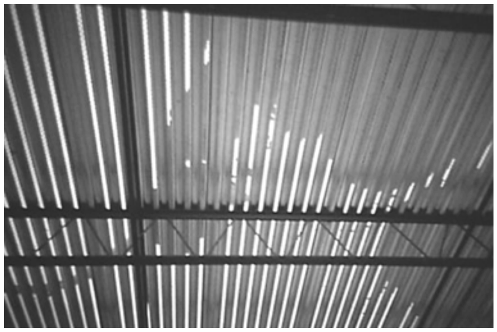

Fig. 6.1—Casting cellular concrete over vented steel deck.

Fig. 6.2—EPS insulation board placed in cellular concrete slurry over structural concrete deck.

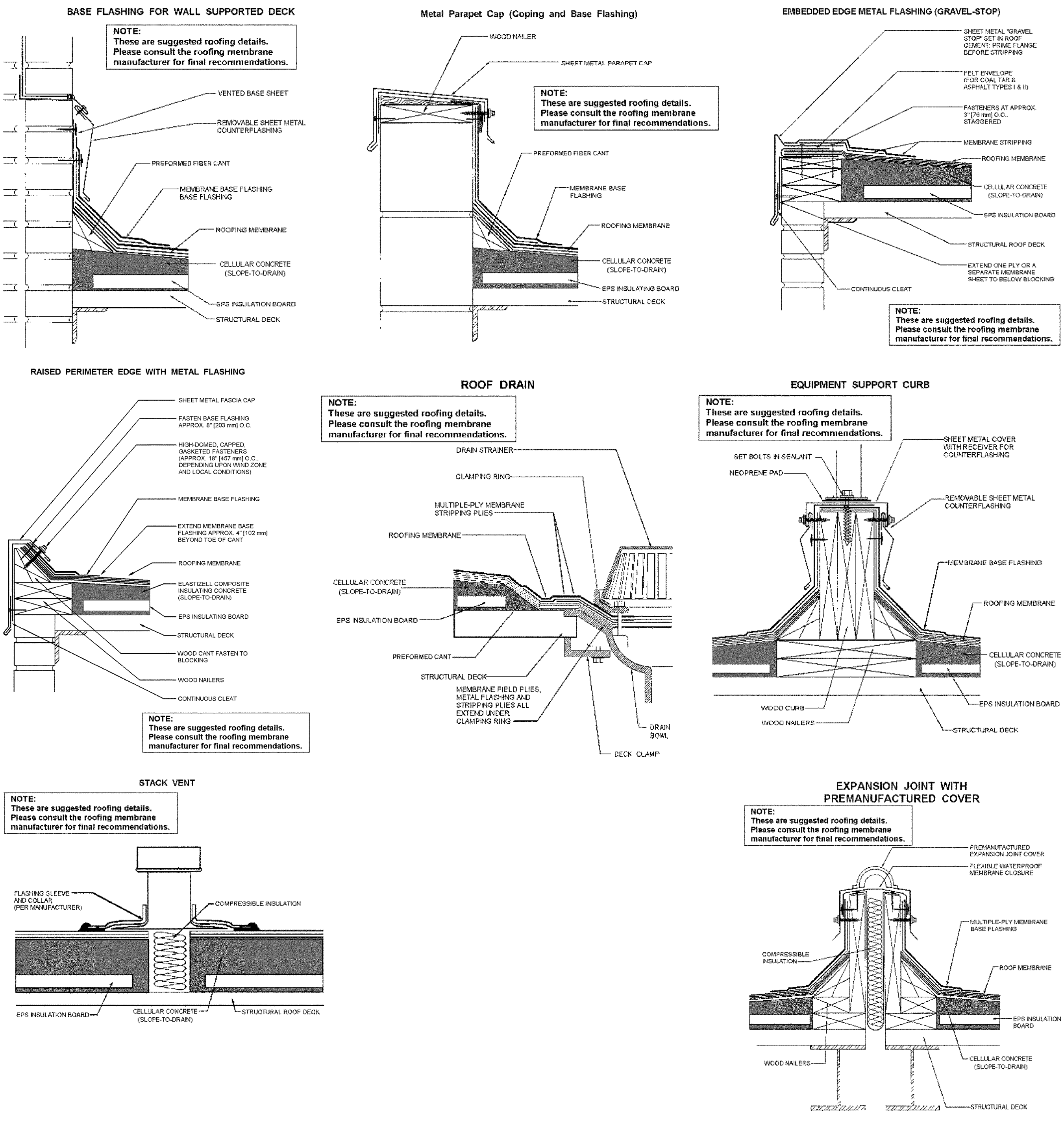

Fig. 6.3—Typical roofing details for cellular concrete roof decks.

Fig. 6.4—Wood frame roof deck substrate from below.

the cellular concrete and with the substrate (the structure that provides the required wind uplift resistance).

6.3—Load-carrying capacity

Specific structural design requirements for cellular concrete depend on the type of substrate used. The most common substrates are galvanized steel and precast or cast-in-place concrete. Although cellular concrete is not designed for composite action with the substrate, it provides additional stiffness. Designers should obtain information from substrate manufacturers regarding the ultimate flexural capacities and in-plane stiffness and strength characteristics of various systems.

6.4—Expansion and contraction joints

Cellular concrete exhibits drying shrinkage when placed in large monolithic placements such as roof decks. Because shrinkage of cellular concrete is much greater than its thermal expansion, expansion joints are generally not necessary. Expansion joints are required, however, in a cellular-concrete roof deck at expansion joints in the structural system, and at changes in the direction or type of substrate material.

6.5—Relief of vapor pressure

Under certain temperature conditions, moisture in cellular concrete or moisture intruding from external sources may cause undesirably high vapor pressure under roofing membranes covering a roof deck system. The vapor pressure can be reduced by postponing the application of the roofing membrane until the cellular concrete moisture content is at an acceptable level. A nailed base sheet, combined with perimeter venting at the intersection detail between the edge flashing and the counter-flashing, also helps reduce the vapor pressure.

The rate of drying of cellular concrete is a function of placing conditions, density and thickness, substrate, venting, and environmental conditions. The overall roof deck system, building use, and climatic conditions should be evaluated before specific recommendations regarding venting are made. This evaluation is especially important in re-roofing applications where dry portions of the existing roof membrane and insulation can be left in place and the cellular concrete cast over it.

Fig. 7.1—Geotechnical application under a bridge structure with mechanically stabilized earth (MSE) containment walls.

Fig. 7.2—Geotechnical application at bridge widening approach.

6.6—Standard roofing details

For information on generally accepted roofing details (Fig. 6.3), refer to *NRCA Roofing and Waterproofing Manual* (The National Roofing Contractors Association 2001).

CHAPTER 7—GEOTECHNICAL APPLICATIONS

In most applications, the major advantage of cellular concrete is its low density. Other advantages include ease of excavation (a requirement in some applications) and more controllable strength as compared with standard CLSM.

7.1—Backfill

Low-density cellular concrete placed around and next to structures such as bridge abutment and retaining and building walls significantly reduces the dead load over poor soils (Fig. 7.1 and 7.2).

Once low-density cellular concrete sets, it does not exert active lateral pressure against the wall structure, as does standard granular backfill. Because low-density cellular concrete is cementitious, it does not require compaction, and because it has low density, settlement is minimal.

Bridge approach applications may often be from 10 to 40 ft (3.0 to 12 m) or more in height. A low-density fill that does not require compaction is often a preferred alternative to heavy, compacted fill.

Most of the fill thickness of cellular concrete should be cast at a density of 30 lb/ft^3 (480 kg/m^3). The top 2 to 3 ft (610 to 910 mm) is usually 42 lb/ft^3 (675 kg/m^3) cellular concrete, which has excellent resistance to freezing and thawing and provides a solid base for an approach slab or pavement structure.

7.2—Roadway bases

Low-density cellular concrete is often used for a roadway base over poor soil. The use of the material becomes even more important when raising or widening the roadway over poor soil, and added weight and settlement are concerns for the designer (Fig. 7.3). These designs often involve load-balancing and buoyancy calculations. Specific site conditions may require the development of special drainage details.

When constructing a roadway over poor soil, a geotextile fabric should be placed after the excavation is complete. The low-density cellular concrete should be cast directly onto the geotextile fabric. This fabric acts as a tension skin and, in conjunction with the low-density cellular concrete, can span localized settlements up to 3.2 ft (1 m).

Fig. 7.3—Geotechnical roadway base at bridge approach.

Fig. 7.4—Geotechnical fill around steel culvert under existing bridge.

7.3—Pipeline and culvert fills

Low-density cellular concrete is often a supporting fill in pipeline applications over poor soils or a containment fill cast around these drainage structures to provide support and stability. Compaction is not necessary as it would be with a granular fill.

Culvert applications include concrete box culverts, segmented or pipe sections, and metal culvert systems including multi-plate culverts of significant size (Fig. 7.4).

Low-density cellular concrete reduces the dead weight on the culvert. The cementitious nature of all CLSM mixtures provides erosion control, which is an advantage over standard granular fills that erode when subjected to moving water. These mixtures may need to be evaluated for freezing-and-thawing resistance.

Placing low-density cellular concrete on both sides of the culvert simultaneously minimizes eccentric loading. In addition to supporting the culvert from below, the low-density cellular concrete cast around these drainage structures provides lateral support because compaction is not necessary.

7.4—Void fills

Low-density cellular concrete is commonly used as a void fill when the reduction of dead load is critical. It is also applicable to mass structures where access may be limited and flowability is important. Void-fill applications include pipeline abandonment, filling around excavations, annular space fills between slip-lined pipes, and structures that are to be abandoned rather than demolished (Fig. 7.5).

Fig. 7.5—Filling abandoned swimming pool with low-density concrete.

Because every void-fill application is unique, each one should be examined for special conditions. To contain the easy-flowing low-density cellular concrete, the entire fill area should be sealed, including pipes, drains, and structural discontinuities such as holes in walls or under footings. Lift heights for void fills may be greater than normal if the low-

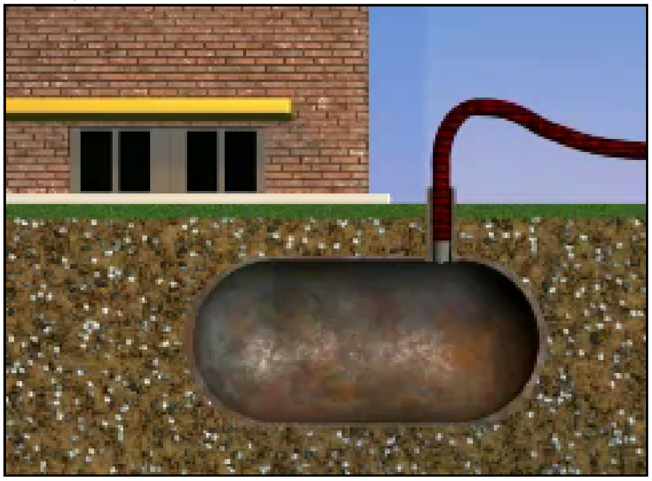

Fig. 7.6—Filling abandoned underground fuel- or oil-storage tank with cellular concrete (click on picture to view video).

Fig. 7.7—Cellular concrete as wall fill with stay-in-place forms.

density cellular concrete can be reasonably contained by earth, forms, or a structure.

7.5—Tank fills

An acceptable abandonment alternative to the excavation and removal of underground fuel- or oil-storage tanks required by many agencies is a low-density cellular concrete tank fill (Fig. 7.6). Federal regulations refer to low-density cellular concrete fills as an "inert substance."

7.6—Insulation and isolation fills

The discrete air-cell structure within the cementitious matrix of low-density cellular concrete provides thermal-insulation and physical shock-mitigation properties to this material for applications such as walls (Fig. 7.7), roofs, and other similar structures. Giannakou and Jones (2004) describe the use of cellular concrete to thermally insulate foundations and slabs.

CHAPTER 8—REFERENCES

8.1—Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Since frequent revisions occur with some of these documents, the reader is advised to contact the appropriate sponsoring group for reference to the latest version.

American Concrete Institute

222R Protection of Metals in Concrete Against Corrosion

229R Controlled Low-Strength Materials

ASTM International

A 653 Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process

C 150 Specification for Portland Cement

C 157 Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot-Plate Apparatus

C 332 Specification for Lightweight Aggregates for Insulating Concrete

C 494 Specification for Chemical Admixtures for Concrete

C 495 Test Method for Compressive Strength of Lightweight Insulating Concrete

C 513 Test Method for Securing, Preparing, Obtaining and Testing Specimens of Hardened Lightweight Insulating Concrete for Compressive Strength

C 518 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus

C 595 Specification for Blended Hydraulic Cements

C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing

C 796 Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam

C 869 Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete

C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

C 1157 Performance Specification for Hydraulic Cement

C 1240 Specification for Silica Fume Used in Cementitious Mixtures

C 1363 Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus

D 2434 Test Method for Permeability of Granular Soils (Constant Head)

E 119 Test Methods for Fire Tests of Building Construction and Materials

The above publications may be obtained from:

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
www.concrete.org

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
www.astm.org

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