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RESEARCH

CONCRETE SHRINKAGE AND THERMAL EXPANSION
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"CONCRETE SHRINKAGE AND THERMAL EXPANSION"

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1. "A Short-time Test for Effect of Type of Cement on Concrete Shrinkage" G. E. Troxell - Nov. 1938, pp 73-80 (V. 35.).

   Procedure using short-time test results on 3 x 6 in. concrete cylinder and on 1½ x 1½ x 12-in. mortar bars from which the long-time shrinkage of concrete can be predicted with reasonable accuracy. Use is made of conversion factors determined for the special test conditions.

2. "Factors Affecting the Thermal Expansion of Concrete Aggregate Materials" Willard H. Parsons and Walter H. Johnson - Apr 1944. pp 457-468 (V. 40).

   As a part of a study of the properties of concrete aggregates, thermal expansion determinations were made on 137 specimens of aggregate materials and single crystals by the optical interferometer method over the temperature range -4 to +140F. The thermal expansivities of most aggregate materials are close to or within the range of expansivities of hardened portland cements. Crystal orientation, rock texture, and composition are discussed with regard to their effect on the thermal expansion of aggregate materials and their relation to the durability of concrete.

3. "Shrinkage Stresses In Concrete" Gerald Pickett - Jan 1946, pp 165-204, Feb. 1966, pp 361-400 (v. 42).

   Theoretical expressions for deformations of concrete beams and slabs that occur during the course of drying and expressions for distribution of the accompanying shrinkage stresses are derived in Part I. These expressions are derived on the assumption that the laws governing the development of shrinkage stresses in concrete during drying are analogous to those governing the development of thermal stresses in an ideal body during cooling. Three cases are considered:
   (a) slab or beam drying from one face only;
   (b) slab or beam drying from two opposite faces; and
   (c) prism drying from four faces.

   The applicability of the equations to concrete is considered in Part 2. It is shown that the course of shortening of prisms is in good agreement with the theoretical equations and that from a test on one prism the shortening versus period of drying of other prisms of the same material differing in size and number of sides exposed to drying can be predicted with fair accuracy if the differences in size are not too great. However, it is

shown that the theory must be modified to take into account in elastic deformation and to permit the supposed constants of the material to vary with moisture content and size of specimen if the theory is to be in agreement with all results on all types of specimen of a given concrete.

Various tests are described which, when used in conjunction with the theory, provide a means for studying some of the more fundamental properties of concrete and for predicting the performance of concrete under same conditions in the field.

4. "Lightweight-Aggregate Concrete" Ralph W. Kluge, Morris M. Sparks and Edward C. Tums - May 1949, pp 625-644, (V 45) J-Amer Conc Inst.

Results of studies on Lightweight-aggregate concretes made by the National Bureau of Standards at the request of the Housing and Home Finance Agency (formerly the National Housing Agency) are reported. Aggregates included were expanded Clay, shale, and slate; three types of expanded blast-furnace slag, expanded vermiculite and perlite, sintered diatomite and fly ash, and a mumice. Concrete of various proportions was made from these aggregates and determinations were made of the weight per cubic foot, compressive and transverse strength, shrinkage, elastic modulus, absorption, resistance to freezing and thawing, and thermal conductivity. Test results are briefly discussed and summarized.

5. "Slab Warping Affects Pavement Joint Performance" F. N. Hveem - J Amer Conc Inst June 1951, pp 797-808 (V 47)

An investigation of joint troubles and failure is discussed and method of determining thermal and moisture expansion in thin concrete specimens described. Evidence of warping and curling of pavement slabs and the sequence of events leading to pumping and subsequent faulting of joints are considered. It was evident that curling was due to combined effects of temperature differential and moisture. Profilograph studies of pavement surfaces are described.

6. "Thermal Expansion of Aggregates and Concrete Durability" Edwin J Calan - J Amer Conc Inst Feb. 1952, pp 485-504 (V 48)

Differences in durability of concretes containing aggregates from the same source and similar concretes containing different fine and coarse aggregates are explained partially by differences in thermal expansion of the coarse aggregate and the mortar. Methods were developed to obtain simply the thermal coefficients for numerous aggregates. Concretes were tested in accelerated freezing and thawing, yielding durability factors, DFE, for each combination. The DFE's were statistically analyzed with the difference between the thermal coefficients of coarse aggregates

and mortars, α_c, and corase aggregate absorption, A, as variables, For 78 concrete combinations a relation DFE = 109.65 − 8.76 α_c − 15.22 A was developed with a correlation expansion of mortar and coarse aggregate increased. Stresses set up by such differential expansion and their effects on concrete durability are discussed briefly. It is concluded that thermal effects of this type should be considered in choosing aggregates for highly durable concretes. The methods developed for determining coefficients of thermal expansion of coarse aggregate and mortar are described.

7. "Effect of Aggregate on Shrinkage of Concretes and a Hypothesis Concerning Shrinkage" Gerald Pickett - J Amer Conc Inst Jan. 1956, pp 581-590 (V 52)

   In addition to indicating the validity of the formula, the data give the following indications; (1) First shrinkage is greater than any subsequent expansion or shrinkage resulting from moisture change (2) At a given aggregate content the shrinkage is approximately proportional to water-cement ratio. (3) After first shrinkage, subsequent volume changes are approximately independent of water-cement ratio. (4) When shrinkages of specimens of the higher water-cement ration are plotted against the square root of period of drying, the shapes of the curves for second shrinkage are appreciably different from those for first shrinkage in that they have considerable curvature near the origin. An explanation of these effects is given.

8. "Lightweight Concrete Made With Expanded Blast Furnace Slag" D. W. Lewis - J Amer Conc Institute Nov. 1958, pp 619-634. (V 55)

   The tests reported provide data on both insulating and structural concretes made with typical expanded slag aggregates. The test data provide information on strength, durability, heat transmission, and unit weight of concretes made with various cement contents and amounts of entrained air. The effects of different aggregate top sizes and of various natural sand substitutions for the fine aggregates are discussed.

9. "Some Physical Properties of Concretes at High Temperatures" Robert Phillco - J Amer Conc Inst Apr. 1958, pp 857-864 (v 54)

   Experimental techniques are described and data are presented on the thermal expansion, density, and dynamic modulus of elasticity of concrete in the range 75-1500 F. Such information is necessary to evaluate stresses due to nonuniform heating which could result from a building fire or jet aircraft blast. The results indicate that weight loss due to loss of water is substantially complete at 800 F. At higher temperatures changes in weight are determined by the chemical nature of the aggregates. The coefficient of expansion increases above 800 F since expansion is no longer inhibited by drying shrinkage. At 1400 F the modulus of elasticity

10. "Lightweight-aggregate Concrete for Structural Use" J. J. Sideler J Amer Conc Inst , Oct. 1957, pp. 299-328(V 54)

Describes tests employed and results obtained in an investigation of properties of lightweight-aggregate concrete of structural quality. Eight lightweight aggregates and one normal weight sand-and-gravel aggregate are included. The total program includes tests of plain, conventionally reinforced, and prestressed concrete speciments, but except for pull-out tests of reinforcing bars, only the data on plain concrete are given. Data are reported on concrete mix proportions, compressive and flexural strength, modulus of elasticity, bond, creep, and drying shrinkage. Concrete mixes were designed to produce compressive strengths of 3000 psi and 45000 psi with each aggregate, and 7000 to 10,000 psi with three selected aggregates.

Comparing the various concretes on the basis of equal compressive strengths, normal weight sand-and-gravel concrete showed somewhat superior performance in most tests. In many structural applications, however, this superiority will doubtless be overshadowed by advantages resulting from reduced unit weight of the lightweight-aggregate concretes.

11. "Elevated Temperatures of Portland Cement Mixtures Related to Surface Removal" R. H. Heiskell, R. H. Black, R. J. Crew, and H. Lee, J Amer Conc Inst. Jan. 1958, pp 591-604 (54)

The effect of heat on the surface removal of concrete was studied by conducting brush tests on samples which had been subjected to prolonged high temperatures in an oven or in direct contact with an oxypropane flame. Other method of heat treating surface layers of concrete were investigated by direct application of an oxyaluminum torch on the surface and by the exothermic chemical reactions of pyrotechnic compositions placed directly on the surface.

Tests showed that an oven temperature of 1100 F is required to decompose portland cement compounds sufficiently to reduce the resistance of concrete surfaces to abrasive removal methods. The temperature produced at the surface ofconcrete by an oxypropane burner varied depending on the rate of traverse of the flame, from 200 to 800 F. Spalling of concrete surfaces can be accomplished by prolonged flame treatment with an expropane oxyacetylene burner. Flame treating with a moving oxpropane burner gave a termperature of 120-600 F at 2/64 in. below the surface.

No Spalling was observed when an oxyaluminum flame passed over the surface at a speed of 10 ft. per min; however, prolonged heating resulted in a rather violent spalling reaction.

12. "Analysis of the Strength and Fracture of Concrete Based On An Unusual Insensitivity of Cement-Aggregate Bond To Curing Temperature" K. M. Alexander and J. H. Taplin, Australian Journal of Applied Science Vol. 15, No. 3 pp 160-70. Sept. 1964.

Bond Strength of Cement and Aggregate typifying the materials most commonly used in Melbourne was independent of curing temperature. Therefore, since paste strength is temperature dependent, a fixed concrete strength for a given mix may arise from many different combinations of bond and paste strength, depending on the curing temperature. There is, in fact, a linear multiple regression of concrete strength on paste and bond strength, in which the coefficient for paste is approximately twice that for bond. The existance of a similar dependence of aggregate breakage on bond and paste strength is established, in keeping with the observation that the proportion of coarse aggretate broken when concrete ruptures under transverse loading is linearly related to concrete strength.

13. "The Flexural Strength of Plain Concrete: Its Measurement and Use In Designing Concrete Mixes" P. J. F. Wright, Great Brit. Road Research Lab.

This paper describes investigations into the dependence of the apparent flexural strength of plain concrete on the manner in which it is determined and the influence on flexural strength of changes in the concrete mix. The testing variables examined were the deminsions and method of the test specimens, the alternate techniques of central and third-point loading, and the rate at which the load was applied. The various effects of dimensions and method of loading are largely explained on a "weakest link" principle together with an observed difference in quality of concrete between large and small specimens. Increased rates of application of the load gave increased flexural strength; the observed value was linearly related to the logarithm of the rate of loading.

The investigation into the effect of variations in the concrete mix included the use of rounded gravel, irregular gravel and crushed-stone aggregates of 3/4-in. maximum size with water/cement (W/C) ratios between 0.4 and 0.7 by weight. Mixes were of very low workability and tests were made at ages from 7 days to 1 year. In addition more limited range of tests was made with the same three aggregate types but of 1½-in. maximum size and with a wider variety of aggregates of 3/4-in. maximum size. The tests with the wider variety of aggregates suggested that the three principal aggregates, rounded gravel, irregular gravel, and an angular crushed stone, gave results which

may be considered typical for their classes. For the same W/C ratio the crushed material gave appreciably higher strengths; curves are given relating the flexural strength at various ages to the W/C ratio.

14. "Gap Graded Mixes For Cast-In-Place Exposed Aggregate Concrete" Albert Litvin and Donald W. Pfeifer, Journal of the American Concrete Inst. No. 5 Proc V 62, p 521-537, May 1965.

Attractive uniform exposed aggregate surface of cast-in-place concrete may be achieved by the use of low-slump, gap-graded aggregate mixes. These mixes required a high percentage of coarse aggregate and low water-cement ratio, resulting in excellent strength and elastic properties with low creep and drying shrinkage.

Laboratory tests and field experience indicate that concretes with matrix volumes (air, water, cement, and sand) of 45 to 50 percent can be satisfactory consolidated and will possess excellent architectural characteristics. The importance of special care in such matters as taping of form joints, proper treatment of form ties, adequate vibration, etc., is stressed. Three typical structures are cited in which cast-in-place, gap-graded concrete was used to obtain excellent exposed aggregate surfaces.

15. "Changes In Weight and Dimensions in The Drying and Carbonation of Portland Cement Mortars" K. Kaminura, P. J. Sereda, and E. G. Swenson, Magazine of Concrete Research Vol. 17, No. 50, pp 5-14, March 1965.

Small specimens of mortar and paste were cured for 28 days and then subjected to various conditions of drying and carbonation. In general, the extense of carbonation, for a given CO_2 concentration, depends on permeability, moisture content and time, but the extent of carbonation shrinkage and ultimate volume stability depend on the compressibility of the aggregate, the water/cement ratio, the maturity of the paste, the drying environment and rate, and on the sequence of drying and carbonation. Some of the practical implications of these results are noted.

16. "Expansion of Concrete Through Reaction Between Cement and Aggregate" Thomas E. Stanton, Paper No. 2129 Trans Amer Soc of Civil Engrs. v 107, 1942, pp 54-126 (Discussion)

Tests have demonstrated that excessive expansion of concrete may occur through chemical reactions between cements of relatively high alkali content and certain mineral constituents in some aggregates, such as certain types of shales, cherts, and impure limestones found along the coast of California between Monterey

limestones found along the coast of California between Monterey Bay on the north and Los Angeles County on the south. A new test procedure is described in this paper through which it is possible, in a comparatively short time, to develop the deleterious characteristics of cement-aggregate combinations similar to those reported in the California study. The procedure consists of curing the specimens in sealed containers at normal temperatures.

17. "Properties of Expansive Cement Made With Portland Cement, Gypsum, and Calcium Aluminate Cement" G. E. Monfore, Journal of the PCA, Research And Development Laboratories, Vol. 6, No. 2, pp 2-9, May 1964.

Expansive cements made by mixing portland cement, calcium aluminate cement, and gypsum were studied. Mortars were used to evaluate the effects of composition and time and temperature of cure on strength, free expansion, shrinkage, and development of stress in restrained specimens.

Information on concretes made with the expansive cement developed at the University of California is reviewed. The properties of such concretes appear generally comparable to those obtained with the mixtures of portland cement, calcium aluminate cement, and gypsum. More information concerning loss of steel stress and durability of self-stressed concrete is needed.

18. "Impact Strength of Concrete" H. Green, Proc. Inst of Civil Engrs, July 1964, 28, 383-396. Road Abstracts, Vol. 31, No. 4 p 80, April 1964.

An investigation has been made of the effect of certain variables on the impact strength of concrete, and the results of impact and static loading were compared. Impact tests were made on 4-in. cubes and modulus of rupture and compression tests were made on 20- to 4- by 4-inch beams. A freely suspended ballistic pendulum was used to eliminate the effects of the rigidity of the foundation and framework. The specimens were subjected to repeated blows and the energy absorbed by the specimen during each blow was recorded. The impact strength of concretes made with ordinary portland cement and superersulfate cements increased with the compressive strength and age. The relationship between impact strength and compressive strength varied with the method of curing, the shape and surface texture of the coarse aggregate, and the type of cement. The impact strength of concrete made with high-alumina cementwas apparently not related to its compressive strength and was very variable. The modulus of rupture was not a good guide to the impact strength of the concretes tested.

19. "Investigation of Properties of Lightweight Concrete" Dean C. McKee and H. T. Turner, Louisiana State University, Div. of Eng. Res, Eng. Res. Bull. No. 74, 1964, 70 pp.

Results are reported of a study of the shrinkage characteristics of structural quality lightweight concrete. Aggregate absorption and volume change characteristics are the principal reasons for the differences in behavior between these lightweight concrete mixes and comparable sand and gravel mixes. The aggregates absorb moisture from the mix to such an extent that slump and water/cement ratio have little meaning unless qualifying conditions are stated. The aggregates change colume with changes in absorbed moisture so that measurable specimen shrinkage is increased up to two times that of comparable aand and gravel specimens. Curing conditions are most important insofar as shrinkage is concerned.

The techniques used for the determination of shrinkage during the first 24 hours after a specimen has been cast and of aggregate volume changes with absorbed moisture appear promising; however, additional studies in these areas are justified.

When initial aggregate moisture is the only variable, the unit weights of the various specimens tend to approach the same value if the same storage conditions are maintained.

Lightweight aggregate concrete specimens may be prepared with compressive strengths comparable to companion sand and gravel specimens with high air contents. The tensile strengths (at 28 days) will not usually compare favorably to those obtained from sand and gravel concrete, probably due to almost 100 percent aggregate fracture on the failure plane for lightweight aggregate and less than 20 percent for gravel.

20. "Role of Cement in the Creep of Mortar" A. M. Neville, American Concrete Institute Journal Vol. 30, No. 9, pp 963-984, March 1959.

Creep of mortar specimens made with 15 different portland cements and subjected to a sustained compressive stress was measured over a period of several months. These tests, involving as many as 700 specimens, indicate that creep is approximately proportional to the ratio of applied stress to strength of mortar at the time of load application, regardless of the identity of the cement. The relationship between creep and the stress-strength ratio appears to hold good for both dry and humid storage conditions, provided specimens are free from shrinkage. A wide range of stresses has seen investigation and, for the mix proportions used, the stress-strength ratio seems to be the most important factor influencing the magnitude of creep. Cement fineness was not found to affect creep in the range tested.

The paper reviews in some detail factors influencing strength of cement, and also discusses the creep data of other investigation in relation to the proposed creep versus stress-strength ratio relationship.

21. "Curing Concrete with Febcure Liquid" Highways and Bridges and Engineering Works Vol. 27, No. 1277, p 11, January 21, 1959.

A new folder on Febcure Concrete Curing Liquid has been issued by FEB (Great Britain) Ltd., of 102 Kensington High Street, London, W. 8, and Manchester, which describes the liquid, its action, method of application and economic advantages.

Febcure is simply sprayed on to the concrete surface, one laborer being able to treat an area of 450 sq. yd. per hr. A fugitive dye is incorporated for a visual check to be made on coverage when spraying.

The Febcure liquid dries quickly to form an impervious surface skin that locks the mixing water in the concrete. Its action is effective for approximately 30 days, when the Febcure skin or membrane commences to disintegrate and then gradually disappears from the surface. Febcure has no purely deleterious or chemical action on the concrete itself, its function being purely to seal the surface. In order to reduce the surface stresses brought about by temperature differentials in concrete subjected to hot sun, the Febcure can be supplied with a light and heat-reflecting pigment incorporated.

22. "New Membrane Calimed to Revolutionize Concrete Laying Practice" Highways and Bridges and Engineering Works, Vol. 26, No. 1261, p 8, October 1, 1958.

The ability to employe successfully a concrete with a minimum compressive strength of 2,500 psi at 28 days and which also needs only one expansion joint in 500-600 ft are claimed to be two of the results of using a new membrane or solid lubricant known as "Lubrithene." This membrane, .003 in. thick, and giving a coefficient of friction between raft and base of less than 0.25, has been introduced by British Cellophane, Ltd., of 9 Henrietta Place, London, W. 1.

Greatly reducing base restraint, Lubrithene, claims the company, makes possible revolutionary improvements and economies in concrete-laying. This new multi-ply, thermoplastic material has a high-slip finish which permits the slabs to float horizontally. Lubrithene is said further to be extremely tough, flexible, stable and clean under all climatic conditions. It cannot be wetted by water and is easy to handle on site. It can be laid by hand or automatically by machine.

Normally, to meet safely a stress of 100 psi in a 45-ft raft, a concrete with a modulus of rupture of 150 psi would be required. With curing at 64 F, this demands a concrete design with a minimum compressive strength of 6,500 psi in 28 days. Such a design calls for a water-cement ratio of .42 which makes a harsh and uneconomical concrete.

The use of Lubrithene, however, permits concrete with a minimum compressive strength of 2,500 psi at 28 days to be employed without risk of early, uncontrolled cracking.

The economic implications are considerable. Such a concrete would have a water-cement ratio of .50 against .42. And with a water-cement workable ratio of .50, the aggregate -cement ratio is 6.7 to 1, while, for the same workability with the water-cement ratio of .42, the aggregate-cement ratio is 5 to 1.

23. "An Accelerated Test for the Seven-and-Twenty-Eight-Day Compressive Strengths of Concrete" J. W. H. King, Journal of Applied Chemistry Vol. 10, Pt. 6, pp 256-262.

As it is usually impossible to remove work made of concrete not up to standard at an age of 28 days (because there is much more recent work on top of it), in place of the present-day standard test for concrete, viz., the crushing strength of sample cubes 28 days after casting, a test has been evolved to predict the 7- and 28-day strength in as little as 7 hours. The sample cubes are subjected to a specified heating procedure, after which their immediate crushing strength can be used to predict the value of 7 or 28 days, be means of curves established experimentally. These have been checked with a wide range of concrete mixes, and with a wide range of cements, and in general, predict with a standard deviation of less than 200 psi at 7 days and 225 psi at 28 days. This is in general more consistant than the results of 28 days on site samples of what is reputedly the same concrete.

24. "Effect of Sand Characteristics on the Cracking of Small Bars of Mortar in Which Shrinkage is Restrained" F. A. Blakey and R. K.Lewis, Civil Engineering and Public Works Review, V. 55 No. 644, pp. 389-393, March 1960.

The influence of water-cement ratio on the strength of fully compacted pastes, mortars or concretes is too well known to need further emphasis, but because of its importance it might reasonably have been expected that changes of water/cement ratio in mortars or in pastes would bring about changes in the

stress and strain at the instant at which these materials cracked. It was found that changes of water/cement ratio did bring about changes in the cracking stress in both pastes and mortars, but that only in the pastes was there any change in the cracking strain. The cracking strains in the cement paste were generally much greater than in the mortars. A hypothesis developed to explain these results considered, among other things, that cracking started in the cement paste phase of the mortars and subsequently spread to the boundaries between aggregate and paste.

Although this hypothesis appeared to be the most likely one, the reverse could not be completely ruled out, namely, that the cracking started at the aggregate-paste boundary and not in the paste phase of the mortar. If this were so, however, it could be expected that the area of the contact between aggregate and paste, which may be interpreted as the specific surface of the aggregate, would affect the conditions for cracking of mortars. It has also been recognized that shrinkage of concretes can be reduced if the maximum size of aggregate is increased, so that this characteristic of the aggregate might also influence the cracking of mortars. The present investigation was made therefore to determine how the cracking stress and strain of a mortar is affected by changes in the specific surface and maximum particle size of the aggregate.

Very few of the restrained shrinkage specimens cracked, apparently because the relative humidity of the air in which they were stored was slightly higher than in work previously reported. If there is acceptance that the maximum elastic strains recorded in each specimen are nearly equal to the cracking strains, then it appears that the mortar containing sand A of low specific surface cracked at a lower strain then the others. No explanation can be afforded for this.

Because a large number of the specimens did not crack it has been possible to get information on the dreep behavior of the mortars. This appears to be independent of degree of restraint and properties of aggregate within the limits of the expetiment, and the deformation of the mortar under load may be represented by:

$$d\epsilon/dt = d\epsilon_e/dt + (\epsilon_e/\epsilon_{eu})\ (12 \times 10^{-5}/t)$$

When constant proportions of water, cement and sand are used the shrinkage has been shown to decrease as the voids in the sand increase.

25. "A Report Differential Shrinkage in Composite Prestressed Concrete Beams" D. E. Branson and A. M. Ozell, Journal of the Prestressed Concrete Institute, Vo. 4, No. 3, pp 61-79, Dec. 1959.

The purpose of this investigation was to study, both experimentally and analytically, the effects of shrinkage and creep in composite construction consisting of a prestressed-concrete beam and cast-in-place slab. The effect of shrinkage and creep of concrete and the relaxation of steel stress in ordinary prestressed beams is known to be a major cause of loss of prestress, but little is known about the magnitude of the induced stresses resulting from differential shrinkage of the composite beam.

26. "The Shrinkage and Creep of Concrete" Inge Lyse, Magazine of Concrete Research v. 11, No. 33, pp. 143-150, November 1959.

This paper describes an investigation made at the Laboratories du Batiment et des Travaux Publics at Paris into the principal factors influencing the creep and shrinkage of concrete.

Because of the limited number of tests reported in this paper the following conclusions should be considered applicable only to the expansion and map cracking that occurs in concrete made with certain sand-gravel aggregates in the Kansas and Nebraska area.

The shrinkage of the concrete may be considered as directly proportional to the amount of cement paste in the concrete, regardless of the composition (water/cement) of the paste.

The creep of the concrete may also be considered as directly proportional to the amount of cement paste in the concrete, regardless of the composition of the paste, provided that the sustained stress is based upon the ultimate strength of the concrete at the time of application of the load. The age at loading is not very important.

The creep is directly proportional to the sustained stress. There is no creep at all only when there is no sustained stress.

The relative humidity of the ambient atmosphere has an important effect upon the shrinkage and the creep of the concrete.

At any given relative humidity of the ambient atmosphere, if a given sustained stress is applied the curve for creep will be nearly the same as the curve for shrinkage.

The creep at 100 percent relative humidity of the ambient atmosphere is much less than at lower relative humidities, being only about 40 percent of the creep at 50 percent relative humidity.

27. "A Cement-Aggregate Reaction that Occurs with Certain Sand-Gravel Aggregates" William Lerch, Journal of the Research and Development Laboratories, Portland Cement Association, Vol. 1, No. 3, pp 42-50, Sept. 1959.

This report reviews the various studies that have been made relative to the expansion and map cracking that occurs in concrete made with certain sand-gravel aggregates in the Kanaas and Nebraska area.

Concretes made with sand-gravel aggregates of the Kansas and Nebraska area sometimes develop abnormal expansion and map cracking. The expansion and cracking appears to result from a not yet clearly defined cement-aggregate reaction. Durable concrete can be produced by sweetening the sand-gravel aggregate with coarse aggregate. However, coarse aggregates are not available in large parts of the area involved. Pozzolans that greatly reduced the expansion in laboratory tests did not prove to be a satisfactory corrective for concrete pavements. Some cements produce durable concrete with sand-gravel aggregates. The characteristics of the cements that will produce durable concrete have not been clearly defined.

28. "The Use of Flyash in Concrete by Ontario Hydro" J. N. Mustard and C. MacInnis, Jr. Engineering Journal (Vol. 42, No. 12, pp 74-79, 62, December 1959.

This paper is a resume of Ontario Hydro's experiences with the use of flyash as a partial cement replacement in grouting mixtures and concrete. Field trials have shown that flyash, because of its pozzolanic properties, can be used to replace substantial percentages of the cement in normal concrete mixes and grouts without adversely affecting, and usually enhancing, the long-time strength attained. Flyash was also found to (a) reduce the temperature rise in the concrete, thereby lessening the danger of thermal cracking in massive sections; (b) enhance the workability of concrete and grout; (c) provide a somewhat increased setting time, thereby producing concretes and grouts that remain workable for a longer period, and (d) in most instances provide economies. The use of flyash in both high- and low-pressure grouting mixtures at Nigara and to replace from 20 to 30 percent of the cement in appropriate mass and structural concrete applications at the Ontario Hydro's St. Lawrence, Caribou, Whitedog and Otter Rapids projects are described. An account is also included of the method developed for batching the ash as a slurry.

29. "Shrinkage, Swelling and Creep in Cement" A. Hrennikoff American Soc of Civil Engineers V 85, no. EM3, Journal of Engineering Mechanics Divisions, pp 111-135, July 1959.

The study of shrinkage and swelling of hardened cement is described in the paper. It has been observed that both phenomena are associated with presence of water, and that they both manifest themselves in linear and volumetric changes. This suggests a common origin for the two phenomena related to water. The shrinkage study has led to the enunciation of the active water theory, which is described in this paper in detail. The theory attributes the phenomena considered to the stress condition in the film of water surrounding cement grains when cement is moist. The theory agrees well with several aspects of cement behavior in the course of shrinkage and swelling.

All discussion is based on observations of shrinkage and swelling of cement prisms 3/4 by 3/4 by 4 in. subjected to various conditions of drying and wetting, and described by means of graphs whose abscissac represent the internal volumes emptied or filled by the liquid, and the ordinates-the corresponding changes in length of prisms. The shapes of these graphs, and especially the behavior of prisms after placing them first in inert liquid and later in water, suggest the explanation for the volumetric changes in the form of the active water theory, according to which the water films are responsible for shrinkage, swelling and creep in cement. A detailed discussion of mechanical action of film water in the light of the theory is given. The theory is confirmed by the experimental evidence related to the behavior of the drops of water and kerosene on the cement surface and the rise of these liquids in dry cement. Partial additional corroboration is also provided by the plausibility of explanation of the quantitative relation between the amount of shrinkage and the loss of water.

30. "The Effects of Age and Water/Cement Ratio Upon the Relation Between Ultrasonic Pulse Velocity and Compressive Strength of Concrete" M. F. Kaplan. Magazine of Concrete Research v 11, No. 32, pp 85-92, July 1959.

Experiments have been made on concretes with varying aggregate/cement and water/cement ratios, with the main object of ascertaining the effects of changes in age and water/cement ratio upon the relation between ultrasonic pulse velocity and the compressive strength of concrete. It was due to a change in water/cement ratio which caused the ratio of changes in pulse velocity and compressive strength and this is not generally the same as that due to a change in age. Because of this, the relation between pulse velocity and compressive strength cannot be expected to be independent of age and water/cement ratio,

It appears, however, that, for compressive strengths up to about 4,000 lb/in^2, the relation may for practical purposes be regarded as being so. For concrete of the same aggregate/cement ratio, it was found that low pulse velocity at an early age predicts low strength at later ages.

31. "Temperature Measurements with Thermistors in Concrete" Knud E. C. Nielsen Swedish Cement and Concrete Research Institute Bulletin No. 34, 1959, 43 pp (In English)

This bulletin deals with the users of thermistors (thermally sensitive resistors) for temperature measurements, automatic temperature recording, and automatic temperature control in laboratory equipment. The general properties of thermistors and the accuracy in measurements are studied. Stability is the subject of a special investigation.

The test made to study the properties of thermistors, to develop thermometers for temperature measurements in the interior of concrete, and to devise laboratory equipment for automatic temperature control in laboratory equipment, have shown that thermistors are very well adapted for these uses. The reasons are stated in what follows.

1. The accuracy in measurements is high, and can easily be brought to ±0.1 C or still better values, even in long-time tests.

2. The method of calibration and the evaluation of the results of measurements are simple.

3. The dimensions of the therometers are small.

4. The measuring equipment can in a simple manner be rendered sufficiently rugged to withstand the stresses met with on the site.

5. Relatively simple standard instruments can be used for taking readings.

6. Use can be made of simple, standard type long cables and contacts.

7. Thermistors are inexpensive.

32. "Thermal Analysis of the Freeze-Thaw Mechanisms in Concrete" James H. Havens, University of Kentucky (Lexington Ky.), Engineering Experiment Station Bulletin No. 59, Vol. 15, No. 3, March 1961, 38 pp.

The time-temperature histories recorded in these experiments, while perhaps not the ultimate in precision and accuracy, reveal basic information regarding the progress of saturation and the freezing point depressions attending freeze-thaw. The work clearly demonstrates a direct application of the elementary principles of the thermal analysis. The specific conclusions drawn from the work are as follows:

Multiple-junction thermocouples provide an effective method of increasing the temperature sensitivity of potentiometer-type recorders. Since the depression of the freezing point by 1 F corresponds to approximately an increase of pressure of 1,000 psi, and since the maximum depression expected to develop in concrete is about 8 F, a sensitivity in the order of 10 F per inch of scale is necessary to define clearly the development of the freezing-point step. An ice-water bath provides a convenient reference junction temperature.

In every case where a freezing-point step was registered, freezing began at or very near 32 F. Consequently, there was no noticeable indication of supercooling. Also, since there were no indications, within the accuracy of the records obtained, of any depressions in initial freezing points, the effects of dissolved solutes and surface forces on the freezing point of the absorbed water are very slight in comparison to the effects of pressure. This is further confirmed by the fact that each step exhibited a rather definite terminus.

Since the concrete specimens carried to failure showed a complete subsidence of any depression in the final freezing point, the depressions that occurred during the intermediate cycles are attributable entirely to pressure.

The maximum pressures produced by the freezing of absorbed water are in the same order of magnitude as the compressive strength of the concrete.

33. "Creep and Stress Relaxation of Concrete" Torben C. Hansen, Swedish Cement and Conc. Res. Inst. at the Royal Inst. of Tech. Proc. No. 31, 1960, 112 pp.

It is shown that creep of concrete is a mainly visco-elastic and not a plastic type of deformation. This implies that the principle of super-position of stresses applies to concrete and that creep should be taken into account in the design of concrete structures on the basis of the theory of elasticity and not on the basis of the theory of plasticity. The theory of plasticity should be applied when concerned with ultimate strength design.

Three practical problems concerning the design of creep tests are dealt with. First the planning and evaluation of creep tests on a statistical basis. Second the influence of load eccentricity upon creep tests, and third the influence of shrinkage stresses upon creep.

Basic creep is defined as creep when no moisture diffusion takes place in the concrete while loaded. It is asserted that any empirical connection between basic creep and the different factors that influence creep can be directly analyzed in a theoretical way, by means of volumetrical or rheological considerations, since the results obtained from tests have not been distorted by the different effects of drying or wetting on the various concretes. It is therefore more likely that a possible connection between creep and the factors influencing creep should be revealed if basic creep has been determined by creep tests, than if creep of drying concrete has been determined.

Creep of cement mortar beams has been investigated while the beams were exposed to cyclic variations in the relative humidity of the surroundings. It was found that the first period of drying greatly do increase the creep over the amount which is observed when specimens are stored constantly under the average humidity. During any subsequent period of drying after intermediate exposure to a higher relative humidity, the amount of creep is smaller than is observed when specimens are stored under constant average humidity.

34. "Creep of Concrete: The Influence of Variations in the Humidity of the Ambient Atmosphere" T. C. Hansen, Swedish Cement and Concrete Research Institute at the Royal Institute of Technology, Stockholm Reprint 8, pp. 57-65, 1960.

Creep of cement mortar beams has been investigated while the beams were exposed to cyclic variations in the relative humidity of the surroundings. It was found that the first period of drying greatly increases the creep over the amount which is observed when specimens are stored constantly under the average humidity. During any subsequent period of drying after intermediate exposure to higher relative humidity, the amount of creep is smaller than the creep observed when specimens are stored under constant average humidity.

It is a practical conclusion of the investigation that creep of concrete structures on building sites can be estimated from laboratory experiments only with difficulty. To be on the safe side, the lower rather than the average humidity on the building site should be used as a basis for an estimation. Moreover, due consideration should be paid to the fact that concrete behaves differently during the first period of drying and in any subsequent period.

35. "Shrinkage and Creep of Specimens of Thin Section" C. De La Pena RILEM Bulletin No. 3, New Series, PP. 60-70, July 1959, j-Amer Concrete Inst (Current Reviews), Vol. 32, No. 4, pp 475-476, October, 1960.

Testing method used makes it possible to avoid the effects produced on usual test pieces by the gradient of shrinkage between the core of the test piece and the surface.

Shrinkage and creep tests were carried out on mortar test pieces having the form of a tube--length 100 mm, inside diameter 46 mm, thickness in center of tube 2 mm. With this type of test piece the value of the shrinkage and final creep can become known more quickly than with usual test pieces. Altogether 216 test pieces were made for these tests.

36. "Note on the Maturity and Creep of Concrete" A. D. Ross, RILEM Bulletin No. 1, New Series, pp 55-57, March 1959, Journal of the American Concrete Institute, Vol. 32, No. 3, pp 350-351, Sept. 1960.

From studies carried out in numerous laboratories we know that creep in concrete, under constant load, is a function of age at which the load is applied. The temperature of curing before loading also has a marked influence on creep in concrete. The increase in the strength of the concrete is connected with its hardening, which depends on age and temperature of curing.

The temperature is measured in relation to a reference temperature this defined: "At the temperature the chemical reactions diminish to the point where the strength does not increase." The hardening unit is thus expressed in deg C x hr and if we take -10 deg C as reference temperature we find that concretes have the same strength if they are at the same temperature whether the latter be reached after a long period at low temperature or a short period at higher temperature.

Creep is also a function of the hardening at the time of first loading and it can be aaid that it is more sensitive to changes in hardening then the strength or the static modulus.

These results do not contradict previous experiments since the temperature is constant, the hardening is directly proportional to time and thus different creep values correspond to different loading ages.

37. "Effects of Aggregate Size on Properties of Concrete" Stanton Walker and Delmar L. Bloem. Journal of the American Concrete Institute Vol. 32, No. 3, pp 283-298, September 1960.

Researching is described supplementing earlier work which indicated a lack of improvement in concrete strength resulting from increased maximum size of aggregate. The more recent program provided a broader range of classes of concrete and test variables for the purpose of checking the degree of applicability of the earlier finding.

The tests were made with maximum sized of coarse aggregate ranging from 3/8 to 2½ in., using 3 cement factors, from 4 to 8 sacks per cu. yd., both with and without air entrainment. Compressive and flexural strength tests were made at ages of 7, 28, and 91 days, and specimens are available for test at 1 year. Tensile splitting tests were made at 28 and 91 days. Drying shrinkage measurements were also made on all concretes.

Results indicate that increasing the maximum size of coarse aggregate may not necessarily be beneficial to concrete strength. Drying shrinkage was not substantially increased by reduced size of aggregate down to about 3/4 in.

38. "Shrinkage and Creep in Concrete" A. M. Neville, Journal of the Reinforced Concrete Assoc., Vol. 1, No. 2, pp 49-85, March-April, 1962

Shrinkage and creep, and their inter-relationship, are insufficiently understood by most engineers. Dr. A. M. Neville, who will soon be taking up the appointment of Professor of Concrete Technology at the University of Saskatchewan, presents a detailed examination of these phenomena. He points out that on the whole creep, unlike shrinkage, is beneficial in relieving stress concentrations and has contributed considerably to the success of concrete as a structural material.

This paper, which was presented at a meeting of the Reinforced Concrete Association in London on the 8th of November 1961, is based on Chapter IV - Elasticity, Shrinkage and Creep - of the author's book "Properties of Concrete" (Pitman, in press)

39. "The Chemical and Physical Effects of Aggressive Substances on Concrete" P. E. Halstead, Structural Engineer Vol. 39, No. 12, pp. 405-410, December 1961.

The paper describes how the basic structure of concrete is attacked by acids or substances like soft water, esters and alcohols which dissolve lime. Concrete is also weakened by exposure to liquors containing magnesium or ammonium ions, which replace calcium.

Expansive reaction occurring in concrete destroy it and examples are delayed hydration of lime and magnesia (unsoundness), formation of calcium sulphoaluminate by reaction with sulphates from external sources, and the rusting of embedded steel reinforcement.

Temperature changes damage concrete by causing differential movement initially by trying shrinkage and later by thermal expansion. Exposure to temperatures above 300 C weakens all concrete by destruction of the cementive matrix but at higher temperatures aluminous cement concrete by development of a ceramic bond to make refractory concrete.

Concrete is permanently damaged by mechanical overloads but has good fatigue resistance.

Intense gama-ray and neutron fluxes may weaken the bond of concrete but in practice damage is cheifly caused by heat generated by asorption of the radiation or neutrons.

40. "Design Methods for Structurally Reinforced Concrete Pavements" Anders Losberg, Trans-Chalmers Univ. of Tech. No. 250, 1961, 143 pp. (In English)

This thesis concerns the results of an investigation concerning manner of function and calculating methods for concrete pavements on airfield and roads with flexurally rigid active so-called structural reinforcement.

The behavior of the reinforced concrete pavement within the elastic stage is studied.

The results from tests on model slabs on artificial subgrade as well as full-scale slabs on natural soil were analyzed according to the elasticity theory, and good agreement has been proved between the test results and the theory concerning depression and soil reaction pressure as well as concerning flexural moment, in the latter case however only below yield point in the bottom reinforcement.

Reinforced concrete pavement from the viewpoint of the yield line theory, and good agreement has been proved and discussed in theory and an ultimate strength method is presented for the calculation of the load carrying capacity of the pavement which should be assumed to be equal to the load that gives rise to cracks in the top surface for a single-reinforced slab and yield in the top reinforcement for a double-reinforced slab.

A study of the influence of temperature variation and shrinkage on the reinforced concrete pavement is presented.

The paper contains a review of the experiences from pavement work already carried out with structurally reinforce pavements, mainly in Sweden. Several airfield pavements have been built in accordance with the principles and partly on the basis of the calculating methods presented in this paper, and it has been found that these pavements have functioned well during the time they have been in use.

41. "Summary Reviews of Soil Stabilization Process: Electrical Stabilization of Fine-Grained Soils" G. R. Kozan and W. B. Fenwick, U. S. Army Engineer Waterways Experiment Station, Corps of Engineers, Misc. Paper No. 3-122, Rept. 7, October 1961, 29 pp.

A review of literature on soil stabilization by electrical methods is presented, with particular emphasis on the techniques that might be applied by the military to improve mobility of surface vehicles over very wet and unstable fine-grained soils. The mechanics of the phenomenon of electroosmosis are described, and the quantitative expressions for electrosmotic flow based on the theories of Helmholtz-Smoluchowski and Schmid are compared. It is apparent that the applicability of the theoretical concepts and their validity in relation to practical engineering problems remain to be established. However, it is known that in addition to enhancing drainage of soils of relatively low permeabilities, the process of electroosmosis results in a consolidation of the soil that contributes to an improved strength and stability. For possible military application, electrokinetic stabilization appears to have many advantages over techniques of soil stabilization involving the use of additives, particularly for very wet soils. Its primary disadvantage appears to be the excessive length of time required to achieve stabilization.

42. "Effect of Curing Humidity on the Shrinkage of High Alumina and High Gypsum Portland Cement" Masayoshi Hujisake, Journal of American Ceramic Society, Ceramic Abstracts, Vol. 45, No. 2, p. 28. Feb. 1962.

Two series of portland cement were prepared; (1) Al_2O_3 5 to 9, gypsum 3 percent; (2) Al_2O_3 5 to 9, gypsum 4 to 16 percent. Mortars made with these cements were cured at a relative humidity of 45 to 65 percent and at 20 C. The relations between the content of Al_2O_3 and gypsum, curing humidity, drying shrinkage and loss in weight were determined. The cement with the composition of Al_2O_3 and SO_3 3 to 4 percent showed a low drying shrinkage and a strength of approximately 80 to 90 percent of commercial ordinary portland cement.

43. "Structurally Reinforced Concrete Pavements" A. Losberg, Chalmers Tekniska Hogskola, Doktorsavhandlingar No. 29, 1960, 444 pp (In English) Road Abstracts, Vol. 28, No. 5, p 106, May 1961.

This thesis is the result of an investigation begun in 1945 in Sweden. Part 1 points out the need for reinforced concrete surfacings with higher load-carrying capacity than unreinforced surfacings. In Part 2 the behavior of the reinforced concrete surfacing is discussed with reference to the theory of elasticity. Part 3 concerns the reinforced concrete surfacing in relation

to the yield line theory; an ultimate strength method for calculating the load-carrying capacity of the pavement is presented. In Part 4 cases of loading where the load operates on a free edge or on a joint which cannot transfer flexural moment are considered. Part 5 describes three series of field tests carried out at airfields in Sweden. In Part 6 a study of the influence of temperature variation and shrinkage on reinforced concrete surfacings is included; methods of calculating stresses due to temperature and shrinkage in normal surfacings with joints are rveiewed and a theory is suggested for calculating the reinforcement required in jointless reinforced surfacings and the cracking to be expected. Part 7 includes a review of expetiences of work carried out with structurally reinforced surfacings, mainly in Sweden; suggestions are presented for design methods. A bibliography of 79 references is appended.

44. "Young's Modulus and Poisson's Ratio of Concrete Cured at Various Humidities" J. M. Plowman, Magazine of Concrete Research, Vol. 15, No. 44, pp 77-82, July 1963.

Tests are described designed to determine values of E and ν for concretes of various mix proportions and water/cement ratios. The influence of age (maturity) and humidity of curing have also been investigated.

Conclusions reached indicate that concrete cured in water at 64 F tends to obey the following maturity law.

Percentage of Young's modulus which is obtained at a maturity of 35,600 F h = A + B $\log_{10}$ (maturity/1,000) up to maturities of about 40,000 F h. Values of the constants A = 69 and B= 20 give values of E in close agreement with the test results. Concrete cured at 90, 65 and 40 percent relative humidity has a value of E which increases with maturity up to approximately 60,000 F h and thereafter increases at a slower rate, finally decreasing. Young"s modulus for concrete is independent of mix proportions but may be dependent upon the concrete strength. Poisson's ratio is independent of mix proportions, strength, maturity and humidity of curing.

44. "Sand Displacement and Compaction Around Model Friction Piles" E. I. Robinsky and C. F. Morrison, Canadian Geotechnical Journal Vo. 1, No. 2, pp 81-93, March 1964.

By means of radiography techniques the displacement and compaction of sand around strain gage instrumented model piles has been studies. Tests reveal a possible explanation for the low transfer of load through "skin friction" developed by a straight-sided pile, and the high transfer of load through "skin friction" by the tapered pile. The limits of "visible" soil movement (displacement envelopes) have been determined for nine different

pile conditions and a direct relationship has been found to exist between the magnitude of the displacement envelope and pile capacity, indicating interdependence of transfer of load through the pile point and pile wall.

45. "Petrographic Studies on Concrete Containing Shrinking Aggregate" Harold Roper, J. E. Cox, Bernard Erlin, J-Portland Cement Ass. Research and Development Laboratories, Vol. 6, No. 3, pp 2-18 Sept. 1964.

Petrographic techniques have been useful not only in detecting and diagnosing distress in concrete, but in supplying new information which contributes to a more complete understanding of the phenomena involved. One type of distress in concrete is caused by the use of aggregates subject to large drying shrinkage. Such aggregates are common in one or more limited areas of the world, but are relatively unknown elsewhere. Petrographic techniques for studying these concrete which result from the shrinkage of aggregate.

46. "A review of Literature Pertaining to Creep and Shrinkage of Concrete" Bernard L. Meyers, University of Missouri, Engineering Series Bulletin No. 56, Feb. 26, 1963, 19 pp.

An extensive literature search of the factors influencing creep and shrinkage of concrete was conducted at the University of Missouri in conjunction with the Missouri State Highway Commission and the United States Bureau of Public Roads. The majority of the information available was easily divisible into two main catagories; viz., the factors influencing creep and shrinkage, and the effect of creep and shrinkage on concrete as a structural material. Over two hundred articles and papers were reviewed.

Many of the factors that influence the creep and shrinkage of concrete have been investigated, and some rather important conclusions can be drawn. Some of the conclusions are summarized: Hard, dense, non-porous aggregates produce concrete which exhibits the lowest creep and shrinkage strains; well-graded aggregates with a high fineness mudulus produce concrete low in creep and shrinkage; for concrete mixes of equal water-cement ratios, a decrease in cement content decreases creep and shrinkage; a reduction of the water-cement ratio and the water content helps to reduce creep and shrinkage for mixtures of similar workability; a reduction in the aggregate-paste ratio tends to increase shrinkage; increasing the percentage of reinforcement reduces the creep and shrinkage strains of reinforced concrete; creep and shrinkage strains of reinforced concrete; creep and shrinkage strains are smaller in massive concrete structures than in thin sections; proper compaction of fresh concrete tends to reduce both creep and shrinkage.

45. "Thermal Conductivity of Concrete at Very Low Temperatures" A. E. Lentz, G. E. Onnfore, Journal of the Portland Cement Association Research and Development Labortories, Vol. 7, No. 2, pp 39-46, May 1965.

The theory and practical application of a non-steady state "Hot-wire" method for measuring the thermal conductivity of concrete at temperatures ranging from -250 to 75 F are discussed in detail. Since a determination required only 10 minutes, errors due to migration of moisture in wet concrete were minimized. Thermal conductivities of rock specimens were also determined by the use of a 'split-specimen' technique espedally developed for such measurements.

Thermal conductivities of sand and graval concrete containing 5.5 bags of cement per cubic yard of concrete ranged from 32 btu/hr (sq. ft.) (F/in.) at -250 F to 23 at 75 F for moist concrete, and ranged from 25 at -250 F to 19 at 75 F for concrete equalibrated at lightweight aggregate concrete in a moist condition was nearly constant at about 6 btu/hr (sq. ft.) (F/in.) over the same temperature range.

49. "Effect of Retarding Agents On The Extended Agitating Time of Portland Cement Concrete" R. W. Lindley, Jr. and William Gartner, Jr. State Road Dept. of Florida, Division of Research and In-Service Training, Res. Bull. No. 69, June 1962, 40 pp.

Agreement about an acceptable length of agitating time for transit mixed concrete has often been a problem both to the contractor and the ready-mixed supplier. Several studies have shown that there is some loss of strength and some degradation of aggregate after extended agitating periods. Because all previous studies dealt with a plain mix using no set retardent or air-entraining agent, it was decided that the Florida State Road Department would benefit from a study that included both of these admixtures as they are now in wide use in Road Department construction.

Therefore, a study was initiated with the following primary objectives: (a) to determine if the addition of a retarding agent to the concrete mix will permit longer agitating periods than are presently being specified, and (b) to determine the effect extended agitating has on the various physical properties of portland cement concrete (that is, 28-day compressive strength slump, air content, particle breakdown, mix temperature, time of set, etc.) for mixes with and without set-regarding admixtures.

Conclusions reached indicate that extended agitation does not reduce the 28-day compressive strength of concrete containing the admixture tested. This is supported by the results that all tests showed continual increases in the 28-day compressives strength during the period of prolonged agitation, except of course when additional water was added to the mix.

Extended agitation reduces the amount of entrained air in the concrete. The decrease in air content of all mixes during the period of prolonged agitation appears to be directly responsible for the increase in strength previously noted. Retarding agents tend to reduce the rate of loss of entrained air during the prolonged agitation period. The set retarder used most its effectiveness when agitated for periods over two hours, but until that time it appeared normal. This is shown by the curves of setting time vs agitating time.

50. "Expansive Cement Opens Era of New Concretes" Chemical and Eng. News Vol. 42, No. 32, pp 38-39, Aug. 10, 1964.

In Los Angeles recently, a contractor poured a 12,000 sq. ft. concrete grade slab, completely free of joints, for a new office building.

Such applications (the pouring of large concrete areas without joints) are not possible with ordinary portland cement concrete because drying caused shrinkage, which, in turn, causes substantial cracks to develop. Making such techniques possible now is a new cement that causes concrete to expand just enough during the first few days of cure to offset the shrinkage that follows. Thus cracks do not develop unless other forces, such as setting, are at work.

The expansive cement, known as Chem Comp, was developed by Alexander Klein, an engineer at the University of California, Berkeley. The manufacturing process belongs to Chemically Prestressed Concrete Corp., Nan Nuys, Calif.

The component that makes Chem Comp expand is one of the two forms of calcium sulfoaluminate, a well-known compound in concrete chemistry. The expanding form, called ettringite, has an analysis that works out to $(CaO)_3 \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31\text{-}32H_2O$. When it forms on the surfaces of aggregate particles, disruptive forces result. Early literature, in fact, often refers to it as concrete bacillus.

In almost all applications the new cement has performed as expected; concrete slabs are virtually crack-free. Two notable exceptions are two stretches of highway in California. However, California does not use steel reinforcing in its roads. It is pointed out that steel reinforcing of some kind, road or mesh, is necessary to restrain the concrete.

The number of applications are expected to grow steadily. In time, it is believed, Chem Comp may replace Type I portland cement completely. One drawback, at the moment, is price. The producer, for example, charges $1.40 per barrel more than the price of Type I portland cement. Even with volume production, the producer feels that because of the high coats of raw materials, the premium will probably drop very little, if any.