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Structural Lightweight Aggregate Concrete (Concrete Technology, Structural Design)

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Section 1. Introduction

The increased emphasis on more efficient use of materials in structures, coupled with the increasing scarcity in many parts of the world of good-quality natural aggregates, has led to the rapid increase in the use of manufactured lightweight aggregates in concrete. Because structural-quality concrete can readily be made with many of these aggregates, large amounts are being used in concrete construction; not only in the United States of America but also in other parts of the world. In the United States and Canada alone, the current annual production of manufactured lightweight aggregates of all types is approaching ten million cubic meters. Almost forty percent of the total production is employed in structural lightweight concrete, the remainder being used primarily for concrete block production and insulating concrete. The rate of growth in the use of lightweight aggregate for structural concrete is especially significant. For rotary kiln type aggregate, which represents about seventy percent of the total production of all types, the use for structural concrete has increased from less than 30,000 cubic meters in 1952 to a present consumption in excess of 3,000,000 cubic meters. Lightweight structural concrete has been used for many different applications including multi-storied buildings such as apartment houses, office buildings, garages, hotels and the like; innumerable types of shells including folded plates; in the decks of bridges and overpasses; and in fact in all types of structures where a reduction in weight can reflect overall economy. A few of the significant projects constructed with structural lightweight concrete include the monumental TWA Terminal Building at Kennedy

International Airport, the 60-story Marina Towers in Chicago and the Statler Hilton Hotel in Dallas. Thus structural lightweight aggregate concrete can be seen to have rapidly emerged as an important sector of the structural concrete industry.

Since the mechanical properties of structural-quality lightweight aggregate concrete are very similar to those of normal-weight concrete, except for unit weight, design of both conventionally reinforced and prestressed lightweight concrete can be based on the same premises as those used for conventional concrete. Structural lightweight aggregate concrete, however, possesses unique properties differing in significant aspects from those of normal-weight concrete. To fully exploit the potential of this material requires careful consideration of these unique properties and their effect on structural behavior.

Although the use of lightweight aggregate concrete has rapidly expanded and the potential for increased use in the future is unquestioned, for many engineers, architects and contractors, lightweight concrete is still a subject of confusion. This confusion is partly the result of the wide variety of natural and manufactured lightweight aggregates available for making concretes having a wide range of densities and other physical properties. Fig. 1 shows the spectrum

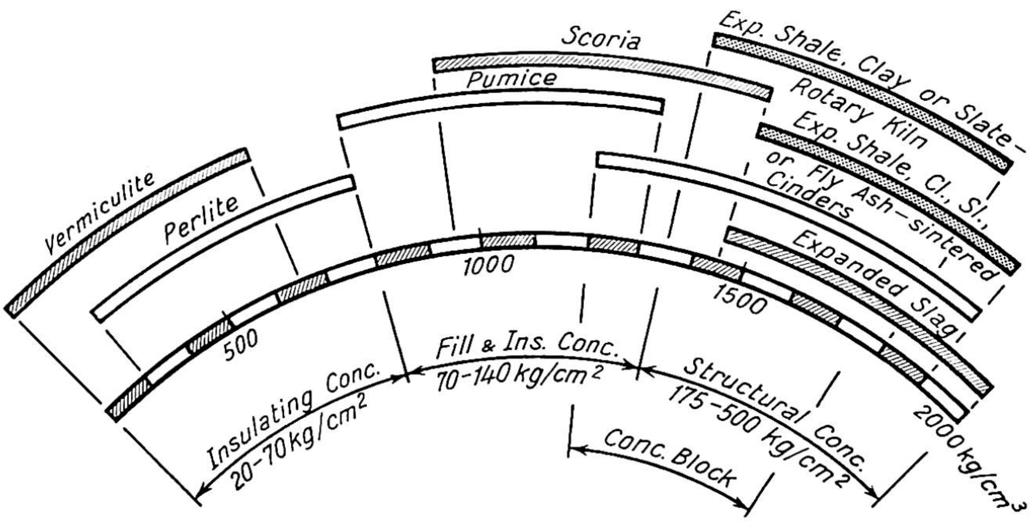

Fig. 1. Spectrum of Lightweight Aggregate Concretes

of lightweight aggregate concrete, ranging from insulating concretes weighing as little as 240 kg/m³ to the denser structural-quality concretes weighing as much as 2000 kg/m³. The discussion in this report is limited to lightweight aggregate concrete of structural quality which is defined as:

Structural Lightweight Aggregate Concrete. Concrete containing expanded or porous aggregates and having a unit weight of 1350–2000 kg/m³ and a 28-day cylinder strength of 175–500 kg/cm².

For comparison purposes, conventional structural concrete is defined as:

Structural Normal-Weight Concrete. Concrete containing natural crushed stone or sand and gravel aggregates and having a nominal unit weight of 2400 kg/m³ and a 28-day cylinder strength of 175 to 500 kg/cm².

Section 2. Lightweight Aggregates for Structural Concrete

The production of structural quality lightweight concrete is predicated on the availability of lightweight aggregates of high quality. Referring again to Fig. 1 it may be seen that several types of aggregates at the upper end of the scale are available for structural concrete. Not all of these materials, however, can be used to produce high strength concrete without the addition of natural materials and/or excessively high cement factors. The natural aggregates in this range, pumice, scoria and tuff are lightweight materials generally found in volcanic deposits. Combined with natural sand some of these materials can be used to produce fairly good concrete but high strengths are difficult to obtain and generally require excessive cement content.

The raw materials used in the commercial production of structural lightweight aggregate are either materials found in a natural state, such as certain clays, shales and slates, or by-products from other commercial operations such as slag from blast furnaces or fly ash from the burning of coke or coal in power plants. Cinders, while used extensively for concrete block, have poor and variable concrete-making properties and are not currently used as a structural lightweight aggregate.

At the present time there are at least one hundred plants in the U.S.A. alone producing structural lightweight aggregate. Of these, approximately sixty plants employ the rotary kiln process. In this process, raw clay, shale or slate is heated and expanded under controlled conditions in rotary kilns. The other forty plants are about equally divided between sintering plants and blast furnace expanded slag plants. In the sintering process, raw clay, shale, slate or fly ash, is mixed with pulverized fuel and burned and expanded under controlled conditions on a moving grate. Expanded slag is produced by subjecting molten blast furnace slag to jets of water, steam and/or air, under controlled conditions.

In these processes expansion is produced by the formation of cells in the aggregate either by (1) formation of gases such as SO_2 or CO_2 which bloat the plastic mineral components; (2) burning off of combustible materials; or (3) formation of steam contained in the minerals. The resulting product is a lightweight cellular aggregate with cells ranging from microscopic to several millimeters in their longest dimension, dependent on the manufacturing process employed and the raw material used. For an ideal structural aggregate the resulting cell structure would be a honeycomb structure consisting of voids, moderate in size and completely separated by strong cell walls.

The output from most plants is a clinker which must be cooled, crushed and screened to produce a suitably graded aggregate. These aggregates are generally sharp, angular, and have a pitted or porous surface texture. By presizing or pelletizing the raw material feed and controlling burning to prevent or minimize agglomeration a more rounded aggregate can be produced, both with the rotary kiln and the sintering process.

It is evident from the above that the several different processes and materials available can produce many different types of aggregates ranging widely in their properties. It must be recognized, however, that all these processes and materials have been used successfully to produce lightweight aggregates with good service records and that as much or more variation is encountered in conventional aggregates now in service.

Section 3. Properties of Structural Lightweight Aggregates

While the properties of lightweight aggregates, as a class, can vary considerably, the physical characteristics of a lightweight aggregate from a single source is usually quite consistent—and should be expected to be so. As a class, however, lightweight aggregates possess unique properties which distinguish them from normal-weight aggregates. An understanding of these unique properties is required to exploit the full potential of these materials.

3.1. *Unit weight* of these aggregates is significantly lower. Structural lightweight aggregate concrete provides a 30% weight reduction to make it a practical material in many applications where the use of normal-weight concrete would not be feasible. The finer fractions generally have a somewhat greater unit weight due to the fact that they tend to include fractions of material which have bloated least. This difference in density between aggregate fractions explains a somewhat greater tendency for segretation in stockpiles. Consistent aggregate gradation is more critical for lightweight aggregate because changes in gradation can cause fluctuation in both the unit weight and other properties of the concrete.

3.2. *Maximum size* of lightweight aggregates is generally smaller than most normal-weight materials. For expanded slags and shales, the top size is usually 1–2 cm, although some of the rotary kiln shales are available in sizes up to 2.5 cm. In certain respects, the requirements for normal weight, compared to those for lightweight concrete, as for example optimum air content, are about the same if maximum aggregate size is considered.

3.3. *Particle shape* of lightweight aggregate, as previously noted, can be quite varied, ranging from the rough and irregular crushed aggregates, with pitted and harsh surfaces, to the rounded and smooth pebbles produced by presizing the feed and controlling the burning process.

3.4. *Apparent specific gravity* of the particles is very low, as compared to conventional aggregates. Since the expanded particles contain voids or dead air spaces, this property is difficult to determine, especially in the fine fraction, because of variable absorption. The specific gravity varies, as does the unit weight, with the size of the particles. Larger pieces have the lowest values while the smaller particles are heavier.

3.5. *Strength* of the aggregate particles varies from type to type. Some may be weak and friable, whereas others are tough and hard. This property need not necessarily preclude its use in structural lightweight concrete but is reflected in the range of compressive strengths for a given cement content and consistency, particularly for higher strength concretes.

3.6. *Aggregate soundness*, as determined by performance tests of concrete using standard freezing and thawing procedures, is generally equal to that for good quality normal-weight aggregates. Inclusions of pop-out materials, such as burned lime or iron compounds, which contribute to unsoundness and staining, respectively, should not be permitted to be present in deleterious amounts.

3.7. *Absorption* of lightweight aggregates is high compared to the one to two percent water, by weight of dry aggregate, absorbed by normal-weight aggregates. The latter usually contain sufficient internal moisture at the time of batching so that they absorb little if any additional water during the mixing operation. Hence in normal-weight concrete the amount of mixing water required can readily be adjusted to compensate for absorption. In contrast, most lightweight aggregates can absorb 5 to 20% water by weight of dry material. Total absorption does not normally occur during mixing and before placing hence allowance must be made for the aggregate's water demand to prevent stiffening of the mixture during the interval between mixing and placement.

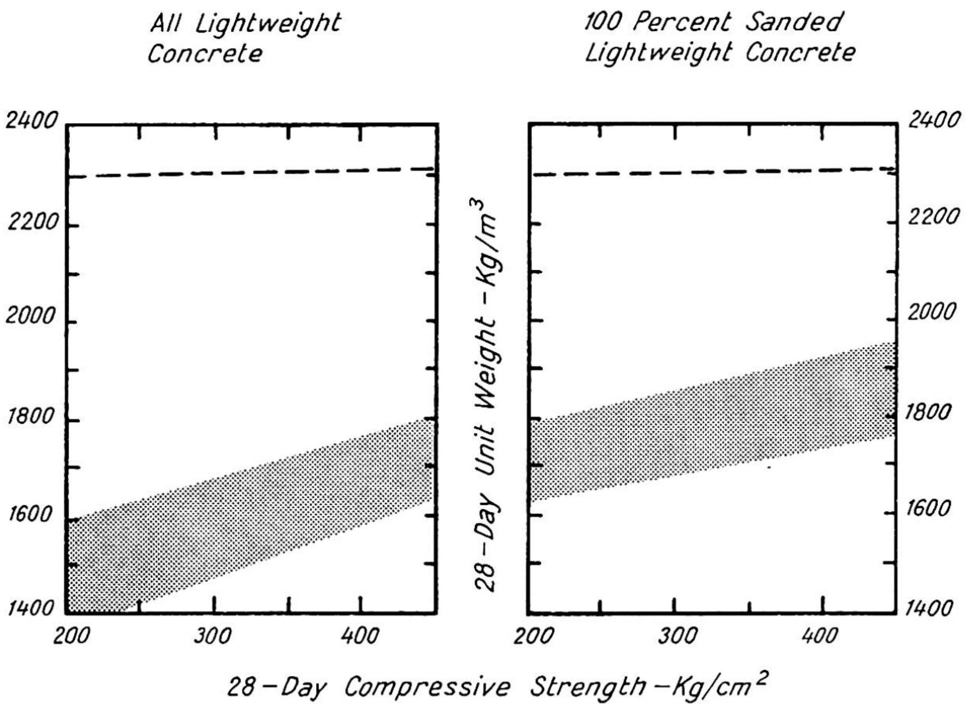

Fig. 2. Unit Weight

Thus the rate of absorption is an important factor which must be considered when uniform consistency is required in successive batches.

It should be noted that the absorbed water is not available to the cement paste in the mix during the hydration process and therefore bears no influence on the water-cement ratio. The *net* effective water-cement ratio for lightweight concrete is essentially the same, at comparable strengths, as that of normal-weight concrete.

The high-absorptive property of these aggregates, however, is not without its advantages. The absorbed water provides an internal reservoir of curing water which is available for the continued hydration of the cement, even after normal curing procedures have been discontinued. As a result, most lightweight aggregate concretes will continue to show significant gains in strength for several months after curing is discontinued.

Section 4. Physical Properties of Lightweight Aggregate Concrete

The summary of properties below is restricted to that part of the lightweight aggregate concrete spectrum in Fig. 1 considered suitable for structural concrete in load-bearing reinforced and prestressed concrete construction. With this restriction, the properties of almost all structural lightweight aggregates produced in the U.S.A., Canada and Australia fall within a broad band, but with a spread not much wider than that exhibited by conventional normal-weight aggregates. To a somewhat greater extent than with normal-weight aggregate concrete, the properties of lightweight aggregate concrete are affected by the moisture condition of the concrete. Also, many of the properties appear to bear a direct functional relationship to the unit weight, e. g. lighter concretes will have a lower modulus of elasticity and lower thermal conductivity than heavier concretes of comparable strength. On the other hand, there is no clear line of demarcation in properties on the basis of the type of aggregate, either as a function of the raw materials or the process employed in manufacture. Figures 2 to 8, inclusive, show the range of some of the more significant physical properties discussed below. The properties of Elgin sand and gravel concrete of comparable strength and consistency are shown by dotted curves for purposes of comparison.

4.1. *Unit weight* of structural lightweight aggregate concrete ranges from about 1350 to 2000 kg/m³ or about 60 to 80% that of normal-weight concrete of equivalent strength. This property is of course the principal justification for its use and can make it an economical structural material in spite of the higher cost of the lightweight aggregate (Fig. 2).

4.2. *Compressive strengths* up to a practical maximum of about 400 kg/cm² can be obtained with minor increases in cement content compared with normal-weight concretes of equivalent gradation and strength. Strengths in excess of

600 kg/cm² have been reported using certain aggregates and rather high cement contents. On the other hand, for a few aggregates the maximum strength is limited to about 350 kg/cm², presumably due to the lower strength of the aggregate particles. With most lightweight aggregates and foı a fixed cement content and consistency, replacement of the lightweight fines with natural sand increases the compressive strength. This increase is usually, but not always, accompanied by an increase in unit weight (Fig. 3).

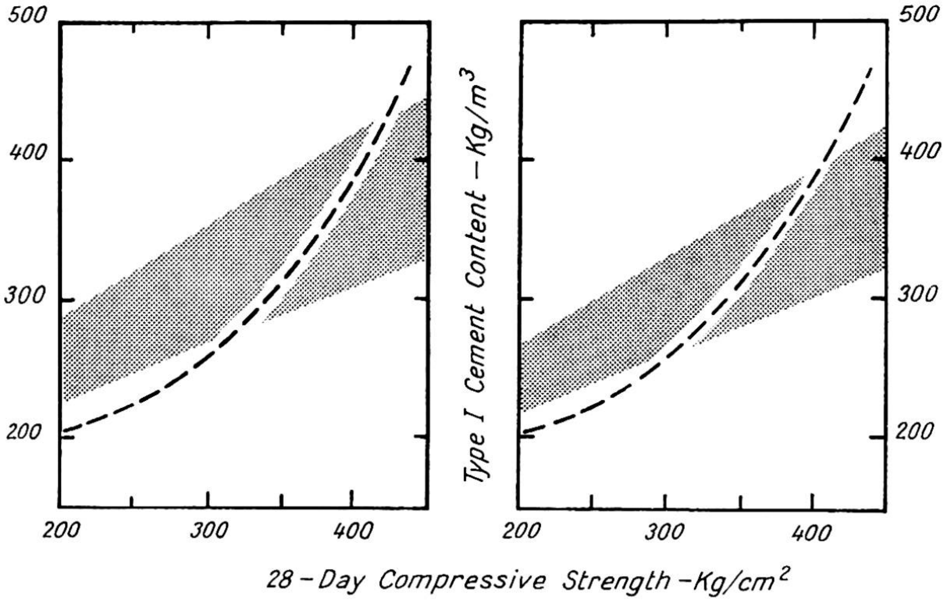

Fig. 3. Cement Content

As with normal-weight concrete, steam curing accelerates development of compressive strength. Due to the effects of better insulation qualities of lightweight concrete, somewhat higher accelerated strengths may be obtained than with comparable normal-weight concrete cured under identical steaming conditions.

4.3. *Shear (Diagonal Tension), Tensile Splitting Strength and Modulus of Rupture* are all properties closely related to the tensile strength. The tensile splitting strength can therefore be used as a convenient index of these properties. For continuously moist-cured lightweight concretes the tensile splitting strengths fall within a relatively narrow band which is not essentially different from the band for normal-weight concretes. The tensile splitting strength for lightweight concrete specimens which have undergone drying, however, is considerably less than that of continuously moist cured specimens. This decrease appears to be due to differential shrinkage stresses resulting from a differential moisture content between the interior and exterior portions of the specimen. This differential shrinkage induces tensile stresses in the exterior shell which are balanced by compressive stresses in the interior zones and a decreased tensile splitting strength results. Sand replacement of some of the lightweight fines

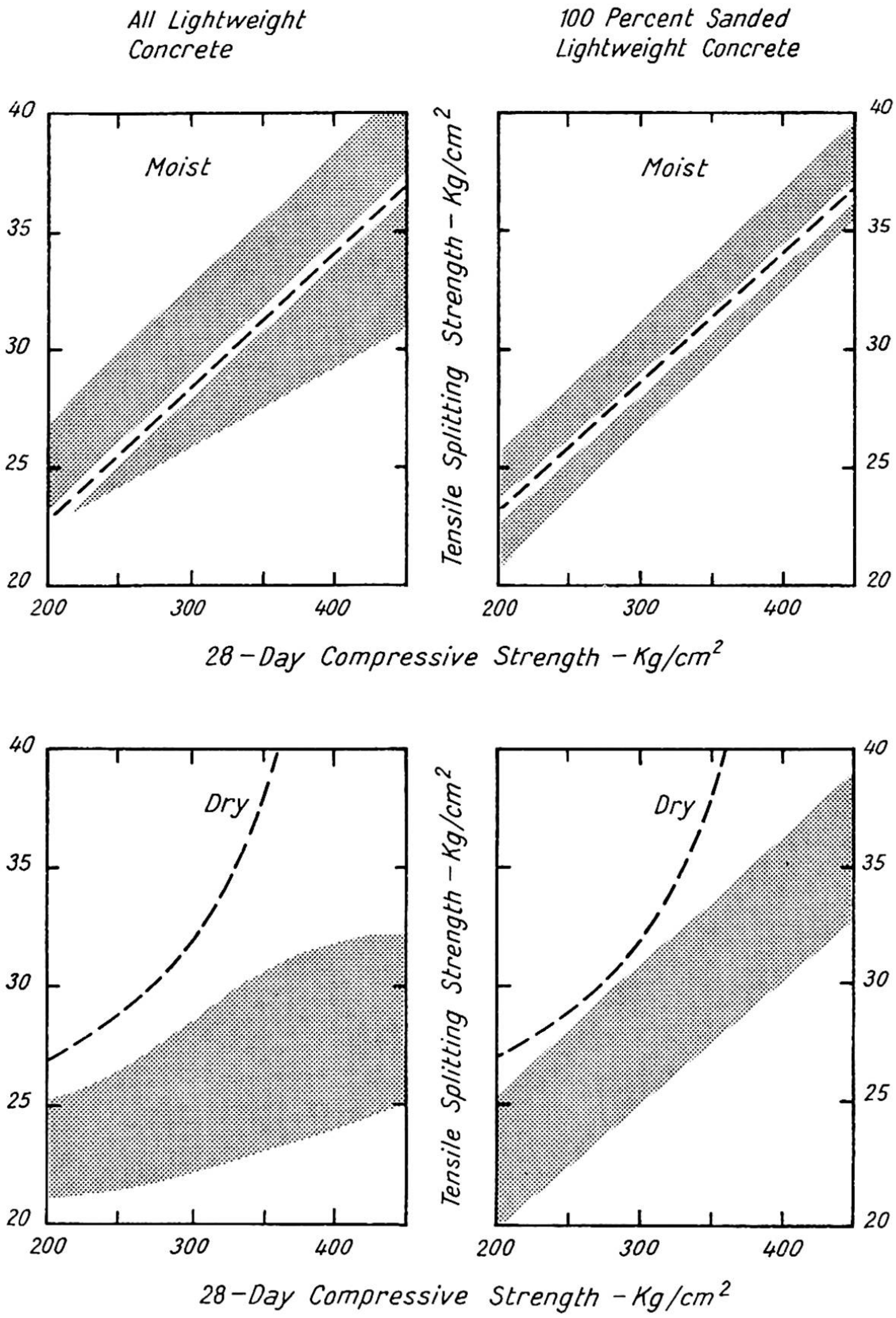

Fig. 4. Tensile Splitting Strength

has been found to improve the tensile splitting strength of dried lightweight concrete, with, in many cases, a partial replacement of as little as one third being almost as effective as full replacement (Fig. 4).

4.4. *Bond strengths* as determined by pull-out tests of deformed bars average about seventy percent of the values for normal-weight concretes of comparable compressive strength. Pull-out bond strength values tend to vary over a wide range, both for normal-weight and lightweight concrete, and failure may either be due to splitting, as a result of a wedging action, or due to crushing of the concrete under the bar deformations. Sand replacement appears to be beneficial for some lightweight aggregate concretes. Further research is needed to determine the effect of the aggregate on bonds strength as well as to establish the relevancy of the pull-out test as a measure of bond strength (Fig. 5).

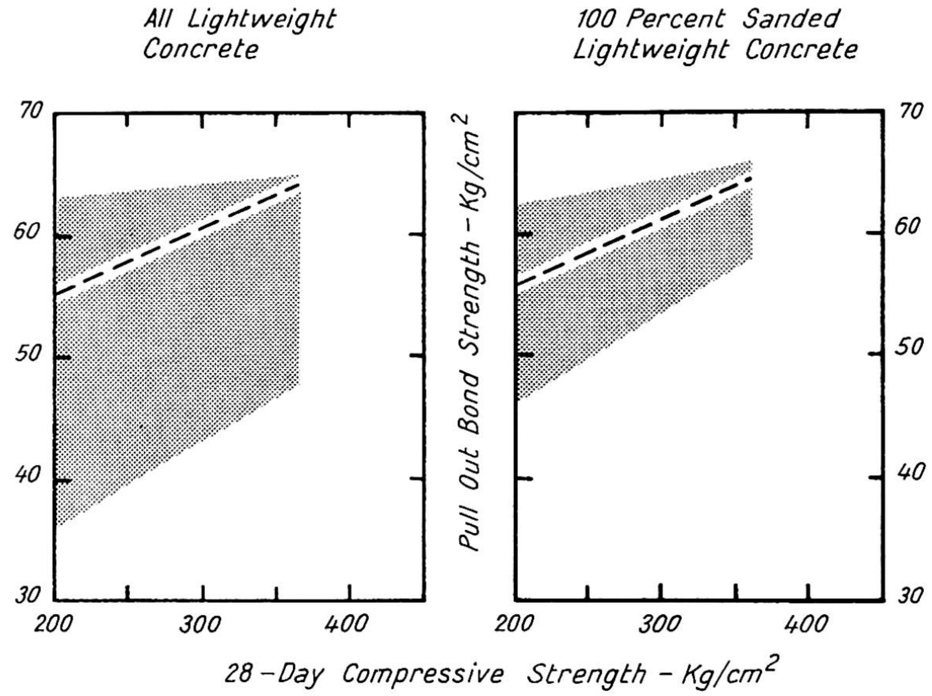

Fig. 5. Bond Strength

4.5. *Modulus of elasticity* normally ranges from 110,000 to 210,000 kg/cm², and is therefore about ½ to ⅔ the value for normal-weight concrete. The modulus for both normal and lightweight concretes can be approximated by an empirical formula of the form:

$$E = a \sqrt{f_c' W^3}$$

The value of a is a function of the aggregate and ranges from about 0.12 to 0.16, when

E = modulus of elasticity, kg/cm²
f_c' = compressive strength, kg/cm²
and W = unit weight, kg/m³.

The limited test data available indicates that, for all practical purposes, for lightweight concrete the modulus of elasticity for tension is the same as for compression (Fig. 6).

4.6. *Poisson's ratio* is about the same for both normal-weight and lightweight structural concrete. A value of 0.20 is usually assumed for design purposes.

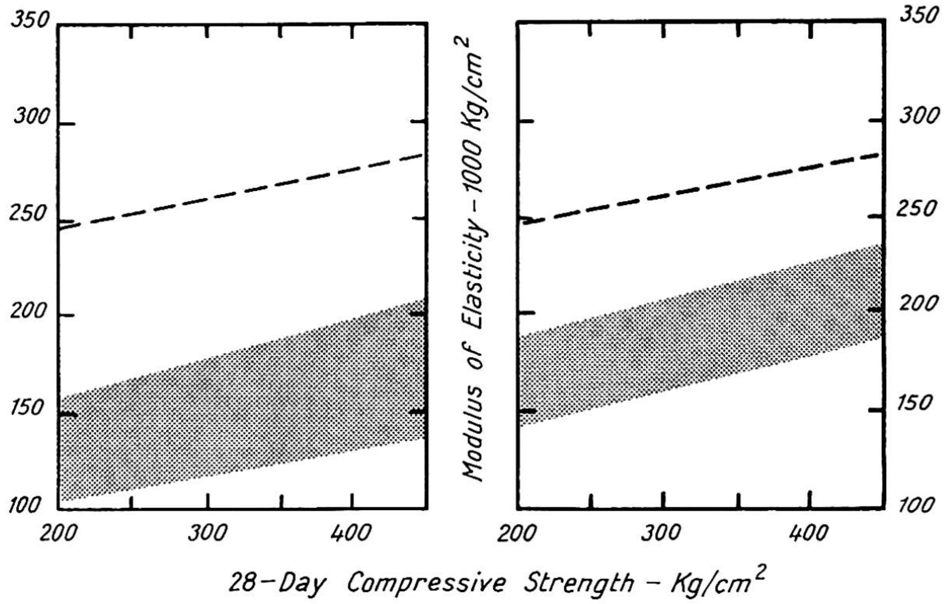

Fig. 6. Modulus of Elasticity

4.7. *Creep and Shrinkage* are closely related phenomena which vary over a wide range for both normal and lightweight concrete. On the average, however, both creep and shrinkage are considerably greater for lightweight concrete. For convenience, it is generally assumed that the principle of superposition applies. Hence, creep, i.e. the dimensional change with time due to sustained stress, is usually measured by subtracting the drying shrinkage of companion unloaded specimens from the total deformation of loaded specimens. Creep, thus determined, appears to be an inverse function of the strength, with most of the creep growth taking place during the early months after load is applied. The fact that lightweight concrete gains strength at a lower rate is therefore a partial explanation for increased creep values. Shrinkage, on the other hand, is primarily related to the rigidity of the aggregate and may increase with strength (Figures 7 and 8).

The use of sand as fines reduces both creep and shrinkage, probably through the reduction of mixing water required. Steam curing also reduces both creep and shrinkage by amounts ranging from 20 to 40%.

4.8. *Ultimate Strains* for most lightweight concretes are somewhat greater than the value 0.003 permitted by the ACI code. The stress-strain curve for lightweight concretes tends to be linear up to higher ratios of compressive strength and as a result both the area ratio, $k_1 k_3$, and the depth ratio to the centroid of the stress block, k_2, are somewhat less than for structural normal-weight concretes. Additional research is needed to substantiate the use of the coefficients for normal-weight concrete for ultimate strength design with structural lightweight concrete.

4.9. *Other Physical Properties.* Structural lightweight concretes are surprisingly durable. Resistance to freezing and thawing has been shown to be

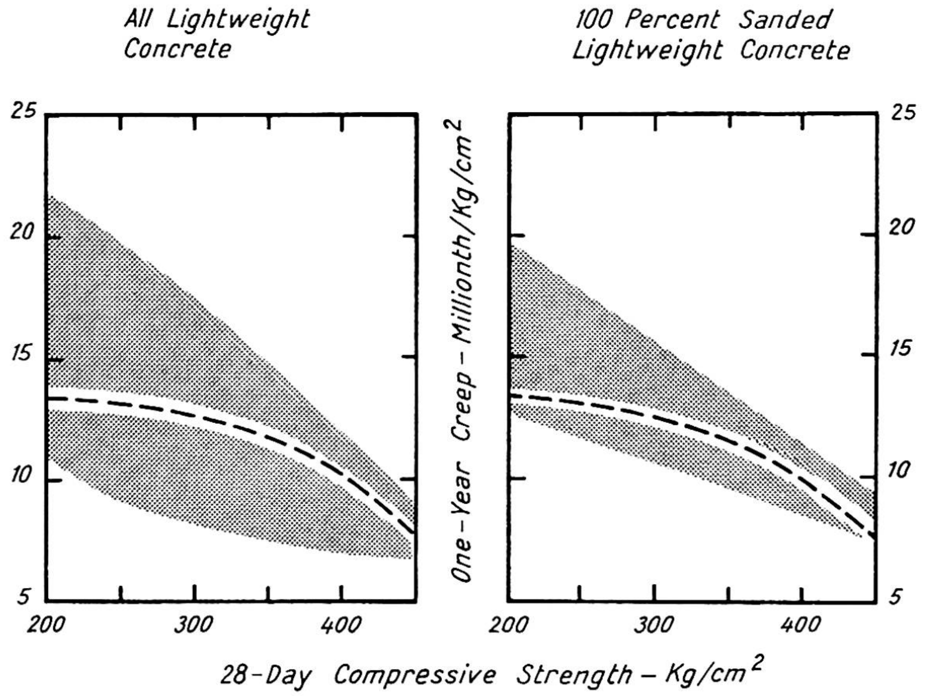

Fig. 7. One-Year Creep

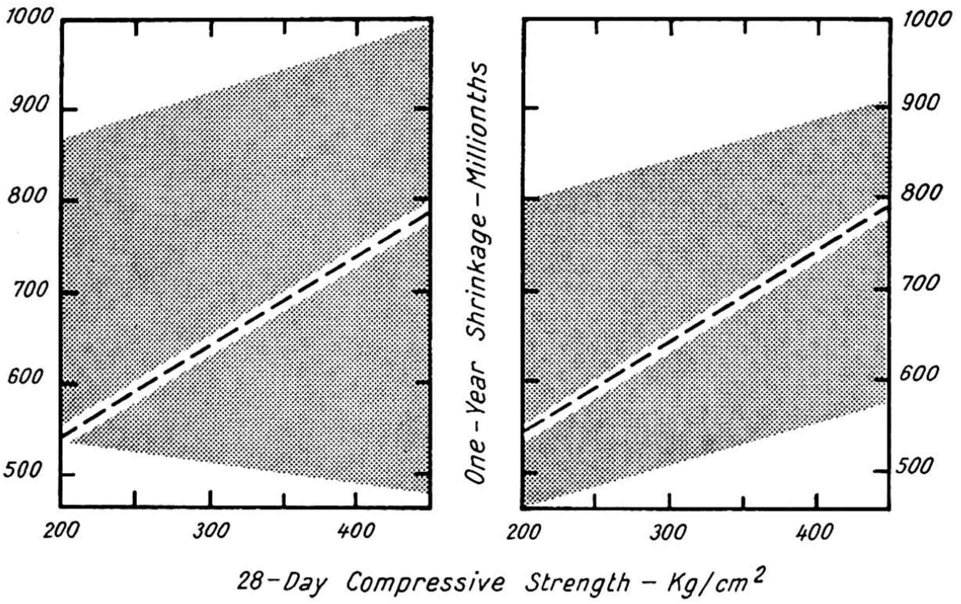

Fig. 8. One-Year Shrinkage

equal to or better than that of normal-weight concrete, both with and without air entrainment. Air entrainment not only provides a high degree of durability against freeze-thaw and salt scaling but also materially improves workability. Lightweight concrete can absorb from 12 to 22% water by volume as compared to about 12% for normal-weight concrete. Any relationship which may exist between absorption and durability is uncertain and devious, as witnessed by the fact that air entrainment improves durability without appreciably altering absorption.

Cover over reinforcement is generally specified the same as for normal-weight concrete. No evidence of any material difference in corrosion protection has been reported. The rough and hard surface characteristics of the aggregate result in good wearing qualities as testified by the excellent service record of many bridge decks constructed with lightweight aggregate concrete. Because of its lower tensile strength, however, this material is subject to "plucking" and spalling under localized impact. A thin epoxy surfacing has been found to be a good solution for restoring and protecting areas subjected to extreme localized abrasion or wear.

The thermal coefficient of expansion is about 80% that of normal-weight aggregate concrete with intermediate values resulting when sand is used as a replacement of lightweight fines. Thermal conductivity is a function of the dry unit weight of the concrete, and ranges from a fifth to a third that of normal-weight concrete. As a result, lightweight aggregate concrete provides 20–50% better fire resistance as well as improved thermal insulation.

Section 5. Design Rules

Lightweight aggregate concrete structures have been shown, both by tests of structural elements and by field performance, to behave in much the same manner as those constructed of conventional concrete. With respect to most concrete properties, the performance is merely one of degree; the basic design principles are the same and at most only minor adjustments need be made to accommodate the effect of property differences. In the past, many successful structures have been designed using structural lightweight aggregate concrete with no other design modifications than a reduction in the dead load assumed.

For many of the properties of lightweight concrete, the difference does not warrant design modifications under usual design conditions. Thus, while the thermal coefficient of expansion is slightly lower and shrinkage is somewhat greater, modification of shrinkage and temperature reinforcement requirements is not justified. Similarly, the permeability of structural lightweight aggregate concrete and the crack width and spacing are not sufficiently different to warrant changes in minimum cover requirements over reinforcement. For other properties, such as creep and shrinkage, the dispersion is so greath, both for normal and lightweight concrete, that average values can only be used as a guide for engineering judgement. When such properties are critical in determining performance, design should be based on test data for, or experience with, the specific materials used.

Other than weight, the properties of structural lightweight aggregate concrete that are significantly different to require design modifications are tensile strength and modulus of elasticity.

5.1. *Flexural elements* governed by flexural strength may be proportioned the same as conventional concrete beams and slabs subjected to the same total load. This procedure is justified since the ultimate strength design requirements for flexural computations apply without modification to structural lightweight aggregate concrete. The effect of lower tensile strength, however, should be considered in: (a) Providing for shear and diagonal tension; (b) Calculating the cracking load capacity of prestressed elements; and, (c) For deflection calculations, in determining the point where the section changes from a homogeneous to a cracked section. Similarly, the bond capacity may be reduced, although, bond is rarely a design criterion for high bond reinforcement.

When deflection criteria govern the design, minimum depths may need to be increased as much as 20% to compensate for the effects of the reduced modulus of elasticity and increased shrinkage and creep. It should be noted that the decrease in flexural stiffness of the member is not directly proportional to the decrease in the elastic modulus of the concrete due to the increase in the modular ratio, i.e. the ratio of the modulus of elasticity of the steel to the modulus of the concrete. This increase in modular ratio is also beneficial, at working-load levels, in terms of distribution of stresses in the compression zone. Thus for comparable sections with equal reinforcement ratios, the neutral axis is lower in a beam section with lightweight concrete than in a beam with normal-weight concrete. As a result, concrete stresses at working-load levels are somewhat lower in lightweight concrete flexural members than in conventional concrete members of equal depth. These factors, together with reduced dead load, tend to compensate for the reduced stiffness due to decreased modulus of elasticity. Similarly the moment induced by shrinkage is comparable; the increased shrinkage potential for lightweight concrete being compensated by the lowering of the neutral axis.

While the lower *E*-value for lightweight structural concrete results in more flexible members, this reduced stiffness can at times be beneficial. In cases of impact or dynamic response, and in certain types of highly redundant structures, including shells with fixed edges, the reduced stiffness tends to reduce localized stress concentrations.

The size and shape of structural members has been shown to be of considerable importance with respect to creep and shrinkage and, to some extent, the tensile strength of lightweight concrete. Because these properties are related to a loss of moisture and because the rates of both creep and shrinkage tend to be greater at early ages, before the concrete has gained its full strength, thin sections and sections having a large exposed surface area to volume ratio tend to exhibit much greater creep and shrinkage as well as reduced tensile strength. At the present time, American design codes do not take this shape factor into account although this phenomenon has been recognized in some of the European codes and in the C.E.B. recommendations.

While lightweight structural concrete may be used in prestressed concrete members, the effect of decreased modulus and lower tensile strength must be taken into consideration in computing prestress losses and in the design of end anchorages. Although the dead load deflections will tend to be balanced by the camber due to prestress, axial shortening of the member will be greater and result in greater end movements at bearing supports. The net camber of prestressed structural lightweight concrete members tends to vary somewhat more widely. Because of the greater thermal insulation offered by lightweight concrete, temperature differentials tend to be somewhat greater. Also, being more absorptive, lightweight structural concrete members are more susceptible to warping and other distortions due to differential moisture changes.

5.2. *Columns* can also be proportioned on the same basis, regardless of whether lightweight or normal-weight concrete is employed, provided buckling is not a design criterion. While the stress division of axial loads to concrete and steel is somewhat different, because of somewhat greater shrinkage and creep, ultimate strength capacity, being independent of modulus of elasticity, is the same. For long columns, however, the reduced stiffness of the section must be taken into account. Insufficient evidence is available on the performance of long columns, with a slenderness ratio greater than fifteen, made of lightweight concrete. At the present time, it would seem logical to apply a factor of 0.8 to constants in load reduction formulas when lightweight aggregate concrete is used.

Because columns constitute a relatively small fraction of the total volume of concrete used in multi-story buildings, and because of the present trend toward greater column spacing coupled with smaller column size, it has become standard American practice to use very high-strength concrete in the columns and lower strength concrete in the floor systems. The use of normal-weight concrete in columns together with lightweight concrete in the floor system is both an economical and a practical solution and helps to avoid accidental use of the wrong type of concrete in the columns.

Section 6. Construction Procedures

High quality structural lightweight concretes, that present no particular problems in either placing or finishing, can readily be obtained by adhering to the fundamental principles of concrete mix design and control and by considering the unique properties of the aggregate. Field problems can arise if these unique properties are not taken into consideration. Most of the difficulties—as well as the potential benefits—derive from the increased absorption and lower unit weight of lightweight aggregate.

Because of variable absorption, conventional mix design procedures and control methods are not directly applicable. Satisfactory substitute procedures, however, have been developed and should be employed. Air entrainment is almost always desirable, not only to improve durability but also to improve workability of the mix. Maintenance of uniform and consistent gradation is somewhat more critical because of variability of unit weight with aggregate size. Due to the lighter weight of the aggregate, lightweight concrete of a given workability does not slump as much as sand and gravel concrete. These lower slump consistencies are an advantage in placing concrete on steep slopes as, for example, in the case of shell roofs.

With respect to placing and finishing, lightweight concrete presents some advantages and also some disadvantages in comparison with normal-weight concrete. The principal advantage is, of course, the reduction in weight of the material which must be handled. Forms and shores therefore can be designed for much lighter loads. The reduced weight of the concrete which must be handled requires less energy and reduces wear and handling of equipment. The principal disadvantages resulting from the reduced weight of the aggregate are a tendency toward segregation, especially when the concrete is overworked or the mix is improperly designed. While some entrained air is desirable to increase the plasticity of the mix, an excess may produce blow holes and pock marks on the surface and make the concrete difficult to finish. Excessive vibration should be avoided to prevent segregation which, in lightweight concrete, is much more undesirable because the lighter coarse aggregate tends to float to the top while the heavier paste and the fines sink to the bottom.

Section 7. Applications

Structural lightweight aggregate concrete has been most widely utilized in buildings and similar applications where the reduced dead load justifies the increased cost of the material. In general, application of structural lightweight concrete falls into one of two categories.

The first category includes structures in which the dead load constitutes a large fraction of the total load and where lightweight concrete can be specified regardless of the cost of the material. Examples of such applications include the use of lightweight concrete in ships and in the reconstruction or modification of structures using existing foundations and/or substructures and where the total load is limited.

The second category includes applications where the decision to use structural lightweight aggregate concrete must be made on the basis of economic considerations. Factors which must be considered in selecting structural lightweight concrete include: (a) Reduction in the dead load, permitting shallower sections and smaller columns and footings; (b) Reduction of seismic loads; (c) Construction economies resulting from lighter forms, reduction of concrete handling costs, and for precast members, easier handling and erection and lower transportation costs; (d) Reduced modulus of elasticity and its beneficial and adverse effects on flexibility, including increased prestress losses in tendons; (e) Thermal characteristics, including the increased insulation and improved resistance to fire damage.

Structural lightweight concrete has been used successfully for floors and roofs, both in situ and precast, precast wall panels, bridge girders, bridge decks, and shell roofs. This material has been particularly useful in marine applications including floating structures such as ships and floating docks, because the submerged weight is only about half that of conventional concrete.

Recent design innovations and current developments in materials should make economically feasible an even wider range of applications. Structural lightweight aggregate concrete decks and floors in composite with either steel stringers or precast and/or prestressed girders have proven to be extremely economical. Voided slabs and composite sections consisting of precast units and cellular concrete fills can be used effectively to increase both the rigidity and the insulating properties of the section. Other developments currently under study and which may radically effect the application of structural lightweight concrete include the use of expansive cements to compensate for increased shrinkage, and the use of chopped wire or other fiber reinforcement to improve the tensile characteristics of concrete. While these modifications would increase the cost, this increase relative to the cost of structural lightweight aggregate concrete would be considerably smaller than for conventional concrete and therefore more readily justified.

In this summary report it was only possible to give an overview of the range of properties of lightweight aggregate concrete and to briefly touch upon the present applications of this material. The more detailed discussions by the Congress participants of such problems as quality control, both for lightweight aggregate production and of lightweight concrete; of the design and construction practices which best exploit the characteristics of this material; and of new developments and innovations for improvement, both of the material and of structural designs, should provide a comprehensive coverage of the status of lightweight aggregate concrete. These contributions should do much to bring into sharp focus the unique properties and potentialities of this superior construction material.

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