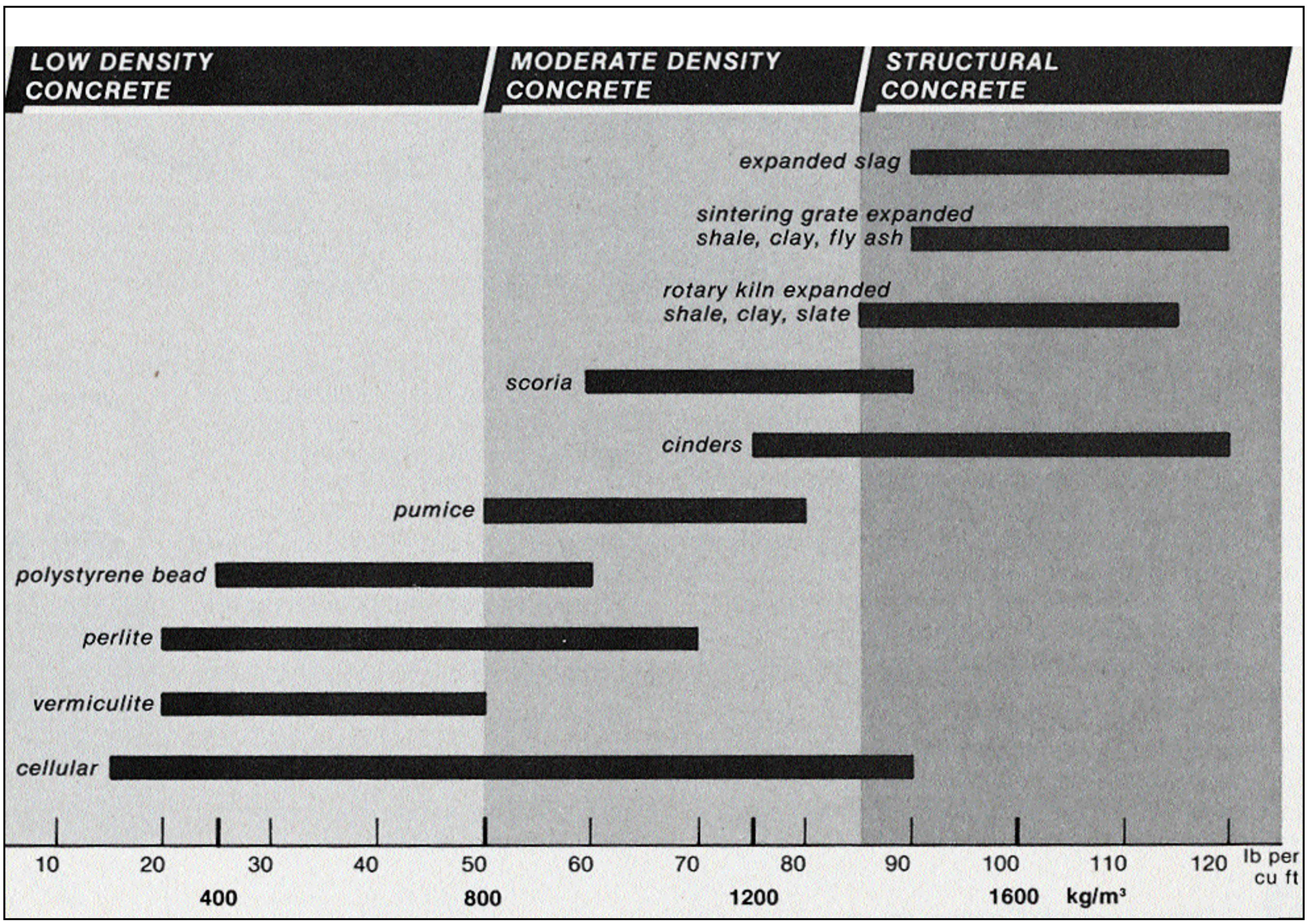
At the high end of the lightweight concrete spectrum

Structural lightweight concrete

Lightweight concrete is concrete weighing substantially less than that made using gravel or crushed stone aggregates. This loose definition is generally agreed to cover a broad spectrum of concretes ranging in weight from 12 to 120 pounds per cubic foot.[1]* Many types of concrete fall within this range; some are cellular concretes made with foam or foaming agents; some are made with lightweight aggregates; and some cellular concretes also contain lightweight aggregates. Other lightweight concretes may contain some normal weight sand. The compressive strength of these concretes covers an even broader spectrum, with structural lightweights at 6000 psi[2] and higher at one extreme, and cellular fill concretes at 5 psi[3] at the other extreme. A related article beginning on page 253 describes the lowest density concretes.

Lightweight aggregate concrete is usually chosen for structural purposes where its use will lead to a lower overall cost of structure than would be expected with normal weight concrete. The generally higher unit cost of lightweight structural concrete is offset by reduced dead loads and lower foundation costs. There may be a special advantage when existing structures are being altered or expanded. For example, four stories were added to an existing Cleveland department store without modifying the foundation. When the Tacoma Narrows Bridge was replaced, the original piers were able to carry the load of additional traffic lanes, thanks to the use of struc-

* Superscript numbers refer to metric equivalents listed with this article.



Air-dry densities of lightweight concrete range from 12 to 120 pounds per cubic foot. Structural lightweight concretes at the right end of the spectrum have strengths of 2500 psi and above. Adapted from ACI 213R-79, Reference 1.

tural lightweight concrete in the bridge deck.

Types of aggregates

According to ACI (the American Concrete Institute), structural lightweight aggregate concretes have a 28-day compressive strength of 2500 psi[4] or more and a weight not exceeding 115 pounds per cubic foot.[5] Lightweight concretes for structural use derive their special properties from the use of low density aggregates whose particles have an internal cellular structure. These may be either processed or naturally occurring and unprocessed materials. The ACI guidelines for structural lightweight concrete are based on concretes made with processed aggregates meeting the requirements of ASTM Standard C 330. These include:

- rotary kiln expanded clays, shales, and slates
- sintering grate expanded shales and clays
- pelletized or extruded fly ash
- expanded slags

However, lightweight structural concrete may also be made with other types of aggregates such as naturally occurring pumice and scoria and with suitable cinders.

Properties of the lightweight aggregates such as particle shape and surface texture, specific gravity, unit weight, particle size, strength, moisture content, and absorption all affect properties of fresh and hardened lightweight concrete, just as comparable properties of normal weight aggregates do, but the quality of the cement paste also has an important influence on properties of the concrete.

Compressive strength

Lightweight aggregate particle strength varies with type and source of aggregate, and there is no reliable correlation between aggregate strength and concrete strength. All aggregates have strength ceilings, that is, a maximum strength attainable with a reasonable quantity of cement. The compressive strength of lightweight aggregate concrete is usually related to the cement content at a given slump, rather than to the water-cement ratio. The table shows some approximate relationships between average strength and cement content. In some cases, compressive strength can be increased by replacing part of the fine lightweight aggregate with good quality natural sand.

APPROXIMATE RELATIONSHIP BETWEEN CEMENT CONTENT AND AVERAGE STRENGTH FOR CONCRETES WITH 3- TO 4-INCH SLUMP AND 5 TO 7 PERCENT AIR[6]

Compressive strength, psi	Cement content, pounds per cubic yard *All lightweight*	*Sanded lightweight*
2500	400 - 510	400 - 510
3000	440 - 560	420 - 560
4000	530 - 660	490 - 660
5000	630 - 750	600 - 750
6000	740 - 840	700 - 840

Based on data from ACI 213R-79.

Fire endurance and thermal properties

In addition to advantages based on their lightness, structural lightweight concretes resist fire better than ordinary concretes because of their lower thermal conductivity, lower coefficient of thermal expansion, and the inherent fire stability of aggregates already burned to over 2000 degrees F.[7]

For concretes exposed to the elements, structural lightweight has some advantages over normal weight concrete. The lower conductivity lengthens the time required for exposed members to reach a steady state temperature, and this resistance reduces interior temperature changes under transient conditions. Such a time lag moderates solar buildup and nightly cooling effects. In tall buildings, the lower coefficient of thermal expansion for exposed lightweight columns means a reduction in volume changes and the stresses associated with them.

Specifications

Many structural lightweight aggregate suppliers have suggested specifications and mix proportioning information pertaining to their materials, and some offer field control and technical service to ensure that the specified quality of concrete will be used. Usual specifications for structural lightweight call for a minimum compressive strength, maximum slump, maximum weight, and both maximum and minimum values for air content. However, the contractor will also be concerned with properties of the freshly mixed concrete, such as bleeding, workability, and finishability.

Air entrainment, admixtures

As with normal weight concretes, water-reducing or plasticizing admixtures are frequently used to increase workability and make concrete easier to place and finish. Entrained air also contributes to workability, and improves durability of lightweight structural concrete just as it does for normal weight concrete. ACI recommendations for total air content by volume in lightweight structural concrete are:

4 to 8 percent for ¾-inch[8] maximum aggregate

5 to 9 percent for ⅜-inch[9] maximum aggregate

Compressive strength can be lowered 150 psi[10] or more for each extra percent of air beyond the above limits, and it is not wise to increase air content beyond specified limits in an effort to reduce concrete unit weight.

Mixing and placing

In general, procedures for mixing lightweight structural concrete are similar to those for regular weight concretes, but some of the more absorptive aggregates may require prewetting prior to addition of other mix ingredients. Water added at the batching plant should be sufficient to provide the specified slump at the building site; slump at the batching plant will probably be appreciably higher.

Adequate workability, as indicated by the concrete slump, is necessary in order to realize all of the desired properties of the hardened concrete. Slump for floor concretes is generally limited to 4 inches,[11] but a lower slump of 3 inches[12] may be better for maintaining cohesiveness of the mix and preventing lighter coarse particles from working up through the mortar to the surface during finishing. With certain aggregates deficient in minus No. 30[13] sieve material, finishability can be improved by using a portion of natural sand to supplement the lightweight fines.

A well proportioned lightweight mix can generally be placed, screeded and floated with less effort than that required for normal weight concrete. Surface preparation prior to troweling is best done with aluminum or magnesium screeds and floats to minimize surface tearing and pullouts of aggregate. Vibrating screeds may be advantageous, but overvibration and overworking may cause finishing problems. Too much finishing effort can drive the heavier mortar away from the surface where it is needed and bring an excess of the lighter coarse aggregate to the surface.

Pumping lightweight structural concrete

When considering the pumping of a lightweight aggregate concrete mix, specifiers, suppliers, and contractor should all be consulted regarding mix adjustments, so that the best possible pump mixture can be determined. A field trial using the pump and the mix planned for the job is recommended. It is usually important to presaturate the lightweight aggregate that is to be used in a pumped mix. Presaturation reduces the ability of the aggregate to absorb water during the pumping process, and so it minimizes loss of slump during pumping. The extra moisture absorbed increases the density of the aggregate, which in turn increases the concrete density, but this added weight will eventually be lost to the air during drying, and it provides added moisture for curing the concrete during the drying period. Such concrete should be allowed to dry adequately before exposure to freeze-thaw cycles.

Conclusion

Lightweight aggregate concrete has been shown by test and by performance to behave structurally in much the same manner as normal weight concrete. For properties which differ, the differences are largely those of degree. The designer must consider the benefits of lighter weight and better insulation in relation to the extra cost of the lightweight mix. The builder must recognize the few different requirements relative to transporting, plac-

STRUCTURAL LIGHTWEIGHT CONCRETE REDUCES DEAD LOADS IN WORLD'S TALLEST REINFORCED CONCRETE BUILDING

The building reaches 74 stories into the air, but Water Tower Place in Chicago doesn't rest on bed rock. Instead, the caissons go down only about 80 feet to hard pan. Structural engineers attribute the saving to the use of structural lightweight concrete weighing 105 pounds per cubic foot instead of a more conventional 145-pound concrete mix. Their decision, the first of its kind on this scale, reduced slab dead loads more than one third.

Experience with the John Hancock Building, immediately north of Water Tower Place, indicated dimensions of the challenge. Without the lightweight concrete, Water Tower Place foundations would have had to go 120 feet to reach bed rock—plus another 5 or 6 feet into the rock.

Construction of Water Tower Place began in 1972 and was completed in 1976 at a cost of about $195 million. At 870 feet, it still holds the record as the world's tallest reinforced concrete building.

ing, and finishing. Much helpful information is available from producers of lightweight aggregates through their field control and technical service.

Acknowledgement:

The foregoing article is based on information contained in "Guide for Structural Lightweight Aggregate Concrete (ACI 213R-79), published by the American Concrete Institute, Box 19150, Detroit, Michigan 48219.

Metric equivalents

(1) 7 to 71 kilograms per cubic meter

(2) 41.36 megapascals

(3) 0.0345 megapascals

(4) 17.24 megapascals

(5) 68 kilograms per cubic meter

(6) Approximate relationship between cement content and average strength for concretes with 75- to 100-millimeters slump and 5 to 7 percent air

Compressive strength, megapascals	Cement content, kilograms per cubic meter	
	All lightweight	Sanded lightweight
17.24	237 - 303	237 - 303
20.68	261 - 332	249 - 332
27.58	314 - 392	291 - 392
34.47	373 - 445	356 - 445
41.37	439 - 498	415 - 498

(7) 1100 degrees Celsius

(8) 19 millimeters

(9) 10 millimeters

(10) 1.03 megapascals

(11) 100 millimeters

(12) 80 millimeters

(13) 0.6 millimeter

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