Department of

College of Engineering
The University of Iowa
Iowa City, Iowa

The Prediction of Creep and Shrinkage Properties of Concrete

by
B. L. Meyers
D. E. Branson
C. G. Schumann
M. L. Christiason

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THE PREDICTION OF CREEP & SHRINKAGE PROPERTIES OF CONCRETE

Final Report of

Creep & Shrinkage Properties of Lightweight Concrete Used in the State of Iowa

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FOREWORD

This is the final report of the research conducted under Phase II of the Iowa State Highway Commission Research Project No. HR-136. The project was initiated in February 1968.

This project was coordinated with the Iowa State Highway Commission Research Project No. HR-137, Time-Dependent Deformation of Non-Composite and Composite Sand-Lightweight Prestressed Concrete Structures (see report No. 69-1, dated February, 1969). Both projects were directed by Drs. D.E. Branson and B.L. Meyers.

Acknowledge is made of the assistance of Messrs. S.E. Roberts, Research Engineer, C. Pestotnik, Bridge Engineer, and Y.H. Gee, Assistant Bridge Engineer of the Iowa State Highway Commission; Mr. J.H. Boehmler, Jr., President, Prestressed Concrete of Iowa, Inc.; and G. Anderson and P. Kline, Graduate Students, University of Iowa.

The authors would also like to acknowledge Idealite Co., Denver, Colorado; Hydraulic Press Brick Co., Brooklyn, Indiana; Carter-Waters Corp., Kansas City, Missouri; and Buildex, Inc., Ottawa, Kansas for donating materials used in the experimental program.

The opinions, findings and conclusions expressed in this publication are those of the author and not necessarily those of the Iowa State Highway Commission.

ABSTRACT

This report is concerned with the prediction of the long-time creep and shrinkage behavior of concrete. It is divided into three main areas.

1. The development of general prediction methods that can be used by a design engineer when specific experimental data are not available.

2. The development of prediction methods based on experimental data. These methods take advantage of equations developed in item 1, and can be used to accurately predict creep and shrinkage after only 28 days of data collection.

3. Experimental verification of items 1 and 2, and the development of specific prediction equations for four sand-lightweight aggregate concretes tested in the experimental program.

The general prediction equations and methods are developed in Chapter II. Standard Equations to estimate the creep of normal weight concrete (Eq. 9), sand-lightweight concrete (Eq. 12), and lightweight concrete (Eq. 15) are recommended. These equations are developed for standard conditions (see Sec. 2.1) and correction factors required to convert creep coefficients obtained from equations 9, 12, and 15 to

valid predictions for other conditions are given in Equations 17 through 23. The correction factors are shown graphically in Figs. 6 through 13.

Similar equations and methods are developed for the prediction of the shrinkage of moist cured normal weight concrete (Eq. 30), moist cured sand-lightweight concrete (Eq. 33), and moist cured lightweight concrete (Eq. 36). For steam cured concrete the equations are Eq. 42 for normal weight concrete, and Eq. 45 for lightweight concrete. Correction factors are given in Equations 47 through 52 and Figs., 18 through 24.

Chapter III summarizes and illustrates, by examples, the prediction methods developed in Chapter II.

Chapters IV and V describe an experimental program in which specific prediction equations are developed for concretes made with Haydite manufactured by Hydraulic Press Brick Co. (Eqs. 53 and 54), Haydite manufactured by Buildex Inc. (Eqs. 55 and 56), Haydite manufactured by The Cater-Waters Corp. (Eqs. 57 and 58), and Idealite manufactured by Idealite Co. (Eqs. 59 and 60). General prediction equations are also developed from the data obtained in the experimental program (Eqs. 61 and 62) and are compared to similar equations developed in Chapter II.

Creep and Shrinkage prediction methods based on 28 day experimental data are developed in Chapter VI. The methods are verified by comparing predicted and measured values of the long-time creep and

shrinkage of specimens tested at the University of Iowa (see Chapters IV and V) and elsewhere. The accuracy obtained is shown to be superior to other similar methods available to the design engineer.

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NOTATION

A	= air content in percent
B	= bags of cement per cubic yard
C_t	= creep coefficient at time t, defined as ratio of creep strain to initial strain
C_u	= ultimate creep coefficient
C. F.	= correction factor to account for conditions other than standard
c, d	= empirical constants in standard creep equation
e, f	= empirical constants in standard shrinkage equation
F	= ratio of fine aggregate to total aggregate (by weight), expressed as a percentage
H	= ambient relative humidity in percent
i	= subscript denoting initial value
LA	= subscript denoting loading age
S	= slump of concrete in inches
sh	= subscript denoting shrinkage
T	= minimum thickness of member in inches
t	= time in days
u	= subscript denoting ultimate value
ϵ_i	= initial strain due to applied load

NOTATION (cont.)

$(\epsilon_{sh})_t$ = shrinkage strain at time t

$(\epsilon_{sh})_u$ = ultimate shrinkage strain

σ_i = initial applied stress

Chapter 1

INTRODUCTION

1.1 Background Information

It has been suggested that the three main criteria for the serviceability of structures are:

1. the limit state of excess deflection
2. local damage; and
3. collapse.[1]

Work being carried out at the University of Iowa, under the sponsorship of the Iowa State Highway Commission, has been concerned with the limit state of deflection. In particular, the projects "Creep and Shrinkage Properties of Lightweight Concrete Used in the State of Iowa" (HR-136), and "Time-Dependent Deformation of Non-Composite and Composite Sand-Lightweight Prestressed Concrete Structures" (HR-137) were designed to investigate the long term state of limit deflection.

The familiar creep prediction methods developed by Ross[2] and Jones et al.[3] were combined and fairly accurate methods to estimate the creep of shrinkage of concrete mixes made with Idealite aggregate were suggested in the Phase 1 report of Project HR-136[4]. A close evaluation of these methods indicate the following:

1. Using the methods described in Reference (4), creep and shrinkage characteristics can be adequately predicted from equations derived based on 100-day creep and shrinkage data.

2. For structures made with the aggregate investigated, predictions can be made using the equation suggested in Reference (4) without gathering additional data.

3. The general form of the creep equation used in Reference (4) although yielding adequate results, does not seem to accurately represent measured creep values from 1 day to 28 days.

4. The general form of the shrinkage equation suggested in Reference (4) seems to adequately represent measured shrinkage values for all time intervals.

Building on the procedures developed in Reference (4), Branson, Meyers, and Kripanarayanan[5] modified the suggested creep and shrinkage prediction methods and proposed the following standard prediction equations.

$$C_t = \frac{t^c}{d + t^c} C_u \tag{1}$$

$$\epsilon_{sh} = \frac{t^e}{f + t^e} (\epsilon_{sh})_u \tag{2}$$

where

C_t = creep coefficient at any time t; ϵ_{sh} = shrinkage strain at any time t; c, d, e, and f are empirical constants; C_u = ultimate creep

coefficient and $(\epsilon_{sh})_u$ = ultimate shrinkage strain. It was further suggested in Reference (5) that c = 0.6, d = 11.0 and C_u = 1.75; e = 1.0, f = 23.6, $(\epsilon_{sh})_u = 590 \times 10^{-6}$ in/in, for the moist cured concrete used in that study.

It is apparent from comparisons with measured data that the form of the creep prediction equation suggested in Equation (1) is more representative of the full range of creep behavior than the form originally suggested by Ross[2] and used in Reference (4). Such a comparison is made in Fig. 1.

1.2 Review of Literature

Much has been written on the creep of concrete in the last 70 years[6] and a number of authors[7, 8, 9, 10] have adequately reviewed the subject. Since this report is primarily concerned with prediction methods and their accuracy this section will be limited to a review of these methods.

Prediction methods that might be useful to the engineer fall into two general categories. The first category, expressing the creep time relation in the form of an equation, usually requires that one or more empirical constants be determined experimentally. The second category, expressing creep using a standard curve which can be modified by a number of factors to allow for various mix and storage conditions, does not require experimental data but is usually less

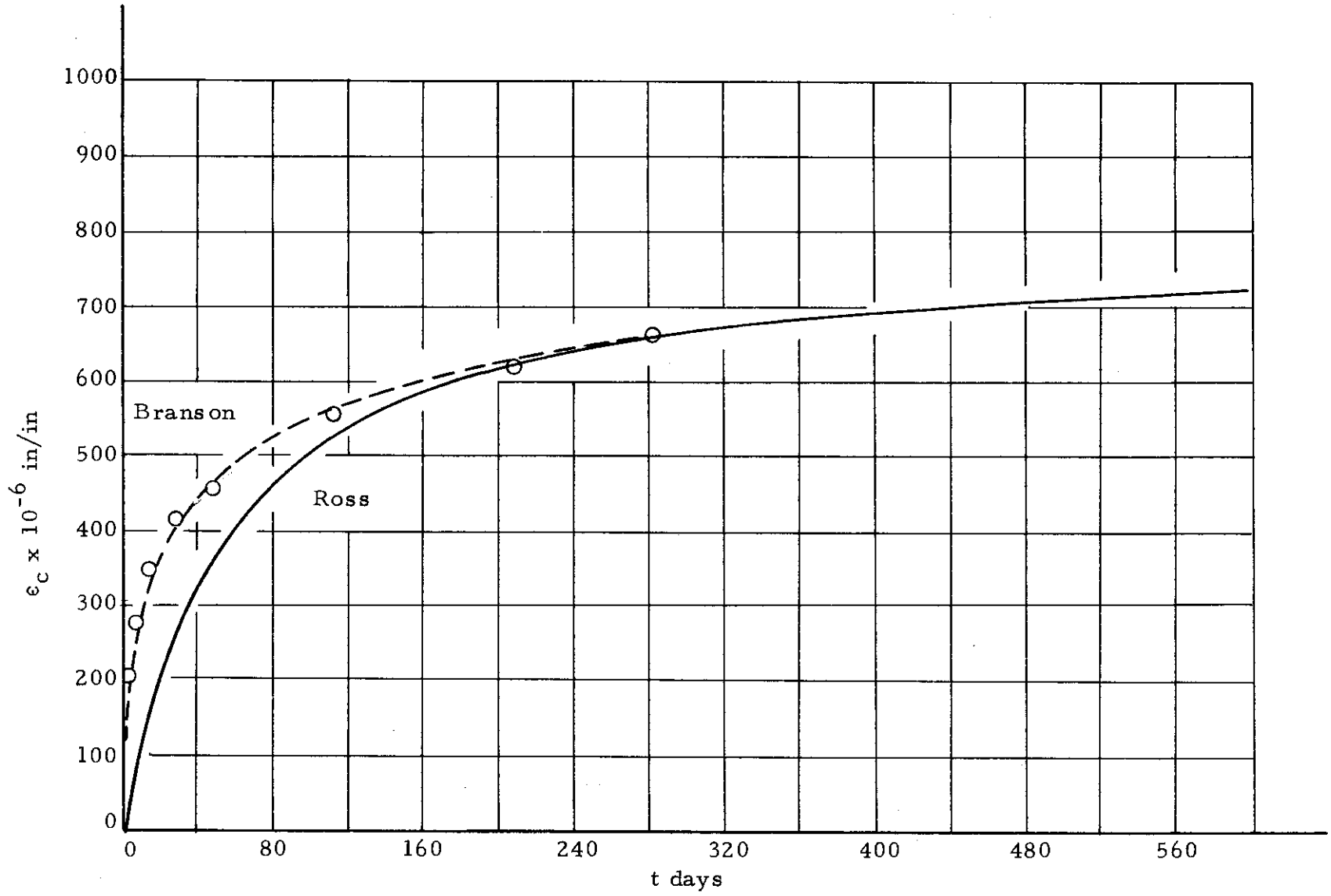

Fig. 1 Predicted Creep Using Ross Equation vs. Branson Equation

accurate than the use of an empirical equation based on actual measurements.

About a dozen exponential or hyperbolic equations have been suggested in the literature. The exponential equations, which have the disadvantage of not approaching a finite limit, are of doubtful practical value because they are usually unwieldy or require extended periods of data collection. Such equations have been proposed by Thomas[11], McHenry[12], Saliger[13], Shank[14], and Troxel et al.[15].

A number of hyperbolic equations, which do approach a finite limit, have also been suggested. Those used most often are the equations of Ross[2]

$$c = \frac{t}{a + bt} \tag{3a}$$

and Lorman[16]

$$c = \frac{mt}{n + t}\,\sigma \tag{3b}$$

where c = creep, t = time, σ = stress, and a, b, m, and n are empirical constants.

The methods using standard creep curves can be represented by those suggested by Jones, Hirsch, and Stephenson[3], and Wagner[18]. Jones et al.[3] use a standard curve which is valid for specific mix and storage parameters. The standard curve is corrected for other conditions using a set of correction factors. Wagner's method differs only in that standard values of ultimate specific

creep are given in lieu of the standard creep curve.

An excellent check for any of the methods described above was supplied by Troxell, Rapheal and Davis[15]. Based on an extensive 30-year study they concluded that approximately 1/4 of the 20-year creep occurred during the first two weeks under load, about 1/2 in the first 2 or 3 months, and about 3/4 in the first year. An additional 10% occurred the second year and the remaining 15% required 18 years.

The accuracy of any method can be evaluated in terms of an error coefficient M suggested by Neville and Meyers[7].

$$M = \sqrt{(C_t - C_1)^2 / n} \,/\, C_1$$

where C_t = creep after one year predicted from measured creep after t weeks under load; C_1 = actual creep after one year under load; n = number of specimens or experimental sets for which creep was observed at time t. M is thus analogous to the coefficient of variation but deviation is measured from the true creep.

In their paper Neville and Meyers[7] suggested that the error coefficient for most available methods is as shown in Fig. 2. The data shown in the figure represents only prediction based on a fixed amount of experimental data. It can be concluded that in order to predict creep within an error coefficient of 10%, twenty weeks of data is required. A typical prediction using the methods of Jones et al.[3], and Wagner[18] is shown in Fig. 3.

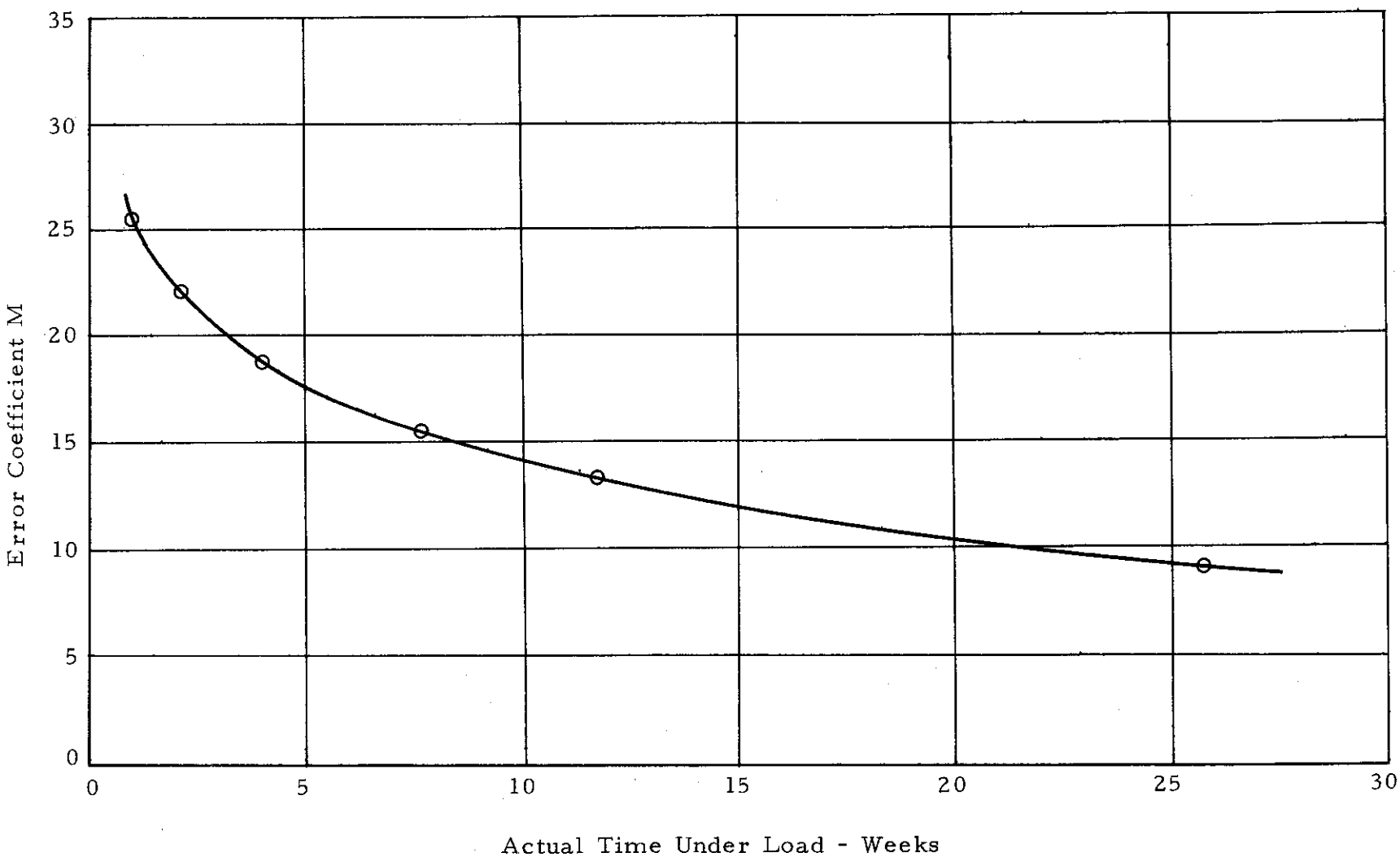

Fig. 2 Accuracy of Predicting 1 Yr Creep From Short Time Tests

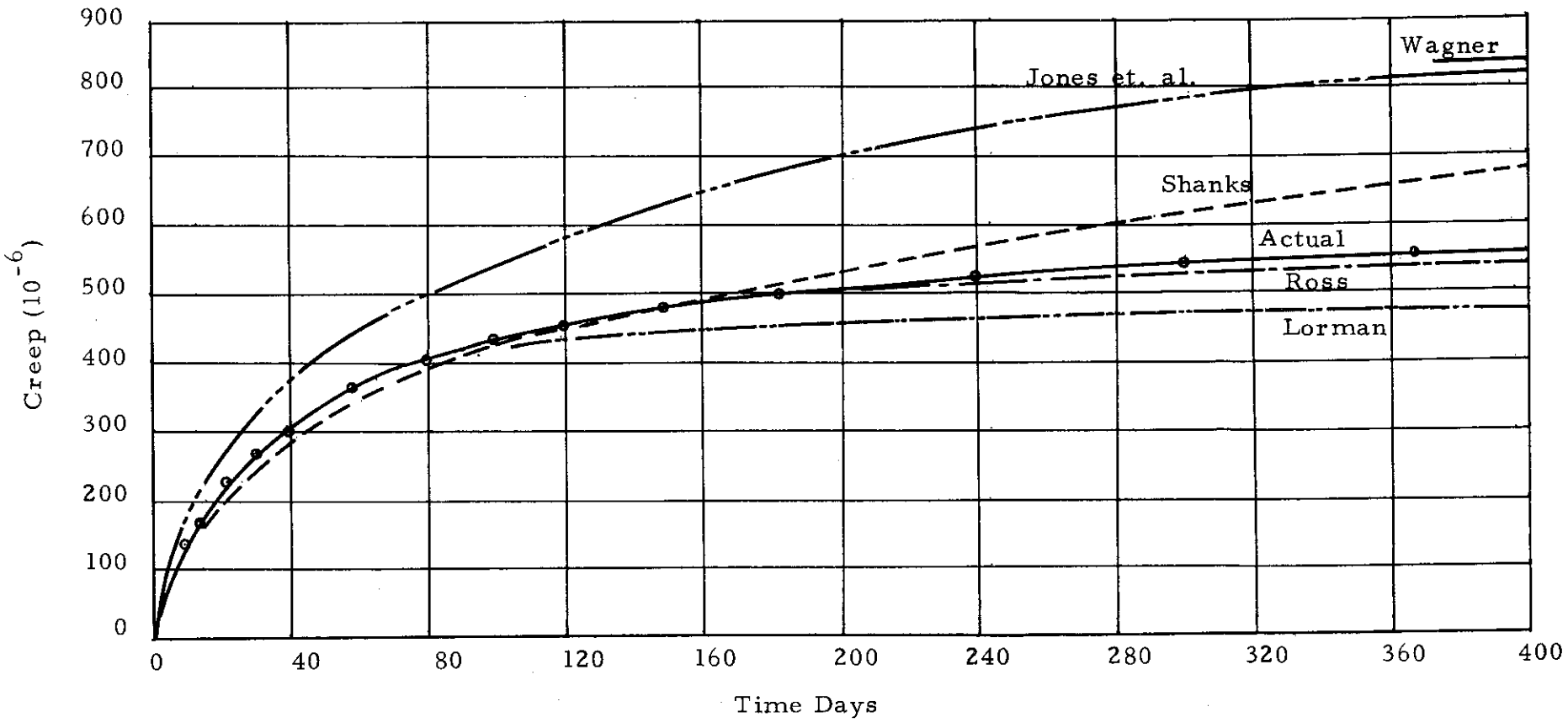

Fig. 3--Comparison of Prediction Methods

1.3 Statement of the Problem

Based on the above brief review of available prediction methods and the work carried out at the University of Iowa[4 and 5] it is suggested that the following developments are necessary so that the designer can control the deflection of structures within acceptable and specified limits of uncertainty.

1. Develop accurate general prediction methods that do not require data collection.

2. Develop prediction methods that require a minimum of data collection (less than 20 weeks). In many cases the inherent uncertainties of prediction without data will not result in deformation estimates not sufficiently accurate for many structures (e.g., nuclear reactors, etc.).

The research reported herein is concerned with these areas as well as the development of accurate relations that can be used to predict the creep and shrinkage behavior of lightweight aggregate concretes available in the State of Iowa.

Therefore the work described in this report can be divided into three main sections.

1. The development of general prediction methods for creep and shrinkage of concrete based on the mathematical representation for time-dependent deformation suggested by Branson et al.[5, 17].

2. An experimental verification of the methods developed in Item 1 above. The experimental program was carried out using a

number of lightweight aggregate concretes available in the State of Iowa. Accurate relationships that can be used to predict creep and shrinkage behavior of these materials are recommended.

3. The development of creep and shrinkage prediction methods based on only 28 days of data collection. These methods take advantage of the increased accuracy of the equations suggested by Branson et al.[5].

Chapter 2

GENERAL PREDICTION METHODS: CREEP AND SHRINKAGE

2.1 Creep of Concrete

It has been demonstrated that creep of a concrete specimen with fixed mix parameters and storage conditions can be predicted using an equation in the form of Eq. (1) [5]. Creep of a specimen subjected to other than standard conditions can then be estimated by applying experimentally determined general correction factors to the value obtained using the standard equation. This type of design procedure is similar to those proposed by Branson et al. [5], Jones et al. [3], and the CEB report [19]. This technique has been adopted in this report, and all standard equations are developed for the following standard conditions: 3" or less slump, 40% ambient relative humidity, and loading ages of 7 days for moist cured and 2-3 days for steam cured concretes.

In order to determine a general relationship, creep data from References 3, 4, 20-29 (tabulated in the Appendix) were reduced to the above-mentioned standard conditions using correction factors described in Sections 2.2 and 2.4 of this report. A creep coefficient versus time curve was prepared for each specimen from which ultimate creep coefficients were extrapolated. The data were then normalized in terms of the ultimate creep coefficient and are plotted in Fig. 4.

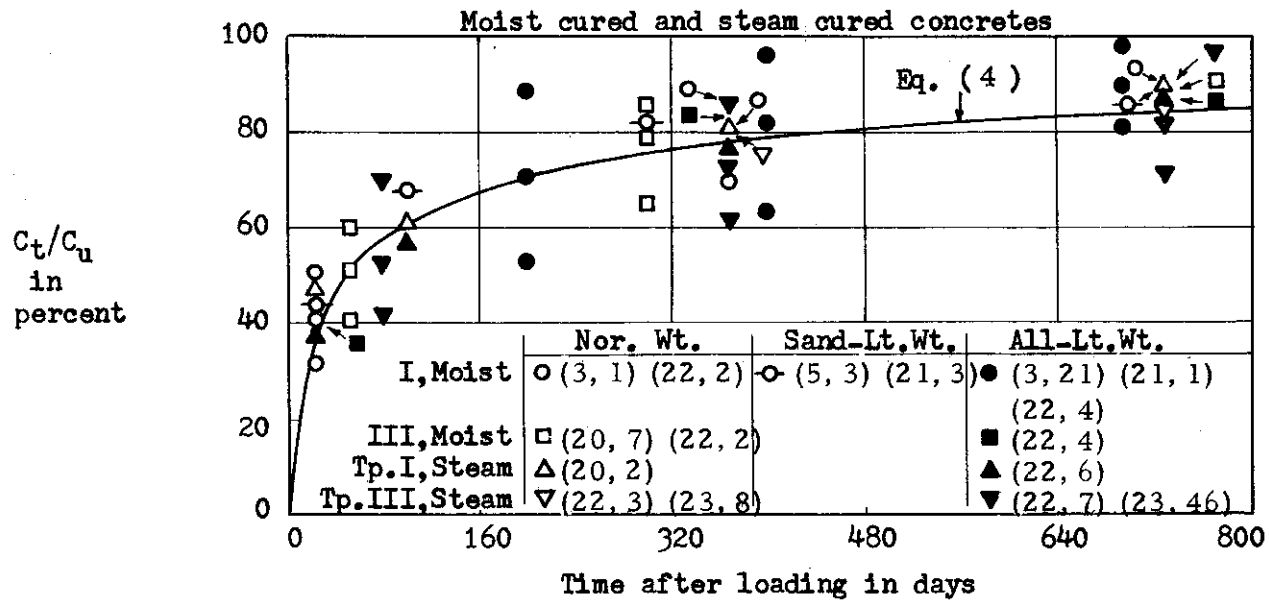

Fig. 4--Creep coefficient in percent of ultimate creep coefficient versus time curve using Eq. (4) for moist cured and steam cured concretes, and comparison with data. Loading ages are 7 days for moist cured and 2-3 days for steam cured concretes. In each set of parentheses, the first and second numbers, respectively, refer to the source of the data and the number of specimens from that source. Three data points shown for a specific time refer to the upper and lower limits and the average value for the data. Where only one data point is shown, the range of the data is too small to indicate

In most cases, three data points are shown for a particular specimen category and time. They represent the upper and lower limit and average values for these data. Only one data point is shown for a specific value of time when the spread between upper and lower values is small. Eq. (4) was derived by fitting a curve to the average values of the data plotted in Fig. 4 .

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} C_u \tag{4}$$

The same data are shown in Fig. 5 where creep coefficients are plotted versus time after loading in days. From this plot specific equations can be determined for upper bound, average, and lower bound values. These equations are

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} 4.15 \tag{5}$$

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} 2.35 \tag{6}$$

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} 1.30 \tag{7}$$

These data can also be further separated and a similar set of equations developed for normal weight concrete only, sand-lightweight concrete only and all lightweight concrete only.

For the normal weight concrete data, the upper-limit, average-value, and lower-limit curves, respectively, are given by:

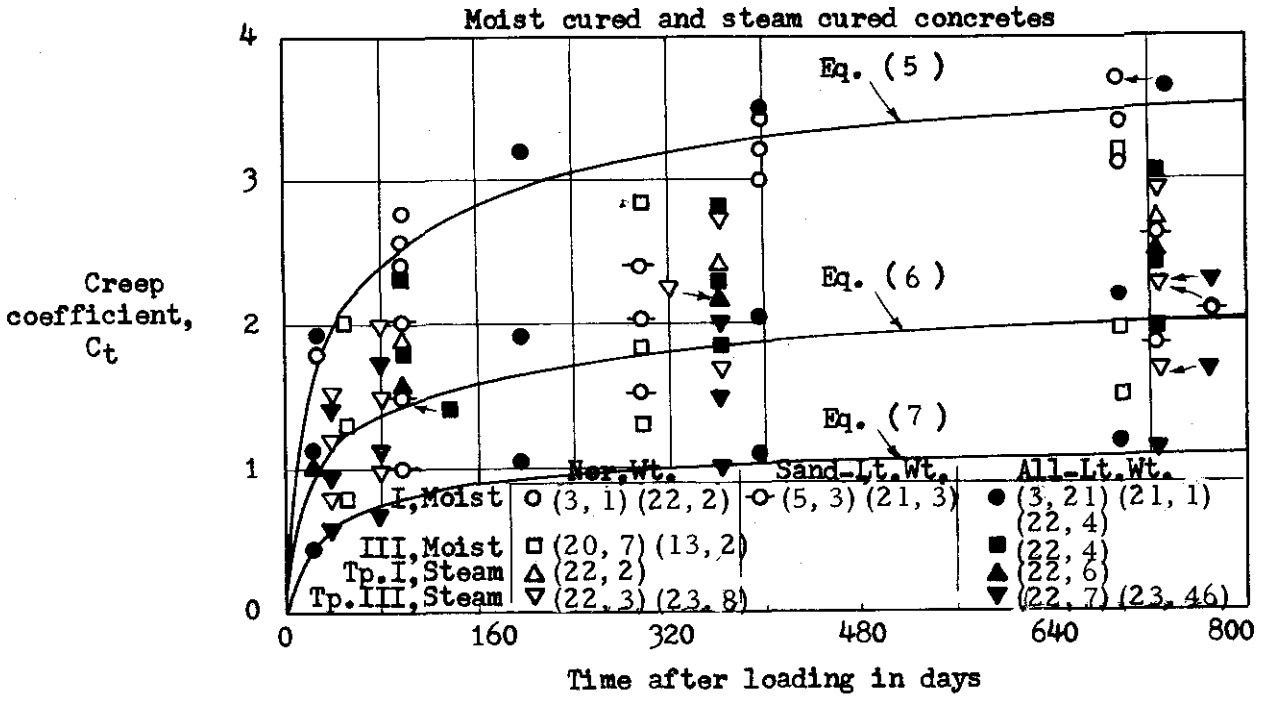

Fig. 5--Standard creep coefficient equation, Eq. (6), and upper and lower-limit curves compared with data. In each set of parentheses, the first and second numbers, respectively, refer to the source of the data and the number of specimens from that source. Three data points shown for a specific time refer to the upper and lower limits and the average value for the data. Where only one data point is shown, the range is too small to indicate. The standard conditions are 3" or less slump, 40% ambient relative humidity, and loading ages of 7 days for moist cured and 2-3 days for steam cured concretes

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 4.07 \tag{8}$$

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 2.75 \tag{9}$$

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 1.98 \tag{10}$$

For the sand-lightweight data, the upper-limit, average-value, and lower-limit curves are defined by:

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 2.97 \tag{11}$$

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 2.00 \tag{12}$$

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 1.35 \tag{13}$$

Similarly, the upper-limit, average-value, and lower-limit curves for the all-lightweight concrete are:

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 4.15 \tag{14}$$

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 2.30 \tag{15}$$

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 1.30 \tag{16}$$

Therefore Eq. 9, 12, and 15 represent average value general prediction equations for normal weight, sand lightweight and all lightweight concrete respectively.

2.2 Correction Factors for Creep

It has already been indicated that the equations developed in the previous section are only valid for a fixed set of standard conditions. Therefore correction factors are required to convert creep coefficients obtained from Eq. 5 thru 16 to valid predictions for other conditions. Such correction factors are presented for the following parameters.

1. Ambient relative humidity
2. Age when loaded
3. Minimum thickness of member
4. Slump
5. Percent fines
6. Cement content
7. Air content

The correction factors were determined from test data for which the only variable was the parameter under consideration. Relative creep coefficients for specimens tested under other than standard conditions were obtained by dividing the observed values by the creep coefficients obtained from specimens tested under standard conditions.

These relative values were then plotted vs the parameters under consideration and a curve fit to the data.

The effect of ambient relative humidity is shown in Fig. 6. It is suggested no correction factor be used when the humidity is less than 40%, but when the humidity is greater than 40%, use Eq. (17) to obtain the correction factor.

$$\text{Creep (C.F.)}_H = 1.27 - 0.0067H \quad \text{for } H \geq 40\% \tag{17}$$

where H is the ambient relative humidity in percent.

Fig. 7 indicates the effect of age when loaded on creep coefficients for moist cured and steam cured concretes. The average curves are suggested for use as creep coefficient correction factors. For moist and steam cured concretes, respectively, these average curves are closely approximated by the following equations:

$$\text{Creep (C.F.)}_{LA} = 1.25(t)^{-0.118} \quad \text{for moist cured} \tag{18}$$

$$\text{Creep (C.F.)}_{LA} = 1.13(t)^{-0.095} \quad \text{for steam cured} \tag{19}$$

where t is the loading age in days.

The effect of the minimum thickness of a member, as shown in Fig. 8, tends to decrease as the age of the concrete increases. This indicates the ultimate creep coefficient of a larger member approaches that of a smaller member, though the ultimate creep coefficient of a small member is attained sooner than that of a larger member. The average effect of minimum thickness is given by Eq. (20).

$$\text{Creep (C.F.)}_T = 1.12 - 0.02T \tag{20}$$

where T is the minimum thickness in inches.

Eq. (21) is recommended for use in obtaining correction factors for the effect of slump on creep coefficient.

$$\text{Creep (C.F.)}_S = 0.82 + 0.067S \tag{21}$$

where S is the observed slump in inches. Eq. (21) is plotted with the experimental data in Fig. 9.

Creep coefficient correction factors for the effect of percent fines are given by Eq. (22), which is plotted in Fig. 10.

$$\text{Creep (C.F.)}_F = 0.88 + 0.0024F \tag{22}$$

where F is the ratio of fine aggregate to total aggregate (by weight) expressed as a percentage.

As shown in Fig. 11, an increase in cement content causes a reduced creep strain. However data indicates a proportional increase in modulus of elasticity accompanies an increase in cement content. Thus, cement content has a negligible effect on creep coefficient. The data plotted in Fig. 12 confirms this observation.

Eq. (23), which gives correction factors for the effect of air content on creep coefficient, is illustrated in Fig. 13. The data indicate little effect for air contents less than 6%. Thus, Eq. (23) is to be used for air contents greater than 6%, and no correction factors for air contents less than 6%.

$$\text{Creep (C.F.)}_A = 0.46 + 0.09A \quad \text{for } A \geq 6\% \tag{23}$$

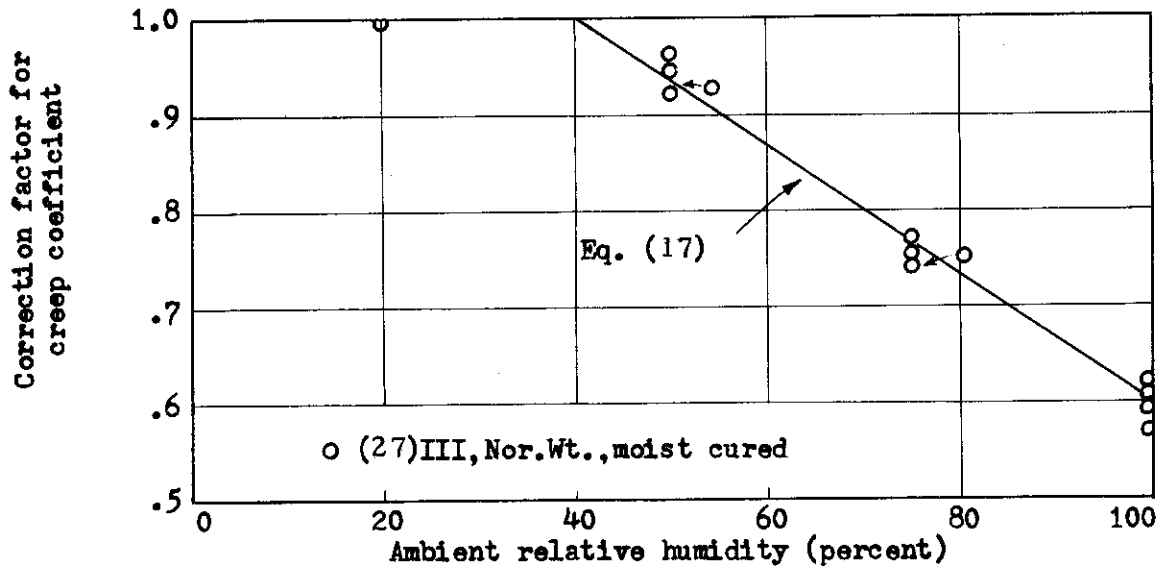

Fig. 6--Creep coefficient correction factors for humidity, with source of data, type of cement, weight classification, and curing technique indicated

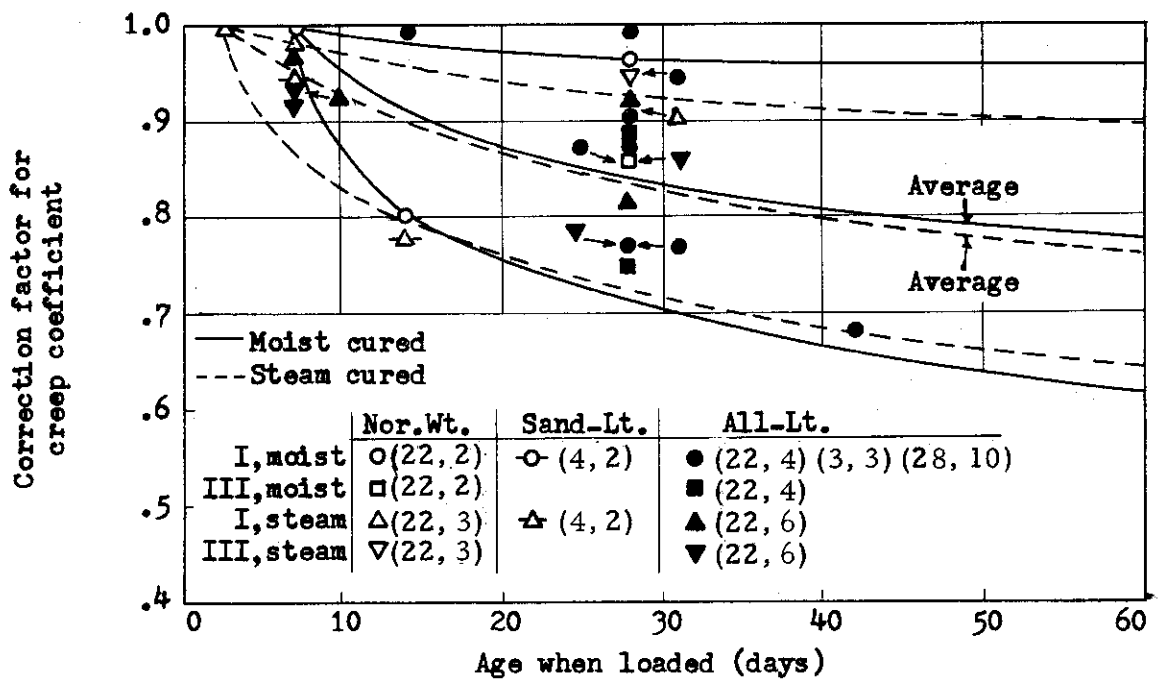

Fig. 7--Creep coefficient correction factors for age when loaded. The first and second numbers in each set of parentheses, respectively, indicate the source of the data and the number of specimens. Average and limit curves are shown for moist and steam cured concretes

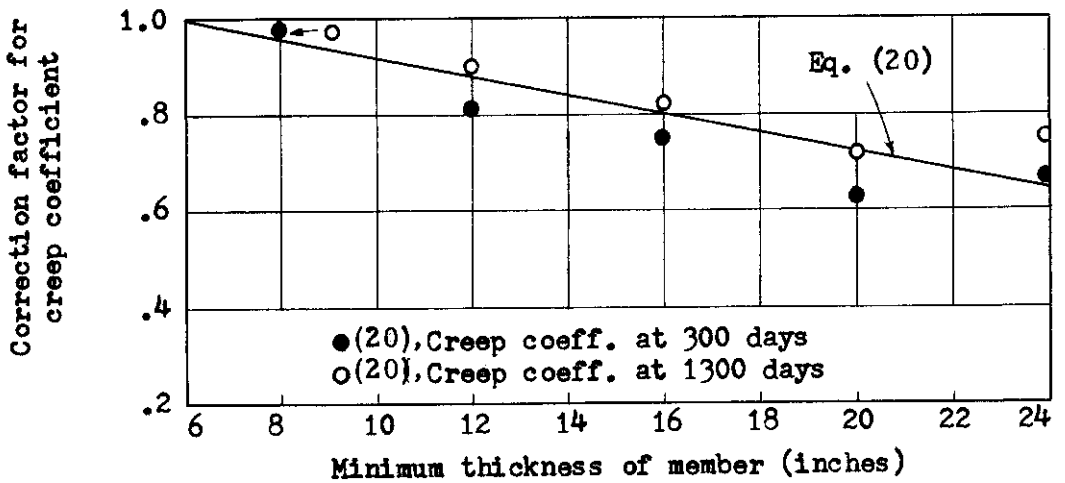

Fig. 8 --Creep coefficient correction factors for minimum thickness of member, with source of data and age at time of reading indicated

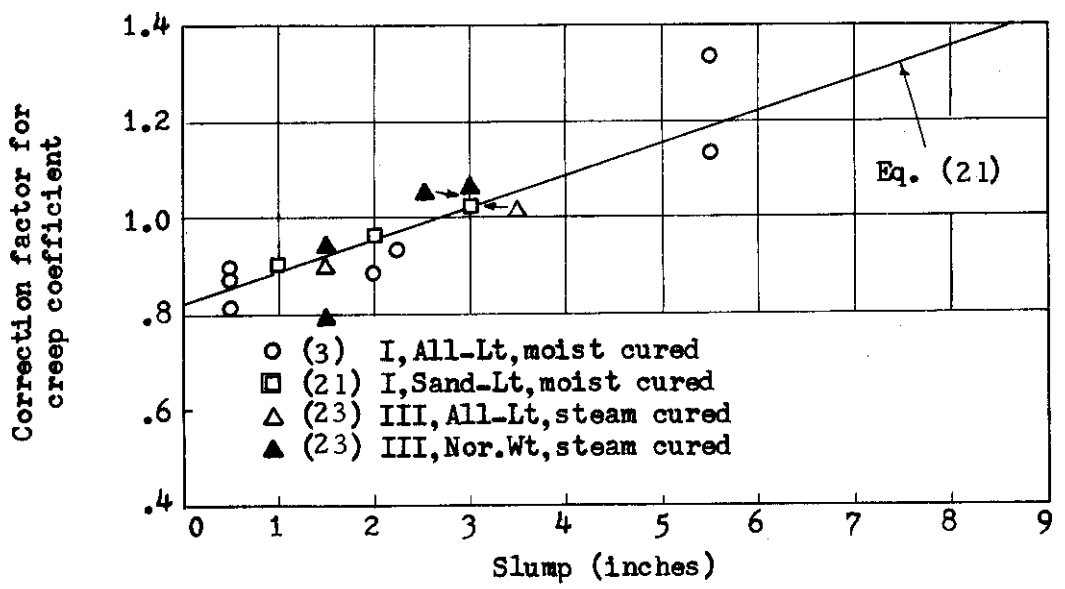

Fig. 9 --Creep coefficient correction factors for slump, with source of data, type of cement, weight classification, and curing technique indicated

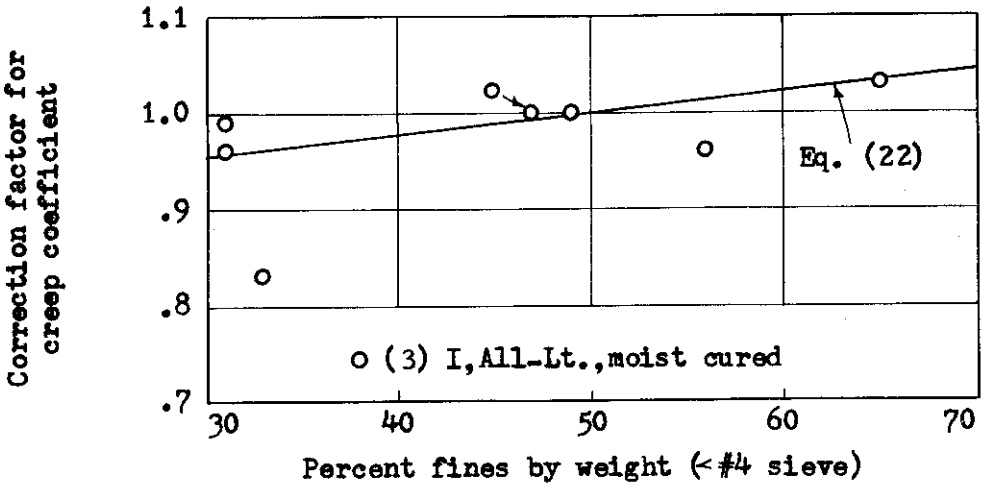

Fig. 10--Creep coefficient correction factors for percent fines, with source of data, type of cement, weight classification, and curing technique indicated

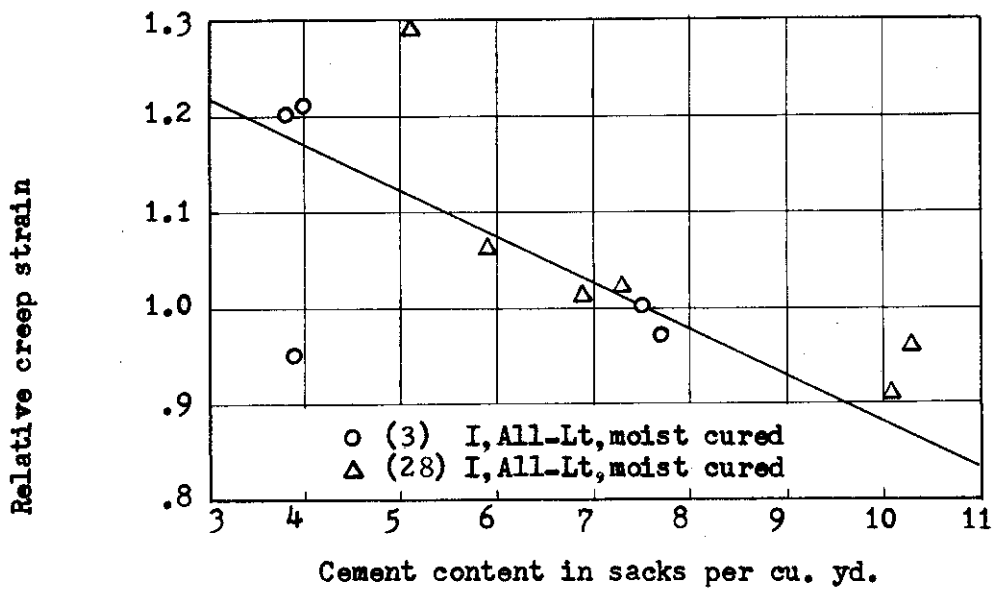

Fig. 11--Relative values of creep strain versus cement content, with source of data, type of cement, weight classification, and curing technique indicated

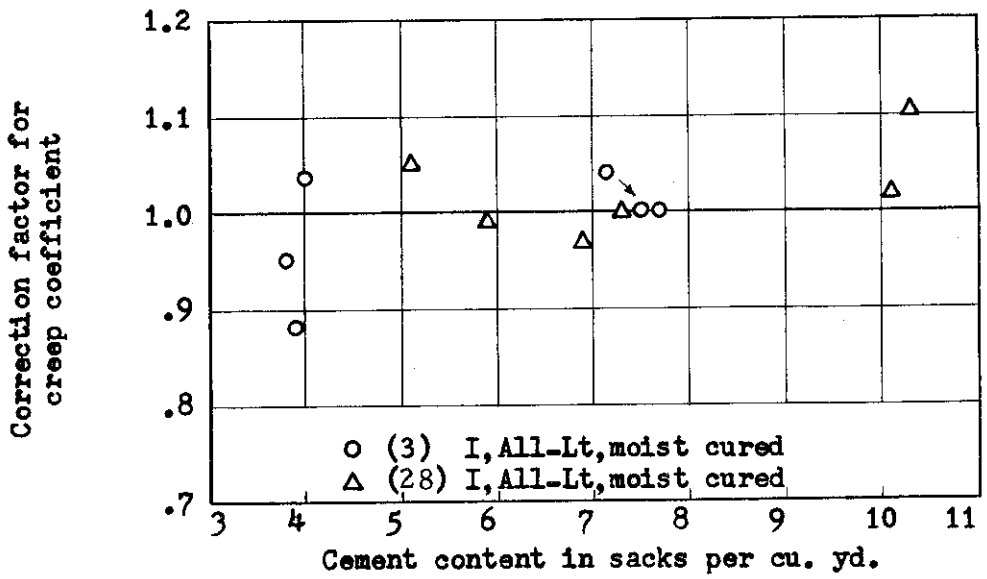

Fig. 12--Creep coefficient correction factors for cement content, with source of data, type of cement, weight classification, and curing technique indicated

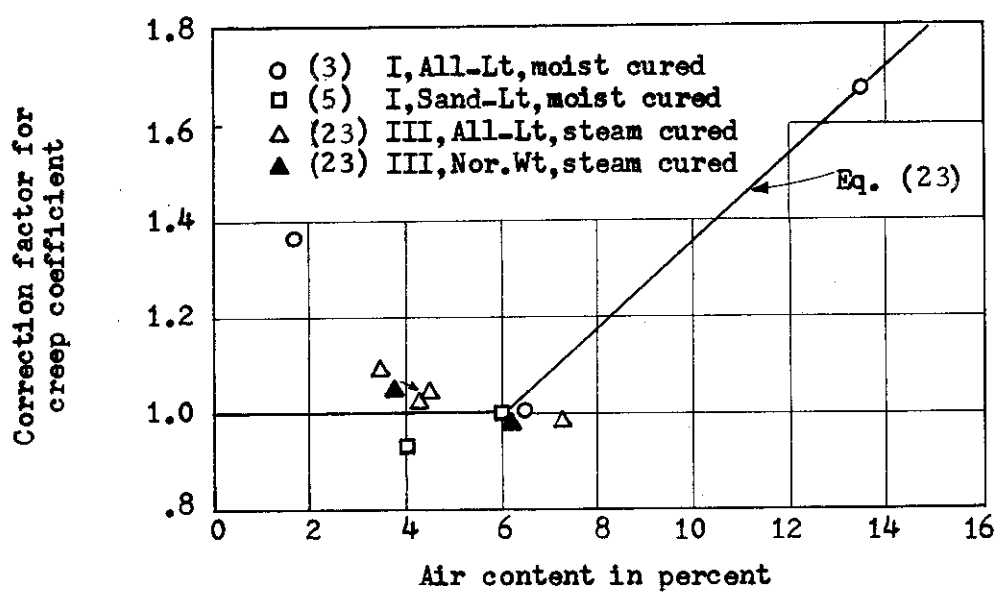

Fig. 13--Creep coefficient correction factors for air content, with source of data, type of cement, weight classification, and curing technique indicated

where A is the air content in percent.

Further comments on these correction factors are presented in Chapter 3.

2.3 Shrinkage of Concrete

It has been demonstrated that the shrinkage of a concrete specimen with the fixed mix parameters and storage conditions can be predicted with reasonable accuracy using an equation based on the form given in Eq. (2)[4,5]. The shrinkage of specimens subject to other conditions can be estimated using correction factors (see Section 2.4).

Techniques similar to those utilized in the development of the creep prediction equations were used to develop Eq. (24) and (25). These equations were derived from the data shown in Figs. 14 and 15. The standard conditions for these and subsequent shrinkage equations are 3" or less slump, 40% ambient relative humidity, minimum thickness of member 6" or less, and shrinkage considered from 7 days for moist cured concrete and from 2 to 3 days for steam cured concrete.

$$(\epsilon_{sh})_t = \frac{t}{35 + t} (\epsilon_{sh})_u \quad \text{for moist cured} \tag{24}$$

$$(\epsilon_{sh})_t = \frac{t}{55 + t} (\epsilon_{sh})_u \quad \text{for steam cured} \tag{25}$$

The actual shrinkage strains for moist cured concrete are plotted versus time in Fig. 16, and the steam cured concrete data in

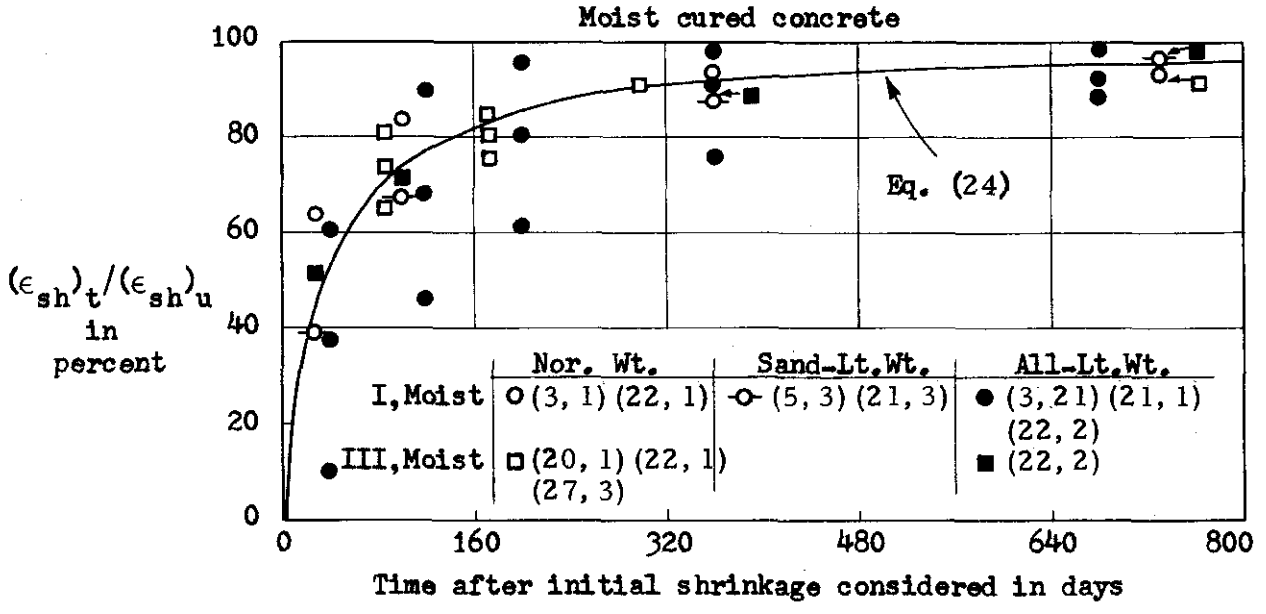

Fig. 14--Shrinkage (considered from 7 days) in percent of ultimate shrinkage versus time curve using Eq. (24) for moist cured concrete, and comparison with data. In each set of parentheses, the first and second numbers, respectively, refer to the source of the data and the number of specimens from that source. Three data points shown for a specific time refer to the upper and lower limits and the average value. Where only one data point is shown, the range is too small to indicate

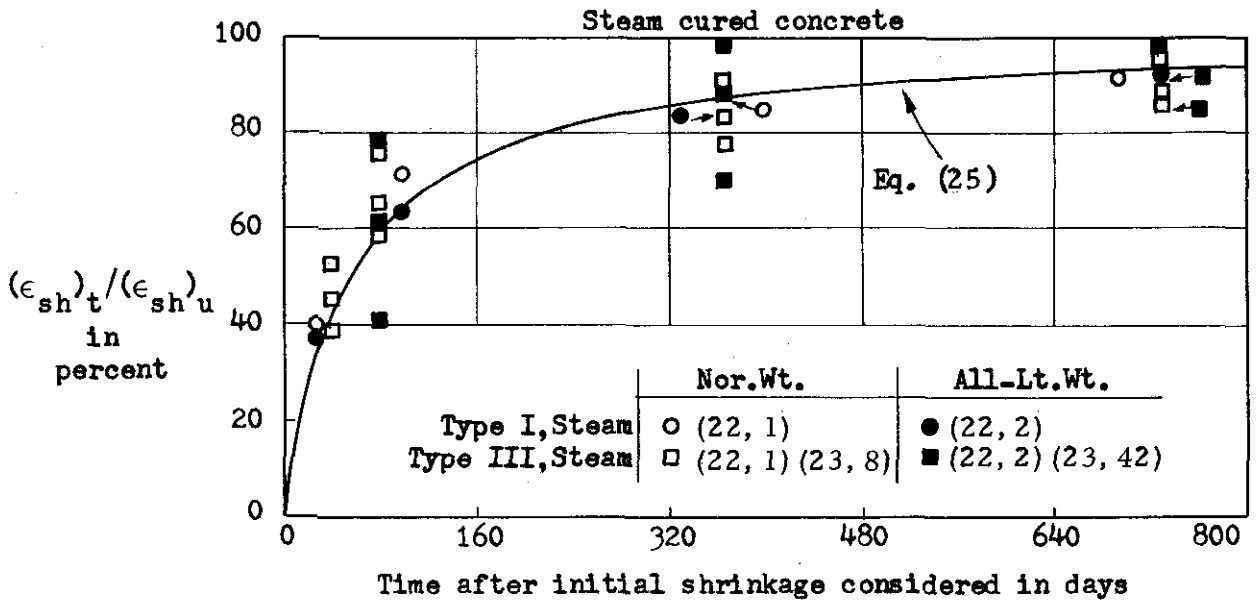

Fig. 15--Shrinkage (considered from 2-3 days) in percent of ultimate shrinkage versus time curve using Eq. (25) for steam cured concrete, and comparison with data. In each set of parentheses, the first and second numbers, respectively, refer to the source of the data and the number of specimens from that source. Three data points shown for a specific time refer to the upper and lower limits and the average value. Where only one data point is shown, the range is too small to indicate

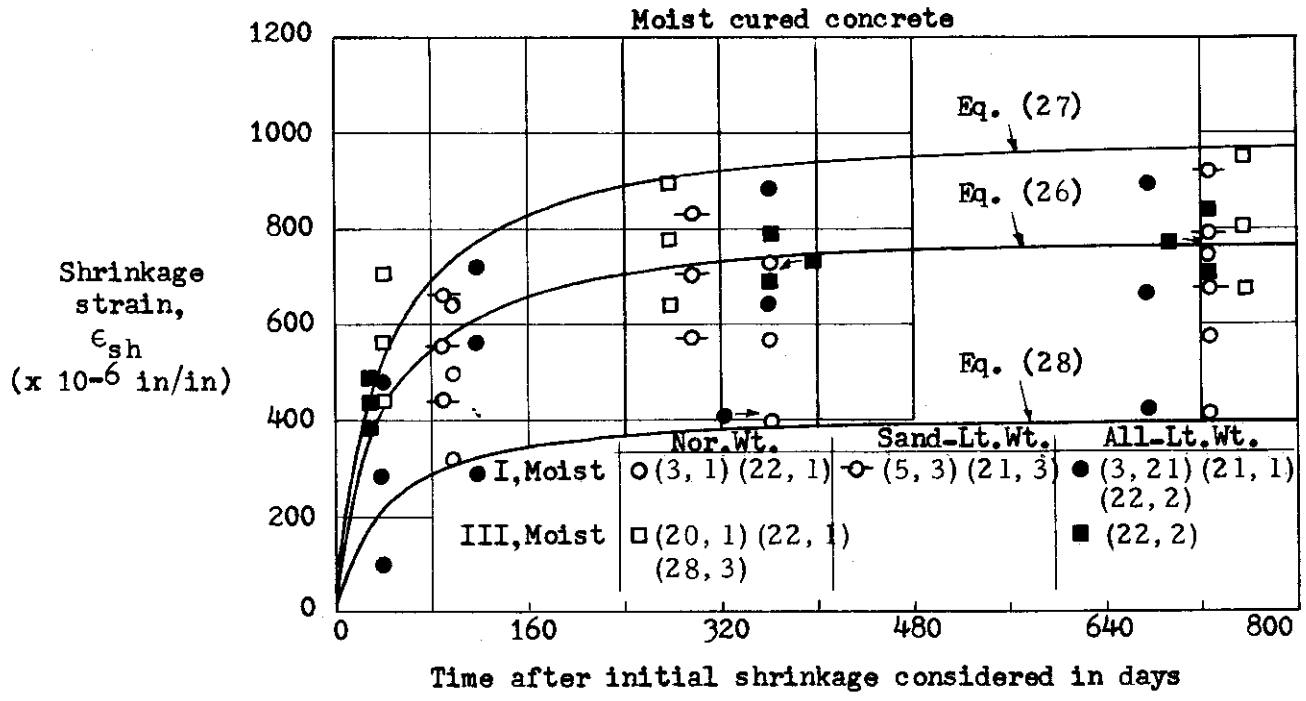

Fig. 16--Shrinkage versus time curve using Eq. (26) and upper and lower-limit curves for moist cured concrete compared with data. In each set of parentheses, the first and second numbers, respectively, refer to the source of the data and the number of specimens from that source. Three data points shown for a specific time refer to the upper and lower limits and the average value. Where only one data point is shown, the range is too small to indicate. The standard conditions are 3" or less slump, 40% ambient relative humidity, minimum thickness of member 6" or less, and shrinkage considered after age 7 days

Fig. 17. The significance of the data points is the same as the interpretation of the standardized creep data in Fig. 5. The average-value and upper- and lower-limit curves for the data are also plotted in Figs. 16 and 17. The average-value curves were obtained in the same manner as was the standard creep equation (Eq. (6)).

Normal ranges of the constants in Eq. (1) for normal weight, sand-lightweight, and all-lightweight concretes (using both moist and steam curing, and types I and III cements) for the data in Figs. 10 and 17 are: $e = 1$, $f = 10$ to 130, $(\epsilon_{sh})_u = 415$ to 1070×10^{-6} in/in.

Eq. (26) represents the average-value curve for the moist cured concrete data plotted in Fig. 16, and is recommended for predicting shrinkage at any time for moist cured normal weight, sand-lightweight, and all-lightweight concretes. The ultimate value of 800×10^{-6} in/in should be used, however, only in the absence of specific shrinkage data for local aggregates and conditions.

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \, 800 \times 10^{-6} \text{ in/in} \tag{26}$$

The upper- and lower-limit curves, respectively, are defined by:

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \, 1010 \times 10^{-6} \text{ in/in} \tag{27}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \, 415 \times 10^{-6} \text{ in/in} \tag{28}$$

For the moist cured, normal weight concrete data, the upper-limit, average-value, and lower-limit curves, respectively, are

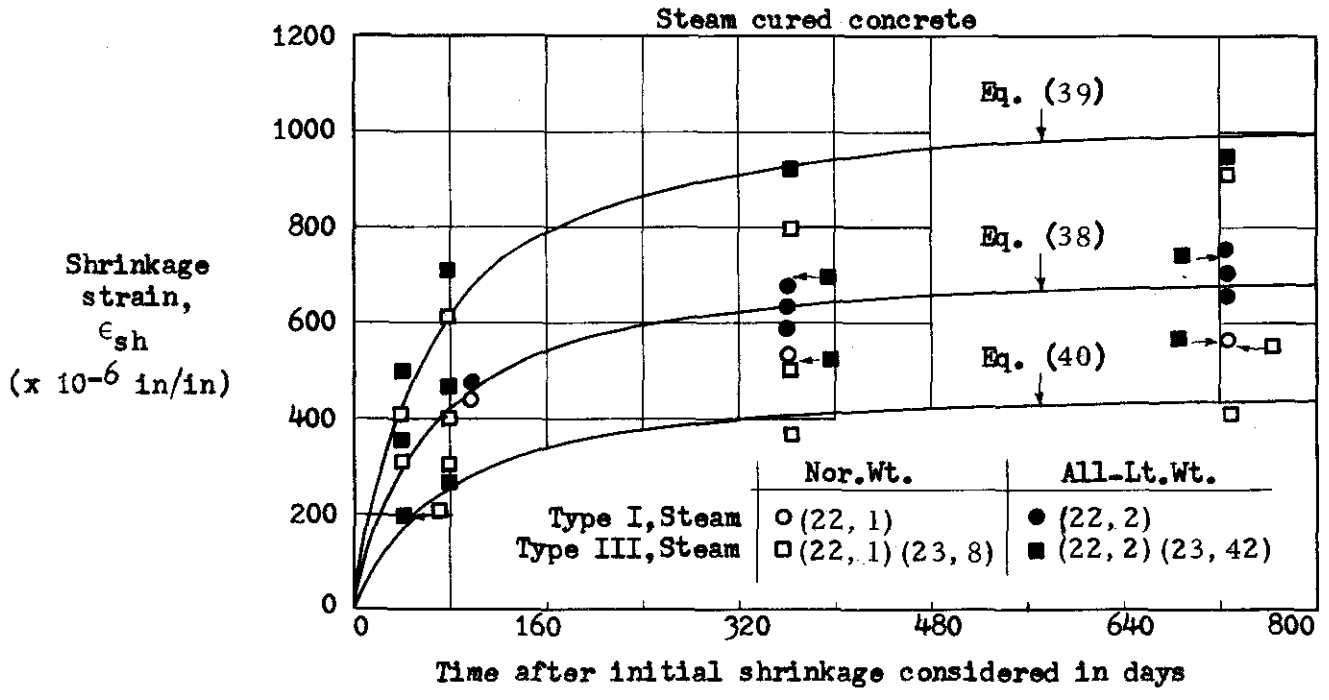

Fig. 17--Shrinkage versus time curve using Eq. (38) and upper and lower-limit curves for steam cured concrete compared with data. In each set of parentheses, the first and second numbers, respectively, refer to the source of the data and the number of specimens from that source. Three data points shown for a specific time refer to the upper and lower limits and the average value. Where only one data point is shown, the range is too small to indicate. The standard conditions are 3" or less slump, 40% ambient relative humidity, minimum thickness of member 6" or less, and shrinkage considered after age 2-3 days

given by:

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad 1000 \times 10^{-6} \text{ in/in} \tag{29}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad 825 \times 10^{-6} \text{ in/in} \tag{30}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad 415 \times 10^{-6} \text{ in/in} \tag{31}$$

For the moist cured, sand-lightweight data, the upper-limit, average-value, and lower-limit curves are defined by:

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad 965 \times 10^{-6} \text{ in/in} \tag{32}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad 785 \times 10^{-6} \text{ in/in} \tag{33}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad 620 \times 10^{-6} \text{ in/in} \tag{34}$$

Similarly, the upper-limit, average-value, and lower-limit curves for the moist cured, all-lightweight concrete data are:

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad 1010 \times 10^{-6} \text{ in/in} \tag{35}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad 800 \times 10^{-6} \text{ in/in} \tag{36}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad 435 \times 10^{-6} \text{ in/in} \tag{37}$$

Eqs. (30), (33), and (36) indicate very little difference between the ultimate shrinkage values of normal weight, sand-lightweight, and all-lightweight concretes. The numbers of specimens for each of the

different weight concretes are unequal, however. Seven normal wieght, six sand-lightweight, and twenty-six all-lightweight specimens were considered. Thus, it is difficult to draw conclusions about relative ultimate shrinkage strains for the different weight concretes.

It is felt, however, the average ultimate shrinkage ($(\epsilon_{sh})_u$ = 800 x 10^{-6} in/in), as used in Eq. (26), represents the average conditions quite accurately. The overall numerical average of $(\epsilon_{sh})_u$ for all the data is 803 x 10^{-6} in/in.

Eq. (38) represents the average-value curve for the steam cured concrete data plotted in Fig. 17, and is recommended for use as a standard shrinkage equation for all steam cured concretes. The ultimate value of 730 x 10^{-6} in/in should be used, however, only in the absence of specific shrinkage data for local aggregates and conditions.

$$(\epsilon_{sh})_t = \frac{t}{55 + t} \; 730 \times 10^{-6} \text{ in/in} \tag{38}$$

The upper- and lower-limit curves plotted in Fig. 17, respectively, are defined by:

$$(\epsilon_{sh})_t = \frac{t}{55 + t} \; 1070 \times 10^{-6} \text{ in/in} \tag{39}$$

$$(\epsilon_{sh})_t = \frac{t}{55 + t} \; 470 \times 10^{-6} \text{ in/in} \tag{40}$$

For the steam cured, normal weight concrete data, the upper-limit, average-value, and lower-limit curves, respectively, are given by:

$$(\epsilon_{sh})_t = \frac{t}{55 + t} \quad 1050 \times 10^{-6} \text{ in/in} \tag{41}$$

$$(\epsilon_{sh})_t = \frac{t}{55 + t} \quad 640 \times 10^{-6} \text{ in/in} \tag{42}$$

$$(\epsilon_{sh})_t = \frac{t}{55 + t} \quad 470 \times 10^{-6} \text{ in/in} \tag{43}$$

Similarly, the upper-limit, average-value, and lower-limit curves for the steam cured, all-lightweight concrete data are:

$$(\epsilon_{sh})_t = \frac{t}{55 + t} \quad 1070 \times 10^{-6} \text{ in/in} \tag{44}$$

$$(\epsilon_{sh})_t = \frac{t}{55 + t} \quad 820 \times 10^{-6} \text{ in/in} \tag{45}$$

$$(\epsilon_{sh})_t = \frac{t}{55 + t} \quad 630 \times 10^{-6} \text{ in/in} \tag{46}$$

Although Eqs. (42) and (45) indicate the ultimate shrinkage of steam cured, lightweight concrete is greater than that of steam cured, normal weight concrete, the amount of lightweight concrete data analyzed is considerably more than the amount of normal weight concrete data. Ten normal weight and forty-six all-lightweight specimens were considered. Thus, it is difficult to draw conclusions about the relative ultimate shrinkage strains of the different weight concretes.

It is felt, however, the average ultimate shrinkage ($(\epsilon_{sh})_u$ = 730×10^{-6} in/in), as used in Eq. (38), represents the average conditions quite accurately. The overall numerical average of $(\epsilon_{sh})_u$ for all the data is 788×10^{-6} in/in.

A comparison of Eqs. (26) and (38) indicates steam cured concretes experience slightly smaller shrinkage strains than moist cured concretes.

2.4 Factors Influence Shrinkage

Correction factors for the effects of the following parameters on shrinkage of moist and steam cured concretes are developed in this section:

1. Ambient relative humidity
2. Age from which shrinkage is considered
3. Minimum thickness of member
4. Slump
5. Percent fines
6. Cement content
7. Air content

These correction factors are to be applied to values given by Eq. (26) or Eq. (38), respectively, depending on whether the concrete is moist cured or steam cured, to correct data for conditions other than the standard conditions. The correction factors developed herein are derived in the same manner as are the creep correction factors developed in Section 2.2 of this report.

The effect of ambient relative humidity is shown in Fig. 18, an analysis of which indicates no correction factor is required when the humidity is less than 40%. When the humidity is greater than 40%

use either Eq. (47a) or Eq. (47b), depending upon within which range the humidity falls.

$$\text{Shrinkage } (C.F.)_H = 1.40 - 0.01H \tag{47a}$$

$$\underline{\text{for } 40\% = H = 80\%}$$

$$\text{Shrinkage } (C.F.)_H = 3.00 - 0.03H \tag{47b}$$

$$\underline{\text{for } 80\% = H = 100\%}$$

where H is the ambient relative humidity in percent.

For shrinkage considered from later than 7 days for moist cured concrete, first determine the standard shrinkage value for any time using Eq. (26). Next, compute the shrinkage occurring between 7 days and the age from which shrinkage is desired, again using Eq. (26). Thus, the shrinkage occuring after a certain age is merely the shrinkage considered from 7 days less the shrinkage occurring between 7 days and the age from which shrinkage predictions are desired. A similar procedure is suggested for steam cured concrete, using Eq. (38) and considering shrinkage from 2-3 days.

For shrinkage of moist cured concrete from 1 day, a correction factor of 1.20 is proposed to correct the standard value given by Eq. (26). The basis of this correction factor is presented in Fig. 19. For shrinkage of moist cured concrete from between 1 day and 7 days, linearly interpolate between correction factors of 1.20 for 1 day and 1.00 for 7 days.

The effect of the minimum thickness of a member, as shown in Fig. 20, decreases as the age of the concrete increases. Thus,

the ultimate shrinkage of a large member approaches that of a smaller member, though the ultimate shrinkage of a small member is reached sooner than that of a larger member. The average effect of minimum thickness is given by Eq. (48).

$$\text{Shrinkage } (C.F.)_T = 1.193 - 0.0322T \tag{48}$$

where T is the minimum thickness in inches.

Eq. (49) is recommended for obtaining correction factors for the effect of slump on shrinkage.

$$\text{Shrinkage } (C.F.)_S = 0.89 + 0.0407S \tag{49}$$

where S is the slump in inches. Eq. (49) is plotted with experimental data in Fig. 21.

Shrinkage correction factors for the effect of percent fines are given by Eqs. (50a) and (50b), which are plotted in Fig. 22.

$$\text{Shrinkage } (C.F.)_F = 0.30 + 0.014F \tag{50a}$$

$$\underline{\text{for } F = 50\%}$$

$$\text{Shrinkage } (C.F.)_F = 0.90 + 0.002F \tag{50b}$$

$$\underline{\text{for } F = 50\%}$$

where F is the percent of fine aggregate by weight.

As shown in Fig. 23, a variation in cement content has a considerable affect on shrinkage. The shrinkage correction factors for cement content are given by Eq. (51).

$$\text{Shrinkage } (C.F.)_B = 0.75 + 0.034B \tag{51}$$

where B is the number of bags of cement per cubic yard.

Eq. (52), which gives shrinkage correction factors for the effect of air content, is plotted with observed data in Fig. 24.

$$\text{Shrinkage } (C.F.)_A = 0.95 + 0.008A \tag{52}$$

where A is the air content in percent.

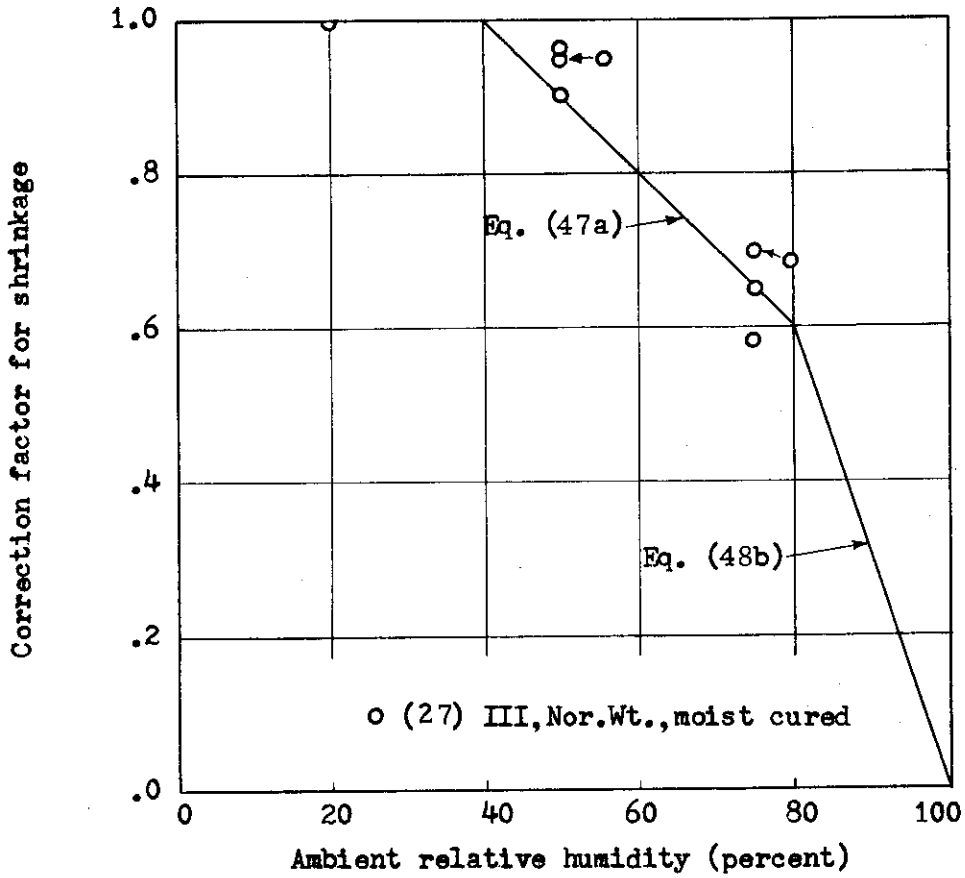

Fig. 18--Shrinkage correction factors for humidity, with source of data, type of cement, weight classification, and curing technique indicated

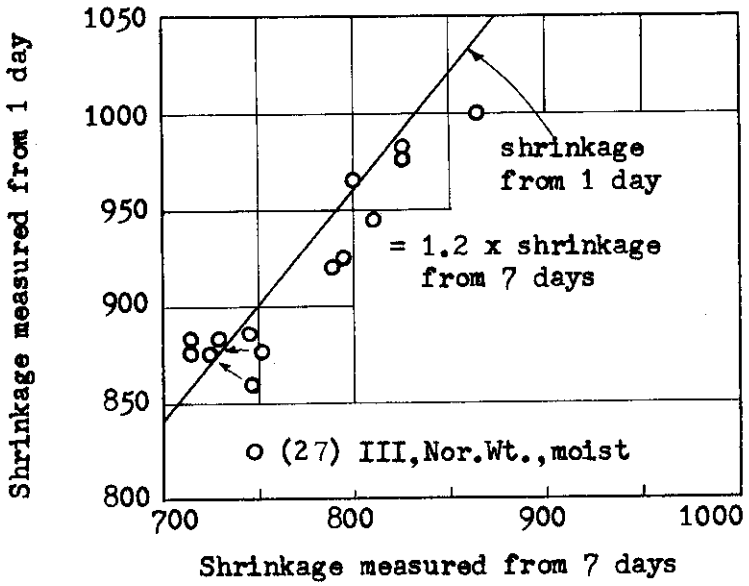

Fig. 19--Observed values of shrinkage strains measured from 1 day versus values of shrinkage strains measured from 7 days, with source of data, type of cement, weight classification, and curing technique indicated

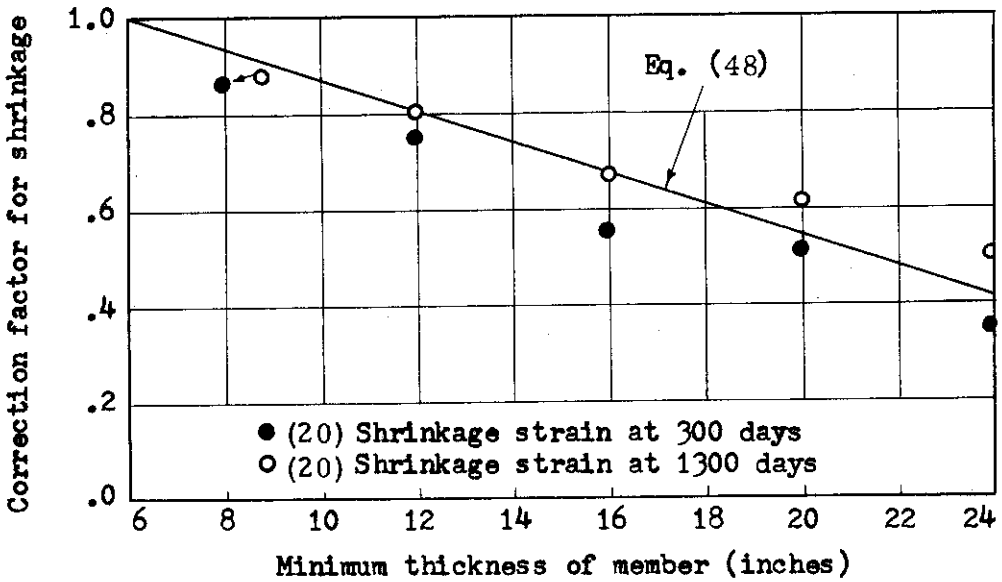

Fig. 20--Shrinkage correction factors for minimum thickness of member, with source of data and age at time of reading indicated

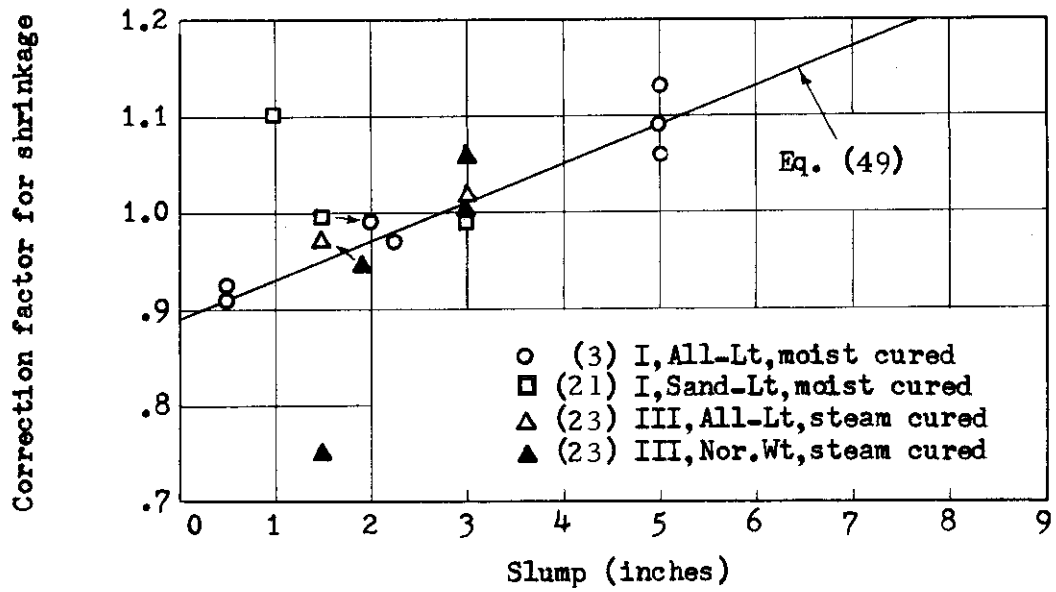

Fig. 21--Shrinkage correction factors for slump, with source of data, type of cement, weight classification, and curing technique indicated

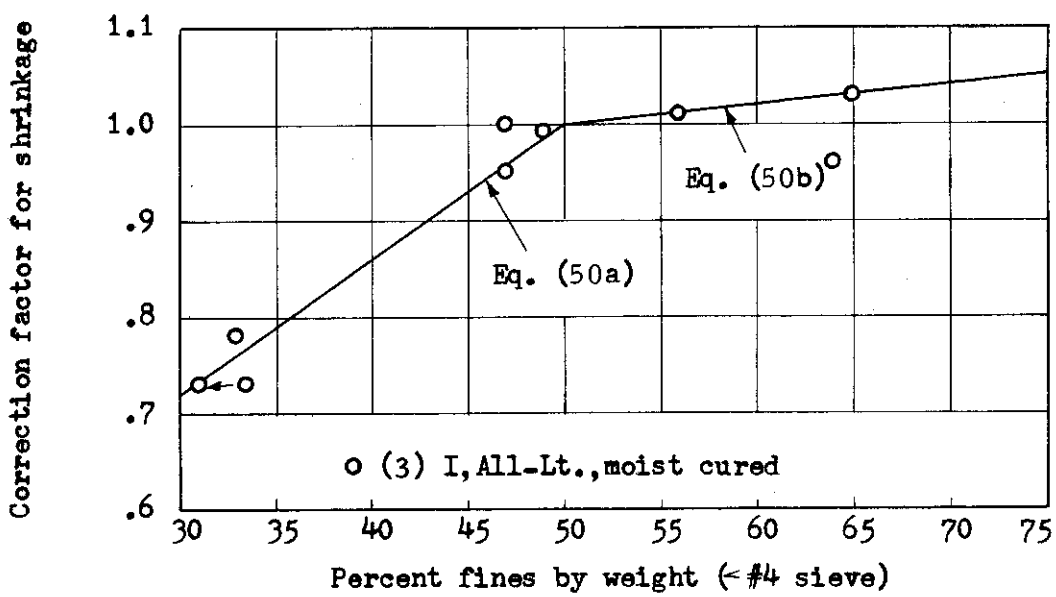

Fig. 22--Shrinkage correction factors for percent fines, with source of data, type of cement, weight classification, and curing technique indicated

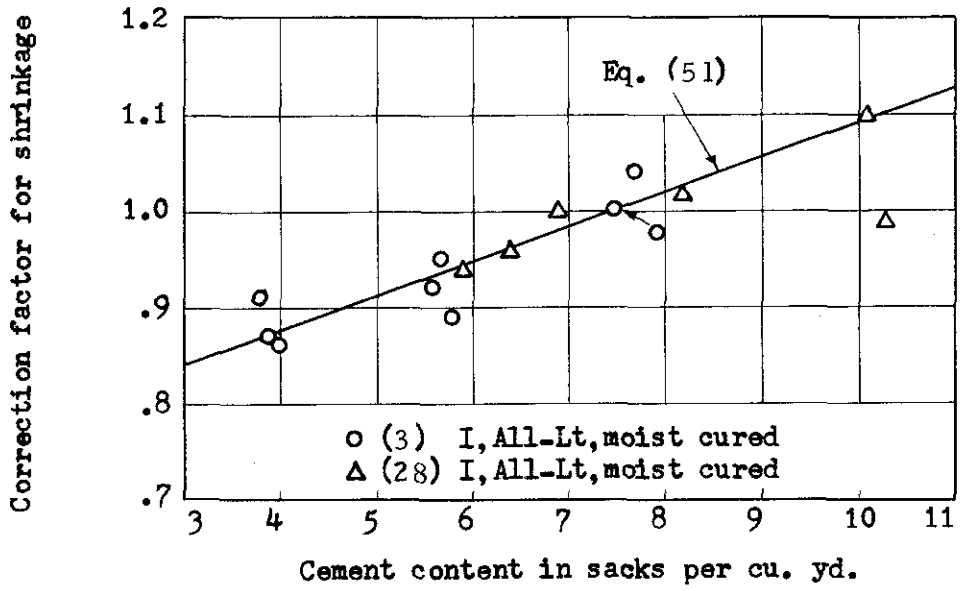

Fig. 23--Shrinkage correction factors for cement content, with source of data, type of cement, weight classification, and curing technique indicated

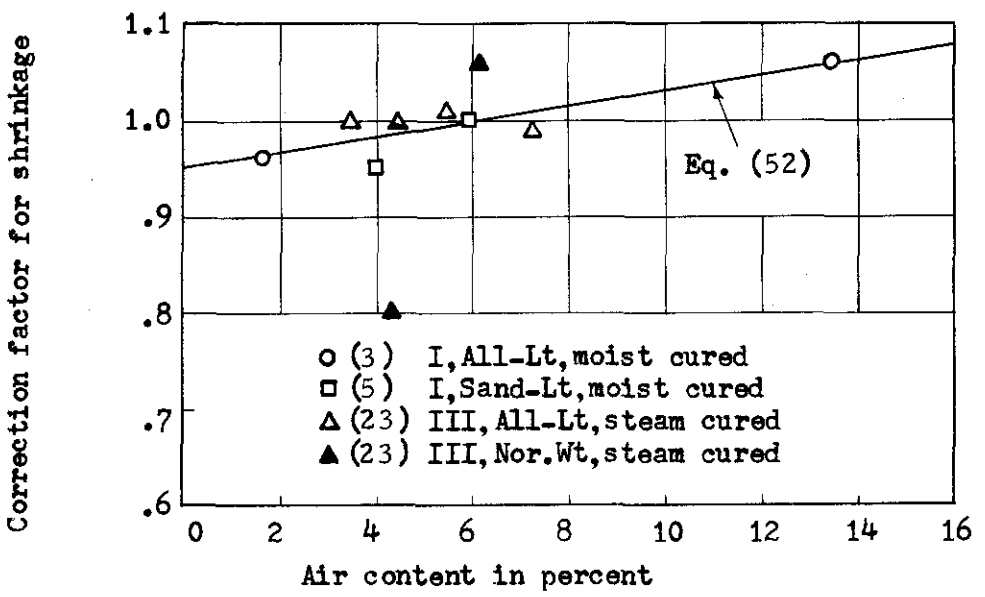

Fig. 24--Shrinkage correction factors for air content, with source of data, type of cement, weight classification, and curing technique indicated

Chapter 3

SUMMARY AND EXAMPLE OF CREEP AND SHRINKAGE PREDICTION METHODS

The equations and procedures developed in Chapter II are simple to apply and in some cases can be further simplified. In this chapter two example predictions will be illustrated and the results compared to observed values. In addition, a simplified prediction method will be presented.

3.1 Summary of General Prediction Methods

Standard creep equation -- 3" or less slump, 40% ambient relative humidity, loading age 7 days for moist cured and 2-3 days for steam cured concrete

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \; 2.35 \qquad (6)$$

Creep correction factors

Ambient relative humidity:

$$\text{Creep } (C.F.)_H = 1.27 - 0.0067H \qquad (17)$$

for H = 40%

Loading age:

$$\text{Creep } (C.F.)_{LA} = 1.25\,(t)^{-0.118} \qquad (18)$$

for moist cured

$$\text{Creep (C.F.)}_{LA} = 1.13\ (t)^{-0.095} \tag{19}$$

for steam cured

Minimum thickness of member:

$$\text{Creep (C.F.)}_{T} = 1.12 - 0.02T \tag{20}$$

Slump:

$$\text{Creep (C.F.)}_{S} = 0.82 + 0.067S \tag{21}$$

Percent fines:

$$\text{Creep (C.F.)}_{F} = 0.88 + 0.0024F \tag{22}$$

Cement content:

No correction factors required.

Air content:

$$\text{Creep (C.F.)}_{A} = 0.46 + 0.09A \tag{23}$$

for A = 6%

Standard shrinkage equations -- 3" or less slump, 40% ambient relative humidity, minimum thickness of member 6" or less

Shrinkage after age 7 days for moist cured concrete

$$(\epsilon_{sh})_t = \frac{t}{35 + t}\ 800 \times 10^{-6}\ \text{in/in} \tag{26}$$

Shrinkage after age 2-3 days for steam cured concrete

$$(\epsilon_{sh})_t = \frac{t}{55 + t}\ 730 \times 10^{-6}\ \text{in/in} \tag{38}$$

Shrinkage correction factors

Ambient relative humidity:

$$\text{Shrinkage (C.F.)}_{H} = 1.40 - 0.01H \tag{47a}$$

for 40% = H = 80%

$$\text{Shrinkage } (C.F.)_H = 3.00 - 0.03H \tag{47b}$$

for 80% = H = 100%

Age from which shrinkage is considered:

For shrinkage considered from later than 7 days for moist cured concrete and later than 2-3 days for steam cured concrete, respectively, determine the differential in Eqs. (26) and (38) for any period starting after this time. For shrinkage of moist cured concrete from 1 day, use Shrinkage (C.F.) = 1.20.

Minimum thickness of member:

$$\text{Shrinkage } (C.F.)_T = 1.193 - 0.0322T \tag{48}$$

Slump:

$$\text{Shrinkage } (C.F.)_S = 0.89 + 0.0407S \tag{49}$$

Percent fines:

$$\text{Shrinkage } (C.F.)_F = 0.30 + 0.014F \tag{50a}$$

for F = 50%

$$\text{Shrinkage } (C.F.)_F = 0.90 + 0.002F \tag{50b}$$

for F = 50%

Cement content:

$$\text{Shrinkage } (C.F.)_B = 0.75 + 0.034B \tag{51}$$

Air content:

$$\text{Shrinkage } (C.F.)_A = 0.95 + 0.008A \tag{52}$$

3.2 Design Example No. 1 Using General Prediction Method

Specimen reference (22) 10N6

Moist cured concrete, lightweight

50% ambient relative humidity

Shrinkage considered from 7 days

Minimum thickness of member 8 inches

Loaded at 6 days of age

2.3 inches of slump

60% fines (assumed)

7.7 bags of cement per cubic yard

6.5% air content

Standard values:

$$C_{365} = \frac{365^{0.60}}{10 + 365^{0.60}} \; 2.35 = \frac{34.3}{44.3} \; 2.35 = 1.82$$

$$(\epsilon_{sh})_{365} = \frac{365}{35 + 365} \; 800 \times 10^{-6} \text{ in/in} = 730 \times 10^{-6} \text{ in/in}$$

<u>Creep correction factors</u>

50% humidity	0.93	(17)
loaded at 6 days	1.01	(18)
8 in. minimum thickness	0.96	(20)
2.3 inches slump	0.97	(21)
60% fines	1.02	(22)
6.5% air content	1.06	(23)

<u>Shrinkage correction factors</u>

50% humidity	0.90	(47a)
shrinkage from 7 days	1.00	
8 in. minimum thickness	0.94	(48)

2.3 inches slump	0.94	(49)
60% fines	1.02	(50)
7.7 bags of cement	1.01	(51)
6.5% air content	1.00	(52)

The desired creep and shrinkage values for one year are then obtained by multiplying the standard values by the respective set of correction factors.

$C_{365} = (1.82)\,(0.93 \times 1.01 \times 0.96 \times 0.97 \times 1.02 \times 1.06) = \underline{1.72}$

Experimental C_{365} from data is $\underline{1.79}$.

$(\epsilon_{sh})_{365} = (730 \times 10^{-6}\ \text{in/in})(0.90 \times 1.00 \times 0.94 \times 0.94 \times 1.02 \times 1.01 \times 1.00) = \underline{596 \times 10^{-6}\ \text{in/in}}$

Experimental $(\epsilon_{sh})_{365}$ from data is $\underline{660 \times 10^{-6}\ \text{in/in}}$.

3.3 Design Example No. 2 Using General Prediction Method

Specimen reference (22) 6R2

Steam cured concrete, lightweight

50% ambient relative humidity

Shrinkage considered from 7 days

Minimum thickness of member 8 inches

Loaded at 2 days of age

2.5 inches of slump

60% fines (assumed)

8.8 bags of cement per cubic yard

6.1% air content

Standard values

$$C_{365} = \frac{365^{0.60}}{10 + 365^{0.60}} \; 2.35 = \frac{34.3}{44.3} \; 2.35 = 1.82$$

$$(\epsilon_{sh})_{365} = \frac{365}{55 + 365} \; 730 \times 10^{-6} \text{ in/in} = 365 \times 10^{6} \text{ in/in}$$

Creep correction factors

50% humidity	0.93	(17)
Loaded at 2 days	1.06	(19)
8 in. minimum thickness	0.96	(20)
2.5 inches slump	0.99	(21)
60% fines	1.02	(22)
6.1% air content	1.01	(23)

Shrinkage correction factors

50% humidity	0.90	(47a)
Shrinkage from 7 days	1.00	
8 in. minimum thickness	0.94	(48)
2.5 inches slump	0.99	(49)
60% fines	1.02	(50)
8.8 bags of cement	1.05	(51)
6.1% air content	1.00	(52)

The desired creep and shrinkage values for one year are then obtained by multiplying the standard values by the respective set of

correction factors.

$$C_{365} = (1.82)(0.93 \times 1.06 \times 0.96 \times 0.99 \times 1.02 \times 1.01) = \underline{1.76}$$

Experimental C_{365} from data is $\underline{1.80}$.

$$(\epsilon_{sh})_{365} = (365 \times 10^{-6} \text{ in/in})(0.90 \times 1.00 \times 0.94 \times 0.99 \times 1.02 \times 1.05 \times 1.00) = \underline{570 \times 10^{-6} \text{ in/in}}$$

Experimental $(\epsilon_{sh})_{365}$ from data is $\underline{595 \times 10^{-6} \text{ in/in}}$

3.4 Summary of a Simplified Prediction Method

Quite often, the effects of many variables on creep and shrinkage are not excessive and tend to offset each other. These may normally be neglected in design calculations. The following summary and comments form the basis of a simplified prediction method.

Creep correction factors

Minimum thickness of member: C.F. = 0.96 for 8", 0.88 for 12". Comment--Tends to be offset by high slumps, probably negligible in most cases.

Slump: C.F. = 0.95 for 2", 1.00 for 2.7", 1.09 for 4". Comment--Negligible for slumps below 5".

Percent fines (by wt.): C.F. = 0.72 for 30%, 1.00 for 50%, 1.04 for 70%. Comment--Negligible for percent fines less than 45%.

Cement content (bags/cu.yd.): C.F. = 0.87 for 4 bags, 0.95 for 6 bags, 1.00 for 7.5 bags, 1.09 for 10 bags. Comment--Normally negligible.

Air content (in %): C.F. = 0.98 for 4%, 1.00 for 6%, 1.03 for 10%. Comment--Negligible.

Therefore, in a simplified design procedure, the only variables for which corrections must be made are humidity, age when loaded, and age from which shrinkage is considered. A simplified design procedure should be used, however, only when the comments in the above

summary are applicable. For example, for large structures (minimum thickness greater than 12", for example), correction factors for member size for creep and especially shrinkage should be considered.

3.5 Design Example No. 1 Using Simplified Prediction Method

Standard Values

$C_{365} = 1.82$

$(\epsilon_{sh})_{365} = 730 \times 10^{-6}$ in/in

Creep Correction Factors

50% humidity	0.93	(17)
Loaded at 6 days	1.01	(18)

Shrinkage Correction Factors

50% humidity	0.90	(47a)
Shrinkage from 7 days	1.00	

Modified Creep and Shrinkage Values

$C_{365} = 1.82\ (.93)(1.01) = 1.71$

$(\epsilon_{sh})_{365} = 730 \times 10^{-6}\ (.90)(1.00) = 657 \times 10^{-6}$ in/in

Experimental Values

$C_{365} = 1.79$

$(\epsilon_{sh})_{365} = 660 \times 10^{-6}$ in/in

3.6 Design Example No. 2 Using Simplified Prediction Method

Standard Values

$C_{365} = 1.82$

$(\epsilon_{sh})_{365} = 365 \times 10^{-6}$ in/in

Creep Correction Factors

50% humidity	0.93	(17)
Loaded at 7 days	1.06	(19)

Shrinkage Correction Factors

50% humidity	0.90	(47a)
Shrinkage from 7 days	1.00	

Modified Creep and Shrinkage Values

$C_{365} = 1.82\ (0.93)(1.06) = 1.79$

$(\epsilon_{sh})_{365} = 635 \times 10^{-6}\ (0.90) = 572 \times 10^{-6}$ in/in

Experimental Values

$C_{365} = 1.80$

$(\epsilon_{sh})_{365} = 595$

3.7 General Remarks on Prediction Methods

It has been shown that the general prediction methods developed in Chapter II can be easily and accurately applied to predict the long-time creep and shrinkage behavior of concrete. In addition, simplified

prediction methods were also shown to yield accurate estimates of time dependent behavior.

Chapter 4

EXPERIMENTAL PROGRAM

In order to independently verify the development of the general prediction methods, the experimental program described below was carried out. In addition, specific prediction equations for concrete mixtures made with the aggregates tested are recommended.

Creep and shrinkage behavior for the following four commercial aggregates were obtained.

Idealite - manufactured by Idealite Co., Denver, Colorado.

Haydite - manufactured by Hydraulic Press Brick Co., Brooklyn, Indiana

Haydite - manufactured by Carter-Waters Corp., Kansas City, Missouri

Haydite - manufactured by Buildex, Inc., Ottawa, Kansas.

4.1 Concrete Mixes and Properties

All tests and test specimens for this investigation were produced in the structures laboratory at the University of Iowa, except for one group of steam cured specimens cast and supplyed by Prestressed Concrete of Iowa, Inc.

The concrete mixes listed in Table 1 were designed using specifications for prestressed bridge girders, (i.e., 4,500 psi strength after 7 days moist curing or 2-3 days steam curing and a

28 day strength of 5,000 psi using Type I cement. All mixes used commercially manufactured lightweight artificial aggregate with 100 percent sand substitution for the fine portion of the mix. Table 2 shows the concrete properties that were obtained for the various mixes listed.

4.2 Preparation of Specimens

Preparation of test specimens and performance of tests followed ASTM specifications.[24] Test specimens were standard 6 inch diameter by 12 inch long cylinders cast in three layers, each layer rodded 25 strokes. The cylinders were moist cured five days at 100 percent relative humidity. Forms were stripped on the fifth day and the surface was allowed to dry. The ends of each specimen were scrubbed with a wire brush to remove any loose material in preparation for capping. On the sixth day the specimens were capped with a sulfur base capping compound.

Gage points were fastened to the specimens immediately after capping on the sixth day. The gage points consisted of small stainless steel plugs with a shallow hole drilled in one end. Gage points were arranged in three equally spaced rows about the specimen and were securely fastened to the surface by means of epoxy resins. A standard 10-inch gage length bar was used during initial spacing of the gage points. A strip of masking tap tightened over the gage points prevented their sliding during the four hours required for the adhesive to set. The instrumented specimens were then stored in the

TABLE 1 - DETAILS OF CONCRETE MIXES AND MIXING PROCEDURE

Ingredient for 1 cu. yd. mix	Idealite	Haydite by H. P. B.	Haydite by Buildex	Haydite by C W
Cement (Type I)	705 lb.	705 lb.	611 lb.	658 lb.
Aggregate	820 lb. 60%-3/4" to 5/16" 40%-5/16" to #8	20 cf = 825 lb. 3/4" to #4	22.5 cf = 977 lb. 3/4" to #4	23.5 cf = 1318 lb. 3/16" to 1/8"
Sand	1395 lb.	1150 lb.	1020 lb.	816 lb.
Water	292 lb.	350 lb.	350 lb.	415 lb.
Admixtures	Darex @ 7/8 oz/sack WRDA 50 oz.	---	---	---

MIXING PROCEDURE

1. Proportion and batch sand and aggregate
2. Add approximately one-half of required water
3. Mix for approximately two minutes
4. Proportion and batch cement
5. Add admixtures along with remaining water
6. Mix for approximately three minutes or until homogeneous mixture is obtained

TABLE 2 - CONCRETE PROPERTIES

Property		Idealite			Haydite		
					by: H. P. B.	by: Bldx	by: C-W
Mix Identification		I-1	I-3	I-S	H-1	B-4	CW-4
f'c7	psi	6,700	6,150	5,600	5,150	3,650	3,450
f'c14	psi	8,250	---	5,800	5,900	4,500	4,750
f'c28	psi	9,350	8,750	6,100	---	---	---
Unit Wt. (wet)	pcf	124	125	---	113	105	115
Unit Wt. (dry)	pcf	123	124	122	113	103	113
Meas. Air Ent.	%	4	6	---	---	---	---
Slump	in	2	2-1/2	---	2-3/4	2	1-1/2
Ec (sec @ 0.5 f'c)	psi	---	3.20	3.04	2.93	2.45	2.66
7 (init. tan)	$x10^6$	---	3.33	3.10	3.05	2.84	2.84
day ($33\sqrt{W^3 f'c}$)		3.68	3.55	3.32	3.84	2.21	2.44
Ec (sec @ 0.5 f'c)	psi	---	---	---	3.06	2.51	2.88
14 (init. tan)	$x10^6$	---	---	---	3.28	2.84	3.10
day ($33\sqrt{W^3 f'c}$)		4.08	---	3.38	3.00	2.51	2.70
Ec (sec @ 0.5 f'c)	psi	---	3.28	---	---	---	---
28 (init. tan)	$x10^6$	---	3.38	---	---	---	---
day ($33\sqrt{W^3 f'c}$)		4.35	4.23	3.47	---	---	---
Rel. (range)	%	20-50	25-50	21-50	7-48	10-48	10-48
Hum. (avg)		39	40	40	28	32	32
Temp. (range)	°F	79-84	80-84	78-85	75-87	77-87	77-87
(avg)		83	82	82	82	83	83

Group I-S specimens were steam cured, all others were moist cured

room in which the tests were to be conducted until the time of loading.

4.3 Test Equipment

Compressive strength and modulus of elasticity tests were performed using a Riehle hydraulic testing machine, least count 500 pounds. The sustained load was applied with a hydraulic jack containing a pressure gage, least count 100 pounds. Prior to loading, the jack was calibrated against the testing machine as a standard.

Test specimens were loaded at 7 days and 14 days after casting in standard ASTM type creep racks which consisted of three equally spaced rods through holes in one inch thick steel plates. The sustained load was supplied by three nested coil compression spring units of approximately equal capacity. Figures A1 and A2 in the Appendix illustrate the typical equipment.

Stress-strain data were obtained by an Ames dial gage, least count 0.0001 inches, on a collar apparatus which was attached to a specimen prior to a compressive strength test. Shrinkage and creep data were obtained with a 10-inch Whittemore strain gage, least count 0.0001 inches.

4.4 Data Collection

Three separate specimens were used to determine the compressive strength at each of the 7, 14, and 28 day ages; an average value was then used for each age. Stress-strain data were taken on one specimen during the compressive strength test. Stress-strain

curves for the four concrete mixes listed in Table (1) are shown in Figures 25 - 28.

Shrinkage data for each of the mixes were obtained from three separate specimens, each specimen having three gage lengths; an average of the nine values was then used. Shrinkage specimens were stored in the same environment as the loaded specimens. Creep data for each stress level were obtained from three separate specimens, each specimen having three different gage lengths, thus giving nine values from which an average was determined.

The three specimens under load for each test were stacked vertically in a single creep rack and loaded simultaneously. Care was taken during loading to insure that no significant eccentricity of loading occurred. This was accomplished by checking gage point deformations at about 300 psi, or well within the elastic range, before any further load was applied. If appreciable eccentricity existed the load was removed and the specimens realigned.

Creep and shrinkage data were collected for approximately 200 days after loading (range 168 - 282 days). All data is tabulated in the Appendix. An initial gage length was recorded prior to loading and an elastic deformation was recorded immediately after loading. The value of creep was evaluated as the total deformation of loaded gage length minus the shrinkage value and the initial elastic deformation.

Load checks were performed occasionally and corrections

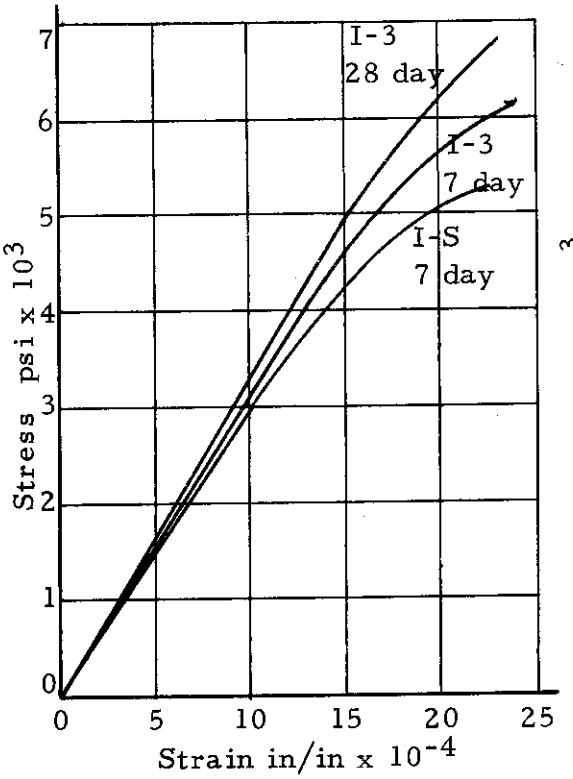

Fig. 25 σ vs. ϵ curve, Mix I-3, I-S

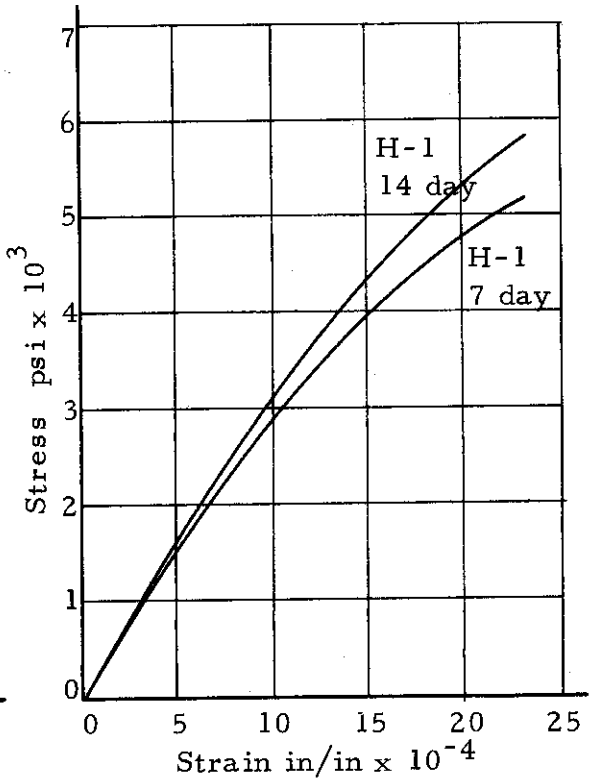

Fig. 26 σ vs. ϵ curve, Mix H-1

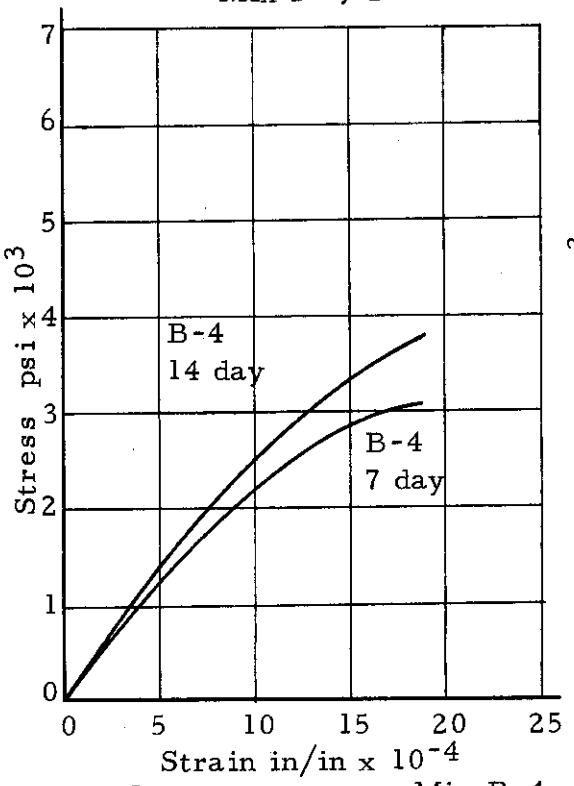

Fig. 27 σ vs. ϵ curve, Mix B-4

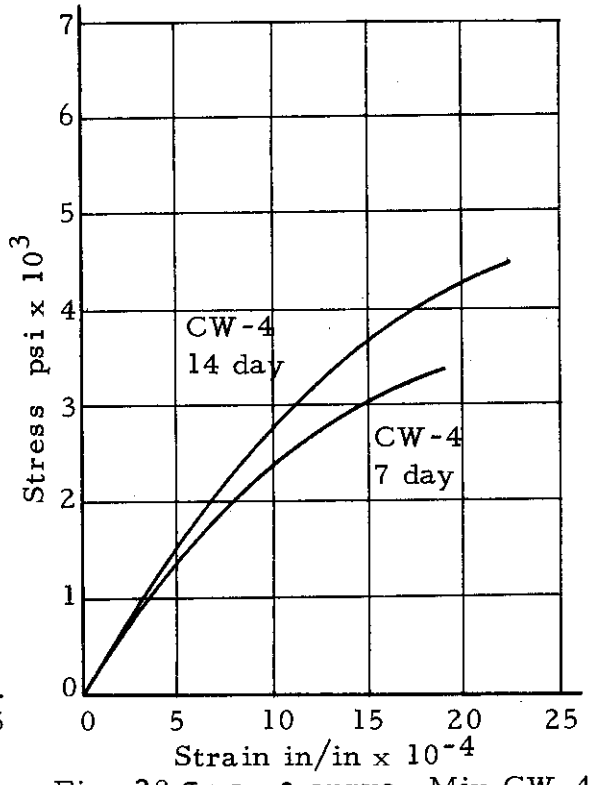

Fig. 28 σ vs. ϵ curve, Mix CW-4

made for any loss of load. At no time was the load allowed to deviate by more than about four percent from the designated stress level.

Temperature and relative humidity were recorded along with each set of creep and shrinkage values. A temperature correction was made by means of the standard steel bar provided with the Whittemore mechanical strain gage. The coefficient of thermal expansion for concrete is nearly equal to that for steel, 0.0000065 in/deg. F.

Chapter 5

CREEP AND SHRINKAGE PROPERTIES OF FOUR LIGHTWEIGHT AGGREGATE CONCRETES

In order to verify the methods suggested in Chapter 2 and in order to develop specific equations that can be used to predict the creep and shrinkage behavior of the materials investigated, the data was analyzed using the general equations suggested by Branson, et al.[5] (Eq. (1) and (2)). In Eq. (1) the exponent c was assumed to be 0.6, and d and C_u were determined experimentally. In Eq. (2) the exponent ϵ was assumed to be 1.0, and f and $(\epsilon_{sh})_u$ were determined experimentally. The specific relations developed are compared to the general methods described in Chapter 2.

Since in all cases the duration of the experimental program was finite, methods to determine ultimate creep coefficients and ultimate shrinkage values were assumed as follows.

The ultimate creep coefficient ($C_u = \epsilon_{cu}/\epsilon_i$) is determined from the following well known relationship[15]

$$\epsilon_{cu} = 4/3\ (\epsilon_{c\ -\ 1\ yr})$$

where $\epsilon_{c-1\ yr}$ is the creep strain 1 year after loading (extrapolated from approximately 200 day data).

Once C_u is known the constant d can be easily obtained.

Since there is no well established relationship between percent of ultimate shrinkage and time the shrinkage equations were determined by trial and error, solving simultaneously for the ultimate shrinkage strain $(\epsilon_{sh})_u$ and the constant f.

Using these methods the following creep and shrinkage equations were developed for moist cured concrete (Type I cement) loaded at 7 days after casting.

5.1 Haydite - Hydraulic Press Brick Co.

The creep coefficient and shrinkage prediction equations determined from these data are listed below:

$$C_t = \frac{t^{0.60}}{12.4 + t^{0.60}} (2.15) \tag{53}$$

where 2.15 is the ultimate creep coefficient; and

$$\epsilon_{sh} = \frac{t}{60 + t} (620) \tag{54}$$

where 620 is the ultimate shrinkage strain x 10^{-6} in/in. Figures 29 and 30 show these equations compared with observed data points.

5.2 Haydite - Buildex, Inc.

The creep coefficient and shrinkage prediction equations determined from these data are listed below:

$$C_t = \frac{t^{0.60}}{9.5 + t^{0.60}} (1.95) \tag{55}$$

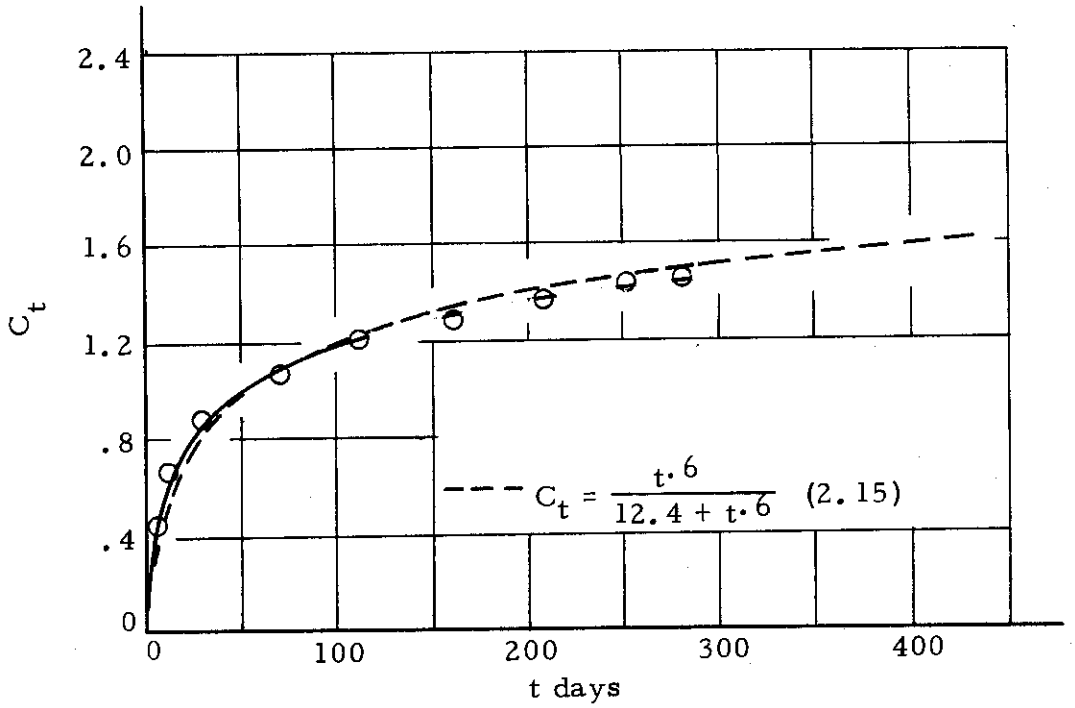

Fig. 29 C_t vs. t, Mix H-1

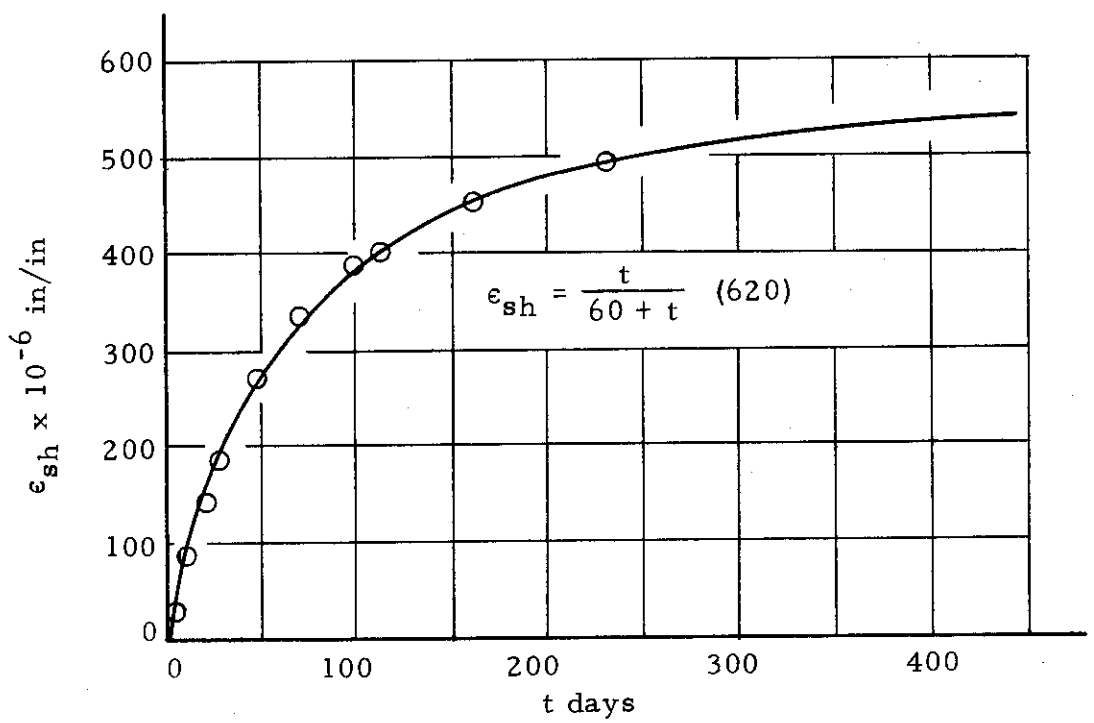

Fig. 30 ϵ_{sh} vs. t, Mix H-1

where 1.95 is the ultimate creep coefficient; and

$$\epsilon_{sh} = \frac{t}{35 + t} (440) \tag{56}$$

where 440 is the ultimate shrinkage strain x 10^{-6} in/in. Figures 31 and 32 show these equations compared with observed data points.

5.3 Haydite - The Carter-Waters Corp.

The creep coefficient and shrinkage prediction equations determined from these data are listed below:

$$C_t = \frac{t^{0.60}}{9.7 + t^{0.60}} (2.40) \tag{57}$$

where 2.40 is the ultimate creep coefficient; and

$$\epsilon_{sh} = \frac{t}{35 + t} (590) \tag{58}$$

where 590 is the ultimate shrinkage strain x 10^{-6} in/in. Figures 33 and 34 show these equations compared with observed data points.

5.4 Idealite - Idealite Company

The creep coefficient and shrinkage prediction equations determined from these data are listed below:

$$C_t = \frac{t^{0.60}}{10.3 + t^{0.60}} (1.75) \tag{59}$$

where 1.75 is the ultimate creep coefficient; and

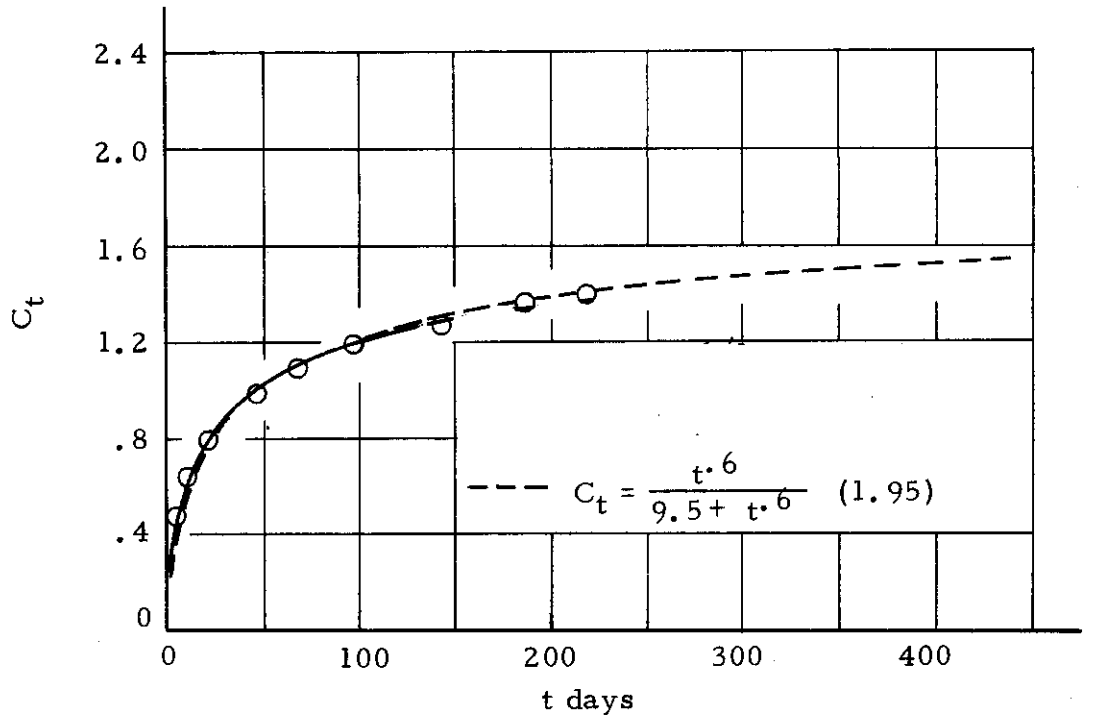

Fig. 31 C_t vs. t, Mix B-4

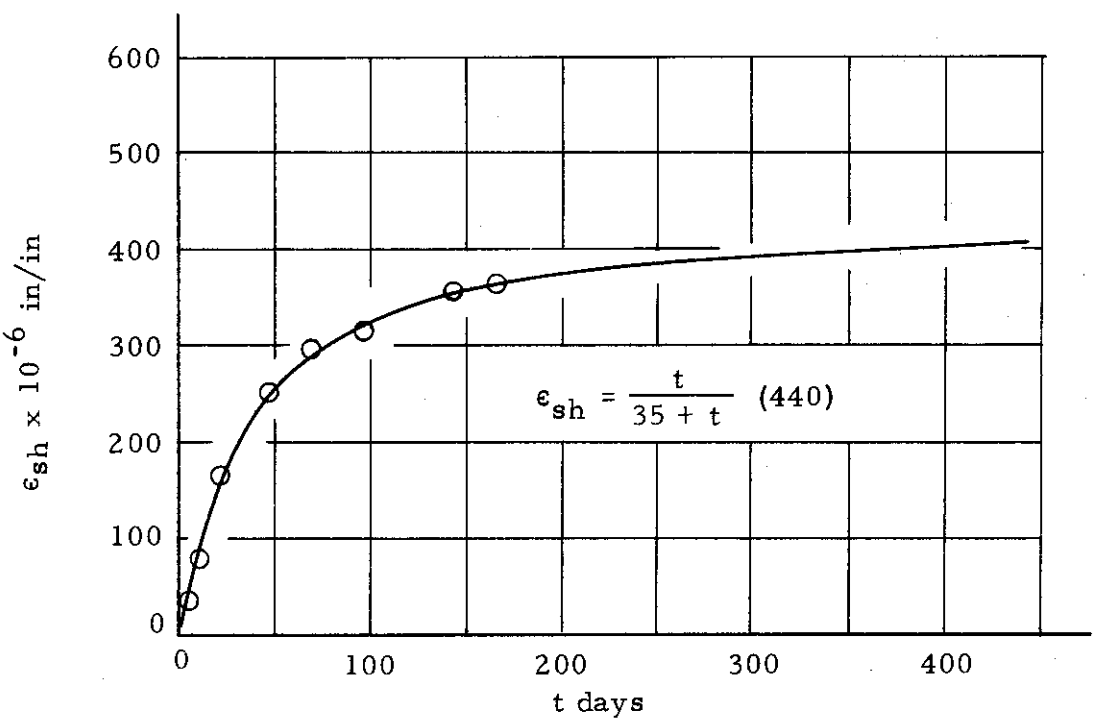

Fig. 32 ϵ_{sh} vs. t, Mix B-4

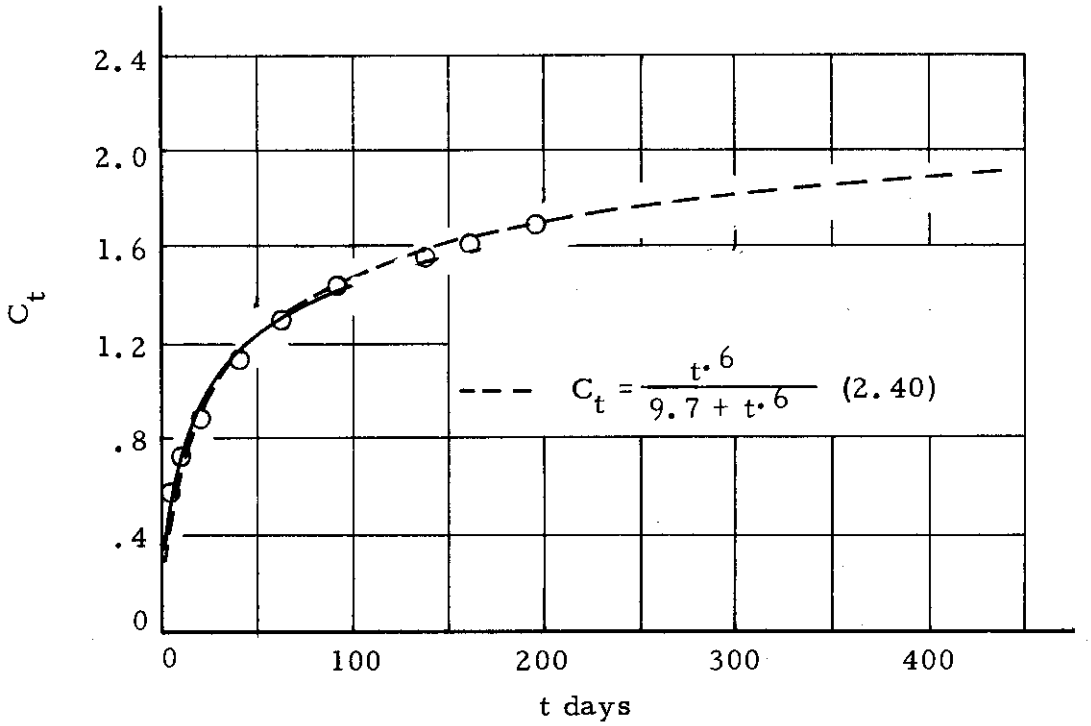

Fig. 33 C_t vs. t, Mix CW-4

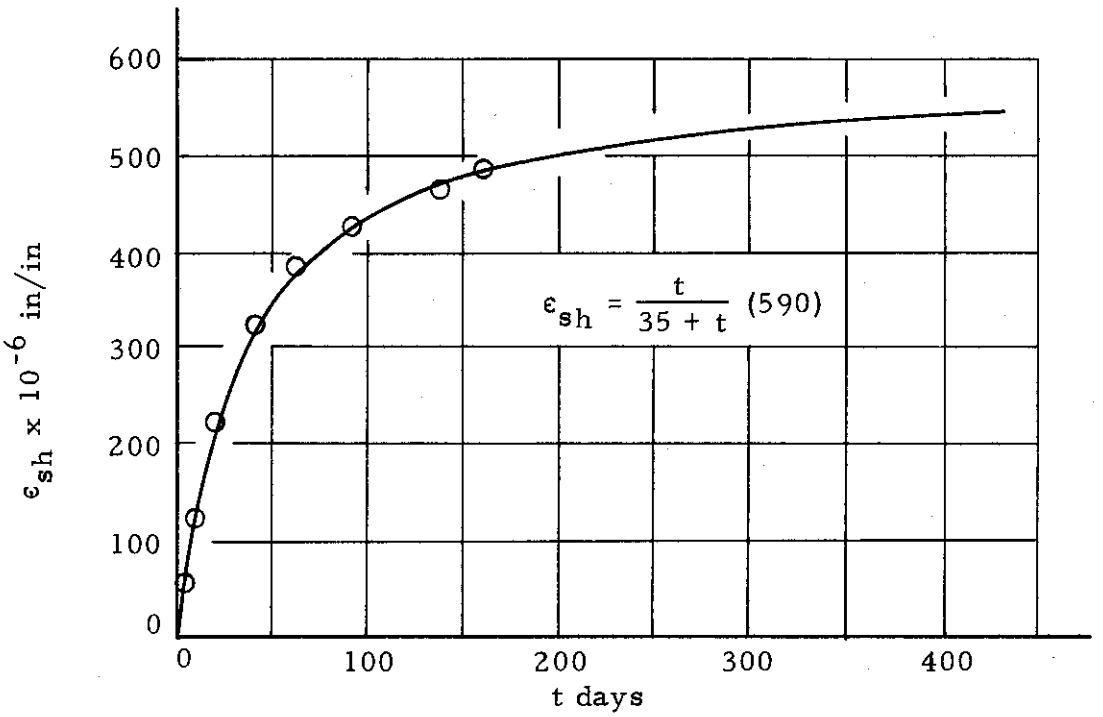

Fig. 34 ϵ_{sh} vs. t, Mix CW-4

$$\epsilon_{sh} = \frac{t}{30 + t} \quad (620) \qquad (60)$$

where 620 is the ultimate shrinkage strain x 10^{-6} in/in. Figures 35 and 36 show these equations compared with observed data poings.

The curves shown in Figures 35 and 36 are an average of two different mixes (I-1 and I-3) with the same mix proportions and curing conditions. Also shown in Figure 35 is the creep coefficient vs time curve for the single steam cured test which has the same mix proportions as the moist cured concrete.

Concrete steam cured 2-3 days and immediately loaded may be assumed to exhibit the same creep vs. time characteristics as concrete which has been moist cured 7 days and immediately loaded. However, in these tests the concrete was steam cured 2-3 days and loaded at 7 days age. Therefore, the creep coefficient data in Figure 35 were increased by 6% (see Fig. 7) to correct for the delay in age of loading. Similar correction factors are not available for steam cured shrinkage data; therefore, no attempt was made to formulate an expression for the steam cured shrinkage. It is recommended that reference (25) and other sources be consulted for properties of steam cured concrete because of the limited testing in this investigation.

Figures 37-40 show a comparison of observed creep vs. predicted creep for the four mixes at various stress levels. The observed initial strain, ϵ_i at each stress level was used to predict creep strain $\epsilon_c = C_t \epsilon_i$. If ϵ_i is not available it may be computed as $\epsilon_i = \sigma E_c$.

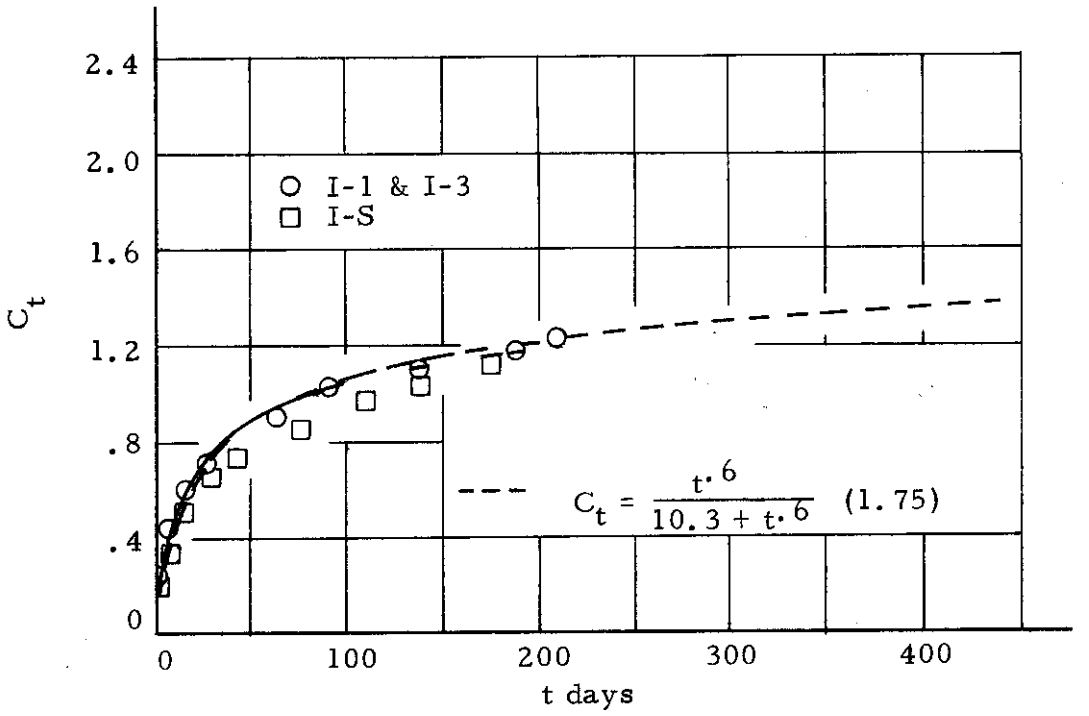

Fig. 35 C_t vs. t, Mix I-1 & I-3, I-S

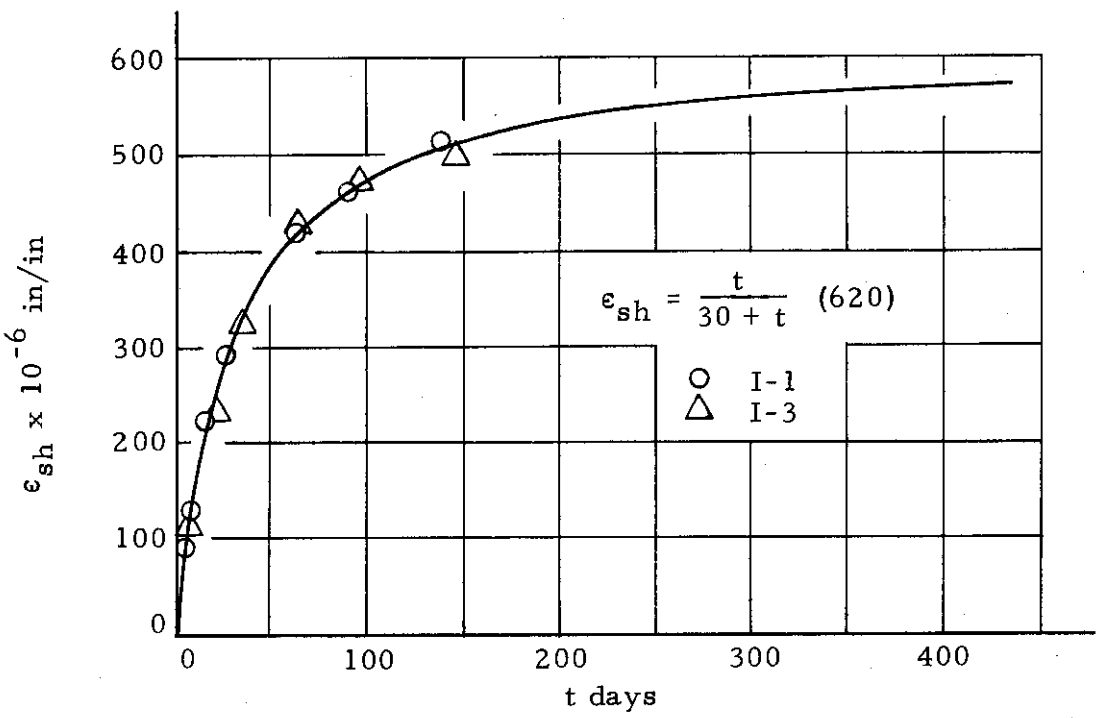

Fig. 36 ε_{sh} vs. t, Mix I-1, I-3

The predicted creep values in Figures 37-40 are shown to occasionally deviate 15 - 20 percent from observed behavior during the first several months of loading. For all stress levels the error of prediction is shown to decrease with time and, in general, the error does not exceed 10 percent after one year.

5.5 General Prediction Equations for Sand-Lightweight Concrete

In order to verify both the form of Eqs. (12) and (33) and the constants suggested for use in these equations for the prediction of the creep and shrinkage characteristics of sand-lightweight concrete, general equations for the materials tested in this study were evaluated by averaging the variable terms C_u and d in Eqs. (53, 55, 57, 59) and $(\epsilon_{sh})_u$ and f in Eqs. (54, 56, 58, 60).

Figures 41 and 42 show these general equations graphically and compare them to the data observed in this experimental program. The equations are:

$$C_t = \frac{t^{0.60}}{10.5 + t^{0.60}} \quad (2.05) \tag{61}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad (570) \times 10^{-6} \tag{62}$$

These equations and all prediction equations for specific sand-lightweight aggregate concretes presented in this section have been developed for standard conditions and the correction factors suggested

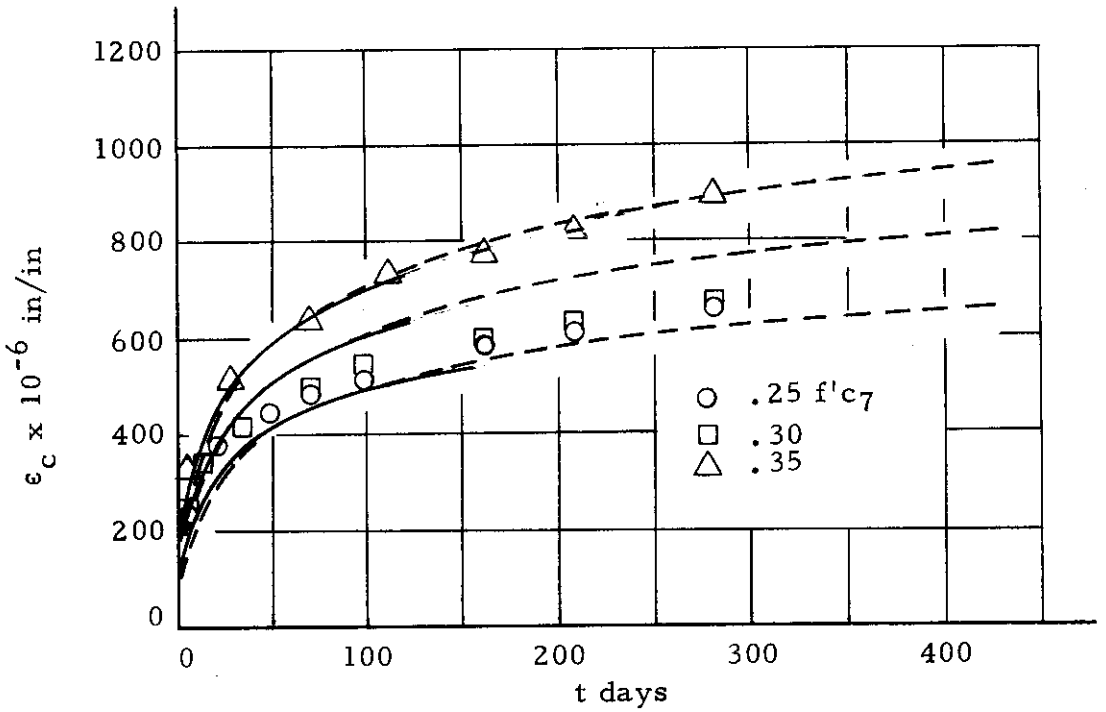

Fig. 37 Predicted vs. Actual Creep, Mix H-1

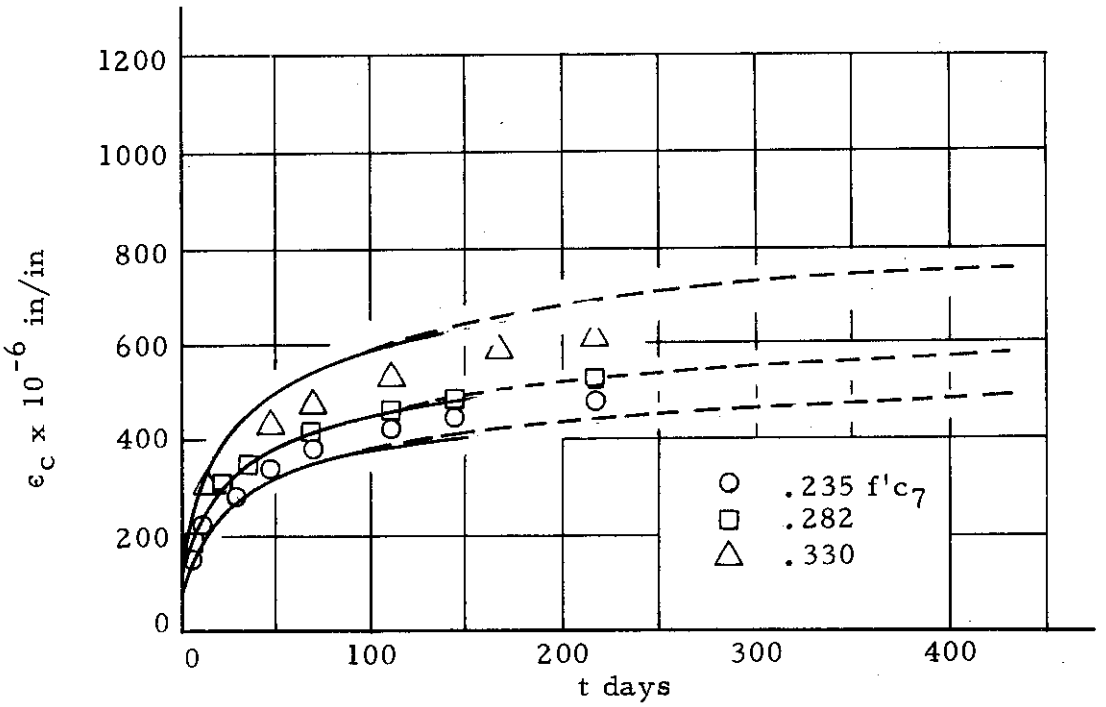

Fig. 38 Predicted vs. Actual Creep, Mix B-4

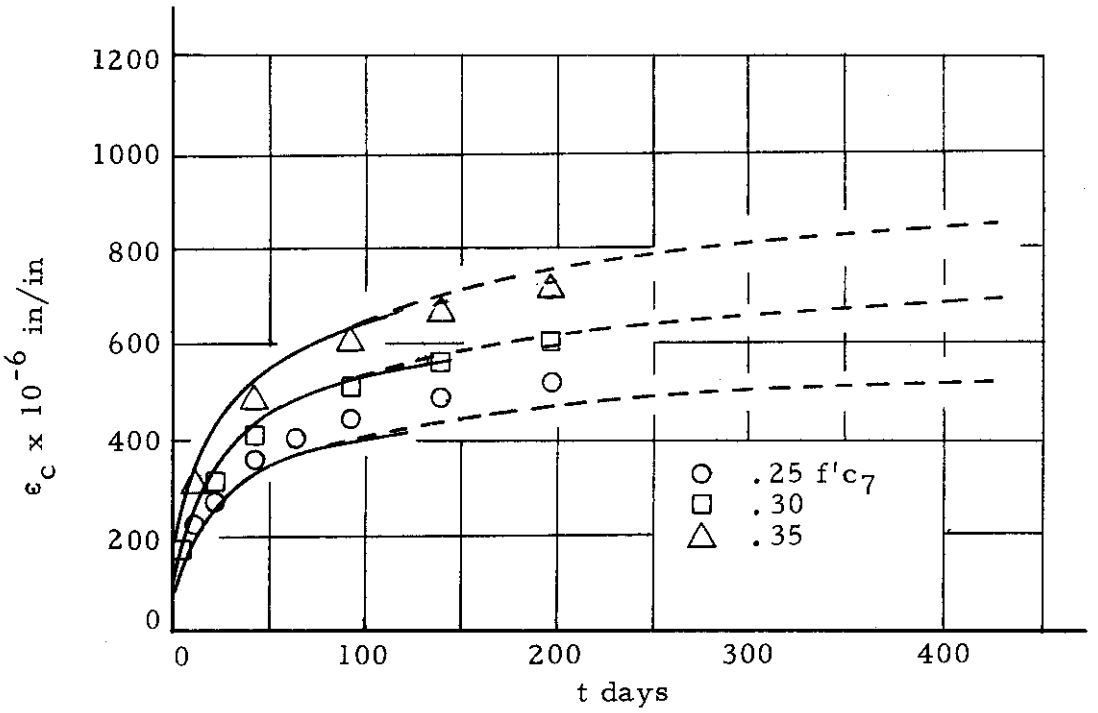

Fig. 39 Predicted vs. Actual Creep, Mix CW-4

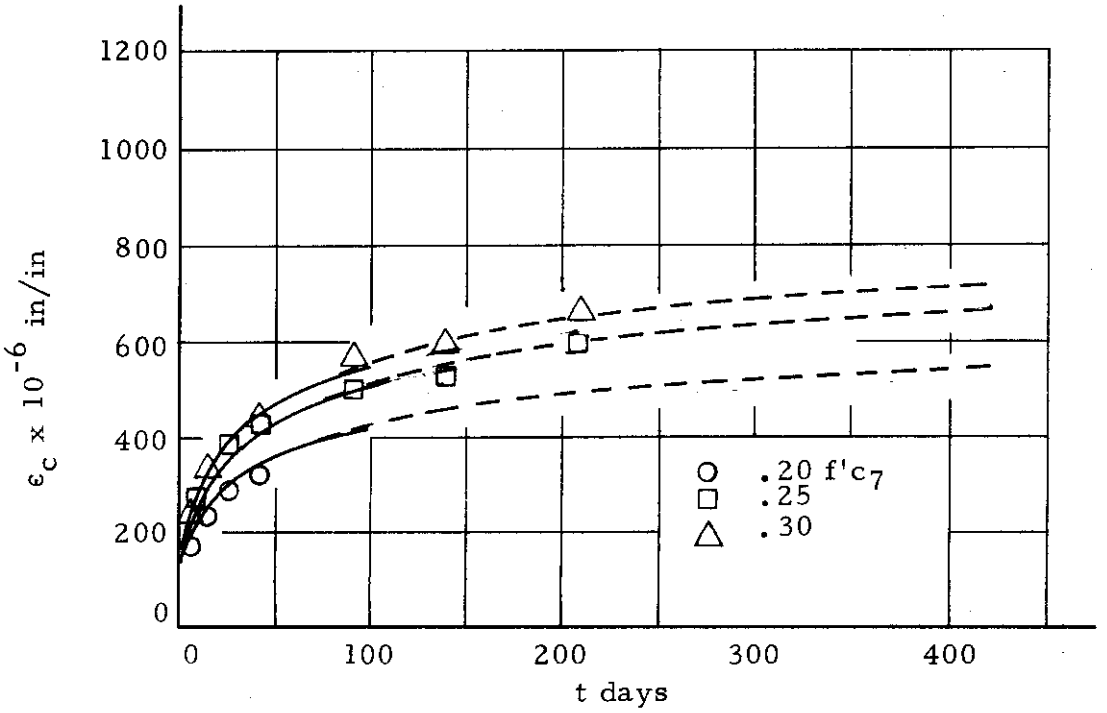

Fig. 40 Predicted vs. Actual Creep, Mix I-1

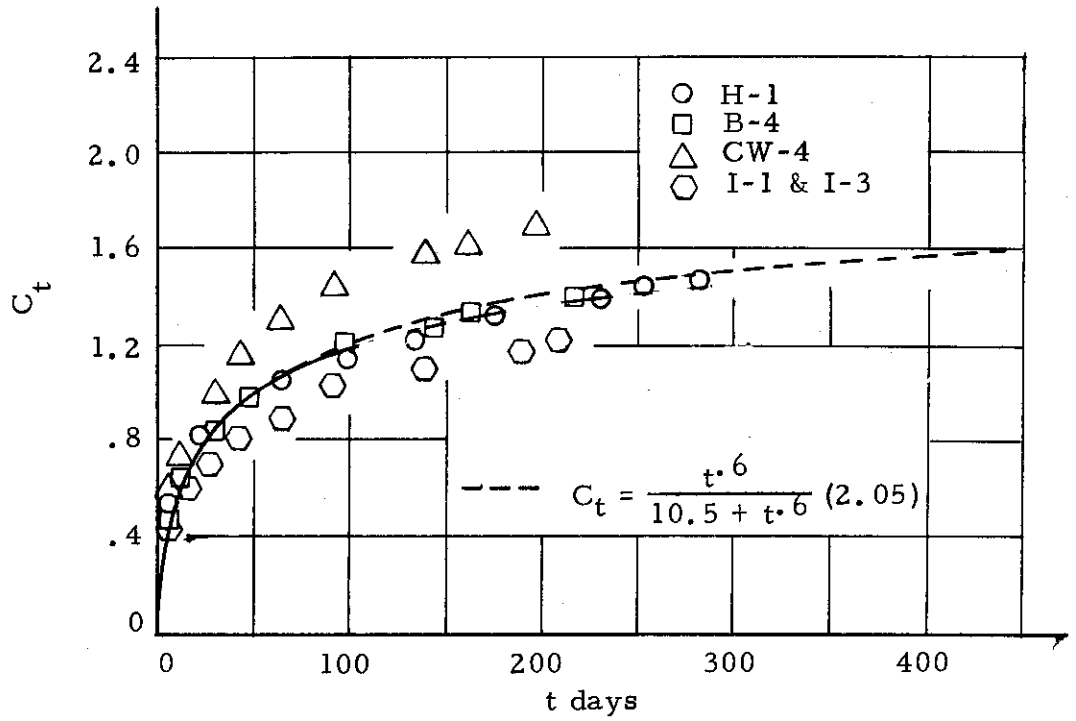

Fig. 41 General Sand-Lightweight Creep

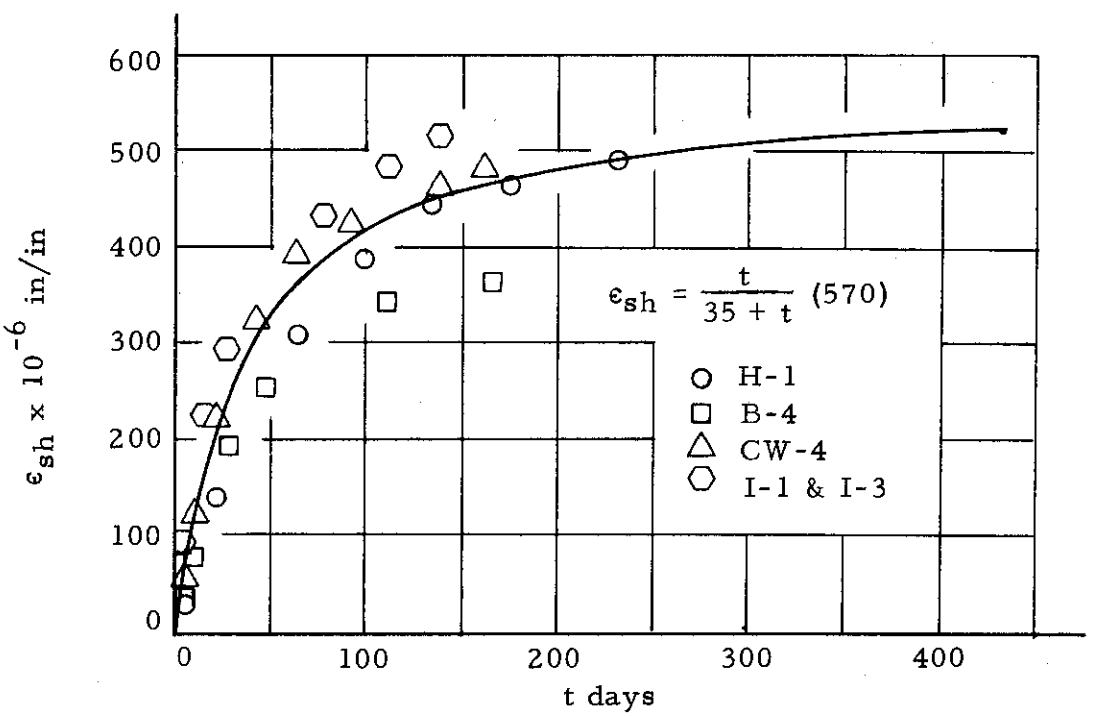

Fig. 42 General Sand-Lightweight Shrinkage

in Chapter 2 should be used to evaluate the time-dependent deformation of specimens subjected to other than standard conditions. It can be seen from the figures that the general equations represent the data with reasonable accuracy, verifying at least the general form of the equations selected.

Figures 43 and 44 show a comparison between Eqs. (61) and (62) and equations (12) and (33), which were developed in Chapter 2, and are recommended as representative of the creep and shrinkage characteristics of the material tested herein.

$$C_t = \frac{t^{0.60}}{10 + t^{0.60}} \quad (2.00) \tag{12}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} \quad (785) \times 10^{-6} \tag{33}$$

The general creep prediction equation developed from the analysis of the data obtained from the University of Iowa tests is almost identical to the general equation developed from the data taken from the literature (Eq. (12)). However this is not the case for the shrinkage prediction equations. The equation developed from the Iowa tests predicts shrinkage values about 25% lower than those predicted by the general equation developed in Chapter 2 (Eq. (33)). Although this is not a significant difference from a design standpoint it is felt that with additional experimentation and a slight modification in the general form of

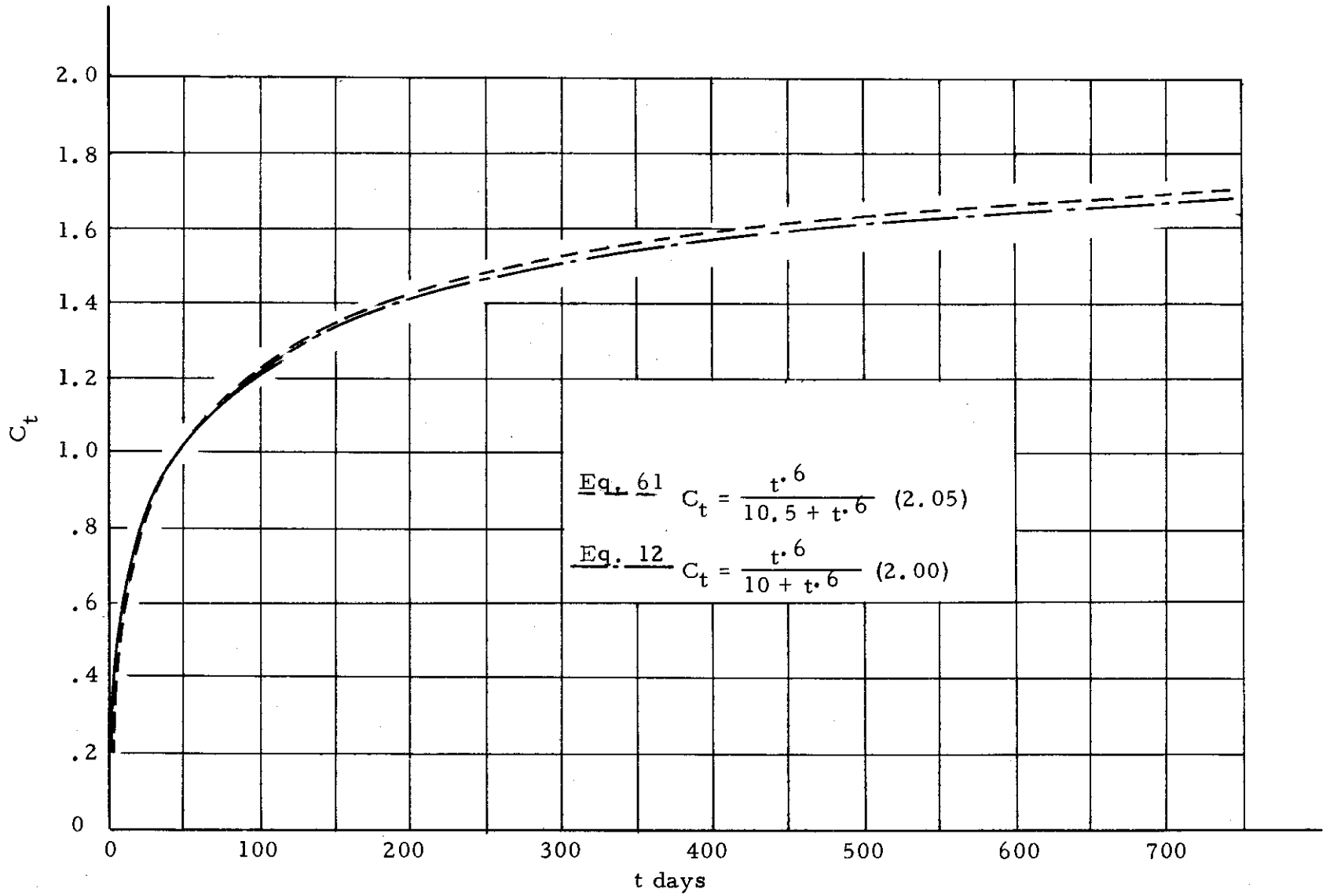

Fig. 43 Comparison of General Creep Equations for Sand-Lightweight Concrete

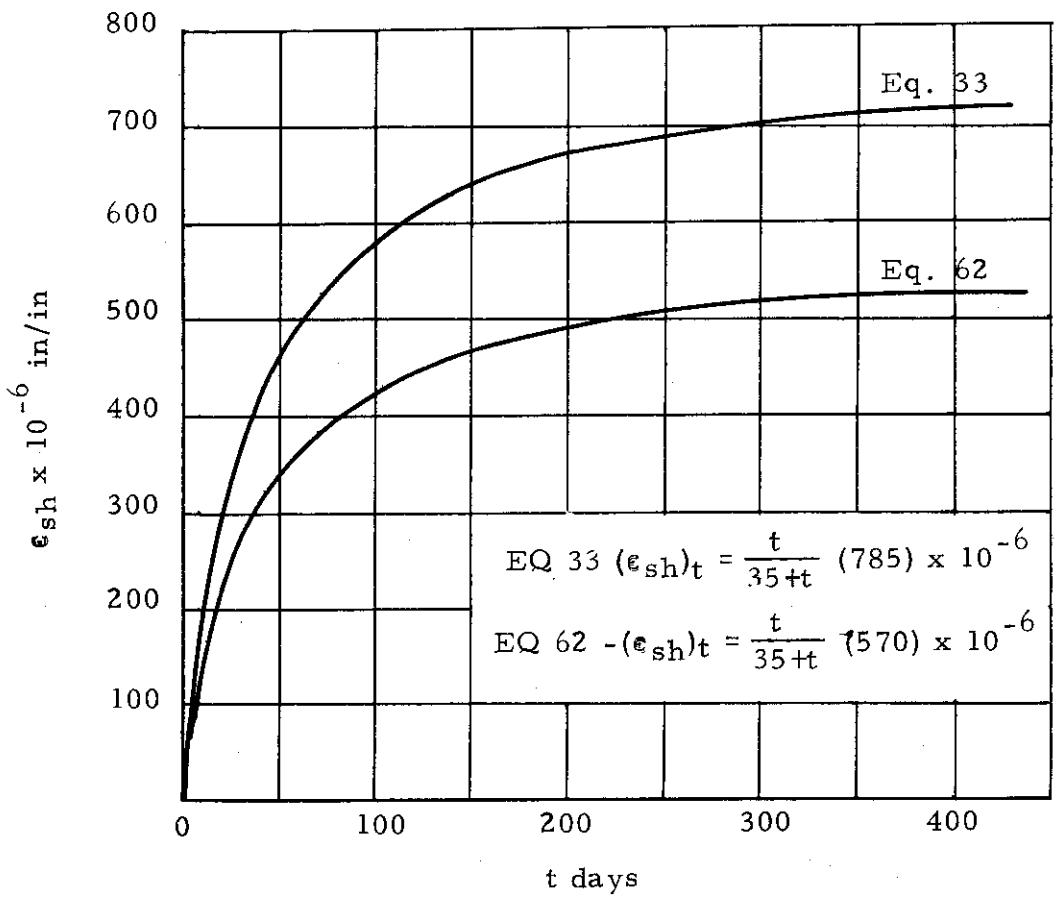

Fig. 44 Comparisons of General Shrinkage Equations for Sand-Lightweight Concrete

the shrinkage equation (i.e., a change in the value of the exponent e in Eq. (2)) would yield better results. However there was not sufficient data available to allow such modification.

CHAPTER 6

CREEP AND SHRINKAGE PREDICTION FROM 28 DAY DATA

All of the equations developed this far are suggested for use by the designer, only when experimental data is not available. For example, if any of the materials investigated in this program (see Chapter V) are to be used in a design project, it is suggested that the equations appropriate for those materials be used to predict creep and shrinkage characteristics (e.g. for moist cured Idealite sand-lightweight concrete use equations 59 and 60). When specific equations are not available it is suggested the appropriate general equations (see Chapter II) be used to predict creep and shrinkage characteristics (e.g. for moist cured normal weight concrete use equations 9 and 30).

In the following sections prediction methods based on a minimal amount of laboratory data are developed for use in those cases when the nature of the structure requires more accurate prediction, or for use in those cases when it is considered economically feasible to perform some laboratory tests.

6.1 Creep Prediction From 28 Day Data

If the general form of Eq. (1) is assumed to accurately represent the creep-time relationship, it can be seen that only one point on an experimental creep-time curve is required to solve the equation for

C_u (i.e. if d and C_t at any time are known then Eq. (1) becomes

$$C_u = C_t \Big/ \frac{t^{0.6}}{d + t^{0.6}} \tag{63}$$

and C_u can be evaluated, thereby giving a continuous equation for creep as a function of time).

The 28 day prediction method was developed using the data obtained from the experimental program described in Chapter V and therefore the constant d was taken to be 10.5 in the initial development. The method was then verified by applying it to the data obtained from the literature and discussed in Chapter II. In those calculations the constant d was taken to be 10.0. It should be noted that the method is valid for any reasonable value of d and has been shown to work for constants within the range of 6 to 12.

Figs. 45 thru 48 show creep coefficient prediction equations that were determined, for the four concrete mixes studied in this investigation, using 28 day data.

These equations were determined as follows. The ultimate creep coefficient was estimated by setting c equal to 0.6 and d equal to 10.5 and substituting the experimental value for C_t at 28 days into Eq. (1).

Table 3 shows a comparison of observed values and calculated values of C_t. The data indicates that 90% of all calculated values are within 10%, and 97% of all calculated values are within 15% of the observed values.

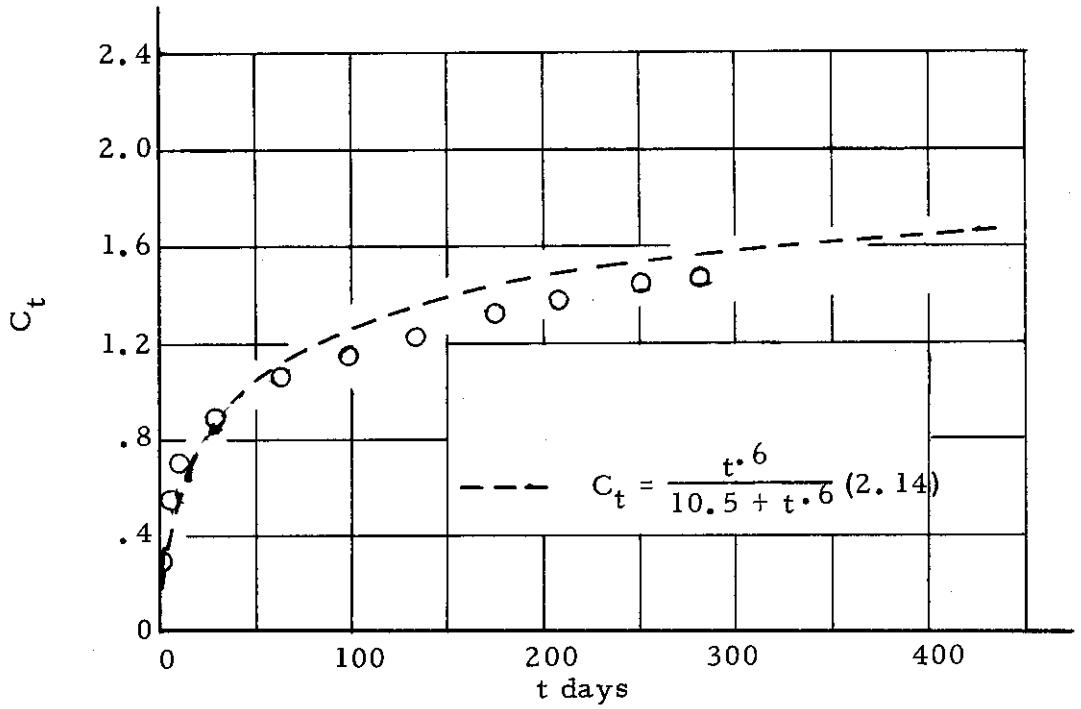

Fig. 45 28 Day Creep Prediction, Mix H-1

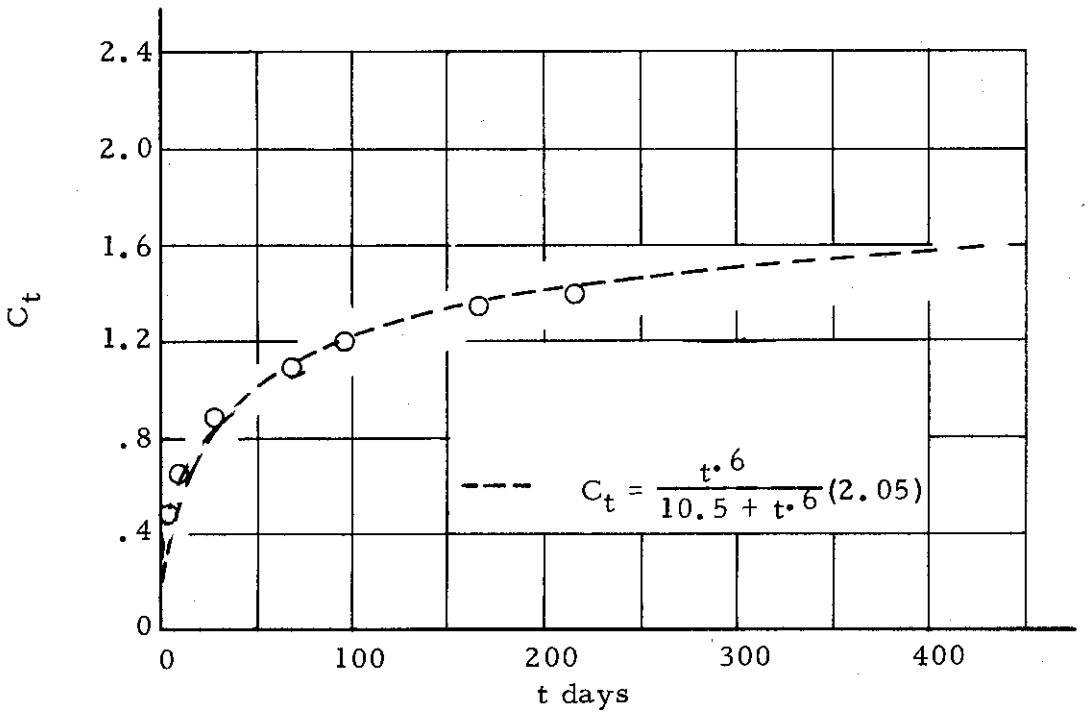

Fig. 46 28 Day Creep Prediction, Mix B-4

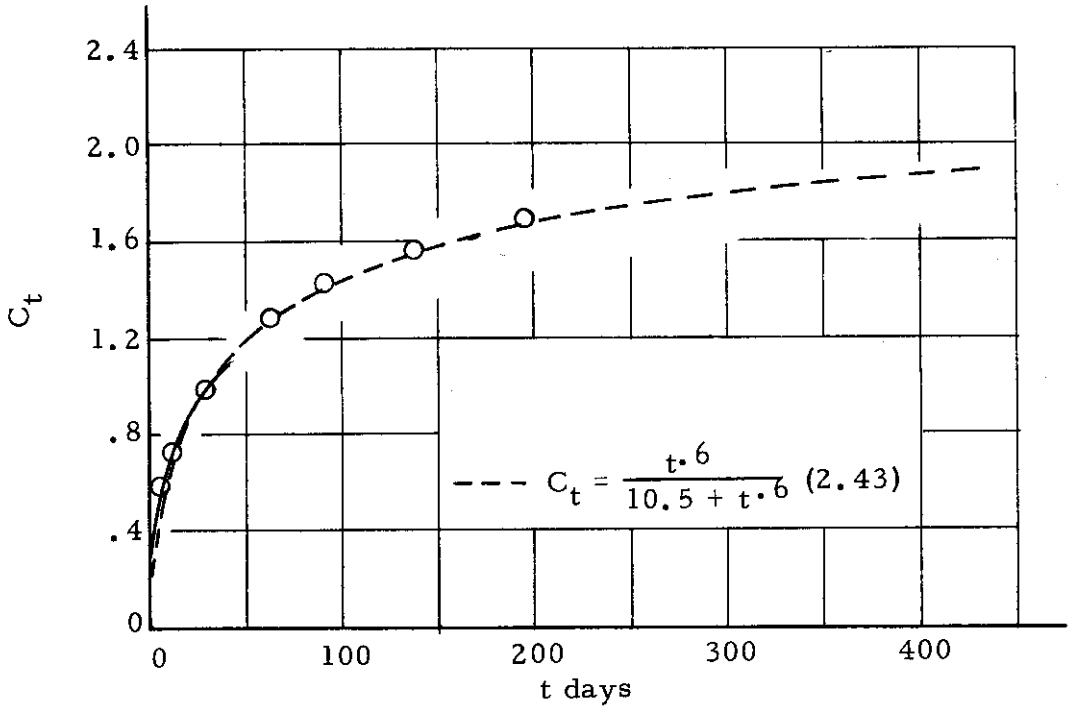

Fig. 47 28 Day Creep Prediction, Mix CW-4

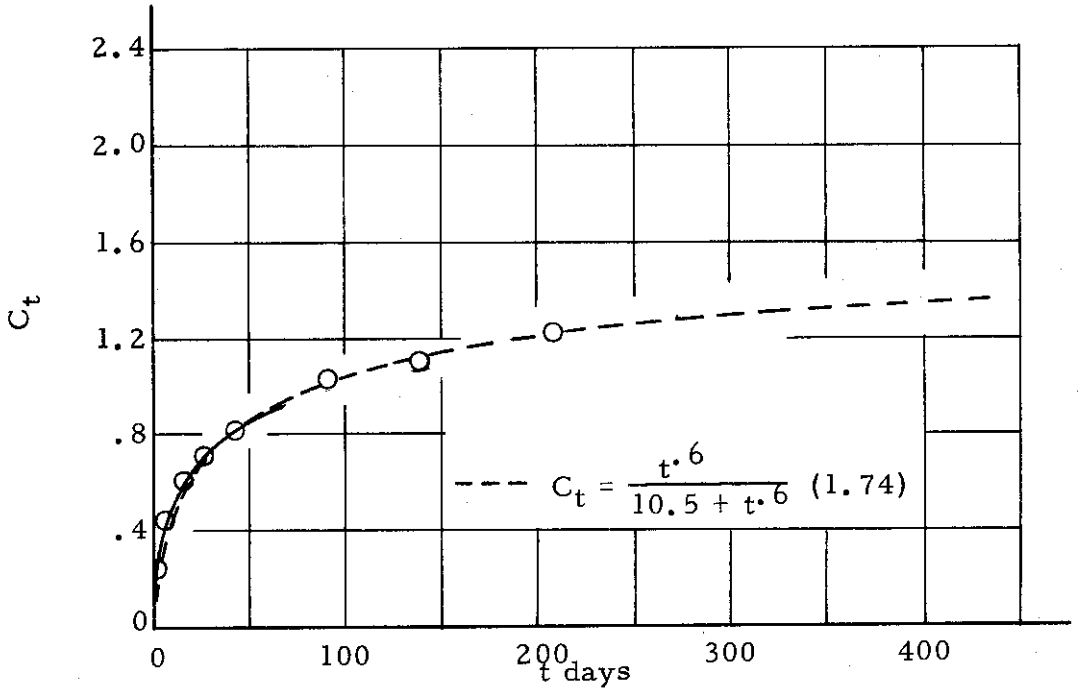

Fig. 48 28 Day Creep Prediction, Mix I-1 & I-3

Table 3

Accuracy of 28-Day Prediction Method for Creep

$B\ C_t = \frac{t^{0.6}}{10.5 + t^{0.6}}\ C_u$	H-1 0.25 f'_{c_7}	H-1 0.30 f'_{c_7}	H-1 0.35 f'_{c_7}	B-4 0.235 f'_{c_7}	B-4 0.282 f'_{c_7}	B-4 0.33 f'_{c_7}	CW-4 0.25 f'_{c_7}	CW-4 0.30 f'_{c_7}	CW-4 0.35 f'_{c_7}	I-1 0.25 f'_{c_7}	I-1 0.30 f'_{c_7}	I-3 0.30 f'_{c_7}
C_u (experimental)	2.29	1.92	2.19	2.12	1.97	1.77	2.58	2.30	2.38	1.65	1.78	1.87
$C_u = C_t(28d)/.414$	2.43	1.90	2.09	2.19	2.15	1.82	2.79	2.28	2.21	1.92	1.85	1.67
$C_u(calc)/C_u(exp)$	1.06	.99	.95	1.03	1.09	1.03	1.08	.99	.93	1.16	1.04	.89
250d $C_t(calc)/C_t(obs)$	1.07	1.08	1.09	1.01	1.01	1.01	.98	.99	1.04	.98	1.02	1.04
200d $C_t(calc)/C_t(obs)$	1.13	1.07	1.05	1.00	1.06	1.00	1.03	.96	.97	1.13	1.04	.98
100d $C_t(calc)/C_t(obs)$	1.16	1.10	1.06	.99	1.06	1.03	1.02	.95	.97	1.12	1.06	.97
50d $C_t(calc)/C_t(obs)$	1.02	1.04	1.01	1.01	1.01	.99	1.01	.95	.96	1.05	1.04	.99

The method was further verified by applying it to the data used in the development of the general equations in Chapter 2. One and two year creep coefficients were predicted from measured 28 day creep coefficients and compared to experimental values. The results of the analysis is shown in Table 4. The data shows that 53% of the calculated values are within 10%, and 83% of the calculated values are within 20% of the one year observed values. Similar figures for 2 year data are 50% of the calculated values are within 10%, and 80% of the calculated values are within 20% of the observed values. In both cases over 90% of the calculated values are within 30% of the observed values.

It can be seen that the 28 day predictions based on the experiments carried out at the University of Iowa seem to result in more accurate long term estimates. This can be attributed to the fact that the conditions of the experiments performed at the University of Iowa are known in all cases. For many of the data taken from the literature, testing conditions had to be assumed. The accuracy obtained is never-the-less excellent.

An additional measure of the accuracy of the method is indicated by the error coefficient (M). The average error coefficients for one year and two year prediction for forty sets of data taken from the literature are calculated in Table 5. It can be seen, by referring to Fig. 2 that to obtain an error coefficient of 10%, Neville and Meyers indicate that tests should be carried out for about 20 weeks. Using the

Table 4

28-Day Extrapolation of Creep

(Ref) Specimen Designation	C_t Experimental	C_u * Predicted	C^e_{365} Experimental	C^p_{365} ** Predicted	C^e_{730} Experimental	C^p_{730} Predicted	$\frac{C^p_{365}}{C^e_{365}}$	$\frac{C^p_{730}}{C^e_{730}}$
(15) 4	.97	2.28	1.82	1.77	1.86	1.91	.973	1.027
(15) 6	1.15	2.70	2.06	2.09	2.17	2.26	1.015	1.041
(15) 8	.92	2.16	2.03	1.67	2.14	1.81	.823	.845
(15) 12	.82	1.93	1.66	1.50	1.71	1.62	.904	.947
(15) 16	.82	1.93	1.55	1.50	1.69	1.62	.968	.959
(15) 20	.64	1.50	1.30	1.16	1.44	1.26	.892	.875
(15) 24	.73	1.72	1.37	1.33	1.52	1.44	.971	.947
(16) 71	1.37	3.22	2.46	2.50	2.73	2.70	1.016	.989
(16) 72	1.25	2.94	2.36	2.28	2.61	2.46	.966	.943
(16) 73	1.20	2.82	2.75	2.18	2.31	2.36	.793	.793
(16) 74	1.28	3.01	2.46	2.33	2.62	2.52	.947	.962
(17) 6N6	1.90	4.47	3.45	3.46	3.72	3.75	1.003	1.008
(17) 6N28	1.52	3.58	3.01	2.78	3.32	2.99	.924	.901
(17) 6S2	1.10	2.59	2.21	2.01	2.53	2.17	.910	.818
(17) 6S7	1.04	2.45	2.20	1.90	2.52	2.06	.864	.817
(17) 6S28	.95	2.24	2.20	1.74	2.51	1.88	.791	.749
(17) 10N6	1.04	2.45	1.79	1.90	1.94	2.06	1.061	1.062
(17) 10N28	.75	1.76	1.59	1.36	1.74	1.48	.855	.851
(17) 10S2	.65	1.53	1.30	1.18	1.45	1.28	.908	.883
(17) 10S7	.72	1.69	1.34	1.31	1.50	1.42	.978	.947
(17) 10S28	.66	1.55	1.43	1.20	1.62	1.30	.839	.802
(17) 8N6	1.73	4.07	3.02	3.16	3.19	3.42	1.046	1.072
(17) 8N28	1.88	4.43	3.40	3.36	3.70	3.72	.988	1.005
(17) 8S7	1.41	3.32	2.45	2.58	2.74	2.78	1.053	1.015
(17) 8S28	1.35	3.18	2.59	2.48	2.95	2.67	.958	.905
(17) 6M5	1.51	3.56	2.78	2.76	3.01	2.98	.993	.990
(17) 6M28	1.10	2.59	2.48	2.00	2.67	2.16	.806	.809

Table 4 (Cont'd)

(Ref) Specimen Designation	C_t Experimental	C_u* Predicted	C^e_{365} Experimental	C^p_{365}** Predicted	C^e_{730} Experimental	C^p_{730} Predicted	$\frac{C^p_{365}}{C^e_{365}}$	$\frac{C^p_{730}}{C^e_{730}}$
(17) 6R7	.74	1.74	1.70	1.35	1.93	1.46	.853	.756
(17) 6R28	.60	1.41	1.54	1.09	1.78	1.18	.708	.663
(17) 10M5	.93	2.18	1.84	1.69	1.97	1.83	.918	.929
(17)10M28	.92	2.16	1.93	1.67	2.12	1.81	.865	.854
(17) 10R2	.68	1.60	1.34	1.24	1.49	1.34	.925	.899
(17) 10R7	.66	1.55	1.33	1.20	1.46	1.30	.902	.890
(17) 10R28	.63	1.48	1.40	1.15	1.56	1.24	.821	.795
(17) 8M5	1.57	3.70	2.96	2.87	3.19	3.10	.970	.972
(17) 8M28	1.73	4.07	3.00	3.15	3.23	3.42	1.05	1.059
(17) 8R2	1.09	2.56	2.10	1.98	2.34	2.14	.943	.914
(17) 8R7	1.13	2.66	2.32	2.06	2.55	2.23	.888	.875
(17) 8R28	1.08	2.54	2.34	1.97	2.64	2.13	.842	.807
(17) 6R2	.90	2.12	1.80	1.64	2.00	1.78	.911	.890

$$* \quad C_u = \frac{C_{28}}{28^{0.6}/10 + 28^{0.6}} = \frac{C_{28}}{0.425}$$

$$** \quad C_{365} = \frac{365^{0.6}}{10 + 365^{0.6}} \; C_u$$

Table 5

Error Coefficient

Predicted (Ct) 365 C_t	Experimental (Ct) 365 C_1	$(C_t - C_1)$ 365	$(C_t - C_1)^2$ 365	Predicted (Ct) 730 C_t	Experimental (Ct) 730 C_1	$(C_t - C_1)$ 730	$(C_t - C_1)^2$ 730
1.77	1.82	.05	.0025	1.91	1.86	.05	.0025
2.09	2.06	.03	.0009	2.26	2.17	.09	.0081
1.67	2.03	.36	.1296	1.81	2.14	.33	.1089
1.50	1.66	.16	.0256	1.62	1.71	.09	.0081
1.50	1.55	.05	.0025	1.62	.169	.07	.0049
1.16	1.30	.14	.0196	1.26	1.44	.18	.0324
1.33	1.37	.04	.0016	1.44	1.52	.08	.0064
2.50	2.46	.04	.0016	2.70	2.73	.03	.0009
2.28	2.36	.08	.0064	2.46	2.61	.15	.0225
2.18	2.73	.57	.3249	2.36	2.31	.05	.0025
2.33	2.46	.13	.0169	2.52	2.62	.10	.0100
3.46	3.45	.01	.0001	3.75	3.72	.03	.0090
2.78	3.01	.23	.0529	2.99	3.32	.33	.1089
2.01	2.21	.20	.0400	2.17	2.53	.36	.1296
1.90	2.20	.30	.0900	2.06	2.52	.46	.2116
1.74	2.20	.46	.2116	1.88	2.51	.63	.3969
1.90	1.79	.11	.0121	2.06	1.94	.12	.0144
1.36	1.59	.23	.0529	1.48	1.74	.26	.0676
1.18	1.30	.12	.0144	1.28	1.45	.17	.0289
1.31	1.34	.03	.0009	1.42	1.50	.08	.0064
1.20	1.43	.23	.0529	1.30	1.62	.32	.1024
3.16	3.02	.14	.0196	3.42	3.19	.23	.0529
3.36	3.40	.04	.0016	3.72	3.70	.02	.0004
2.58	2.45	.13	.0169	2.78	2.74	.04	.0016
2.48	2.59	.11	.0121	2.67	2.95	.28	.0784
2.76	2.78	.02	.0004	2.98	3.01	.03	.0009

Table 5 (Cont'd)

Predicted (Ct) 365 C_t	Experimental (Ct) 365 C_1	$(C_t - C_1)_{365}$	$(C_t - C_1)^2_{365}$	Predicted (Ct) 730 C_t	Experimental (Ct) 730 C_1	$(C_t - C_1)_{730}$	$(C_t - C_1)^2_{730}$
2.00	2.48	.48	.2304	2.16	2.67	.51	.2601
1.35	1.70	.35	.1225	1.46	1.93	.47	.2209
1.09	1.54	.45	.2025	1.18	1.78	.60	.3600
1.69	1.84	.15	.0225	1.83	1.97	.14	.0196
1.67	1.93	.26	.0676	1.81	2.12	.31	.0961
1.24	1.34	.10	.0100	1.34	1.49	.15	.0225
1.20	1.33	.13	.0169	1.30	1.46	.16	.0256
1.15	1.40	.25	.0625	1.24	1.56	.32	.1024
2.87	2.96	.09	.0081	3.10	3.19	.09	.0081
3.15	3.00	.15	.0225	3.42	3.23	.19	.0361
1.98	2.10	.12	.0144	2.14	2.34	.20	.0400
2.06	2.32	.26	.0676	2.23	2.55	.32	.1024
1.47	2.34	.37	.1369	2.13	2.64	.51	.2601
1.64	1.80	.16	.0256	1.78	2.00	.22	.0484
	84.66		2.1195		91.17		3.0894

$$\frac{(C_t - C_1)^2}{n} = \frac{2.1195}{40} = 0.05299$$

$$\frac{(C_t - C_1)^2}{n} = 5.299 \times 10^{-2} = 0.23$$

$$C_1/n = 84.66/40 = 2.12$$

$$M = \frac{0.23 \times 100}{2.12} = \underline{10.85\%} \text{ for 365 day analysis}$$

$$\frac{(C_t - C_1)^2}{n} = \frac{3.0894}{40} = 0.0772$$

$$\frac{(C_t - C_1)^2}{n} = 7.72 \times 10^{-2} = 0.278$$

$$C_1/n = 9.117/40 = 2.28$$

$$M = \frac{0.278 \times 100}{2.28} = \underline{12.20\%} \text{ for 730 day analysis}$$

prediction method developed in this report, similar accuracy can be obtained with only 28 days (4 weeks) of data. A similar calculation indicates an even lower error coefficient for the 28 day predictions performed on the materials tested at the University of Iowa.

6.2 Shrinkage Prediction From 28 Day Data

The techniques described in the previous section (Creep Prediction From 28 Day Data) can also be used to obtain a continuous equation for shrinkage as a function of time, (i.e., if f and $(e_{sh})_t$ at time are known then Eq. 2 becomes

$$(e_{sh})_u = (e_{sh})_t / \frac{t}{f + t} \tag{64}$$

and $(e_{sh})_u$ can be evaluated). Figs. 49 thru 52 show comparisons between shrinkage predicted using equations based on twenty-eight day shrinkage data and measured values of shrinkage strain.

Table 6 shows a comparison between predicted and measured values of $(e_{sh})_t$. The data indicates that 72% of all calculated values are within 10%, 84% within 15% and 96% within 30% of observed shrinkage values.

The method was also applied to the data used in the development of the general equations in Chapter 2 by comparing one and two year predicted shrinkage strains with experimental values. The results of this analysis is shown in table 7. The data indicates that, for moist cured concrete, 45% of the calculated values are within 10% and 82%

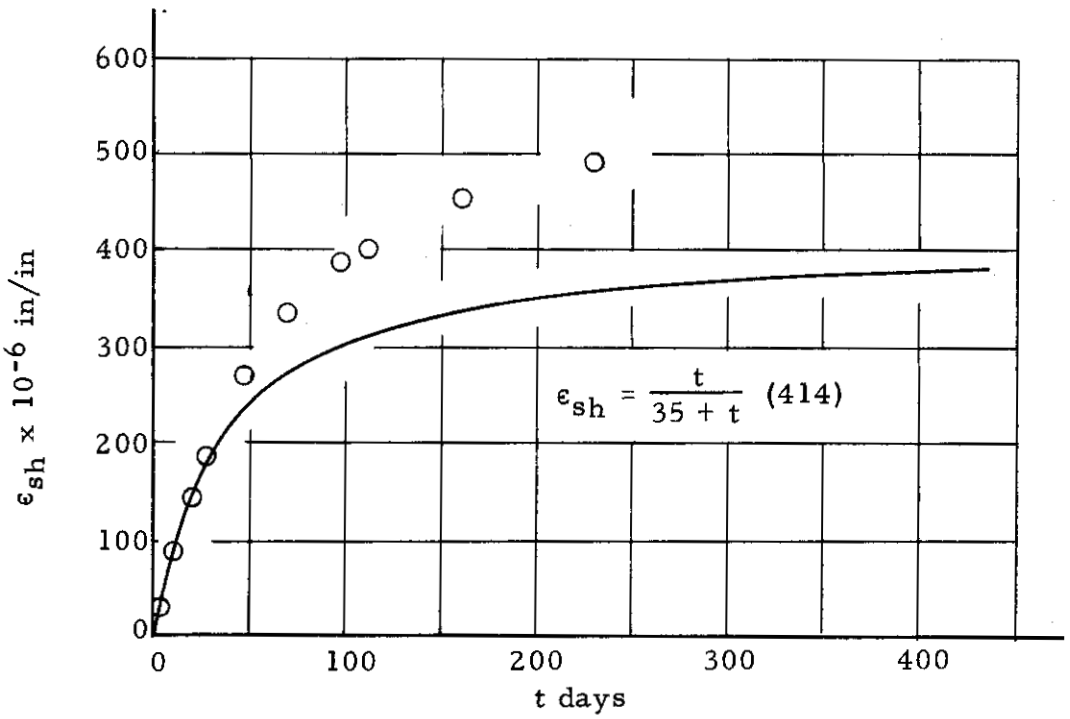

Fig. 49 28 Day Shrinkage Prediction, Mix H-1

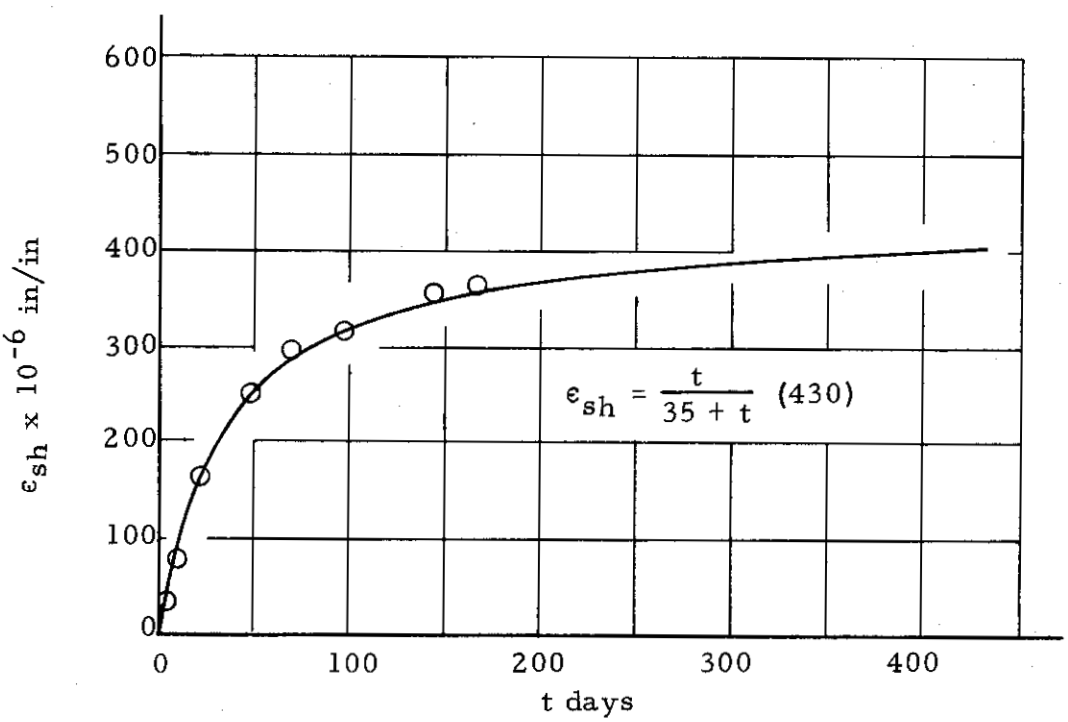

Fig. 50 28 Day Shrinkage Prediction, Mix B-4

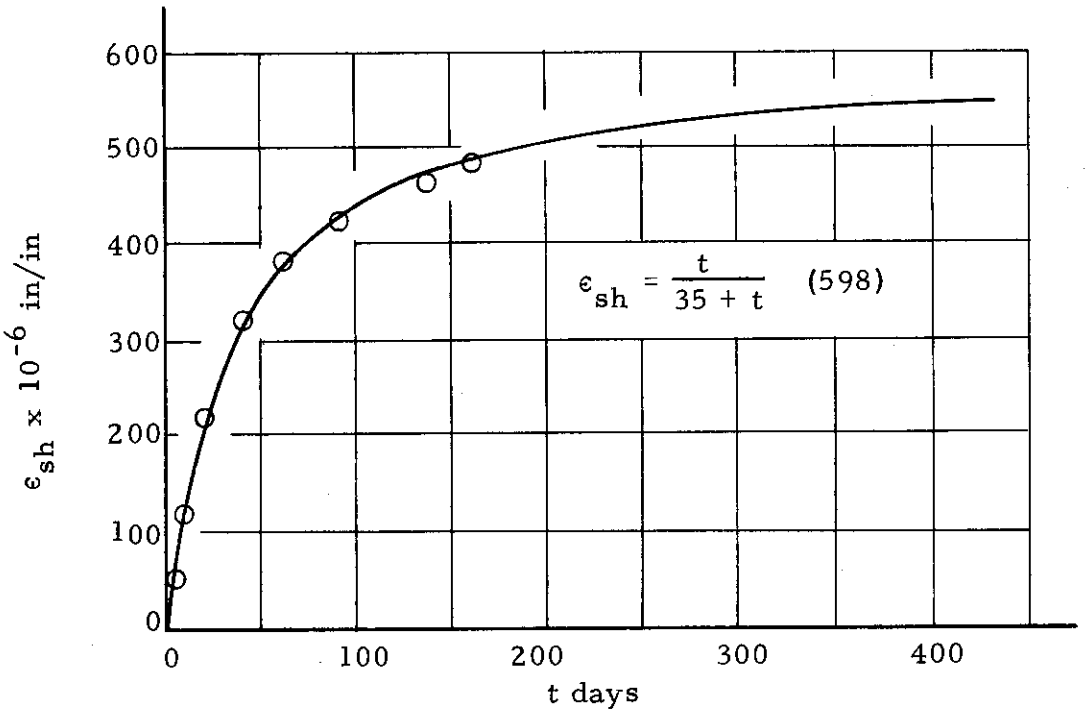

Fig. 51 28 Day Shrinkage Prediction, Mix CW-4

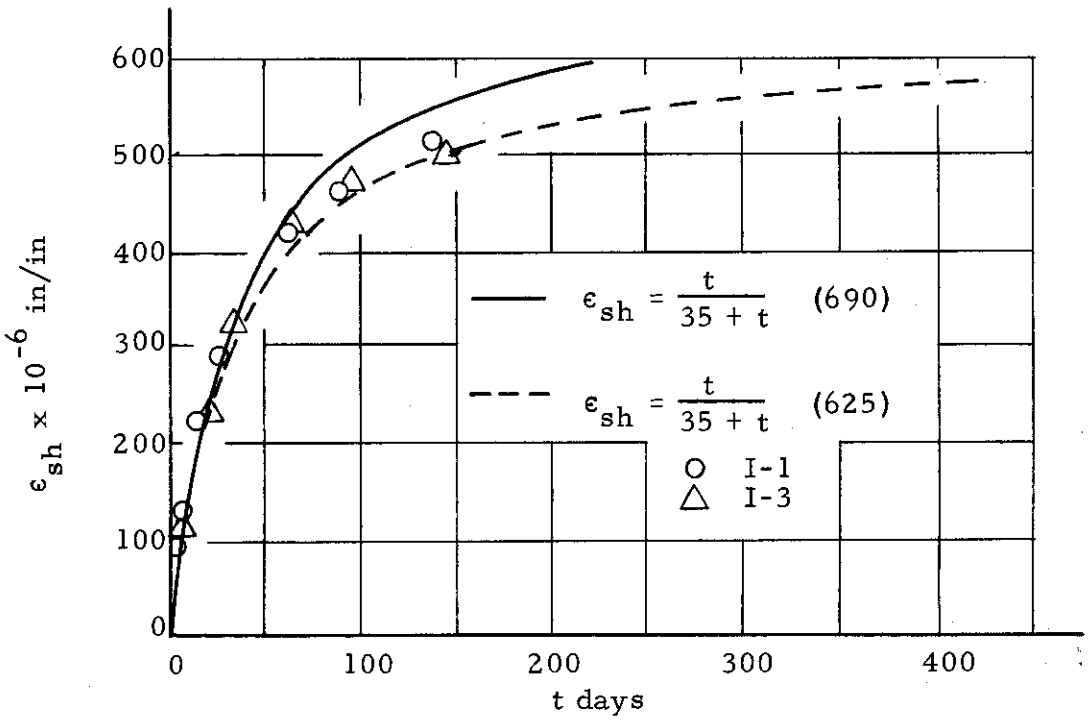

Fig. 52 28 Day Shrinkage Prediction, Mix I-1, I-3

TABLE 6 - ACCURACY OF 28 DAY PREDICTION METHOD FOR SHRINKAGE

28d Eq $\epsilon_{sh} = \frac{t}{35 + t} (\epsilon_{sh})u$	H-1	B-4	CW-4	I-1	I-3
$(\epsilon_{sh})u$(observed)	620	440	590	620	620
$(\epsilon_{sh})u$(28d Eq)	414	430	598	690	625
$(\epsilon_{sh})u$(28d Eq)/$(\epsilon_{sh})u$(observed)	.67	.98	1.01	1.11	1.01
200d ϵ_{sh}(28d Eq)/ϵ_{sh}(obs)	.74	.99	1.02	1.13	1.03
150d ϵ_{sh}(28d Eq)/ϵ_{sh}(obs)	.76	.96	1.02	1.11	1.00
100d ϵ_{sh}(28d Eq)/ϵ_{sh}(obs)	.79	.95	1.02	1.08	.98
50d ϵ_{sh}(28d Eq)/ϵ_{sh}(obs)	.88	.96	1.00	1.04	.96

Table 7

28 Day Extrapolation of Shrinkage

(Ref) Specimen Designation		28d $(\epsilon_{sh})_t$ Experimental	* $(\epsilon_{sh})_u$ Predicted	$(\epsilon_{sh})^e_{365}$ Experimental	$(\epsilon_{sh})^p_{375}$ Predicted	$(\epsilon_{sh})^e_{730}$ Experimental	$(\epsilon_{sh})^p_{730}$ Predicted	$\frac{(\epsilon_{sh})^p_{365}}{(\epsilon_{sh})^e_{365}}$	$\frac{(\epsilon_{sh})^p_{730}}{(\epsilon_{sh})^e_{730}}$
(15)	6	422	948	888	881	918	905	.992	.986
(16)	71	363	816	887	758	955	779	.856	.816
(16)	72	362	815	843	758	915	779	.899	.851
(16)	73	361	813	814	756	865	776	.929	.897
(16)	74	361	813	789	756	840	776	.958	.924
(17)	6N6	354	796	790	740	880	760	.937	.864
(17)	10N6	345	776	660	721	685	740	1.092	1.080
(17)	8N6	490	1105	730	1029	745	1055	1.410	1.416
(17)	6M5	470	1058	765	982	830	1010	1.284	1.217
(17)	10M5	385	866	695	805	710	826	1.158	1.163
(17)	8M5	370	834	660	775	675	795	1.174	1.178

$$* \ (\epsilon_{sh})_u = \frac{(\epsilon_{sh})_{28}}{28/35 + (\epsilon_{sh})_{28}} = \frac{(\epsilon_{sh})_{28}}{2.25}$$

of the calculated values are within 20% of the one year observed values. Similar figures for two year data are 27% of the calculated values are within 10%, and 82% of the calculated values are within 20% of observed values. In both cases all calculated values are within 30% of observed values. Since the shrinkage data was more limited than the creep data, an error coefficient calculation was not made. It is worth noting that in a recent paper Meyers et al[9] suggest that for reasonable accuracy "it is desirable to conduct shrinkage tests for as long as possible, and 56 days is considered the minimum acceptable testing period." It is felt that the accuracy of the 28 day method discussed herein is acceptable.

6.3 General Remarks on 28 Day Prediction Methods

Methods to predict the long time creep and shrinkage characteristics, using 28 day data have been developed and verified. It has been shown that the expected accuracies are $\pm$ 15% for creep prediction and $\pm$ 30% for shrinkage prediction.

From these results it can be concluded:

1. The general form of Eq. (1) is representative of the creep-time function.

2. The general form of Eq. (2) is representative of the shrinkage function.

CHAPTER 7

RECOMMENDATIONS

In this section procedures will be recommended for

1. the prediction of creep and shrinkage properties of the four sand-lightweight aggregate concretes tested in the experimental program.

2. the prediction of creep and shrinkage properties for any type of concrete.

3. the prediction of creep and shrinkage properties of concrete using experimental data.

7.1 Creep and Shrinkage Properties of Four Sand-Lightweight Aggregate Concretes

For standard condition concrete mixes the following equations are recommended for predicting creep and shrinkage respectively:

Haydite-Hydraulic Press Brick Co.----------Eqs. 53 and 54

Haydite-Buildex, Inc.----------Eqs. 55 and 56

Haydite-Carter-Waters Corp.----------Eqs. 57 and 58

Idealite-Idealite Co.----------Eqs. 59 and 60

For conditions other than standard the values obtained from the above equations should be modified using the correction factors cited in Chapter II.

7.2 General Prediction

When specific equations such as those given in section 7.1, or experimental data are not available, it is recommended that Eqs. 9, 12,

and 15 be used to predict the creep of normal weight, sand-lightweight, and lightweight concrete respectively.

Similar equations for shrinkage prediction are Equations 30, 33, and 36 for moist cured concrete and Eqs. (42) (normal weight) and (45) (lightweight) for steam cured concrete.

The constants in the above equations have been averaged and Eqs. 6, 26, and 38 may be used to predict the creep, the shrinkage of moist cured concrete, and the shrinkage of steam cured concrete for any type of concrete.

All equations have been developed for standard conditions and should be modified for other conditions using the correction factors cited in Chapter II.

7.3 Prediction Using Experimental Data

When experimental data is available, the methods described in Chapter VI are recommended to predict the creep and shrinkage behavior of concrete. *It is further recommended that the following Eqs.* be used to evaluate creep and shrinkage-time functions:

$$C_t = \frac{t^{0.6}}{10 + t^{0.6}} C_u \quad \text{(moist \& steam cured)}$$

$$(\epsilon_{sh})_t = \frac{t}{35 + t} (\epsilon_{sh})_u \quad \text{(moist cured)}$$

$$(\epsilon_{sh})_t = \frac{t}{55 + t} (\epsilon_{sh})_u \quad \text{(steam cured)}$$

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LIST OF REFERENCES

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APPENDIX

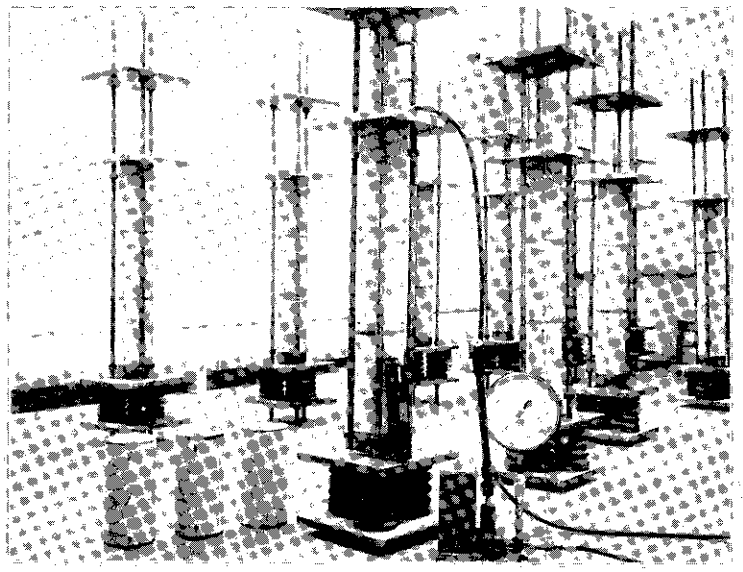

Fig. A1 - Creep racks loaded with test cylinders, shrinkage specimens on floor, hydraulic loading jack, and Whittemore strain gage

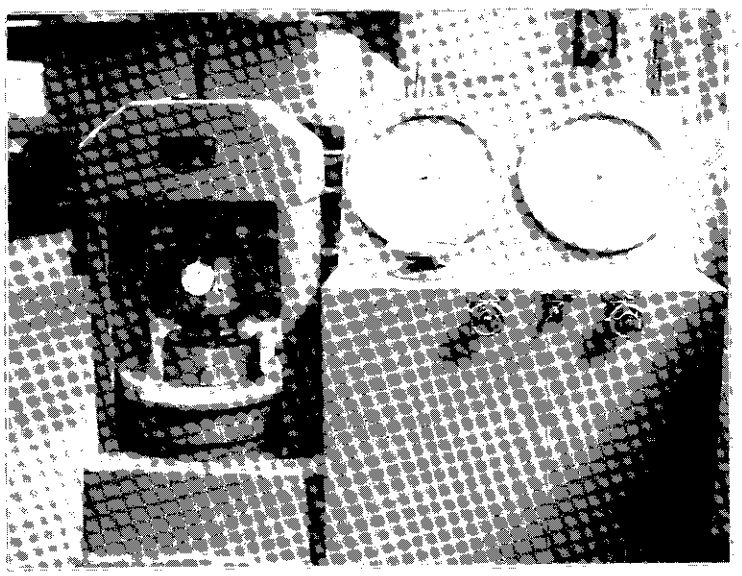

Fig. A2 - Riehle hydraulic testing machine, stress-strain collar apparatus on specimen

TABLE A1 - EXPERIMENTAL CREEP AND SHRINKAGE DATA

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
I-1	0	402			
7 day	1	497	95	0	.237
loading	2	566	142	22	.354
0.20 $f'c_7$	5	671	175	94	.435
	8	738	205	131	.510
	15	857	232	223	.577
	26	980	284	294	.707
	42	1110	316	392	.786
I-1	0	486			
7 day	1	613	127	0	.261
loading	2	675	167	22	.343
0.25 $f'c_7$	5	813	233	94	.479
	8	890	273	131	.560
	15	1030	321	223	.660
	26	1160	380	294	.780
	42	1300	422	392	.866
	63	1355	447	422	.920
	77	1401	479	436	.935
	90	1444	493	465	1.01
	111	1484	512	486	1.05
	138	1526	522	518	1.07
	188	1566	569	511	1.17
	209	1567	587	494	1.21
I-1	0	525			
7 day	1	675	150	0	.286
loading	2	720	173	22	.333
0.30 $f'c_7$	5	865	246	94	.469
	8	948	292	131	.566
	15	1080	332	223	.632
	26	1213	394	294	.751
	42	1350	433	392	.825
	63	1430	483	422	.920
	77	1511	550	436	1.05
	90	1555	565	465	1.08
	111	1600	589	486	1.12

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
I-1	138	1632	589	518	1.12
7 day	188	1664	628	511	1.20
loading	209	1679	660	494	1.26
0.30 $f'c_7$					
(cont.)					
I-1	0	554			
14 day	1	655	96	5	.174
loading	2	690	114	22	.206
0.25 $f'c_{14}$	8	852	205	93	.370
	19	1000	284	162	.512
	35	1152	375	223	.678
	56	1241	395	292	.705
	70	1276	415	307	.750
	83	1340	451	335	.815
	104	1417	507	356	.915
	131	1473	531	388	.960
	181	1512	577	381	1.04
	202	1502	584	364	1.06
I-3	0	506			
7 day	1	605	94	5	.186
loading	3	711	167	38	.330
0.30 $f'c_7$	7	839	216	117	.426
	21	1040	302	232	.596
	35	1201	371	324	.734
	64	1415	479	430	.948
	96	1511	532	473	1.05
	147	1617	611	500	1.21
	168	1606	610	490	1.21

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
I-S	0	477			
7 day	1	571	86	8	.180
loading	7	683	181	25	.264
0.25 $f'c_7$	18	810	245	88	.513
	32	903	293	133	.615
	46	955	311	167	.652
	60	1035	340	218	.713
	75	1110	378	255	.792
	107	1191	424	290	.890
	158	1258	478	303	1.00
	179	1276	492	307	1.03
I-S	0	619			
7 day	1	737	110	8	.178
loading	7	874	230	25	.372
0.35 $f'c_7$	18	1061	354	88	.572
	32	1160	408	133	.660
	46	1228	442	167	.713
	60	1320	483	218	.780
	75	1420	546	255	.882
	107	1501	592	290	.956
	158	1563	641	303	1.04
	179	1577	651	307	1.05
I-S	0	471			
14 day	1	551	57	23	.121
loading	7	641	130	40	.276
0.25 $f'c_{14}$	19	745	187	87	.396
	26	797	217	109	.461
	39	875	262	142	.555
	53	955	291	193	.617
	68	1005	307	227	.653
	100	1109	373	265	.793
	151	1178	429	278	.912
	172	1204	455	278	.967

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
H-1	0	414			
7 day	1	503	127	-38	.307
loading	2	550	167	-31	.404
0.25 $f'c_7$	3	596	203	-21	.490
	4	624	223	-13	.539
	5	648	245	-11	.593
	6	672	261	-3	.630
	7	696	276	6	.666
	11	786	328	44	.793
	14	824	347	63	.839
	21	898	384	100	.928
	28	973	415	144	1.004
	35	1026	428	184	1.033
	48	1097	452	231	1.092
	63	1170	486	270	1.172
	70	1194	484	296	1.170
	84	1238	503	321	1.215
	98	1281	519	348	1.252
	112	1328	554	360	1.338
	133	1382	560	408	1.351
	162	1412	587	411	1.418
	175	1443	603	426	1.456
	208	1463	618	431	1.492
	231	1496	631	451	1.522
	252	1456	654	388	1.579
	266	1462	654	394	1.579
	282	1483	661	408	1.594
H-1	0	513			
7 day	1	609	134	-38	.262
loading	2	659	177	-31	.345
0.30 $f'c_7$	3	701	209	-21	.407
	4	734	234	-13	.457
	5	756	254	-11	.495
	6	777	267	-3	.521
	7	796	277	6	.540
	11	882	325	44	.634

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
H-1	14	920	344	63	.671
7 day	21	990	377	100	.735
loading	28	1060	403	144	.785
0.30 $f'c_7$	35	1112	415	184	.809
(cont.)	48	1187	443	231	.864
	63	1271	488	270	.952
	70	1304	495	296	.965
	84	1350	516	321	1.006
	98	1391	530	348	1.033
	112	1440	567	360	1.102
	133	1484	563	408	1.097
	162	1518	598	411	1.166
	175	1546	607	426	1.182
	208	1578	634	431	1.235
	231	1603	639	451	1.246
	252	1564	663	388	1.291
	266	1569	662	394	1.290
	282	1593	672	408	1.310
H-1	0	596			
7 day	1	752	194	-38	.326
loading	2	809	244	-31	.410
0.35 $f'c_7$	3	851	296	-21	.497
	4	886	303	-13	.508
	5	911	326	-11	.547
	6	947	354	-3	.594
	7	956	354	6	.594
	11	1060	420	44	.705
	14	1102	443	63	.743
	21	1179	483	100	.810
	28	1256	516	144	.865
	35	1316	536	184	.899
	48	1403	576	231	.966
	63	1503	637	270	1.070
	70	1534	642	296	1.077
	84	1587	670	321	1.124
	98	1640	696	348	1.168

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
H-1	112	1693	737	360	1.237
7 day	133	1753	749	408	1.255
loading	162	1788	781	411	1.310
0.35 $f'c_7$	175	1820	798	426	1.339
(cont.)	208	1854	827	431	1.388
	231	1899	852	451	1.430
	252	1863	879	388	1.473
	266	1871	881	394	1.479
	282	1907	903	408	1.514
H-1	0	458			
14 day	1	579	117	4	.256
loading	2	622	140	24	.306
0.25 $f'c_{14}$	3	660	168	34	.367
	4	669	173	38	.378
	5	687	190	39	.415
	6	704	202	44	.442
	7	718	203	57	.444
	10	767	235	74	.513
	14	810	258	94	.564
	21	881	285	138	.622
	28	943	307	178	.670
	41	1024	341	225	.745
	56	1110	388	264	.846
	63	1141	393	290	.857
	77	1194	421	315	.918
	91	1241	441	342	.962
	105	1290	478	354	1.043
	126	1340	480	402	1.048
	155	1381	518	405	1.130
	168	1406	528	420	1.152
	201	1441	558	425	1.218
	224	1471	568	445	1.240
	245	1442	602	382	1.314
	259	1450	604	388	1.318
	275	1476	616	402	1.345

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
H-1	0	668			
14 day	1	823	151	4	.226
loading	2	873	181	24	.271
0.35 $f'c_{14}$	3	914	212	34	.318
	4	941	235	38	.352
	5	960	253	39	.379
	6	990	278	44	.416
	7	1011	286	57	.428
	10	1070	328	74	.491
	14	1134	372	94	.557
	21	1224	418	138	.626
	28	1350	504	178	.755
	41	1400	507	225	.759
	56	1515	583	264	.873
	63	1554	596	290	.892
	77	1606	623	315	.933
	91	1669	659	342	.986
	105	1725	703	354	1.051
	126	1793	723	402	1.081
	155	1834	761	405	1.140
	168	1869	781	420	1.170
	201	1900	807	425	1.208
	224	1943	830	445	1.241
	245	1916	866	382	1.297
	259	1933	877	388	1.313
	275	1959	889	402	1.330
B-4	0	314			
7 day	1	384	73	-3	.232
loading	2	431	115	2	.366
0.235 $f'c_7$	3	460	123	23	.392
	4	483	148	21	.472
	5	499	155	30	.494
	6	531	187	30	.596
	7	549	191	44	.609
	10	607	221	72	.704
	14	660	246	100	.784

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
B-4	21	740	269	157	.856
7 day	28	784	284	186	.905
loading	35	822	301	207	.959
0.235 $f'c_7$	47	909	348	247	1.108
(cont.)	68	990	383	293	1.220
	97	1046	421	311	1.340
	110	1077	426	337	1.357
	143	1109	442	353	1.406
	166	1136	463	359	1.475
	187	1103	472	317	1.502
	201	1114	476	324	1.518
	217	1137	476	347	1.518
B-4	0	372			
7 day	1	471	102	-3	.274
loading	2	521	147	2	.395
0.282 $f'c_7$	3	561	166	23	.446
	4	582	189	21	.508
	5	596	194	30	.521
	6	624	222	30	.597
	7	641	225	44	.605
	10	699	255	72	.686
	14	753	281	100	.755
	21	839	310	157	.834
	28	889	331	186	.890
	35	929	350	207	.941
	47	989	370	247	.995
	68	1079	414	293	1.112
	97	1139	456	311	1.225
	110	1170	461	337	1.239
	143	1208	483	353	1.299
	166	1239	508	359	1.365
	187	1210	521	317	1.400
	201	1216	520	324	1.398
	217	1244	525	347	1.410

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
B-4	0	490			
7 day	1	587	100	-3	.204
loading	2	661	169	2	.345
0.330 $f'c_7$	3	697	184	23	.376
	4	719	208	21	.425
	5	737	217	30	.443
	6	759	239	30	.488
	7	780	246	44	.502
	10	839	277	72	.565
	14	891	301	100	.615
	21	991	344	157	.702
	28	1046	370	186	.755
	35	1079	382	207	.780
	47	1170	433	247	.884
	68	1260	477	293	.974
	97	1319	518	311	1.058
	110	1356	529	337	1.080
	143	1402	559	353	1.140
	166	1440	591	359	1.198
	187	1412	605	317	1.234
	201	1429	615	324	1.275
	217	1449	612	347	1.269
B-4	0	365			
14 day	1	438	64	9	.175
loading	3	508	115	28	.315
0.25 $f'c_{14}$	4	526	132	29	.362
	5	533	125	43	.342
	6	553	134	54	.367
	7	565	144	56	.394
	10	618	168	85	.460
	14	670	192	113	.526
	21	721	214	142	.586
	28	773	245	163	.671
	40	865	297	203	.815
	61	953	339	249	.929
	90	1015	383	267	1.050

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
B-4	103	1051	393	293	1.077
14 day	136	1091	417	309	1.141
loading	159	1123	443	315	1.212
0.25 $f'c_{14}$	180	1095	457	273	1.250
(cont.)	194	1104	459	280	1.258
CW-4	0	279			
7 day	1	393	101	13	.362
loading	2	423	123	21	.441
0.25 $f'c_7$	3	458	152	27	.545
	5	520	185	56	.663
	6	548	205	64	.735
	7	567	204	84	.732
	10	630	229	122	.821
	14	690	241	170	.864
	21	773	273	221	.979
	28	867	322	266	1.155
	42	963	360	324	1.290
	63	1079	406	394	1.455
	92	1153	448	426	1.608
	105	1194	469	446	1.681
	138	1231	488	464	1.750
	161	1272	510	483	1.829
	182	1229	513	437	1.840
	196	1244	524	441	1.878
CW-4	0	367			
7 day	1	496	116	13	.316
loading	2	533	145	21	.395
0.30 $f'c_7$	3	568	174	27	.474
	5	640	217	56	.591
	6	662	231	64	.629
	7	688	237	84	.645
	10	754	265	122	.722
	14	818	281	170	.765
	21	904	316	221	.861
	28	980	347	266	.945

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
CW-4	42	1102	411	324	1.120
7 day	63	1224	463	394	1.260
loading	92	1303	510	426	1.390
0.30 $f'c_7$	105	1343	530	446	1.444
(cont.)	138	1394	563	464	1.532
	161	1434	584	483	1.590
	182	1399	595	437	1.620
	196	1416	608	441	1.657
CW-4	0	449			
7 day	1	596	134	13	.298
loading	2	640	170	21	.378
0.35 $f'c_7$	3	677	201	27	.447
	5	751	246	56	.548
	6	781	268	64	.597
	7	808	275	84	.613
	10	879	308	122	.686
	14	948	329	170	.733
	21	1042	372	221	.828
	28	1126	411	266	.915
	42	1258	485	324	1.080
	63	1390	547	394	1.218
	92	1480	605	426	1.348
	105	1522	627	446	1.398
	138	1578	665	464	1.480
	161	1617	685	483	1.524
	182	1588	702	437	1.561
	196	1606	716	441	1.592
CW-4	0	388			
14 day	1	483	80	15	.206
loading	2	516	106	22	.273
0.25 $f'c_{14}$	3	556	130	38	.336
	4	586	144	54	.372
	5	606	149	69	.384
	6	631	166	77	.428
	7	648	174	86	.449

TABLE A1 (cont.)

Test	Time after loading days	Total strain μ in/in	Creep strain μ in/in	Shrinkage strain μ in/in	Creep coefficient
CW-4	10	697	206	103	.531
14 day	14	751	226	137	.583
loading	21	863	293	182	.755
$0.25\ f'c_{14}$	35	980	352	240	.907
(cont.)	56	1119	421	310	1.085
	85	1207	477	342	1.230
	98	1258	508	362	1.309
	131	1318	550	380	1.418
	154	1363	576	399	1.483
	175	1337	596	353	1.535
	189	1351	606	357	1.560
CW-4	0	523			
14 day	1	664	126	15	.241
loading	2	711	166	22	.318
$0.35\ f'c_{14}$	3	750	189	38	.362
	4	791	214	54	.409
	5	818	226	69	.432
	6	843	243	77	.465
	7	861	252	86	.482
	10	922	296	103	.566
	14	989	329	137	.629
	21	1101	396	182	.757
	35	1262	499	240	.955
	56	1421	588	310	1.123
	85	1529	664	342	1.269
	98	1576	691	362	1.321
	131	1654	751	380	1.435
	154	1713	791	399	1.511
	175	1694	818	353	1.564
	189	1710	830	357	1.588

Table A2

MIX PROPORTIONS - LITERATURE DATA

(Reference) Specimen designation		Diam (in)	Length (in)	Unit weight (pcf)	Cement type	[1]Weight classification	[2]Type of cure	Humidity (%)	Age when loaded (days)	Slump (in)	Percent fines (by wt.)	Cement content (bags per cu. yd.)	Air content (%)
(23)	1A	6	12	105	III	LT	st	50	1	3.5	60	6.7	4.0
(23)	1B	6	12	107	III	LT	st	50	1	3.3	60	6.9	5.3
(23)	1C	6	12	109	III	LT	st	50	1	2.5	60	6.9	5.0
(23)	2A	6	12	103	III	LT	st	50	1	1.0	58	5.9	3.0
(23)	2B	6	12	99	III	LT	st	50	1	1.8	58	6.1	5.0
(23)	4A	6	12	101	III	LT	st	50	1	1.5	60	6.4	4.0
(23)	4B	6	12	101	III	LT	st	50	1	3.0	56	6.8	4.3
(23)	5A	6	12	103	III	LT	st	50	1	2.3	60	6.6	3.5
(23)	5B	6	12	104	III	LT	st	50	1	3.0	60	6.6	4.5
(23)	6A	6	12	100	III	LT	st	50	1	3.0	56	6.1	5.5
(23)	6B	6	12	101	III	LT	st	50	1	1.5	60	6.2	4.0
(23)	6C	6	12	101	III	LT	st	50	1	2.8	56	6.4	4.8
(23)	8A	6	12	106	III	LT	st	50	1	3.0	59	6.6	5.5
(23)	8B	6	12	103	III	LT	st	50	1	2.5	58	6.6	5.5
(23)	9A	6	12	113	III	LT	st	50	1	3.3	61	6.2	3.3
(23)	9B	6	12	113	III	LT	st	50	1	2.8	61	6.3	3.5
(23)	10A	6	12	103	III	LT	st	50	1	2.5	60	5.9	4.0
(23)	10B	6	12	107	III	LT	st	50	1	2.5	62	6.3	3.5
(23)	10C	6	12	102	III	LT	st	50	1	3.0	60	5.5	3.5
(23)	14A	6	12	96	III	LT	st	50	1	2.8	59	7.0	4.5
(23)	14B	6	12	97	III	LT	st	50	1	1.8	60	6.9	5.4
(23)	15A	6	12	99	III	LT	st	50	1	3.5	62	5.9	6.5
(23)	15B	6	12	101	III	LT	st	50	1	2.3	62	6.2	3.8

Table A2 (cont.)

(Reference) Specimen designation	Diam (in)	Length (in)	Unit weight (pcf)	Cement type	[1]Weight classification	[2]Type of cure	Humidity (%)	Age when loaded (days)	Slump (in)	Percent fines (by wt.)	Cement content (bags per cu. yd.)	Air content (%)
(23) 16A	6	12	97	III	LT	st	50	1	1.8	66	5.7	5.0
(23) 16B	6	12	97	III	LT	st	50	1	2.3	66	6.2	4.5
(23) 17A	6	12	108	III	LT	st	50	1	3.0	67	6.2	4.0
(23) 17B	6	12	107	III	LT	st	50	1	2.5	67	6.2	3.8
(23) 18A	6	12	94	III	LT	st	50	1	2.0	60	6.2	6.0
(23) 18B	6	12	91	III	LT	st	50	1	2.5	60	6.1	5.0
(23) 20A	6	12	102	III	LT	st	50	1	2.3	65	6.8	4.5
(23) 20B	6	12	101	III	LT	st	50	1	2.0	65	6.8	4.0
(23) 21A	6	12	93	III	LT	st	50	1	2.5	62	7.2	3.5
(23) 21B	6	12	93	III	LT	st	50	1	2.5	62	7.1	4.5
(23) 23A	6	12	107	III	LT	st	50	1	1.8	57	6.5	5.0
(23) 23B	6	12	107	III	LT	st	50	1	2.3	57	6.4	4.5
(23) 23C	6	12	104	III	LT	st	50	1	2.5	60	5.7	5.5
(23) 24A	6	12	108	III	LT	st	50	1	3.3	64	6.0	7.0
(23) 24B	6	12	109	III	LT	st	50	1	2.3	64	5.8	6.3
(23) 25A	6	12	105	III	LT	st	50	1	2.0	63	6.6	4.0
(23) 25B	6	12	103	III	LT	st	50	1	3.0	63	6.5	3.5
(23) 26A	6	12	98	III	LT	st	50	1	3.0	56	7.8	5.0
(23) 26B	6	12	99	III	LT	st	50	1	3.0	56	7.8	4.3
(23) 27A	6	12	97	III	LT	st	50	1	2.5	68	6.4	7.3
(23) 27B	6	12	98	III	LT	st	50	1	2.8	68	6.5	5.5
(23) 30A	6	12	100	III	LT	st	50	1	3.0	60	6.2	5.0
(23) 30B	6	12	99	III	LT	st	50	1	2.5	60	6.1	4.3
(23) EA	6	12	148	III	Nor	st	50	1	1.5	38	4.8	4.0
(23) EB	6	12	147	III	Nor	st	50	1	3.0	35	4.8	3.8
(23) ED	6	12	147	III	Nor	st	50	1	3.0	38	4.9	5.0
(23) GG	6	12	140	III	Nor	st	50	1	2.5	39	5.0	6.2

Table A2 (cont.)

(Reference) Specimen designation	Diam (in)	Length (in)	Unit weight (pcf)	Cement type	[1]Weight classification	[2]Type of cure	Humidity (%)	Age when loaded (days)	Slump (in)	Percent fines (by wt.)	Cement content (bags per cu. yd.)	Air content (%)
(23) GGA	6	12	144	III	Nor	st	50	1	3.0	37	5.2	5.5
(23) RG	6	12	149	III	Nor	st	50	1	1.8	37	4.8	4.0
(23) TR	6	12	151	III	Nor	st	50	1	2.5	40	5.3	4.4
(23) WM	6	12	143	III	Nor	st	50	1	1.5	38	5.1	5.0
(20) 4	4	18		III	Nor	mst	50	8	3-4		5.7	
(20) 6	6	22		III	Nor	mst	50	8	3-4		5.7	
(20) 8	8	26		III	Nor	mst	50	8	3-4		5.7	
(20) 12	12	34		III	Nor	mst	50	8	3-4		5.7	
(20) 16	16	42		III	Nor	mst	50	8	3-4		5.7	
(20) 20	20	50		III	Nor	mst	50	8	3-4		5.7	
(20) 24	24	58		III	Nor	mst	50	8	3-4		5.7	
(21) A	6	12		I	SL	mst	50	7				
(21) 71	6	12	107	I	LT	mst	50	7	2.8		8.8	6.2
(21) 72	6	12	112	I	SL	mst	50	7	3.0		8.5	5.9
(21) 73	6	12	117	I	SL	mst	50	7	2.3		7.9	5.6
(21) 74	6	12	120	I	SL	mst	50	7	2.3		7.3	5.9
(21) 73B	6	12	110	I	SL	mst	50	7	1.0		5.5	6.5
(21) 73C	6	12	113	I	SL	mst	50	7	2.0		4.8	6.4
(21) 73D	6	12	122	I	SL	mst	50	7	3.0		4.6	5.9
(22) 6N6	6	12	113	I	LT	mst	50	6	2.3		11.0	6.2
(22) 6N28	6	12	113	I	LT	mst	50	28	2.3		11.0	6.2
(22) 6S2	6	12	114	I	LT	st	50	2	2.3		11.2	5.8
(22) 6S7	6	12	114	I	LT	st	50	7	2.3		11.2	5.8
(22) 6S28	6	12	114	I	LT	st	50	28	2.3		11.2	5.8
(22) 10N6	6	12	94	I	LT	mst	50	6	2.3		7.7	6.5
(22) 10N28	6	12	94	I	LT	mst	50	28	2.3		7.7	6.5
(22) 10S2	6	12	93	I	LT	st	50	2	2.0		7.7	5.8

Table A2 (cont.)

(Reference) Specimen designation		Diam (in)	Length (in)	Unit weight (pcf)	Cement type	[1]Weight classification	[2]Type of cure	Humidity (%)	Age when loaded (days)	Slump (in)	Percent fines (by wt.)	Cement content (bags per cu. yd.)	Air content (%)
(22)	10S7	6	12	93	I	LT	st	50	7	2.0		7.7	5.8
(22)	10S28	6	12	93	I	LT	st	50	28	2.0		7.7	5.8
(22)	8N6	6	12	142	I	Nor	mst	50	6	3.3		7.7	5.6
(22)	8N28	6	12	142	I	Nor	mst	50	28	3.3		7.7	5.6
(22)	8S2	6	12	141	I	Nor	st	50	2	3.0		7.6	5.6
(22)	8S7	6	12	141	I	Nor	st	50	7	3.0		7.6	5.6
(22)	8S28	6	12	141	I	Nor	st	50	28	3.0		7.6	5.6
(22)	6M5	6	12	109	III	LT	mst	50	5	2.3		8.8	6.6
(22)	6M28	6	12	109	III	LT	mst	50	28	2.3		8.8	6.6
(22)	6R2	6	12	110	III	LT	st	50	2	2.5		8.8	6.1
(22)	6R7	6	12	110	III	LT	st	50	7	2.5		8.8	6.1
(22)	6R28	6	12	110	III	LT	st	50	28	2.5		8.8	6.1
(22)	10M5	6	12	90	III	LT	mst	50	5	2.0		6.1	6.8
(22)	10M28	6	12	90	III	LT	mst	50	28	2.0		6.1	6.8
(22)	10R2	6	12	89	III	LT	st	50	2	2.3		6.1	6.4
(22)	10R7	6	12	89	III	LT	st	50	7	2.3		6.1	6.4
(22)	10R28	6	12	89	III	LT	st	50	28	2.3		6.1	6.4
(22)	8M5	6	12	141	III	Nor	mst	50	5	3.5		6.1	5.4
(22)	8M28	6	12	141	III	Nor	mst	50	28	3.5		6.1	5.4
(22)	8R2	6	12	144	III	Nor	st	50	2	3.0		6.2	5.7
(22)	8R7	6	12	144	III	Nor	st	50	7	3.0		6.2	5.7
(22)	8R28	6	12	144	III	Nor	st	50	28	3.0		6.2	5.7
(3)	ST15	3x4	16	114	I	LT	mst	60	14	2.0	31	4.0	5.0
(3)	ST16	3x4	16	111	I	LT	mst	60	14	2.0	47	3.9	5.0
(3)	ST17	3x4	16	114	I	LT	mst	60	14	2.0	65	3.8	4.5
(3)	ST18	3x4	16	114	I	LT	mst	60	14	2.0	31	5.5	5.0
(3)	ST19	3x4	16	113	I	LT	mst	60	14	2.0	47	5.6	5.1

Table A2 (cont.)

(Reference) Specimen designation	Diam (in)	Length (in)	Unit weight (pcf)	Cement type	[1]Weight classification	[2]Type of cure	Humidity (%)	Age when loaded (days)	Slump (in)	Percent fines (by wt.)	Cement content (bags per cu. yd.)	Air content (%)
(3) ST20	3x4	16	113	I	LT	mst	60	14	2.0	64	5.7	5.2
(3) ST21	3x4	16	116	I	LT	mst	60	14	2.0	33	7.6	4.3
(3) ST22	3x4	16	112	I	LT	mst	60	14	2.0	49	7.4	5.9
(3) ST23	3x4	16	114	I	LT	mst	60	14	2.0	56	7.4	5.5
(3) ST25	3x4	16	111	III	LT	mst	60	3	2.0	51	6.1	5.2
(3) D15	3x4	16	98	I	LT	mst	60	14	0.5	54	5.4	7.0
(3) D16	3x4	16	99	I	LT	mst	60	14	2.3	52	5.7	6.6
(3) D17	3x4	16	96	I	LT	mst	60	14	5.0	51	5.7	7.5
(3) D18	3x4	16	99	I	LT	mst	60	14	0.5	54	5.7	7.2
(3) D19	3x4	16	97	I	LT	mst	60	14	2.0	55	5.6	7.2
(3) D20	3x4	16	97	I	LT	mst	60	14	5.0	54	5.3	7.2
(3) D21	3x4	16	97	I	LT	mst	60	14	0.5	54	5.5	7.9
(3) D22	3x4	16	99	I	LT	mst	60	14	2.0	56	5.8	7.5
(3) D23	3x4	16	99	I	LT	mst	60	14	5.0	55	5.6	6.6
(3) D24	3x4	16	97	III	LT	mst	60	3	2.0	56	5.7	7.0
(3) R15	3x4	16	119	I	LT	mst	70	14	2.0	50	5.6	1.7
(3) R16	3x4	16	112	I	LT	mst	70	14	2.0	50	5.6	6.5
(3) R17	3x4	16	109	I	LT	mst	70	14	2.0	52	5.3	13.5
(3) R18	3x4	16	114	III	LT	mst	70	3	2.0	50	6.0	7.1
(3) SG1	3x4	16	145	I	Nor	mst	60	14	4.0	32	6.0	4.5
(3) SG2	3x4	16	146	III	Nor	mst	60	3	3.0	33	6.4	7.1
(27) 62A	6	18	147	III	Nor	mst	20	8	2-3		8.0	
(27) 65A	6	18	147	III	Nor	mst	50	8	2-3		8.0	
(27) 67A	6	18	147	III	Nor	mst	75	8	2-3		8.0	
(27) 610A	6	18	147	III	Nor	mst	100	8	2-3		8.0	
(27) 62B	6	18	147	III	Nor	mst	20	8	2-3		8.0	
(27) 65B	6	18	147	III	Nor	mst	50	8	2-3		8.0	

Table A2 (cont.)

(Reference) Specimen designation	Diam (in)	Length (in)	Unit weight (pcf)	Cement type	[1]Weight classification	[2]Type of cure	Humidity (%)	Age when loaded (days)	Slump (in)	Percent fines (by wt.)	Cement content (bags per cu. yd.)	Air content (%)
(27) 67B	6	18	147	III	Nor	mst	75	8	2-3		8.0	
(27) 610B	6	18	147	III	Nor	mst	100	8	2-3		8.0	
(27) 62C	6	18	147	III	Nor	mst	20	8	2-3		8.0	
(27) 65C	6	18	147	III	Nor	mst	50	8	2-3		8.0	
(27) 67C	6	18	147	III	Nor	mst	75	8	2-3		8.0	
(27) 610C	6	18	147	III	Nor	mst	100	8	2-3		8.0	
(27) 62D	6	18	147	III	Nor	mst	20	8	2-3		8.0	
(27) 65D	6	18	147	III	Nor	mst	50	8	2-3		8.0	
(27) 67D	6	18	147	III	Nor	mst	75	8	2-3		8.0	
(27) 610D	6	18	147	III	Nor	mst	100	8	2-3		8.0	
(5) A	6	12	123	I	SL	mst	40	7	2.0		11.1	4.0
(5) B	6	12	124	I	SL	mst	40	7	2.5		11.1	6.0
(5) C	6	12	124	I	SL	mst	40	7	2.5		11.1	6.0
(4) A1	6	12	123	I	SL	mst	30	7	2.0		11.1	4.0
(4) A2	6	12	123	I	SL	mst	30	14	2.5		11.1	4.0
(4) D1	6	12	122	I	SL	st	30	7			11.1	
(4) D3	6	12	122	I	SL	st	30	14			11.1	
(28) 31a	6	12	88	I	LT	mst	50	7	2.8	40	5.5	6.9
(28) 32a	6	12	89	I	LT	mst	50	7	2.5	50	6.3	6.4
(28) 33a	6	12	90	I	LT	mst	50	7	2.8	45	5.1	6.0
(28) 34a	6	12	91	I	LT	mst	50	7	2.3	55	4.4	6.3
(28) 35a	6	12	93	I	LT	mst	50	7	2.5	55	5.8	7.7
(28) 36a	6	12	107	I	LT	mst	50	7	2.3	55	6.7	5.5
(28) 37a	6	12	107	I	LT	mst	50	7	2.5	55	6.4	5.7
(28) 38a	6	12		I	LT	mst	50	7	1.5	48	3.9	5.4
(28) 31b	6	12	88	I	LT	mst	50	28	2.8	40	5.5	6.9
(28) 32b	6	12	89	I	LT	mst	50	28	2.5	50	6.3	6.4

Table A2 (cont.)

(Reference) Specimen designation	Diam (in)	Length (in)	Unit weight (pcf)	Cement type	[1]Weight classification	[2]Type of cure	Humidity (%)	Age when loaded (days)	Slump (in)	Percent fines (by wt.)	Cement content (bags per cu. yd.)	Air content (%)
(28) 33b	6	12	90	I	LT	mst	50	28	2.8	45	5.1	6.0
(28) 34b	6	12	91	I	LT	mst	50	28	2.3	55	4.4	6.3
(28) 35b	6	12	93	I	LT	mst	50	28	2.5	55	5.8	7.7
(28) 36b	6	12	107	I	LT	mst	50	28	2.3	55	6.7	5.5
(28) 37b	6	12	107	I	LT	mst	50	28	2.5	55	6.4	5.7
(28) 38b	6	12		I	LT	mst	50	28	1.5	48	3.9	5.4
(28) 41a	6	12	94	I	LT	mst	50	7	2.8	35	8.2	3.2
(28) 42a	6	12	93	I	LT	mst	50	7	2.8	45	8.2	5.9
(28) 43a	6	12	97	I	LT	mst	50	7	2.8	40	7.3	6.0
(28) 44a	6	12	97	I	LT	mst	50	7	2.8	50	6.0	5.6
(28) 45a	6	12	101	I	LT	mst	50	7	2.5	50	7.8	6.8
(28) 46a	6	12	109	I	LT	mst	50	7	2.8	50	8.4	4.0
(28) 47a	6	12	110	I	LT	mst	50	7	2.8	50	8.2	5.9
(28) 48a	6	12		I	LT	mst	50	7	2.5	39	4.8	4.6
(28) 41b	6	12	94	I	LT	mst	50	28	2.8	35	8.2	3.2
(28) 42b	6	12	93	I	LT	mst	50	28	2.8	45	8.2	5.9
(28) 43b	6	12	97	I	LT	mst	50	28	2.8	40	7.3	6.0
(28) 44b	6	12	97	I	LT	mst	50	28	2.8	50	6.0	5.6
(28) 45b	6	12	101	I	LT	mst	50	28	2.5	50	7.8	6.8
(28) 46b	6	12	109	I	LT	mst	50	28	2.8	50	8.4	4.0
(28) 47b	6	12	110	I	LT	mst	50	28	2.8	50	8.2	5.9
(28) 48b	6	12		I	LT	mst	50	28	2.5	39	4.8	4.6

Table A2 (cont.)

(Reference) Specimen designation	Diam (in)	Length (in)	Unit weight (pcf)	Cement type	[1]Weight classification	[2]Type of cure	Humidity (%)	Age when loaded (days)	Slump (in)	Percent fines (by wt.)	Cement content (bags per cu. yd.)	Air content (%)
(28) 74	6	12	105	I	LT	mst	50	7	0.3	35	6.9	0
(28) 78	6	12	154	I	Nor	mst	50	7	0.3	25	5.9	0
(28) 94	6	12	110	I	LT	mst	50	7	0.3	35	10.3	0
(28) 98	6	12	153	I	Nor	mst	50	7	0.3	25	10.1	0
(29) A	6	12		I	Nor	mst			2-3		4-6	
(29) B	6	12		III	Nor	mst			2-3		4-6	

[1]"LT" indicates all-lightweight concrete, "Nor" indicates normal weight concrete, "SL" indicates sand-lightweight concrete

[2]"st" indicates steam cured, "mst" indicates moist cured

Table A3

CREEP & SHRINKAGE DATA FROM LITERATURE

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(23) 1A	40	1012	1030	1.02	1.04	350	354
	80		1300	1.28	1.30	450	455
	365		1850	1.83	1.86	700	710
	730		2080	2.06	2.11	730	740
(23) 1B	40	978	860	0.88	0.89	380	384
	80		1040	1.06	1.08	530	535
	365		1560	1.60	1.63	740	750
	730		1750	1.79	1.82	720	730
(23) 1C	40	868	1140	1.31	1.39	360	383
	80		1410	1.63	1.72	410	435
	365		1670	1.93	2.04	840	895
(23) 2A	40	1028	860	0.84	0.89	240	255
	80		1030	1.00	1.06	420	445
	365		1450	1.41	1.49	660	700
(23) 2B	40	1070	860	0.80	0.85	350	372
	80		1050	0.98	1.04	460	490
	365		1550	1.45	1.54	700	745
(23) 4A	40	995	700	0.70	0.74	350	372
	80		930	0.94	1.00	420	445
	365		1310	1.32	1.40	720	765
	730		1520	1.53	1.62	760	810
(23) 4B	40	1031	750	0.73	0.77	350	372
	80		890	0.86	0.91	410	435
	365		1600	1.55	1.64	790	840
	730		1810	1.76	1.86	800	850

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(23) 5A	40	1008	1120	1.11	1.17		
	80		1350	1.34	1.42		
	365		1730	1.72	1.82		
(23) 5B	40	985	1160	1.18	1.25		
	80		1390	1.41	1.49		
	365		1720	1.75	1.85		
(23) 6A	40	1147	1010	0.88	0.94	400	425
	80		1230	1.07	1.13	510	540
	365		1770	1.55	1.64	700	745
	730		2030	1.77	1.87	750	800
(23) 6B	40	928	640	0.69	0.73	400	425
	80		830	0.90	0.95	510	540
	365		1210	1.30	1.38	670	710
(23) 6C	40	1070	820	0.77	0.81	400	425
	80		1080	1.01	1.07	500	530
	365		1590	1.49	1.58	740	790
	730		1770	1.65	1.75	790	840
(23) 8A	40	943	820	0.87	0.92	480	510
	80		1020	1.08	1.14	600	640
	365		1430	1.52	1.61	760	810
	730		1630	1.73	1.83	800	850
(23) 8B	40	842	700	0.83	0.88	400	425
	80		860	1.02	1.08	520	555
	365		1190	1.41	1.49	680	725
	730		1350	1.60	1.69	760	810
(23) 9A	40	844	880	1.04	1.06	400	405
	80		1140	1.35	1.37	540	545

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(23) 9A	365		1680	1.99	2.02	800	810
	730		1910	2.26	2.30	830	840
(23) 9B	40	823	910	1.11	1.17	440	470
	80		1010	1.23	1.30	600	640
	365		1520	1.85	1.96	820	870
	730		1700	2.07	2.19	830	880
(23) 10A	40	1038	830	0.80	0.85	270	288
	80		1020	0.98	1.04	400	425
	365		1410	1.36	1.44	660	700
	730		1570	1.52	1.61	730	775
(23) 10B	40	903	880	0.98	1.04	330	350
	80		950	1.05	1.11	520	555
	365		1390	1.54	1.63	770	820
	730		1590	1.71	1.81	780	830
(23) 10C	40	1144	1010	0.88	0.93	290	310
	80		1240	1.08	1.14	420	445
	365		1860	1.63	1.73	670	710
	730		2080	1.82	1.93	730	775
(23) 14A	40	1019	790	0.78	0.83	210	225
	80		1030	1.01	1.07	290	310
	365		1330	1.31	1.39	810	860
	730		1610	1.58	1.67	890	945
(23) 14B	40	928	630	0.68	0.72	170	180
	80		830	.90	0.95	220	235
	365		1170	1.26	1.33	650	690
	730		1350	1.46	1.55	820	870

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(23) 15A	40	1134	1110	0.98	1.00	410	415
	80		1210	1.07	1.09	590	600
	365		1720	1.52	1.55	700	710
	730		1850	1.63	1.66	750	760
(23) 15B	40	965	710	0.74	0.79	400	425
	80		860	0.89	0.94	550	585
	365		1290	1.34	1.42	740	790
	730		1480	1.53	1.62	720	765
(23) 16A	40	1075	580	0.54	0.57	220	235
	80		650	0.61	0.65	400	425
	365		1010	0.94	1.00	560	595
	730		1170	1.09	1.15	580	615
(23) 16B	40	1050	510	0.49	0.52	300	320
	80		630	0.60	0.64	400	425
	365		1070	1.02	1.08	610	650
	730		1220	1.16	1.23	620	660
(23) 17A	40	904	750	0.83	0.88	360	385
	80		860	0.95	1.01	440	470
	365		1340	1.48	1.57	660	700
	730		1520	1.68	1.78	710	755
(23) 17B	40	863	560	0.65	0.69	360	385
	80		780	0.91	0.96	420	445
	365		1110	1.29	1.37	700	745
	730		1250	1.45	1.54	730	775
(23) 18A	40	1078	530	0.49	0.52	310	330
	80		700	0.65	0.69	410	435
	365		1060	0.99	1.05	580	615
	730		1230	1.14	1.21	610	650

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(23) 18B	40	1164	630	0.54	0.57	280	300
	80		720	0.62	0.66	400	425
	365		1100	0.95	1.01	600	640
	730		1270	1.09	1.16	580	620
(23) 20A	40	986	810	0.82	0.87	380	405
	80		930	0.94	1.00	510	540
	365		1420	1.44	1.53	840	895
	730		1650	1.67	1.77	890	945
(23) 20B	40	953	770	0.81	0.86	390	415
	80		990	1.04	1.10	510	540
	365		1290	1.35	1.43	840	895
	730		1510	1.59	1.69	830	885
(23) 21A	40	1199	1070	0.89	0.94		
	80		1380	1.15	1.22		
	365		1790	1.50	1.59		
(23) 21B	40	1231	1240	1.01	1.07		
	80		1320	1.07	1.13		
	365		1790	1.45	1.54		
(23) 23A	40	824	460	0.56	0.59	340	360
	80		600	0.73	0.77	420	445
	365		930	1.13	1.20	570	605
	730		1050	1.27	1.35	610	650
(23) 23B	40	869	490	0.57	0.60	320	340
	80		640	0.74	0.78	420	445
	365		1070	1.23	1.30	590	630
	730		1200	1.38	1.46	610	650

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(23) 23C	40	918	650	0.71	0.75	340	360
	80		800	0.87	0.92	400	425
	365		1140	1.24	1.31	600	640
(23) 24A	40	841	480	0.57	0.58	330	350
	80		650	0.77	0.79	420	445
	365		990	1.18	1.20	560	595
	730		1110	1.32	1.35	620	660
(23) 24B	40	777	520	0.67	0.71	260	275
	80		670	0.86	0.91	400	425
	365		980	1.26	1.34	500	530
	730		1070	1.38	1.46	570	605
(23) 25A	40	900	710	0.79	0.84	280	300
	80		840	0.93	0.98	420	445
	365		1290	1.43	1.52	580	620
	730		1420	1.58	1.67	640	680
(23) 25B	40	940	710	0.76	0.80	350	370
	80		880	0.94	1.01	460	490
	365		1310	1.39	1.47	650	690
	730		1470	1.56	1.65	660	700
(23) 26A	40	1049	1000	0.96	1.02	470	500
	80		1290	1.23	1.30	620	660
	365		1970	1.88	1.98	860	915
	730		2220	2.12	2.24	860	915
(23) 26B	40	1023	1130	1.10	1.17	470	500
	80		1330	1.30	1.38	670	715
	365		1940	1.90	2.01	870	925
	730		2190	2.14	2.26	860	915

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(23) 27A	40	1135	750	0.66	0.70	270	290
	80		900	0.79	0.84	420	445
	365		1280	1.13	1.20	640	680
	730		1490	1.31	1.40	680	725
(23) 27B	40	1063	640	0.60	0.64	340	360
	80		770	0.72	0.76	450	480
	365		1090	1.02	1.08	650	690
	730		1200	1.13	1.20	690	735
(23) 30A	40	1055	740	0.70	0.74	260	275
	80		900	0.85	0.90	400	425
	365		1570	1.49	1.58	650	690
	730		1800	1.71	1.81	690	735
(23) 30B	40	1099	800	0.73	0.77	300	320
	80		1000	0.91	0.96	440	470
	365		1480	1.35	1.43	680	725
	730		1650	1.50	1.59	720	765
(23) EA	40	549	540	0.98	1.04	230	245
	80		570	1.04	1.10	400	425
	365		840	1.53	1.62	490	520
	730		900	1.64	1.74	530	565
(23) EB	40	570	680	1.19	1.26	310	330
	80		800	1.40	1.48	400	425
	365		1150	2.02	2.14	530	565
	730		1250	2.20	2.33	550	585
(23) ED	40	592	580	0.98	1.04	310	330
	80		700	1.18	1.25	410	425
	365		1010	1.71	1.81	490	520
	730		1100	1.86	1.97	540	575

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(23) GG	40	578	690	1.20	1.27	260	275
	80		840	1.45	1.54	380	405
	365		1240	2.15	2.29	490	520
	730		1340	2.32	2.46	530	565
(23) GGA	40	576	560	0.97	1.03	330	350
	80		740	1.29	1.57	400	425
	365		1120	1.95	2.06	530	565
	730		1210	2.10	2.22	610	650
(23) RG	40	596	830	1.39	1.47	380	405
	80		1040	1.75	1.85	580	615
	365		1490	2.50	2.64	760	810
	730		1610	2.70	2.86	860	915
(23) TR	40	498	550	1.10	1.16	210	225
	80		910	1.80	1.94	290	310
	365		1110	2.23	2.36	370	395
	730		1210	2.44	2.58	400	425
(23) WM	40	533	400	0.75	0.79	220	235
	80		480	0.90	0.95	320	340
	365		830	1.56	1.55	350	370
	730		900	1.69	1.79	380	405
(20) 4	25	241	215	0.91	0.93	525	
	50		285	1.18	1.21	650	
	100		355	1.47	1.51	760	
	300		425	1.76	1.81	840	
	1100		450	1.86	1.91	920	

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(20) 6	25	340	375	1.10	1.13	380	405
	50		475	1.40	1.44	510	543
	100		580	1.71	1.75	650	690
	300		675	1.98	2.04	830	883
	1300		770	2.27	2.33	905	965
(20) 8	25	340	300	0.88	0.90	300	
	50		415	1.22	1.25	425	
	100		510	1.50	1.54	542	
	300		665	1.96	2.01	715	
	1300		770	2.26	2.32	790	
(20) 12	25	310	245	0.79	0.81	230	
	50		295	0.95	0.98	330	
	100		405	1.31	1.35	440	
	300		495	1.60	1.64	620	
	1300		590	1.91	1.96	720	
(20) 16	25	296	235	0.79	0.81	135	
	50		285	0.97	1.00	200	
	100		360	1.21	1.24	290	
	300		440	1.48	1.52	455	
	1300		550	1.86	1.91	600	
(20) 20	25	336	205	0.61	0.63	125	
	50		270	0.80	0.82	175	
	100		340	1.02	1.05	255	
	300		420	1.25	1.28	425	
	1300		545	1.62	1.66	550	

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(20) 24	25	330	230	0.70	0.72	60	
	50		295	0.89	0.91	90	
	100		345	1.05	1.08	160	
	300		430	1.30	1.34	290	
	1300		560	1.70	1.75	445	
(21) 71	25	695	870	1.25	1.35	315	350
	100		1230	1.77	1.91	615	682
	300		1550	2.23	2.41	790	875
	730		1760	2.53	2.73	860	955
(21) 72	25	665	760	1.14	1.23	315	350
	100		1140	1.72	1.85	580	643
	300		1420	2.14	2.31	750	830
	730		1610	2.42	2.61	825	915
(21) 73	25	635	690	1.09	1.18	315	350
	100		1030	1.62	1.75	570	632
	300		1240	1.96	2.12	725	805
	730		1360	2.14	2.31	780	865
(21) 74	25	518	600	1.16	1.25	315	350
	100		925	1.79	1.93	560	620
	300		1165	2.25	2.43	705	780
	730		1260	2.43	2.62	755	840
(22) 6N6	28	667	1200	1.80	1.90	320	345
	100		1790	2.68	2.84	540	580
	365		2170	3.26	3.45	740	790
	730		2340	3.51	3.72	820	880

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(22) 6N28	28	702	820	1.17	1.52		
	100		1080	1.77	2.30		
	365		1450	2.32	3.01		
	730		1660	2.56	3.32		
(22) 6S2	28	702	720	1.03	1.10	280	310
	100		1080	1.54	1.65	450	495
	365		1450	2.06	2.21	615	675
	730		1660	2.36	2.53	680	750
(22) 6S7	28	654	600	0.92	1.04		
	100		920	1.41	1.60		
	365		1270	1.94	2.20		
	730		1450	2.22	2.52		
(22) 6S28	28	659	480	0.73	0.95		
	100		810	1.23	1.59		
	365		1120	1.70	2.20		
	730		1280	1.94	2.51		
(22) 10N6	28	876	860	0.98	1.04	320	345
	100		1200	1.37	1.45	500	535
	365		1480	1.69	1.79	615	660
	730		1600	1.83	1.94	640	685
(22) 10N28	28	926	540	0.58	0.75		
	100		860	0.93	1.20		
	365		1140	1.23	1.59		
	730		1240	1.34	1.74		
(22) 10S2	28	885	540	0.61	0.65	230	250
	100		820	0.93	0.99	410	450
	365		1080	1.22	1.30	540	595
	730		1200	1.36	1.45	600	660

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(22) 10S7	28	862	540	0.63	0.72		
	100		780	0.90	1.02		
	365		1020	1.18	1.34		
	730		1140	1.32	1.50		
(22) 10S28	28	855	440	0.51	0.66		
	100		700	0.82	1.06		
	365		940	1.10	1.43		
	730		1070	1.25	1.62		
(22) 8N6	28	586	1000	1.71	1.73	480	490
	100		1440	2.46	2.50	630	640
	365		1740	2.97	3.02	715	730
	730		1840	3.14	3.19	730	745
(22) 8N28	28	515	760	1.51	1.88		
	100		1120	2.22	2.76		
	365		1380	2.74	3.40		
	730		1500	2.97	3.70		
(22) 8S2	28	591				220	240
	100		1040	1.71	1.83	400	440
	365		1320	2.23	2.38	490	540
	730		1460	2.47	2.64	515	565
(22) 8S7	28	565	700	1.24	1.41		
	100		960	1.70	1.93		
	365		1220	2.16	2.45		
	730		1370	2.42	2.74		
(22) 8S28	28	539	560	1.04	1.35		
	100		840	1.56	2.02		
	365		1080	2.00	2.59		
	730		1230	2.28	2.95		

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(22) 6M5	28	715	1050	1.47	1.51	450	470
	100		1620	2.27	2.33	600	625
	365		1940	2.71	2.78	735	765
	730		2100	2.94	3.01	795	830
(22) 6M28	28	775	660	0.85	1.10		
	100		1180	1.52	1.97		
	365		1480	1.91	2.48		
	730		1600	2.06	2.67		
(22) 6R2	28	715	600	0.84	0.90	285	315
	100		940	1.31	1.40	410	450
	365		1200	1.68	1.80	540	595
	730		1340	1.87	2.00	590	650
(22) 6R7	28	705	460	0.65	0.74		
	100		800	1.13	1.28		
	365		1060	1.50	1.70		
	730		1200	1.70	1.93		
(22) 6R28	28	733	340	0.46	0.60		
	100		630	0.86	1.11		
	365		870	1.19	1.54		
	730		1000	1.37	1.78		
(22) 10M5	28	949	860	0.91	0.93	370	385
	100		1400	1.48	1.52	540	560
	365		1700	1.79	1.84	665	695
	730		1820	1.92	1.97	680	710
(22) 10M28	28	953	680	0.71	0.92		
	100		1100	1.15	1.49		
	365		1420	1.49	1.93		
	730		1560	1.64	2.12		

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(22) 10R2	28	918	580	0.63	0.68	255	280
	100		880	0.96	1.03	370	405
	365		1150	1.25	1.34	490	540
	730		1280	1.39	1.49	520	570
(22) 10R7	28	897	520	0.58	0.66		
	100		780	0.87	0.99		
	365		1050	1.17	1.33		
	730		1160	1.29	1.46		
(22) 10R28	28	893	440	0.49	0.63		
	100		710	0.80	1.04		
	365		960	1.08	1.40		
	730		1070	1.20	1.56		
(22) 8M5	28	595	920	1.55	1.57	375	370
	100		1480	2.49	2.53	540	535
	365		1740	2.92	2.96	665	660
	730		1870	3.14	3.19	680	675
(22) 8M28	28	540	750	1.39	1.73		
	100		1040	1.93	2.40		
	365		1300	2.41	3.00		
	730		1400	2.60	3.23		
(22) 8R2	28	548	560	1.02	1.09	200	220
	100		840	1.53	1.64	335	370
	365		1080	1.97	2.10	430	470
	730		1200	2.19	2.34	450	495
(22) 8R7	28	516	515	1.00	1.13		
	100		800	1.55	1.76		
	365		1050	2.04	2.32		
	730		1160	2.25	2.55		

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(22) 8R28	28	491	410	0.83	1.08		
	100		630	1.28	1.66		
	365		890	1.81	2.34		
	730		1000	2.04	2.64		
(3) ST15	30	546	270	0.50	0.66	95	100
	110		470	0.86	1.12	280	290
	200		620	1.14	1.49	380	395
	380		780	1.43	1.87	465	480
	690		950	1.74	2.28	550	570
(3) ST16	30	493	260	0.53	0.69	145	150
	110		440	0.89	1.16	405	420
	200		580	1.18	1.55	555	575
	380		730	1.48	1.94	680	705
	690		880	1.79	2.34	725	750
(3) ST17	30	565	380	0.67	0.88	290	300
	110		580	1.03	1.35	495	515
	200		730	1.29	1.69	620	645
	380		900	1.59	2.08	750	780
	690		1040	1.84	2.41	785	815
(3) ST18	30	526	280	0.53	0.70	130	135
	110		400	0.76	1.00	295	305
	200		500	0.95	1.24	395	410
	380		630	1.20	1.57	515	535
	690		720	1.37	1.80	585	605
(3) ST19	30	500	180	0.36	0.47	370	385
	110		310	0.62	0.81	610	630
	200		430	0.86	1.12	700	725

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(3) ST19	380		580	1.16	1.57	780	810
	690		690	1.38	1.81	800	830
(3) ST20	30	484	270	0.56	0.74	265	275
	110		530	1.10	1.44	480	500
	200		690	1.43	1.87	595	615
	380		880	1.82	2.38	720	745
	690		1020	2.11	2.76	770	800
(3) ST21	30	452	200	0.44	0.58	180	185
	110		330	0.73	0.96	370	385
	200		470	1.04	1.36	485	505
	380		630	1.39	1.82	605	625
	690		760	1.68	2.20	660	685
(3) ST22	30	459	370	0.81	1.06	95	100
	110		620	1.35	1.77	510	530
	200		790	1.72	2.25	715	740
	380		900	1.96	2.56	825	855
	690		930	2.03	2.66	840	870
(3) ST23	30	445	430	0.97	1.27	330	340
	110		620	1.39	1.82	660	685
	200		770	1.73	2.26	780	810
	380		840	1.89	2.47	850	880
	690		870	1.95	2.56	860	890
(3) D15	30	445	380	0.85	1.11	375	390
	110		580	1.30	1.70	705	730
	200		700	1.57	2.06	785	815
	380		770	1.73	2.26	800	830
	690		780	1.75	2.29	800	830

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(3) D16	30	483	340	0.70	0.92	400	415
	110		610	1.26	1.65	650	675
	200		800	1.66	2.17	695	720
	380		880	1.82	2.38	695	720
	690		920	1.91	2.50	700	725
(3) D17	30	581	220	0.38	0.40	495	460
	110		400	0.69	0.72	730	680
	200		490	0.85	0.89	800	745
	380		580	1.00	1.05	815	760
	690		640	1.10	1.16	810	755
(3) D18	30	475	425	0.89	1.16	220	230
	110		620	1.30	1.70	350	365
	200		680	1.43	1.87	380	395
	380		720	1.52	1.99	395	410
	690		760	1.60	2.10	400	415
(3) D19	30	509	285	0.56	0.73	465	480
	110		380	0.75	0.98	685	710
	200		430	0.85	1.11	745	770
	380		460	0.91	1.19	785	815
	690		510	1.00	1.31	785	815
(3) D20	30	562	560	1.00	1.05	325	305
	110		800	1.42	1.49	405	380
	200		910	1.62	1.70	455	425
	380		1020	1.82	1.91	500	465
	690		1150	2.04	2.14	550	515
(3) D21	30	509	220	0.43	0.56	275	285
	110		350	0.69	0.90	390	405

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(3) D21	200		470	0.93	1.22	470	485
	380		605	1.19	1.56	560	580
	690		750	1.48	1.94	650	675
(3) D22	30	496	320	0.46	0.60	230	240
	110		465	0.94	1.23	390	405
	200		570	1.15	1.51	485	505
	380		680	1.37	1.79	600	620
	690		805	1.62	2.12	705	730
(3) D23	30	538	395	0.73	0.77	80	75
	110		680	1.26	1.32	400	375
	200		850	1.58	1.66	570	530
	380		1045	1.94	2.03	700	655
	690		1255	2.34	2.46	750	700
(3) R15	30	359	350	0.97	1.39	180	215
	110		645	1.80	2.57	470	560
	200		830	2.31	3.30	590	700
	330		900	2.51	3.59	645	765
(3) R16	30	489	340	0.70	1.00	265	315
	110		565	1.15	1.64	560	655
	200		680	1.39	1.99	700	830
	330		705	1.44	2.06	750	890
(3) R17	30	557	510	0.91	1.30	220	260
	110		1000	1.79	2.56	530	630
	200		1220	2.19	3.13	650	770
	330		1300	2.34	3.34	710	840

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(3) SG1	30	281	420	1.49	1.66	220	205
	110		610	2.17	2.41	320	300
	200		770	2.74	3.05	350	325
	330		825	2.94	3.27	385	360
	690		830	2.95	3.28	400	375
(4) A1	8	486	273	0.56		131	
	77		479	0.99		436	
	90		494	1.02		465	
(4) A2	8	554	205	0.37		93	
	70		415	0.75		307	
	93		451	0.82		335	
(4) D1	7	477	181	0.38		25	
	60		340	0.71		218	
	75		368	0.77		255	
(4) D2	7	471	130	0.28		40	
	53		291	0.62		193	
	68		307	0.65		227	
(5) A	16			0.60	0.60		
	28					300	300
	42			0.83	0.83		
	90			1.07	1.07	480	480
	180			1.16	1.16	530	530
(5) B	15			0.72	0.72		
	28					360	360
	44			1.05	1.05		
	85			1.27	1.27	525	525
	170			1.48	1.48	560	560

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(5) C	20			0.62	0.62		
	35					340	340
	63			0.98	0.98		
	95			1.04	1.04	470	470
	170			1.21	1.21	505	505
(28) 31a	ult	413	1175	2.84		885	
(28) 32a	ult	455	950	2.09		1006	
(28) 33a	ult	361	770	2.13		885	
(28) 34a	ult	495	900	1.82		923	
(28) 35a	ult	357	870	2.44		866	
(28) 36a	ult	306	960	3.14		880	
(28) 37a	ult	331	1218	3.68		745	
(28) 38a	ult	227	770	3.39		713	
(28) 31b	ult	375	960	2.56			
(28) 32b	ult	405	840	2.07			
(28) 33b	ult	328	710	2.16			
(28) 34b	ult	386	775	2.01			
(28) 35b	ult	366	780	2.13			
(28) 36b	ult	275	905	3.29			
(28) 37b	ult	276	970	3.51			
(28) 38b	ult	170	595	3.50			
(28) 41a	ult	319	965	3.02		983	
(28) 42a	ult	364	810	2.22		987	
(28) 43a	ult	303	612	2.02		795	
(28) 44a	ult	414	720	1.74		1066	
(28) 45a	ult	308	625	2.03		965	
(28) 46a	ult	256	858	3.35		940	
(28) 47a	ult	275	768	2.79		792	

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(28) 48a	ult	196	545	2.78		730	
(28) 41b	ult	306	792	2.59			
(28) 42b	ult	348	672	1.93			
(28) 43b	ult	286	545	1.90			
(28) 44b	ult	335	648	1.93			
(28) 45b	ult	294	570	1.94			
(28) 46b	ult	237	696	2.94			
(28) 47b	ult	245	660	2.69			
(28) 48b	ult	155	454	2.92			
(28) 74	ult	1050	1090	1.04		769	
(28) 78	ult	568	965	1.70		534	
(28) 94	ult	882	1040	1.18		755	
(28) 98	ult	475	834	1.75		620	
(27) 62A	1					110	
	7					250	
	897		1820			1015	
(27) 65A	1					90	
	7					220	
	897		1725			965	
(27) 67A	1					75	
	7					185	
	897		1375			655	
(27) 610A	897		1080				
(27) 62B	1					65	
	7					230	
	897		1040			970	
(27) 65B	1					50	
	7					200	

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(27) 65B	897		960			875	
(27) 67B	1					30	
	7					165	
	897		770			565	
(27) 610B	897		645				
(27) 62C	1					90	
	7					220	
	897		1415			955	
(27) 65C	1					70	
	7					200	
	897		1325			875	
(27) 67C	897		1055				
(27) 610C	897		865				
(27) 62D	1					75	
	7					205	
	897		2270			970	
(27) 65D	1					65	
	7					200	
	897		2205			865	
(27) 67D	897		1740				
(27) 610D	897		1295				
(27) 62A	1					90	
	7					225	
	730					975	
(27) 65A	1					75	
	7					225	
	730					890	

Table A3 (cont.)

(Reference) Specimen designation	Time (days)	Initial strain ($x10^{-6}$ in/in)	Raw Creep strain ($x10^{-6}$ in/in)	Raw Creep coeffi-cient	Standardized creep coefficient	Raw Shrinkage strain ($x10^{-6}$ in/in)	Standardized shrinkage strain ($x10^{-6}$ in/in)
(27) 62B	1					50	
	7					185	
	730					990	
(27) 65B	1					75	
	7					205	
	730					880	
(27) 65C	1					70	
	7					205	
	730					885	
(27) 65D	1					69	
	7					190	
	730					875	