CONTROL OF SHRINKAGE OF CONCRETE

REPORTED BY
THE COMMITTEE ON SHRINKAGE OF CONCRETE
STRUCTURAL ENGINEERS ASSOCIATION OF CALIFORNIA

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I - INTRODUCTION

The SEAOC Committee on Shrinkage of Concrete was formed by the Structural Engineers Association of California as a result of the resolution passed by the members at the 1963 Annual Convention, SEAOC:

> WHEREAS the State has requested this Association to form a committee to recommend realistic methods of controlling shrinkage of concrete,
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> WHEREAS the State has been studying the problem of shrinkage for several years and has sufficient data to show that some aggregates exhibit a high potential for shrinkage,
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> WHEREAS it is our duty to protect ourselves, our clients, the owner and the contractors when this information is available,
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> NOW THEREFORE BE IT RESOLVED that the Board of Directors is hereby requested that a Committee be assigned by the State Association to study the problem to recommend methods of control and to establish reasonable shrinkage factors consistent with sound engineering principles.

The resolution was prompted by many recent experiences with concrete buildings where excessive sagging, cracking and leaking have occurred.

II - THE PROBLEM OF CRACKING AND DISTORTIONS IN CONCRETE STRUCTURES

Cracking and sagging of concrete members is not a new problem. Since the beginning of the use of concrete, engineers, architects and builders occasionally have had unfortunate experiences with sagging floors or cracked, "leaky" walls, which caused anxiety to the owners and inconvenience to the occupants of buildings.

Lately the problem of distortions in concrete buildings has become worse because of an increasing demand for longer buildings and longer shallow depth members. The design of very shallow members is now possible because of the availability of high strength steels and concretes. Precast construction also demands light, shallow, thin members for ease of handling during erection.

It appears that the more advanced principles of design of concrete structures demand that the acceptability of the work should not be based solely on the ultimate strength and workability of concrete. Shrinkage and creep must also be given proper consideration; this is because the deformations due to creep and shrinkage may be two or more times greater than the elastic deformations.

Section 903 of the 1963 ACI Building Code requires that consideration shall be given to the effects of forces due to creep and shrinkage.

The panel on Plant Production of the Prestressed Concrete Institute[2] recommends that the quality control of concrete be so exercised as to insure that

> "It must have low values of shrinkage and creep in order to minimize losses and member shortening which may cause jointing problems."

The above requirement is in addition to the usual criteria for strength, durability, etc.

Deflections and cracks in concrete structures may never be entirely eliminated, but they can be controlled and minimized by

a. Proper selection and proportioning of concrete ingredients.

b. Proper construction methods, such as mixing, placing, consolidating, curing, etc.

c. Proper techniques in the design of concrete members and joints.

All the above items are of equal importance and the order in which they are given is immaterial.

Concrete cannot be used intelligently without taking into consideration its volumetric changes with time.

Concrete deforms elastically and creeps under sustained loads as time goes on. It shrinks and swells due to changes in moisture content under varying temperature-humidity environments. It contracts and expands due to changes in temperature. When some of these movements are restrained by the foundations, the steel reinforcement or by adjacent portions of the structure, tensile stresses in the concrete are induced. Cracks are formed in places where tensile strength and extensibility of concrete are overcome.

Creep and shrinkage of concrete are so intimately interconnected that one cannot be considered without the other. In fact, E. Freyssinet, the famous French Engineer, evolved a theory that shrinkage is a creep due to sustained capillary forces. Wei-Wen Yu and George Winter[3] derived a coefficient which takes care of both shrinkage and creep in the computation of deflections of concrete beams.

In general, when the magnitude of the shrinkage of a concrete mix is controlled, the magnitude of its creep is also controlled to a certain extent because the undesirable factors that affect shrinkage seem to have a similar effect upon creep.

The tendency of concrete to crack under conditions of restraint is a time-dependent process. It depends upon the eventual movement due to temperature changes and shrinkage, on the tensile strength of concrete, its creep properties, effective modulus of elasticity, etc. Creep allows greater extensibility and thus offsets the tendency to crack. However, the higher shrinkage usually overcomes the relief offered by the creep.

In 1962 the State of California built eight similar concrete deck sections in the Webber Creek Bridge[8]. Concrete of four degrees of shrinkage was produced by using combinations of two cements and two aggregates. Shrinkage specimens were cast on the job and tested in the laboratory in accordance with ASTM procedures. A year later one of the concrete decks with higher shrinkage characteristics ($750x10^{-6}$; 3 in. by 3 in. bars, 28 days of drying) showed 69 soffit cracks with a total length of 245 feet, with 13 cracks leaking. One of the concrete decks with lower shrinkage characteristics($290x10^{-6}$; 3 in. by 3 in. bars, 28 days of drying) exhibited 7 soffit cracks with a total length of 29 feet, with 1 crack leaking.

III - AMOUNT OF SHRINKAGE

Most shrinkage is due to diffusion of moisture from the interior of the concrete toward its surface to replace that lost by evaporation. The process is exceedingly slow and complex. The surface of concrete dries more rapidly than its interior. This causes concrete to shrink non-uniformly because the shrinkage of outer fibers is restrained by the inner fibers. A complicated system of sustained stresses is created at which time creep enters into action and modifies the effect of shrinkage. Thus there is no such thing as "free" unrestrained shrinkage. This convenient term is used for total shortening of a laboratory specimen of plain concrete. In some tests, cracks either at the rock-paste interface or in the paste itself, are formed due to internal restraint. These cracks relieve the shrinkage stresses with the result that short-time measurements indicate low shrinkage [4], not indicative of the true shrinkage potential.

Because drying commences at all exposed surfaces, the magnitude of progressing shrinkage varies considerably with the size and shape of the member and depending also upon how many surfaces are exposed to drying. Under ordinary climatic conditions the average shrinkage of structural members one foot or more in thickness probably would never approach that of small bars [8]. This phenomenon is due to the fact that concrete will absorb in one day as much moisture as it will release in two weeks. Thus periodic absorption of moisture by concrete in service prevents the indefinite continuation of drying as in a laboratory under a steady humidity-temperature environment. Tests lasting for 720 days showed that shrinkage in the field of 3 by 4 in. specimens was 0.3 to 0.5 of that of specimens under laboratory conditions [21] for 720 days.

Tests of the California Division of Highways showed that outdoor shrinkage in Sacramento for 112 days of 14 by 20 in. beams was about 0.3 of that of 4 x 5 in. specimens [8] dried under the same conditions.

Carlson [11] assumed that drying shrinkage is approximately proportional to the amount of moisture lost. On this basis he found that 50% of the ultimate shrinkage will take place in 1 month in a 3 in. slab; in 1.8 months in a 4 in. slab; in 4 months in a 6 in. slab, and in 16 months in a 12 in. slab; all drying from both faces at constant 50% relative humidity. The above shows the importance of consideration of the size, exposure and shape of a member in shrinkage studies. A 12 in. thick slab or wall exposed to natural weather may not reach 50% of ultimate shrinkage in 16 months because of periodic absorption of moisture during changes of weather.

For the study of cracking in a larger concrete member the distribution, as well as the average amount, of shrinkage is of importance. Carlson [11] gives an approximate distribution of shrinkage in slabs or walls of any thickness for any period of continuous drying at 50% relative humidity. A 12 in. wall at the end of 100 days drying from one face only will tend to shrink 48% of the ultimate at the first 0.1d (d = thickness) from the drying face, 18% at 0.2d, 7% at 0.3d, 2% at 0.4d, 1% at 0.5d. At 0.6d there will be no shrinkage at all. Under these conditions surface cracking is inevitable for concrete with an ultimate shrinkage of 900 millionths.

Several textbooks and publications treat the subject of warping of concrete due to shrinkage[15, 16, 17, 18, 19, 20, 25].

For practical purposes formulas are usually given in terms of the effective "free" ultimate concrete shrinkage S_u, which is the ultimate shrinkage of the concrete member in the structure, regardless of its cross section or mode of drying, expressed as a dimensionless ratio of the length of shrinkage divided by the length of member under consideration.

Miller[18] gives 500, 600 and 700 millionths as commonly accepted ultimate values for low, medium and high shrinkage respectively.

For the purpose of this report the concretes having ultimate shrinkage of 400, 600 and 800 millionths will be classified as Class A, B and C respectively.

The effect of shrinkage upon deflections is greater than realized. In many cases the deflection due to shrinkage is just as large as immediate deflection due to dead load and in some cases the deflection due to shrinkage is greater than the deflection due to creep[20]

The calculated deflections of a 5" thick canopy slab cantilevered 8' is:[22]

0.43 in. immediate due to dead load
0.42 in. due to creep
0.59 in. due to shrinkage
1.44 in. total

The deflection of 0.59 in. due to shrinkage is based upon a low shrinkage concrete (400 millionths). For high shrinkage concrete (800 millionths) the shrinkage deflection will be 1.18 inches, which is nearly 3 times the immediate dead load deflection. With increased deflection due to the high shrinkage of the concrete, creep and the deflection due to it will also increase somewhat, so that the total deflection will be well over 2 inches.

When deflection and/or cracking are a major consideration it is not advisable to use high shrinkage concrete.

IV - CONTROL OF SHRINKAGE BY LABORATORY SPECIMENS

Compressive strength of a 6 x 12 in. cylinder admittedly does not represent the strength of the concrete in a structure, where the stress distribution differs greatly from that in a test cylinder. However, standard cylinder tests are of considerable value for practical purposes of strength control of concrete.

Similarly, the shrinkage of a laboratory specimen can be used to control and serve as an index of potential shrinkage of concrete to be used on a job.

Shrinkage test specimens are usually small concrete bars 3 x 3 in., 4 x 4 in., or 4 x 5 in. in cross-section. They are moist cured for 7 days. The shrinkage is measured on a 10 in. min. gage length. The specifications usually limit the amount of shrinkage after either 14, 21 or 28 days of drying, and sometimes at later ages.

Tremper and Spellman[8] compared the results of laboratory specimens dried under standard conditions to those of field exposure of full-size or near full-size structures and pavements. There is substantial evidence that suitably designed laboratory tests can be used to predict the effect of the characteristics of the constituents of concrete and the conditions of its manufacture on its shrinkage in service.

The drying shrinkage of small laboratory specimens is approximately proportional to the surface-to-volume ratio. If the relative shrinkage of a 4 x 4 x 11 in. bar is taken as 1.0, the shrinkage of a 3 x 3 in. is 1.3; of a 4 x 5 in. is 0.9; of a 6 in. cylinder is 0.7.

G. E. Troxell[9] made a series of short-time tests on concrete shrinkage. He concluded that the actual long-time shrinkage may be computed from the short-time shrinkage provided a proper conversion factor for the special test conditions has been determined previously. In his tests 28-day laboratory shrinkage tests predicted 200-day laboratory shrinkage with 13% max. and 2% min. error.

In order to arrive at a proper and reasonable shrinkage limit of a laboratory specimen, it is necessary to consider the overall phenomena of shrinkage of concrete including the resulting cracking.

We need the amount of ultimate shrinkage in a structure from all or any sources and the cracking potential it creates. It is difficult to estimate closely the weather conditions under which the concrete will be made in a structure, or to predict the effective temperature-humidity environments such as air conditioning, heating and ambient conditions to which the concrete in a structure will be subjected in different parts of the country. Therefore, it is best to allow for the most unfavorable possibilities.

The rate of shrinkage is rapid at first and then decreases assymptotically with time. Again, it is a function of the size and shape of the member. Shrinkage of 3 x 3 in. specimens dried at 50% R.H. and 75° F appears to approach its ultimate after about 32 weeks[8]. The 28-day drying shrinkage of 3 by 3 in. specimen may be taken equal to about 50 percent of its ultimate shrinkage. The shrinkage of a 4 x 4 in. specimen approaches its ultimate in about 64 weeks; its 28-day shrinkage may be taken about 40 percent of the ultimate. The 28-day shrinkage of 6 in. cylinder specimens may be taken about 35 percent of the ultimate. These are average values taken from various tests.

Troxell, Raphael and Davis[10] tested fifty-six 4 in. cylinder specimens; max. aggregate size 3/4 in. and 1.5 in.; several types of aggregates; cement types I and IV; relative humidity 50 and 70%. The rate of shrinkage was as follows:

14 to 34% of the ultimate shrinkage occurred in 2 weeks.
20 to 50% of the ultimate shrinkage occurred in 4 weeks.
40 to 80% of the ultimate shrinkage occurred in 3 months.
66 to 85% of the ultimate shrinkage occurred in 1 year.

The above values can be used in estimating approximate long-time shrinkage of small laboratory specimens from their short-time shrinkage. These values do not apply to larger members.

Assume that the ultimate "free" concrete shrinkage will be controlled by the laboratory shrinkage of a 4 by 4 in. test specimen, moist cured for 7 days and then dried for 28 or 21 days under 50% ± R.H. and 73.4° ± F (A.S.T.M. Designation C 157-64). Designate 28-day drying shrinkage of laboratory specimen by S. As mentioned before, assume that the 28-day shrinkage is 0.4 of its laboratory ultimate S'. Then

$S' = S \div 0.4 = 2.5S$. Assume that due to variation in humidity, temperature, sizes of members, etc., the effective "free" ultimate shrinkage in a structure will be 0.5 of that of the laboratory specimen. Then the effective average "free" shrinkage in the structure will be $S_u = 2.5S(0.5) = 1.25S$.

Thus the 28-day laboratory shrinkage of 4 x 4 in. specimens dried for 28 days should be:

400 ÷ 1.25 = 320 millionths for Class A concrete.
600 ÷ 1.25 = 480 millionths for Class B concrete.
800 ÷ 1.25 = 640 millionths for Class C concrete.

Due to considerable spread in the properties of concrete of the same nominal strength, a variation of 15 percent can be allowed in the above values.

If specimen is dried for 21 days multiply the above values by 0.83.

These values may be specified as shrinkage limits of test specimens in order to control the shrinkage of concrete for a project. See Appendix I for sample specification.

It should be borne in mind that no laboratory test of small specimens can be expected to predict exactly the shrinkage of concrete members in a structure under all kinds of conditions. Future tests on the correlation between laboratory and field shrinkage may show that the above given values should be decreased or increased.

V - SELECTION AND PROPORTIONING OF CONCRETE INGREDIENTS FOR LEAST CREEP AND SHRINKAGE

The shrinkage of concrete depends on the properties and relative amounts of both the cement paste and the aggregate.

The main ingredient of a concrete mix is the aggregate. It is not an inert material introduced only for economic reasons. It is a building material connected into a cohesive whole by means of the cement paste[5]. The aggregate, which occupies 75% of the total volume of concrete, is normally stronger and more durable than the cement paste. Its physical, thermal and chemical properties have a large influence on the overall performance of concrete. Neat cement paste shrinks as much as 2700 millionths of its length, which is equal to 3.24 inches per 100 feet (1000 millionths of length equal 1.2 inches per 100 feet). Good aggregate shrinks very little. It restrains the shrinkage induced by the cement paste. Not all aggregates are equally effective in restraining the shrinkage of the cement paste. Small 4 to 6 in. laboratory concrete specimens made of such aggregates as quartz, feldspar, good grades of limestone, dolomite and granite ultimately shrink 350 to 550 millionths of their length under constant humidity-temperature environment of 50% ± R.H. and 70° ± F. Concrete specimens made of certain siliceous and/or calcareous mixed gravels, sandstone, marble, slate or low grades of granite ultimately shrink 600 to 1100 millionths of their length under the same constant humidity-temperature environment. The effect of the mineralogical character of aggregates must be given consideration in the control of the magnitude of the shrinkage of concrete, or actual shrinkage data obtained by tests.

Polivka[13, 14] concluded that "the nature of the aggregate is one of the major factors influencing the shrinkage and cracking characteristics of concrete."

Excessive amounts of clay in the aggregate increase the shrinkage up to 25%. Limits of clay content of the aggregate should be specified. See Test Method No. Calif. 217E (Materials Manual, Testing and Control Procedures - Materials and Research Department, State of California, Sacramento, California).

Laboratory tests[6] show that there is a range as much as 2 to 1 in the relative shrinkage exhibited by different cements with the same aggregate. Shrinkage characteristics of a cement cannot be predicted reliably from the ordinary chemical analysis. Type II (low alkali) cement normally exhibits low shrinkage, but there can be a difference of 100% between the Type II cements of different manufacturers.

Tests have shown that for the same water content per cubic yard of concrete the shrinkage remains the same for a wide range of cement contents. For example, concrete mixes with either 6, 7 or 8 sacks per cubic yard, but with 35 gallons of water per cubic yard gave about the same shrinkage of 500 millionths of the length[7]. Mixes with larger maximum size aggregates demand less water. Thus shrinkage can be decreased by about 20% by using $1\frac{1}{2}$ in. maximum size aggregate instead of 3/4 in. maximum. Reduction of water content by the use of proper admixtures should reduce shrinkage. The ideal mix to minimize shrinkage for a given set of materials is one containing in a cubic yard the <u>least</u> amount of water, the <u>largest</u> maximum size aggregate and the <u>lowest</u> possible percentage of sand consistent with good workability. The slump should be the least at which the concrete can be consolidated by intelligent use of modern vibrators. 0" to 2" slump concrete is being used in some fabricating plants and 3" and 4" slump concrete is being placed in field.

VI - TECHNIQUES IN DESIGN OF CONCRETE BUILDINGS TO MINIMIZE THE EFFECT OF SHRINKAGE

It should be kept in mind that most portions of a concrete building, during construction and at service, are constantly in motion due to variations in temperature and humidity. When the movements of adjacent portions are unequal the tensile strength and extensibility of concrete may be overcome and cracks will ensue. The undesirable effect of cracking upon the serviceability of a building may be reduced by trying to provide details and shapes that will minimize the differential movements of adjacent elements.

It can be assumed that the propagation of an average shrinkage with time in a wall is inversely proportional to the square of its thickness[11]. For example, a 12 in. thick wall will tend to shrink in a given time $(8/12)^2 = 0.44$ as much as an 8 in. thick wall. Discontinuities or changes in thickness and horizontal dimensions should be avoided. A fenestration with wide wall panels at the ends of a building and narrow intermediate piers joined by relatively thin spandrels will surely result in cracks in the spandrels at the corners of windows due to restraining action of end walls. A building front with narrow piers throughout, uniformly spaced, is better. If large end wall panels are functionally or esthetically necessary, specially designed contraction joints can be introduced at the points of dimensional or volumetric discontinuity. A wall front with thick and wide piers (say 16 by 48 in.) joined by thin spandrels will result in cracks in the spandrels, because they dry out much faster (inversely to square of a thickness) than the thick piers in between.

Since the rate of the advancing shrinkage front diminishes as a square of a depth from the drying surface, the thick wall may never dry out and reach its ultimate shrinkage because during the changes of seasons it will be absorbing moisture, while the thin wall will dry out and crack before the change in season arrives. However, the thick wall drying from one face only may crack at the outer face due to internal restraint, but the cracks most likely will be shallow and will not reach the inner face. A building with exterior columns and 8 in. thick walls with openings will have more "leaky" cracks than a building with 12 in. thick bearing walls with similar openings.

Observations show that in buildings with basements or large heavy foundations under walls the most numerous cracks are in the first story walls due to the restraining action of the portions of the building below the ground where the shrinkage is the least. The building with columns only in the first story of exterior front will crack less because the columns will accommodate the movements due to differential shrinkage[27].

Observations show that the building fronts having about 60 percent or more of openings crack least, but solid blank walls and walls with relatively small openings (say 25 percent of gross area) present trouble. Cracks are developed at about 10 to 16 feet on centers. The greater the spacing of cracks the wider the cracks. Owners of buildings are faced with the problem of water leakage through cracks. If walls are sprayed with asphaltic compound on the inner face and furred the penetration of moisture will not be as troublesome.

Since shrinkage of concrete walls may never be eliminated, an attempt can be made to distribute the movements due to shrinkage in as many smaller (not "leaky") cracks as possible. "V" or "U" grooves can be used in the hope that the cracks will open within these grooves. The grooves should be located opposite to each other in both faces of wall. Using vertical grooves at about 6 feet on centers and providing vertical and horizontal grooves at extensions of heads, jambs and sills of openings will increase the number of smaller cracks and channel them within the grooves. Wider spacing of grooves decreases the chance of cracks being smaller and occurring within the grooves.

Inspection of existing buildings revealed that concrete walls whose surfaces were coated with oil paint cracked less than those having only a cement wash. The vinyl paints that breathe are best for this purpose. The least cracking was noticed in buildings where walls were covered with stucco, and particularly in those which were painted in addition. Thus, protection of the surfaces of concrete from rapid moisture changes will decrease its cracking tendency.

Precast concrete members, such as wall panels, precast slabs, precast frames should not be joined too soon. If a waiting period of about 3 weeks or more is allowed for drying, much cracking will be eliminated. When a series of precast elements are interconnected, or connected to steel columns, the details of the connections should allow for movements due to shrinkage and temperature changes. A generous use of thiokol, or equal, is recommended at all exposed joints.

Shortening of a reinforced concrete beam and slab due to shrinkage is resisted by the reinforcing steel and by adjacent members. When the reinforcing steel is unsymmetrical with respect to the center of gravity of the cross-section warping takes place. An introduction of compressive steel will reduce the warping due to shrinkage appreciably, particularly in cantilevers. The references 3, 15, 16, 17, 18, 19 and 20 give methods of computing deflections due to shrinkage warping.

Since the deflections due to creep and shrinkage are dependent on time, it is advisable to give consideration to controlling the time of installation of non-structural fragile elements under or over concrete beams. For instance, a certain concrete beam may deflect 0.25 in. immediately after removal of the shores. Eventually it will deflect an additional 0.50 in. due to creep and shrinkage[3]. However, about half of the above added deflection will take place during the first three months after removal of the shores[3]. Thus only 0.25 in. of deflection will be left to hurt the non-structural fragile elements, if they are installed three months after removal of the shores.

VII - CONSTRUCTION METHODS IN FIELD

Strict enforcement of good standards of construction in the field, such as mixing, cooling, placing, consolidating, curing, etc., will reduce drying shrinkage of concrete in the structure.

Concrete which is allowed to dry immediately after it is placed is only 50 percent as strong at 6 months as concrete which has been cured for 14 days before being exposed to dry air. When properly cured, concrete develops tensile strength and resists cracking. In general, the ultimate shrinkage of concrete is not reduced by the prolonged curing, but the number of cracks is appreciably reduced due to the higher tensile strength of concrete as a result of additional curing. Wall forms should be kept in place for at least 10 days and be continuously moist including Saturdays and Sundays. If a concrete wall is allowed to dry rapidly it will be weak in tension with the result of more extensive cracking. Concrete floor slabs should be cured by covering them with curing paper and kept wet for at least 10 days. The ability of sprayed curing liquids to cure concrete should be carefully investigated before being used. The sprayed layer should not be too thin. Curing of concrete is generally inadequate and very often is applied too late to be of benefit. It should begin as soon as the slab has stiffened enough to support the paper. Curing procedures should be strictly enforced if one wants to minimize the number of cracks in the structure.

Hot weather requires special attention in the manufacture, placement and curing of concrete[23]. The temperature of equipment and all ingredients should be maintained at such a level that the temperature of the concrete at the forms is not over 75° F. Adequate personnel, both as to number and skill, are necessary. Delays in placement contribute to slump loss and lead too often to the use of additional water in the field to offset this loss. This practice should be avoided.

Harmful effects of additional water are two-fold: it increases the shrinkage by about 10 to 15 percent and it decreases the tensile strength of concrete which is needed to resist cracking due to shrinkage.

Hot weather also leads to the so-called plastic shrinkage cracks. The plastic shrinkage cracks are the result of very rapid evaporation of water from the surface of concrete while it is still plastic and very weak. The severity of plastic cracking depends upon the rate of evaporation of water, which in turn depends upon temperature, relative humidity and wind velocity. Under average conditions and mild wind, as much as 1/8 lb. of water per sq. ft. of surface per hour could evaporate. For extreme conditions (90° F., dry, high wind) the loss of water observed was 3/4 lb. per sq. ft. of surface per hour[24]. The disappearance of the sheen from the surface of concrete indicates that the evaporation at the surface is faster than the rate of rising water. At that moment the plastic shrinkage cracks will begin to occur.

Plastic shrinkage cracking can be eliminated by providing proper humidity environment using a fog mist. The fog mist should be started after first floating of the concrete and continued until curing paper is applied to the slab. Concrete poured late in the afternoon with a falling temperature will have less plastic shrinkage cracking.

Cracking, checking and crazing of concrete floor slabs often result from improper finishing operations. The concrete slab is "manipulated to death." This procedure brings the fast shrinking fines and water upwards, thus making the top layer of the slab weak in tension. Davis and Troxell[26] investigated the floor slab of a government building. Measurements showed that drying shrinkage of the top inch of the floor was approximately five times as great as that of the bottom inch. Overtroweling or too early trowling should not be allowed.

VIII – CUMULATIVE EFFECT OF ADVERSE FACTORS ON SHRINKAGE

The cumulative effect of adverse factors on shrinkage of concrete due to the departure from the use of best materials and workmanship is alarming. The shrinkage may increase as much as 500 percent of normal[8]. Combination of such unfavorable factors as addition of water in the field necessitated by the high temperature of concrete at discharge and prolonged haul in transit mixers, using large slump, using 3/4 in. maximum size of aggregate instead of $1\frac{1}{2}$ in. may increase the shrinkage to about 160 percent of normal. The remaining increase of 340 percent may be due to lack of control of quality of constituent materials, such as use of cement of relatively high shrinkage characteristics, allowing excessive "dirt" in aggregate, use of weak compressible aggregates and use of unfavorable chemical admixtures.

The above shows that a concrete of minimum shrinkage requires all around control: proper materials, proper design of mix, proper mixing and transporting, and proper placing and curing.

The concrete usually is one of the first items manufactured and placed into a structure. Almost invariably at the outset haste develops. The General Contractor is primarily interested in placing concrete as fast as possible and getting the other trades into the building. In some cases he has to do this because the contract documents do not provide ample time. The time often is so limited that the Contractor must resort to doubtful expedients to get the work out. On account of haste, frequently, the well-intentioned project specifications are relaxed and the man responsible for enforcement must comply tacitly and accept the change as inevitable.

Haste is evident on many jobs:

1. There is a tendency to overload transit mixers in order to get as much concrete to the job as fast as possible, such that the concrete is improperly mixed before it is placed.

2. Sometimes concrete delivered to the job is so stiff that water is added indiscriminately to remedy the situation.

3. The placing (pouring) schedule is rushed such that the vertical lifts are too high and inadequate time lag is allowed between the placement of successive lifts.

4. There is a tendency to use undesirable sloppy wet mixes. Concrete ingredients are flying instead of flowing, resulting in a separation of larger aggregates from concrete. Low slump, drier mixes, producing better concrete, are not favored because it takes more personnel and extra effort to consolidate such concrete thoroughly.

5. Concrete is often placed under adverse weather conditions of temperature, humidity and wind.

6. The advantage of modern vibrators is not fully utilized. The batch is merely flattened and not properly consolidated. Lack of current is frequently responsible for improper consolidation of concrete.

7. Curing operations are delayed and not carried out to completion, or are eliminated entirely.

8. The weight of subsequent pours is imposed upon recently cast "green" concrete, which resists the load but deflects and sags excessively. The excessive deflections are often blamed on shrinkage and creep, and poor design.

9. Slump is a rough measure of the degree of wetness of concrete. Often slump tests are omitted, even where specifications require them.

Concrete of good shrinkage characteristics requires careful step by step unhurried handling. Strict control of concreting operations and temperature is essential. Good drawings and specifications have no meaning, unless they are enforced. Job inspection by competent personnel should be such as to allow and insure enforcement.

The quality of all ingredients of a concrete mix, to satisfy the chosen shrinkage requirements of a project, can be controlled by making a trial batch of a mix using the proposed cement, aggregate and admixture, if any. A set of drying shrinkage specimens can be prepared and tested in a special room in a laboratory. Many testing laboratories in California are equipped to perform this service.

IX - CONCLUSION

Now that designs of concrete systems utilize long, slender, and shallow elements, consideration of shrinkage and creep can no longer be considered as negligible. As is shown in the preceding discussion, consideration of the concrete's strength alone is no longer a sufficient measure of serviceability. This does not imply that concrete is not a satisfactory material, but rather, points up the increased responsibility of the engineer and contractor.

In order to properly consider shrinkage and creep, the engineer needs more knowledge of the shrinkage and creep properties of concrete, particularly as regards local materials. The Committee, therefore, recommends that concrete producers initiate steps toward research on time-dependent shrinkage and creep properties of concrete made with local materials and on the effect these properties have upon concrete in service.

~~APPENDIX I~~

~~SAMPLE SPECIFICATIONS~~

~~For Shrinkage~~

~~(a) Prior to placing any concrete, a trial batch of each mix design of structural concrete shall be prepared using the aggregates, cement and admixture, if any, proposed for the project. From each trial batch at least three (3) specimens for determining the "Drying Shrinkage" shall be prepared in addition to six (6) compression test specimens.~~

~~(b) The "Drying Shrinkage" specimens shall be 4 by 4 by 11 in. prisms, fabricated, cured, dried and measured in the manner outlined in A.S.T.M. Designation C 157-64T. Measurements shall be made and reported separately for 7, 14, 21 and 28 days of drying after 7 days of moist curing. The effective gage length of the specimens shall be ten (10) inches.~~

~~Compression test specimens shall be fabricated, cured and tested in accordance with A.S.T.M. Designation C 192-59. Three (3) specimens shall be tested at an age of 7 days and three (3) at the age of 28 days.~~

~~(c) During construction "Drying Shrinkage" specimens of each class of concrete will be taken to insure continued compliance with these specifications. At least one (1) set of three (3) specimens will be taken from each 1000 cubic yards of concrete placed, but in no case less than three (3) sets of specimens will be taken for the project. Compression test specimens will be taken from the same concrete as used for preparing "Drying Shrinkage" specimens. These compression test specimens shall be considered as part of the normal requirements for tests in connection with this project.~~

~~(d) The average "Drying Shrinkage" of the test specimens after 28 days*) of drying shall not exceed 0.032**) percent. Considering the variations in concrete properties and in testing, a tolerance of 15 percent in the above figure will be allowed.~~

~~Notes to specification writer:~~

~~*) If 21 days drying is specified use 83% of the above values.~~

~~**) The figure of 0.032 percent = 320 millionths to be used if Class A concrete is desired. For Class B concrete the figure is 0.048 percent. For Class C concrete the figure is 0.064 percent.~~

~~The shrinkage limitations of concrete need not apply to foundations (below grade).~~

~~It is possible to require "Drying Shrinkage" test specimens of only one class of concrete with smallest maximum size aggregate, provided that the same materials and about the same or less water per cubic yard is used in other classes of concrete.~~

~~For Cleanliness of Aggregate~~

~~All aggregate shall have a minimum C.V. (cleanliness value) and S.E. (sand equivalent) of not less than 75. Three (3) samples shall be tested in each case and shall~~

~~be taken from weigh hopper. The average of the results of the individual tests will be the accepted value in each case. These values shall be maintained throughout the course of the work and any indicated deviation therefrom will be cause for rejection of such material, pending additional tests. Tests shall conform to Test Method No. Calif. 217E (Materials Manual, Testing and Control Procedures - Materials and Research Department, State of California, Sacramento, California).~~

SEE GUIDELINES

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SUPPLEMENTARY REPORT

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APPENDIX II

SHRINKAGE TEST DATA FOR CONCRETES USED ON SOME PROJECTS IN CALIFORNIA

Fig. 1 shows a plot of the 28-day shrinkage for concrete specimens tested in private and State of California laboratories under environment of approximately 70° F. and 50% relative humidity.

The tests were conducted for concretes actually specified for various projects during the years 1960 thru 1963. Different cements were used (Calaveras, Ideal, Permanente, Santa Cruz) in combinations with aggregates from various sources. Maximum size of aggregates varied from 3/4 to 1½ in. Various admixtures (and no admixtures) were used.

The sizes of test specimens varied (3 by 3 in., 4 by 4 in., 5 by 6 in., etc.). The values of shrinkage plotted in Fig. 1 were converted to 4 by 4 in. specimen.

For this series of tests the total number of specimens was 214. It is seen that 115 specimens (about 53% of the total) met the requirements of 320 + 15% 320 = 368 millionths for Class "A" concrete; 185 specimens (about 86% of the total) met the requirements of 480 + 15% 480 = 552 millionths for Class "B" concrete; and 212 specimens (about 99% of the total) met the requirements of 640 + 15% 640 = 736 millionths for Class "C" concrete.

APPENDIX II

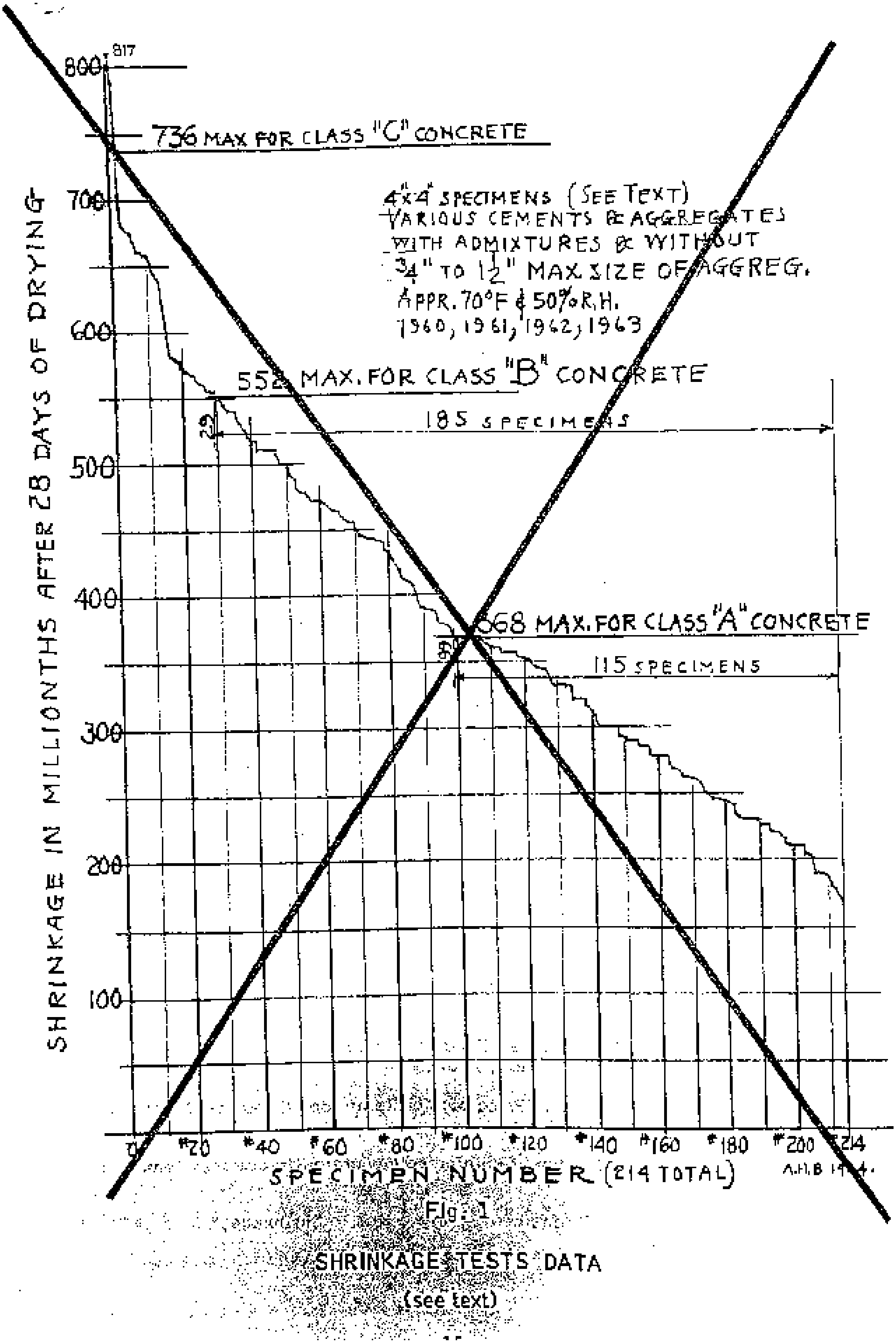

Fig. 1

SHRINKAGE TESTS DATA

(see text)

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