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16. Abstract

The effects of creep and shrinkage strains in concrete are dependent on variables such as materials, stress level, and environment. In this investigation, creep and shrinkage strains as functions of time were determined for four different concretes from four different geographical areas of Texas (Dallas, San Antonio, Odessa, Lufkin). These four locations were chosen to represent four major areas of Texas for climate and aggregate for producing concrete. The concretes were made of materials commonly used in the respective areas. They were made, cured, and stored in those areas.

Standard 6 x 12 in. cylinders were used to determine strength and the stress-strain relationship, and prisms, 3 x 3 x 16 in., were used to determine creep and shrinkage strains. Duplicate sets of specimens were made at each place of fabrication. Each set contained 4 non-loaded prisms for shrinkage strains, 4 loaded prisms for compressive creep strains, and 18 cylinders. One set of specimens were stored in a protected area near the place of fabrication and the other set was stored at laboratory conditions, 73°F and 50 percent relative humidity.

The specimens were cured alongside pretensioned prestressed bridge beams cast at the same time as the test specimens. The curing time in the molds ranged from approximately 20 hours to 42 hours.

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CREEP AND SHRINKAGE OF CONCRETE BASED ON MAJOR VARIABLES ENCOUNTERED IN THE STATE OF TEXAS

by

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Research Report 170-1F

Creep and Shrinkage of Concrete Based on Major Variables Encountered in the State of Texas

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Much of the information developed in this research project was used by the primary author in his thesis for the Master of Science Degree in Civil Engineering at Texas A&M University. The thesis, "Creep and Shrinkage of Concrete Typical of Four Geographical Areas of Texas," by Leonard Lee Ingram, August 1973 is on file in the library of that University. That author extends his sincere thanks to the Texas Highway Department, Federal Highway Administration, and Texas Transportation Institute for permission to publish the material in his thesis.

ABSTRACT

The effects of creep and shrinkage strains in concrete are dependent on variables such as materials, stress level, and environment. In this investigation, creep and shrinkage strains as functions of time were determined for four different concretes from four different geographical areas of Texas (Dallas, San Antonio, Odessa, Lufkin). These four locations were chosen to represent four major areas of Texas for climate and aggregate for producing concrete. The concretes were made of materials commonly used in the respective areas. They were made, cured, and stored in those areas.

Standard 6 x 12 in. cylinders were used to determine strength and the stress-strain relationship, and prisms, 3 x 3 x 16 in., were used to determine creep and shrinkage strains. Duplicate sets of specimens were made at each place of fabrication. Each set contained 4 non-loaded prisms for shrinkage strains, 4 loaded prisms for compressive creep strains, and 18 cylinders. One set of specimens was stored in a protected area near the place of fabrication and the other set was stored at laboratory conditions, 73°F and 50 percent relative humidity.

The specimens were cured alongside pretensioned prestressed bridge beams cast at the same time as the test specimens. The curing time in the molds ranged from approximately 20 hours to 42 hours.

Hyperbolic functions of unit creep with time were developed for the concrete tested from each of the four geographical area. Those functions are suitable for design purposes for computing prestress loss and camber in pretensioned prestressed concrete beams.

Key Words: concrete, shrinkage, creep, compressive stress, modulus of elasticity, concrete strength.

SUMMARY

Shrinkage and creep of prestressed concrete are major factors in camber and loss of prestress in prestressed bridge beams. The concrete, conditions of curing, and climatic conditions to which the member is exposed in service influence creep and shrinkage. The State of Texas has areas that differ in climate, and aggregates for concrete differ through the state.

In this research studies were made of concretes in four different geographical areas of the state to determine the creep and shrinkage of a highway bridge concrete assumed to be typical of the area in which it was made. Tests were made on concretes sheltered, but otherwise exposed, in the four areas, and on companion specimens stored under constant temperature and relative humidity.

Specimens were 3 in. square in section by 16 in. long. The concretes were made and stored at, or near, Dallas, Odessa, San Antonio, and Lufkin, Texas. Strain data were collected from non-loaded specimens and from specimens under sustained stresses of 1000 psi and 2000 psi over a period of almost two years.

It was found that shrinkage of laboratory stored specimens was greater than that of field stores specimens. Field shrinkages at 500 day age were 300, 510, 360, and 280 microinches per inch respectively for Dallas, Odessa, San Antonio, and Lufkin concretes stored in the field. Corresponding values for laboratory storage were 480, 620, 480, and 430. Creep from field stored specimens was generally a little greater than that of laboratory stored specimens.

Unit creep curves and unit creep functions were produced for the four materials. The hyperbolic functions of unit creep and of shrinkage with respect to time are particularly useful to a designer in computing prestress loss and camber at any time in the life of a bridge beam.

A prestressed concrete beam, THD Type B, was used as a subject for comparing camber predictions based on creep and shrinkage functions developed in an earlier study with those developed in this study (1). The earlier study was made in Houston, Texas on concrete produced, cured, and stored in that city. It was found that the camber based on the creep and shrinkage functions of the Houston tests was approximately one-half as much as that found by using some of the functions of the present study.

IMPLEMENTATION

Prestress loss and camber of prestressed beams may be computed from the information developed in the study. The materials should be the same as those reported and the environment of curing, storage, and service should be the same as that of the tests. The creep and shrinkage properties reported here will have to be modified if conditions or materials other than those of the tests are used.

In computing prestress loss and camber of prestressed beams the computer program developed in Ref. 1. may be used. The modulus of elasticity and the functions for creep and shrinkage of the particular material and area of service should be taken from Tables 3 and 6 of this report. The computer program referred to will require input data on the beam and slab, initial stresses, and materials. It gives information on camber, stresses and prestress loss at any age specified.

If the comptuer is not used, the creep coefficients of Table 4, or creep and shrinkage functions of Table 6 may be used in pencil and paper computations for camber and prestress loss.

INTRODUCTION

The collection and use of creep and shrinkage data for use in the design of prestressed concrete highway bridges is the subject of the study reported here. The creep behavior of concrete under sustained stress, such as that of a prestressed beam, is dependent in a large measure on the aggregates used in the concrete and the humidity under which it serves in the structure. The designer must know the properties of the material used in the design in order to determine the creep and shrinkage effects in the structure. Loss of prestress is dependent on both creep and shrinkage, and beam camber is dependent on creep. Elastic strains and other influences are important, but this study is concerned primarily with creep and shrinkage.

An earlier study (1) investigated creep and shrinkage of prestressed concrete bridge beams in Houston, Texas. The study reported here is an extension of that work in that the behavior of other concretes in other parts of the state is determined. It seeks to determine creep and shrinkage of concretes made of natural aggregates typically used in four different areas of the state under climatic conditions of those four areas. The areas are chosen to represent different climatic conditions. The data collected are intended for use in the design of highway concrete structures in the areas studied when they are made of the aggregates typical of those areas.

Data from field tests are of primary interest here, but laboratory tests were made for purposes of comparing field and laboratory creep and shrinkage. If laboratory data are in good agreement with field data, the simpler laboratory tests could be used in future studies of this kind.

The problem of predicting the short time and long time deformational behavior of a given concrete structure has been the subject of about 1500 research papers published since the turn of the century. In modern bridge design, where a smooth riding surface is a necessity, the deformational behavior of the structure must be taken into account. Such deformation is due in part to shrinkage and creep of the concrete in the piers, beams, and deck slab of the bridge.

In prestressed concrete bridge beams, camber (upward deflection) occurs with the release of the prestressing force. That initial beam deflection is caused by elastic strain of the materials. Creep of the concrete, a time dependent strain which is only partially reversible, causes this upward deflection to grow with time. Elastic, shrinkage, and creep strains in the concrete cause, and are accompanied by, elastic strains of the prestressing steel which reduce the prestressing force. The effects of creep and shrinkage strains in prestressed concrete bridge structures are dependent on such variables as materials, stress level, environment and other factors which are generally of lesser importance.

Economy requires that materials used in the fabrication of concrete bridge beams be taken from sources as near to the use area as is practical. This is particularly true for sand and gravel which make up the bulk of the concrete. These materials differ from place to place, but variations within relatively small areas are not so great as those found over wider areas. The differences in the composition of materials as well as differences in climatic conditions contribute to differences in the behavior of concrete. All of these are of concern in a study of creep and shrinkage.

TEST LOCATIONS

There are some twelve prestressing plants that produce prestressed concrete beams for the Texas Highway Department. Of these, four plants were selected to represent four geographical areas of the state. The locations of those four plants are shown in Fiqure 1, climatological data for the locations were taken from U. S. Department of Commerce records (2).

A brief statement about each test follows:

Dallas, located in north central Texas, has hot summers with maximum temperatures of 100°F or higher and relatively mild winters with minimum temperature of about 20°F. The relative humidity at Dallas varies from approximately 75 percent at 6:00 a.m. to approximately 50 percent at 6:00 p.m.

San Antonio, located in south central Texas, has relatively hot summers with maximum temperatures of approximately 95°F. Minimum temperatures during winter months generally range between 20°F and 30°F. The relative humidity in the San Antonio area generally varies between approximately 80 percent at 6:00 a.m. and approximately 55 percent at 6:00 p.m.

Odessa, located on the high plains of Texas, has hot summers with maximum temperatures in excess of 100°F. Minimum temperatures generally are in a range of 0°F to 20°F. The relative humidity at Odessa varies from approximately 70 percent at 6:00 a.m. to approximately 35 percent at 6:00 p.m.

Lufkin, located in east Texas, has relatively hot summers with maximum temperatures of approximately 100°F. Minimum temperatures for

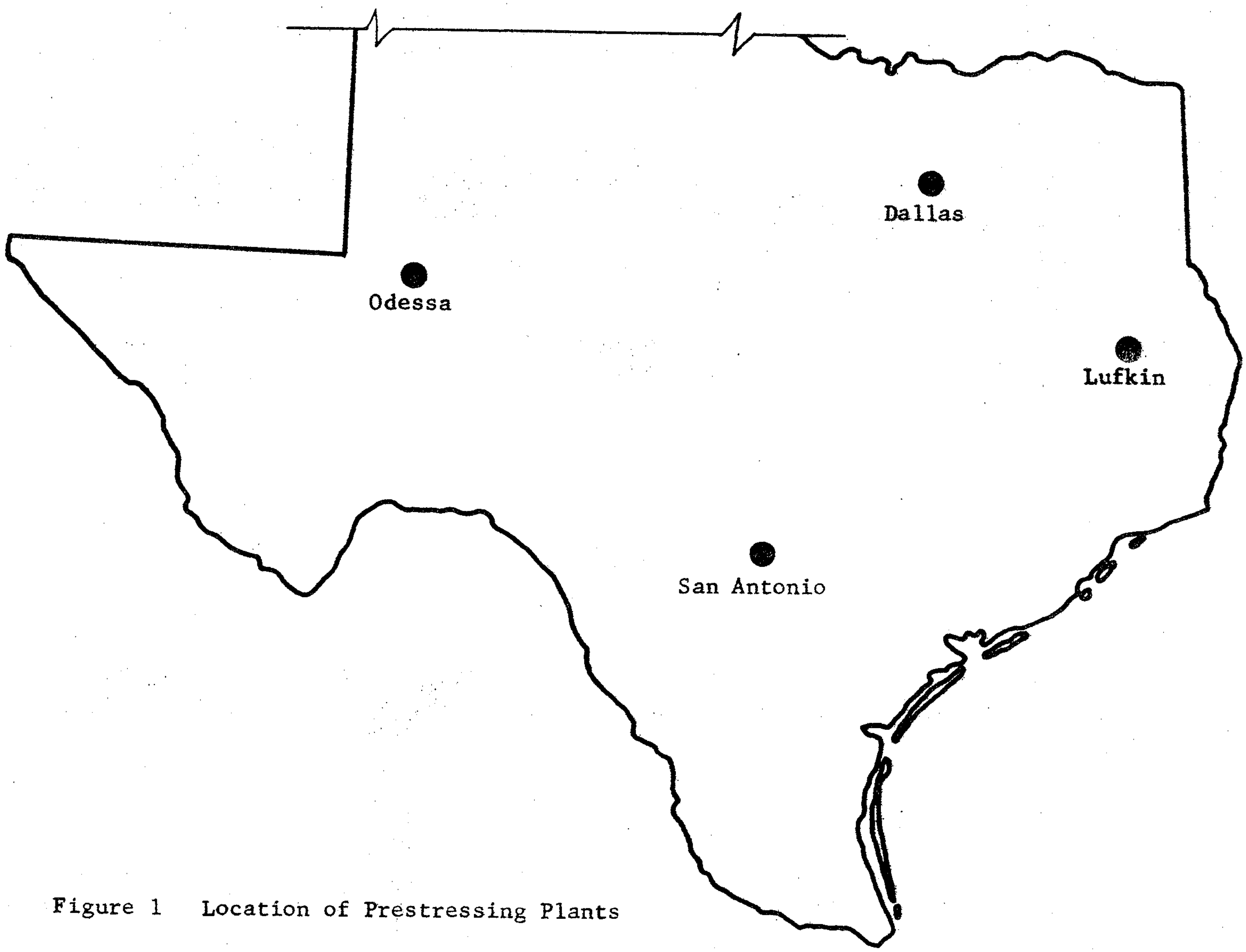


Figure 1 Location of Prestressing Plants

Lufkin generally are on the order of 20^{o}F. The relative humidity in the Lufkin area is generally high, some 70 percent to 95 percent.

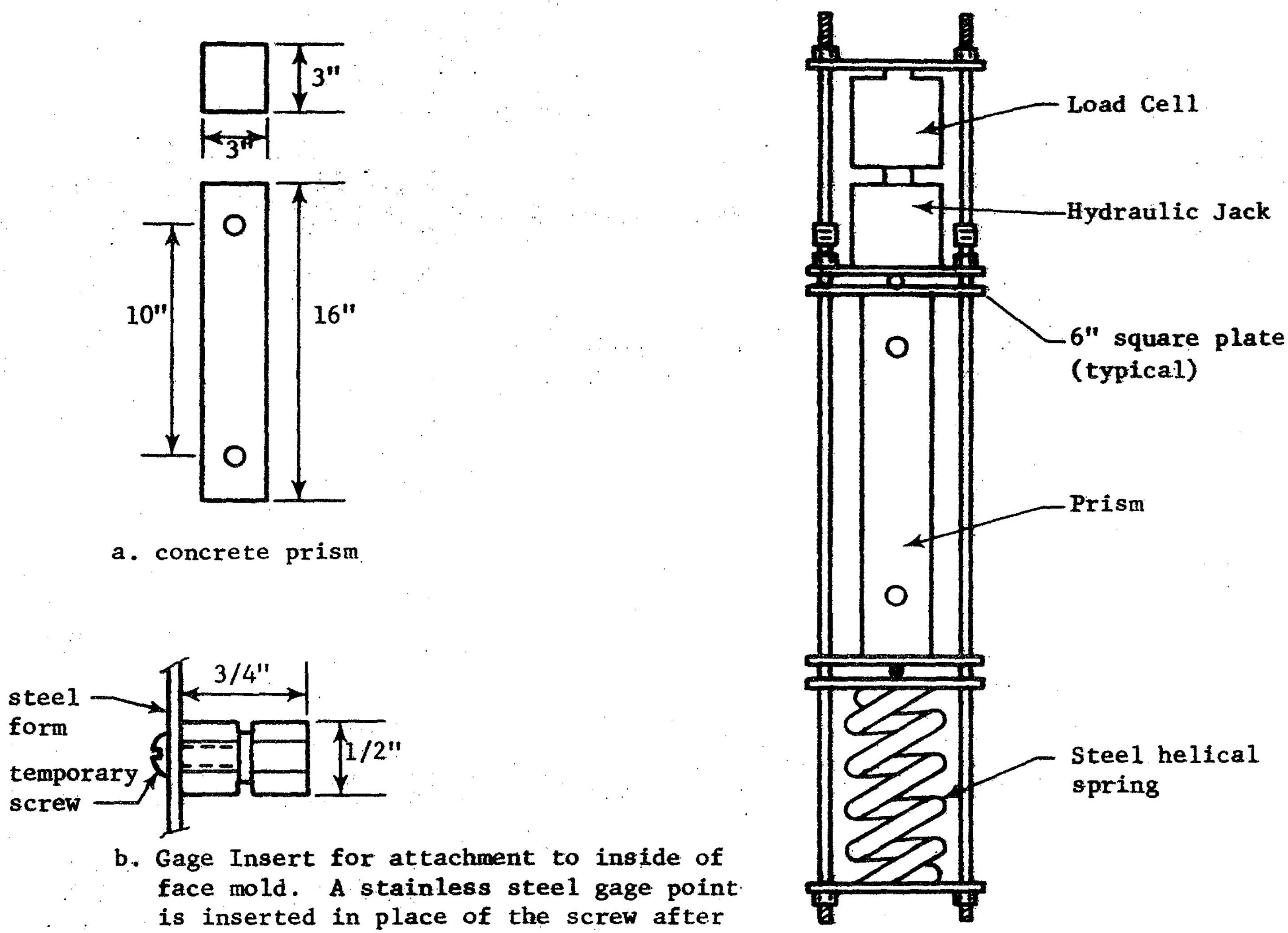
TEST SPECIMENS

Specimens consisted of cylinders and prisms of plain concrete. Table 1 gives the schedule of prismatic specimens. Specimens are described below:

1. Cylinders: Standard cylinders, 6 x 12 in., were cast in steel molds and compacted by rodding. They were used to determine the concrete strength and stress-strain relationship.
2. Prisms: Plain concrete prisms, 3 x 3 x 16 in., were cast to determine shrinkage versus time and unit creep versus time. Steel molds were used with brass inserts 10 in. apart attached to two opposite 3 x 16 in. faces for later installation of gaging points.

A set of specimens consisted of 4 loaded prisms, 4 non-loaded prisms, and 18 cylinders. Of the loaded prisms, two were loaded to 1000 psi and two were loaded to 2000 psi sustained compressive stress. They were axially loaded parallel to the long axes by a hydraulic jack and the load was sustained by means of heavy helical springs. During the loading operation, the load was monitored with a load cell. Figure 2 (a), (b), and (c) show the concrete prism, gage insert, and steel frame for loading the prisms. The 4 non-loaded prisms were monitored for shrinkage strains. It was assumed that the shrinkage of the loaded prisms was the same as the shrinkage of the non-loaded prisms.

Two sets of specimens were made at each plant location. One set was stored in open air under protective cover near the place of fabrication and



a. concrete prism

b. Gage Insert for attachment to inside of face mold. A stainless steel gage point is inserted in place of the screw after the concrete is removed from the mold.

c. Method for loading

Figure 2 Prism, Gage Insert, and Method of Loading

TABLE 1. SCHEDULE OF TEST SPECIMENS FOR CREEP AND SHRINKAGE

(All specimens are 3 in. x 3 in. in section by 16 in. long)

Source of Material	Environment of Test	Specimen Number	Number of Specimens			Date Cast	Date Loaded
			Shrinkage	Creep			
				1000 psi	2000 psi		
Dallas	Field	1 - 8	4	2	2	9/20/71	9/21/71
	Laboratory	9 - 16	4	2	2	9/20/71	9/21/71
Odessa	Field	1 - 8	4	2	2	10/20/71	10/21/71
	Laboratory	9 - 16	4	2	2	10/20/71	10/21/71
San Antonio	Field	1 - 8	4	2	2	11/29/71	11/30/71
	Laboratory	9 - 16	4	2	2	11/29/71	11/30/71
Lufkin	Field	1 - 8	4	2	2	1/27/72	1/29/72
	Laboratory	9 - 16	4	2	2	1/27/72	1/29/72

the companion set was stored in the laboratory at 73°F, 50 percent relative humidity.

MATERIALS

Materials typical of the area where the specimens were made were used at each prestressing plant. Only normal weight concretes were studied. Table 2 gives information on materials and the mix proportions used at each plant. The batches were designed by the Texas Highway Department for material used in prestressed concrete beams for bridges in the Texas Highway System.

CURING AND STORAGE CONDITIONS

The curing of the test specimens was the same as for pretensioned prestressed concrete beams fabricated to meet Texas Highway Department specifications. At San Antonio, the concrete was cured 24 hours under a wet mat. It was then covered with an impervious mat for an additional three days. The plants at Odessa and Dallas utilized steam curing for approximately 15 hours followed by three days under an impervious mat. The plant at Lufkin utilized steam curing for 42 hours, to gain release strength, and three days under impervious covering.

Specimens stored in the field at each site were protected from rain and direct sunlight. The field stored specimens made at San Antonio were stored at Boerne, Texas approximately twenty miles from the fabricator because of a lack of suitable storage space near the fabricator. Those

TABLE 2. Materials and Mix, Pounds per Cubic Yard of Concrete

(From information provided by Texas Highway Department)

	Dallas	Odessa	San Antonio	Lufkin
Cement	705 lb Type III	752 lb Type III	658 lb Type III	705 lb Type III
Aggregate*				
Fine	1,219 lb limestone and siliceous sand	926 lb limestone and siliceous sand	1,177 lb 70% limestone sand, 30% siliceous sand	1,130 lb siliceous sand
Coarse	1,824 lb crushed limestone; 3/4 in. max. size	1,882 lb siliceous and limestone gravel; 3/4 in. max. size	1,861 lb limestone gravel; 1 in. max. size	1,777 lb crushed limestone; 1 in. max. size
Source	Bridgeport	Hoban pit, Pecos	Bexar Co., 12 mi. N. San Antonio on IH 10	Angelina Co., 2 mi. W of Lufkin on State Route 94.
Water	253 lb	273 lb	316 lb	279 lb

* Saturated, surface dry

specimens stored in the laboratory were subjected to controlled conditions of essentially 73°F temperature and 50 percent relative humidity.

The creep specimens were loaded at the fabrication site at essentially the same time that prestress was transferred to the concrete. This was at the end of the initial curing period and prior to the second phase of curing, that under impervious mat.

INSTRUMENTATION

The strength and modulus of elasticity were determined from standard compression tests on 6 x 12 in. cylinders. The ultimate strength of the cylinder was determined before the creep and shrinkage specimens were demolded. At the Lufkin location, the specimens remained in the molds for 42 hours before the required strength was obtained. At the other three locations the specimens were demolded approximately 20 hours after casting. Subsequent compression tests were made in the laboratory. Four Ames dial gages with readings to 1×10^{-4} in. were mounted 90 degrees apart on the compressometer from which strains were read during the loading of the compression cylinders.

Brass inserts were attached to the steel molds by screws before casting the concrete. After removing the forms, stainless steel heads were screwed tightly into the inserts. Each gage reading reflected the relative position of the reference points drilled into these heads. The first strain reading minus the standard invar bar reading was taken as the datum to which all other strains were referred. Special precautions were taken to see that the first reading was verified because that reading served as the datum to which all subsequent strains were referred.

Strain measurements from the 3 x 3 x 16 in. prisms were made with a multi-position 10 in. mechanical gage from which readings were taken from an attached dial gage reading to 1×10^{-4} in. The standard (reference) readings were taken from an invar bar at each time a gage reading was recorded.

The specimens were gaged on two opposite 3 x 16 in. faces and the strain at any time was determined by averaging the strains from the two opposite faces. Initial readings were made on each prism as soon as possible after demolding. Readings from the creep specimens were taken immediately before and after loading in the creep frames. Thereafter, readings were taken each day for three to seven days, then weekly until the end of one month, and monthly for the remaining period. One set of the specimens was transferred to the laboratory on the day of loading with one exception. That exception, the Odessa concrete, require more time for transfer from the casting yard to the laboratory because of the long travel distance.

RESULTS OF TESTS

This section presents the results of the tests described in the previous section. The measured strains, relative humidity, temperature, and mechanical properties data are presented in tables and graphs that follow.

Mechanical Properties

Eighteen standard 6 x 12 in. cylinders were prepared with each set of shrinkage and creep specimens. Those cylinders were used for determining the concrete strength and modulus of elasticity at release, 7, 28, 90, and 180 day ages. The cylinders were stored with each set of shrinkage and creep prisms until testing.

The materials for the four concretes included in these tests satisfied the Texas Highway Department specifications for normal weight prestressed concrete. The strength and modulus data, average slope of the stress-strain curve between 500 psi and 2500 psi, for the concretes are presented in Table 3. Within that stress range the slope of any one diagram was almost constant. The strength and modulus of elasticity for each location was about the same for field storage as for laboratory storage. It is interesting to note that the modulus of elasticity of the Odessa concrete was lower than that of the concrete from the other three areas.

Elastic strains may be found by dividing the stress by the modulus of the elasticity at release.

TABLE 3. Concrete Compressive Strength and Modulus of Elasticity

		Storage Conditions			
		Field*		Laboratory*	
Concrete from	Age, Days	Strength f'_c, psi	Modulus E_c, ksi	Strength f'_c, psi	Modulus E_c, ksi
Dallas	release	7,080	5,200	-	-
	7	7,400	5,710	8,230	5,400
	28	8,490	5,270	9,015	5,310
	90	8,970	5,430	8,710	5,370
	180	8,800	5,310	8,650	5,340
Odessa	release	5,050	3,260	-	-
	7	8,380	4,180	8,130	4,650
	28	8,740	4,020	8,530	4,350
	90	8,900	4,320	8,530	4,820
	180	8,660	3,660	8,600	4,270
San Antonio	release	5,250	4,220	-	-
	7	7,560	5,370	8,020	5,650
	28	8,710	5,400	8,500	5,680
	90	9,270	5,250	8,320	5,430
	180	8,710	5,850	8,500	5,480
Lufkin	release	5,760	4,440	-	-
	7	6,710	5,320	7,080	5,050
	28	6,770	5,130	6,840	5,020
	90	7,530	4,740	7,960	4,400
	180	7,420	4,520	7,350	4,550

*Average of 2 cylinders

SHRINKAGE

Shrinkage strains are shown graphically in Figure 3 and certain tabular information is found in Table 4. All of the four concretes show considerably more shrinkage in laboratory environment (73°F, 50% RH) than under field conditions. The Odessa material has much higher shrinkage in both field and laboratory than any of the other three. Dallas and San Antonio material have the same laboratory shrinkage, but the latter shows more field shrinkage than the former. Since the laboratory reduces all materials to the same environmental conditions the difference between the field shrinkage of the Dallas and San Antonio material would indicate that the humidity in the vicinity of San Antonio was lower than that at Dallas during the period of the test. The data presented in Figure 4 at first sight would not support that conclusion. The temperatures and relative humidities shown in Figure 4 represent the conditions only at the time that strain readings were taken from the specimens. Those readings were taken at one month intervals and the points plotted in Figure 4 should not be taken to represent the continuous trend of temperature and relative humidity. They are, at best, indicators of seasonal variations and cannot be interpreted as prevailing conditions at the field storage sites and should not be used to interpret the effect of climate on shrinkage.

The ratios of field shrinkage to laboratory shrinkage for the four concretes in the small specimens of these tests indicate that the field conditions at Odessa combine to produce shrinkage strains more nearly the same as its laboratory strains than any of the other concretes. The ratios shown in the table might be used to convert laboratory shrinkage strains of

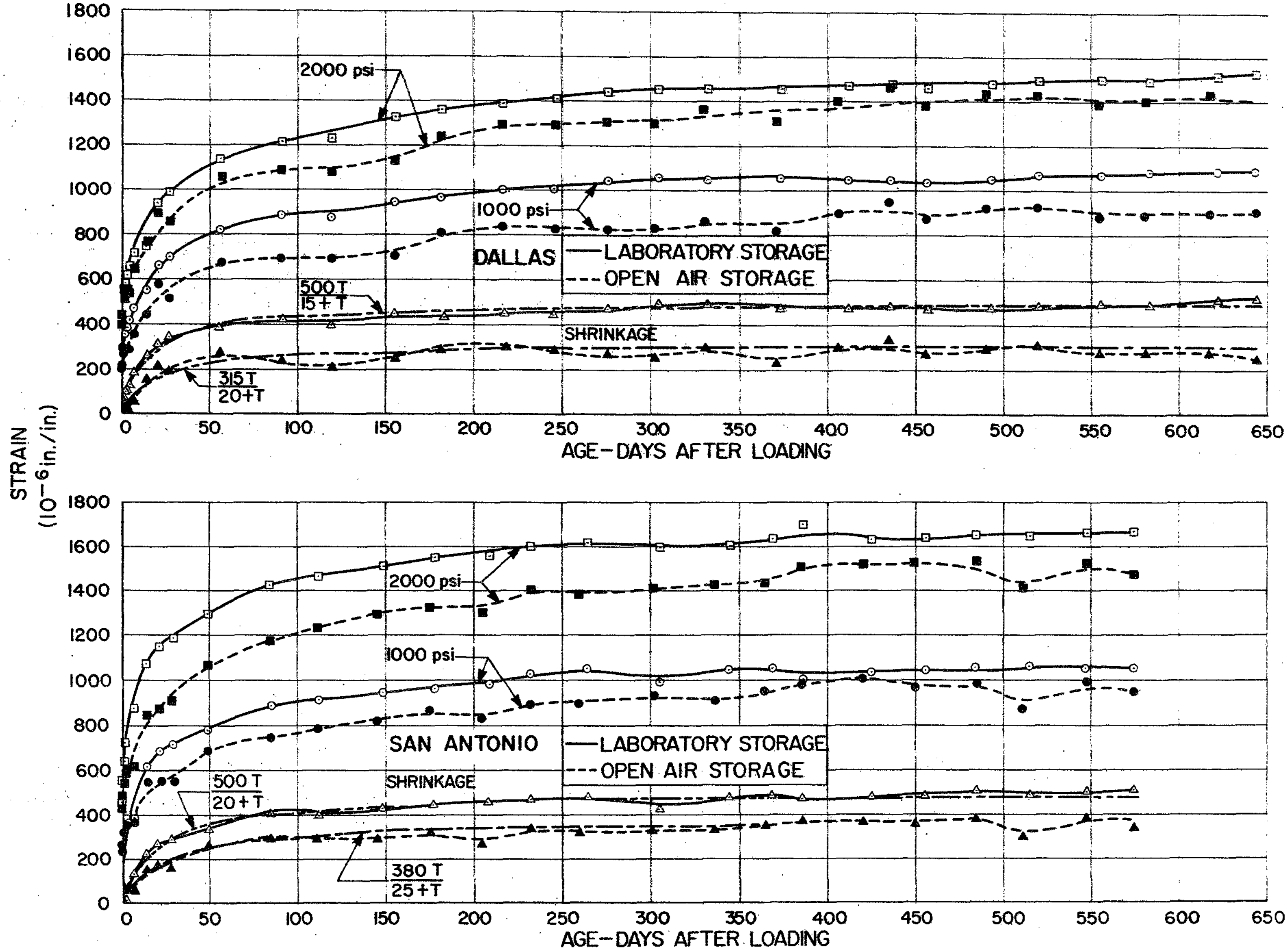


FIGURE 3 — MEASURED STRAINS

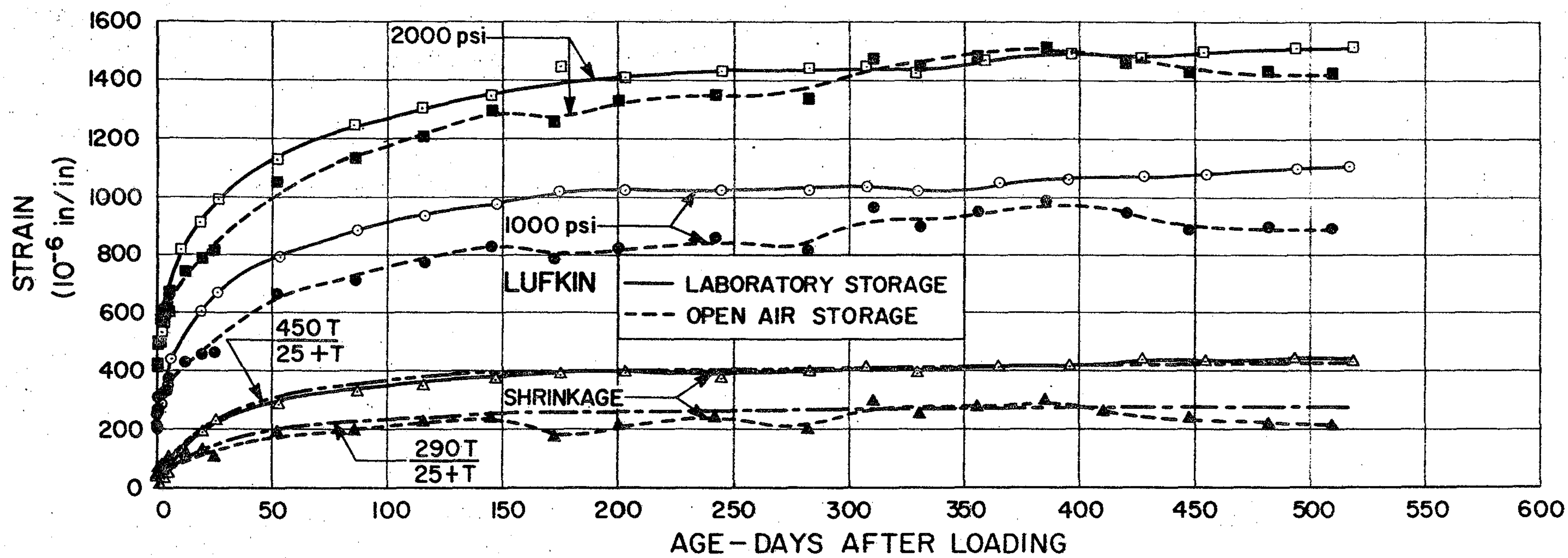
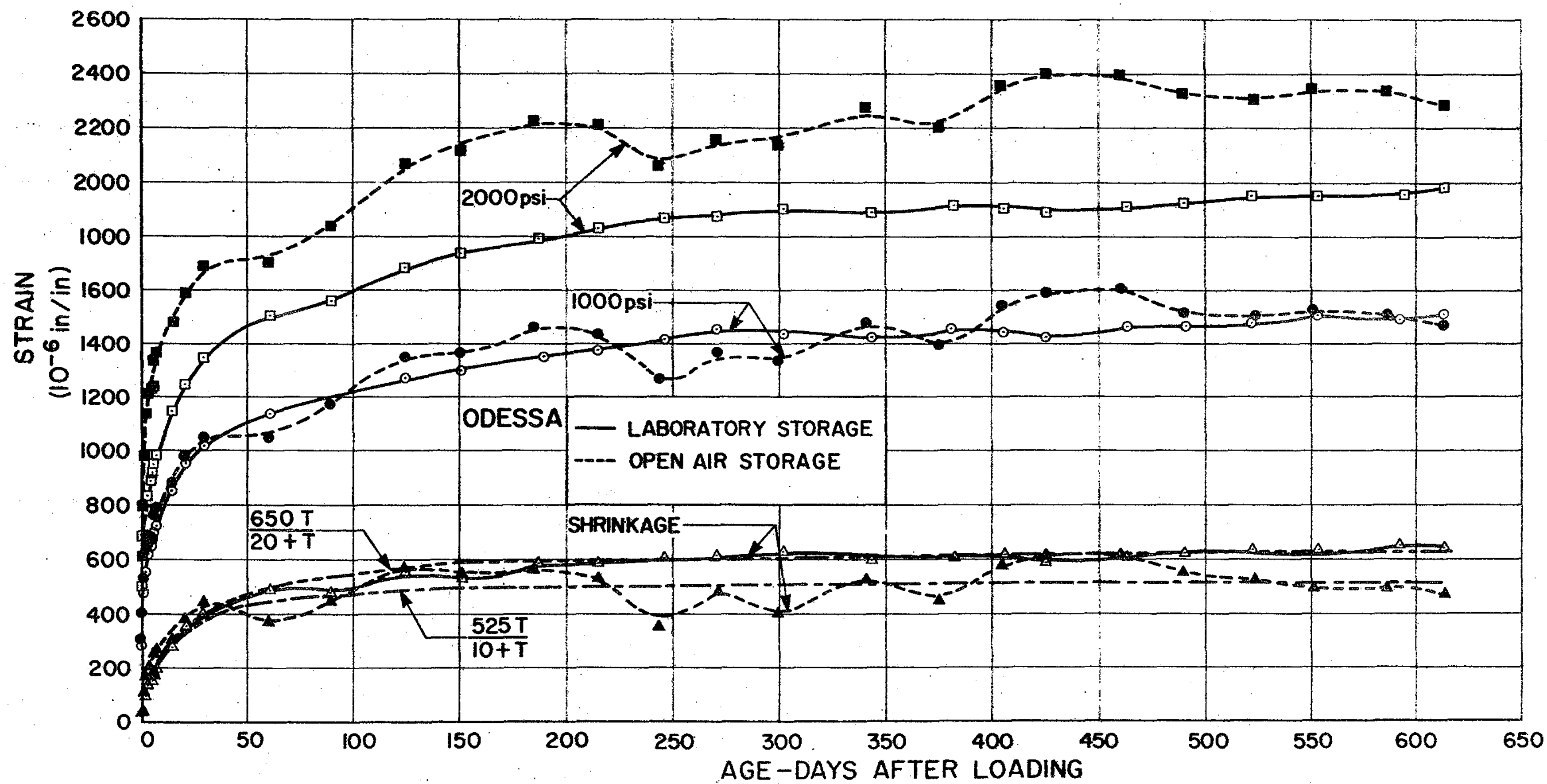


FIGURE 3 - CONTINUED



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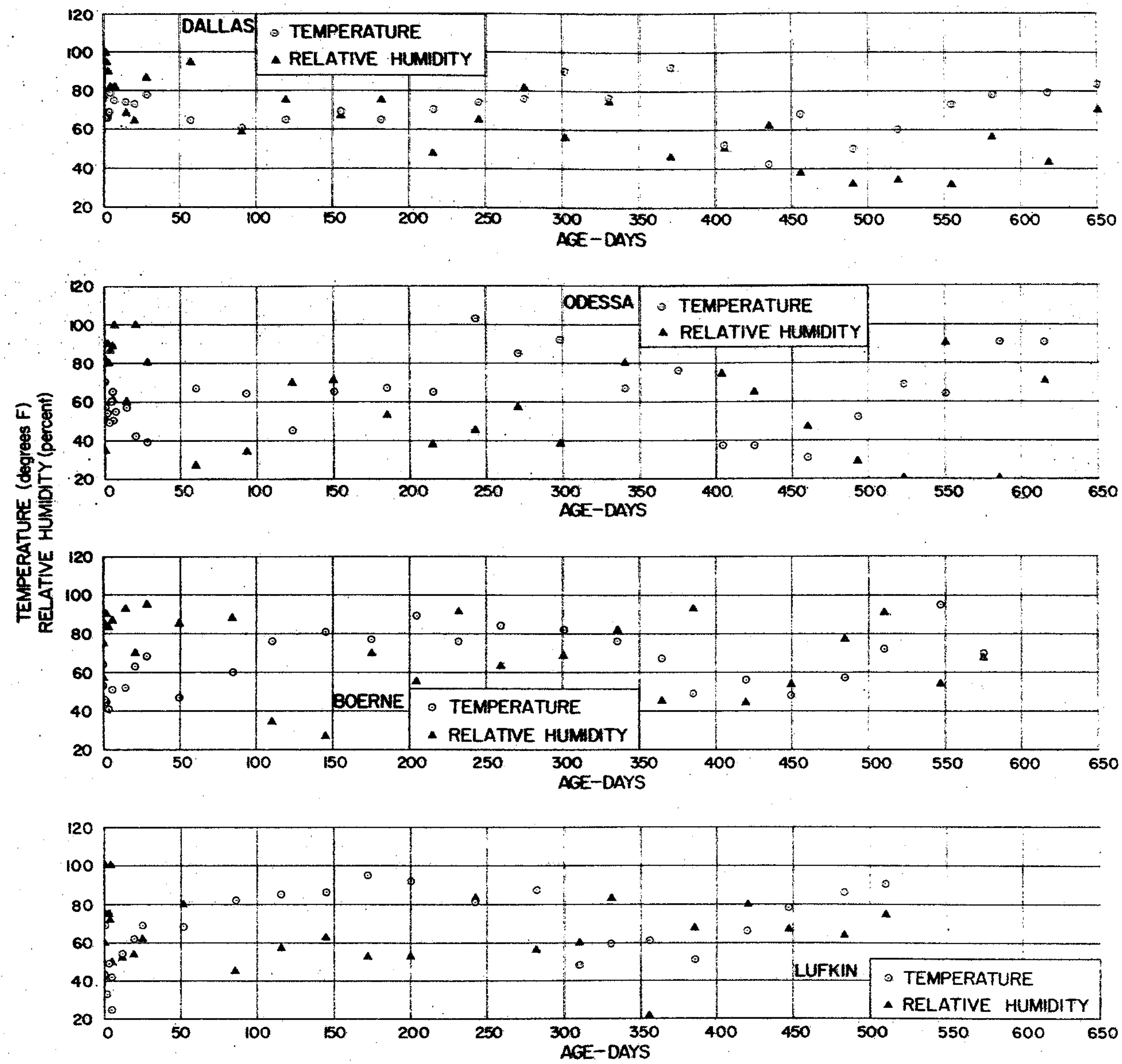

FIGURE 4 - TEMPERATURES AND RELATIVE HUMIDITIES AT TIME OF READING AT FIELD LOCATIONS

specimens of the size used in these tests to what might be expected of them in the field.

Hansen and Mattock (3) have reported a linear relationship between shrinkage strain and the ratio of the volume of a specimen to its surface area for specimens of various sizes and shapes stored under laboratory conditions. This would lead to a greater shrinkage in the small specimens of these tests than would be realized in a full size prestressed beam of normal shape and dimensions such as is used in bridge design. The tests performed on field concrete and reported in Ref. 1, however, showed greater shrinkage in a short length of a full size beam section than was found in the 3 in. x 3 in. x 16 in. specimens in storage in open air at Houston, Texas. The local daily and seasonal climatic changes seem to have considerable bearing on shrinkage behavior. Until more information is developed on the relationship between field and laboratory strains, the ratios shown in Table 4 might be used as indicators, at least, of what might be expected in the field if laboratory behavior is known. From the experience gained in the present series of tests and those reported in Ref. 1, it appears that field strains from the small specimens can be used for design purposes for full size prestressed concrete bridge beams.

The shrinkage functions shown in Table 4 are intended for use in computing camber and prestress losses in prestressed beams. They are explained later in the section entitled Functions for Creep and Shrinkage.

TABLE 4. Shrinkage and Unit Creep at 500 Day Age and Continuous Shrinkage-Time Functions

Shrinkage

Source	Field Storage Shrinkage (10^{-6} in./in.)	Field Storage Function	Laboratory Storage Shrinkage (10^{-6} in./in.)	Laboratory Storage Function	Ratio: Field to Laboratory Shrinkage
Dallas	300	$\frac{315\ T}{20 + T}$	480	$\frac{500\ T}{15 + T}$	0.62
Odessa	510	$\frac{525\ T}{10 + T}$	620	$\frac{650\ T}{20 + T}$	0.82
San Antonio	360	$\frac{380\ T}{25 + T}$	480	$\frac{500\ T}{20 + T}$	0.75
Lufkin	280	$\frac{290\ T}{25 + T}$	430	$\frac{450\ T}{25 + T}$	0.65

Creep (10^{-6}in./in./ksi)

Source	Field Storage	Laboratory Storage	Ratio: Field to Laboratory Creep
Dallas	390	340	1.14
Odessa	630	500	1.26
San Antonio	360	370	.97
Lufkin	430	360	1.20

Creep Coefficients
creep strain ÷ elastic strain

Dallas	1.81
Odessa	1.70
San Antonio	1.60
Lufkin	1.89

Creep of Specimens

Creep curves shown in Figure 5 are derived from measured strains shown in Figure 3. Elastic strains and shrinkage are subtracted from the total measured strains of Figure 3 to produce the creep curves. The periodic variations seen in Figure 3 are primarily seasonal changes, and when they are taken away, the curves of Figure 5 are smoothed out very much.

The ratio of sustained stress to ultimate strength for all the concretes ranged from a minimum of about 12 percent to a maximum of about 40 percent. Various experimental results show substantial evidence of a nearly linear relationship between creep and applied stress (4). An upper limit for the stress-strain ratio somewhere in the rather wide range of 30 and 75 percent has been suggested. The stress-strength ratios in these tests, using the strengths shown in Table 3, fall within that range.

Among the field tests, the San Antonio material shows a consistent linear relationship of creep to stress in that the 2000 psi creep is twice that of the 1000 psi concrete, Figure 5 and Table 5. No other material, field or laboratory stored, shows such good linearity. The ratios of creep shown in Table 5 for Dallas, Odessa, and Lufkin concretes would suggest that the sustained stresses in those materials did not bear the 2 to 1 ratio either from the beginning or that the ratio was reduced during the test period.

During the test there was never any question about the initial stress value because of the care that was taken in applying the initial load. When the specimens had been under load for approximately four months, the loads on all field specimens were checked. At that time, far more than one-half

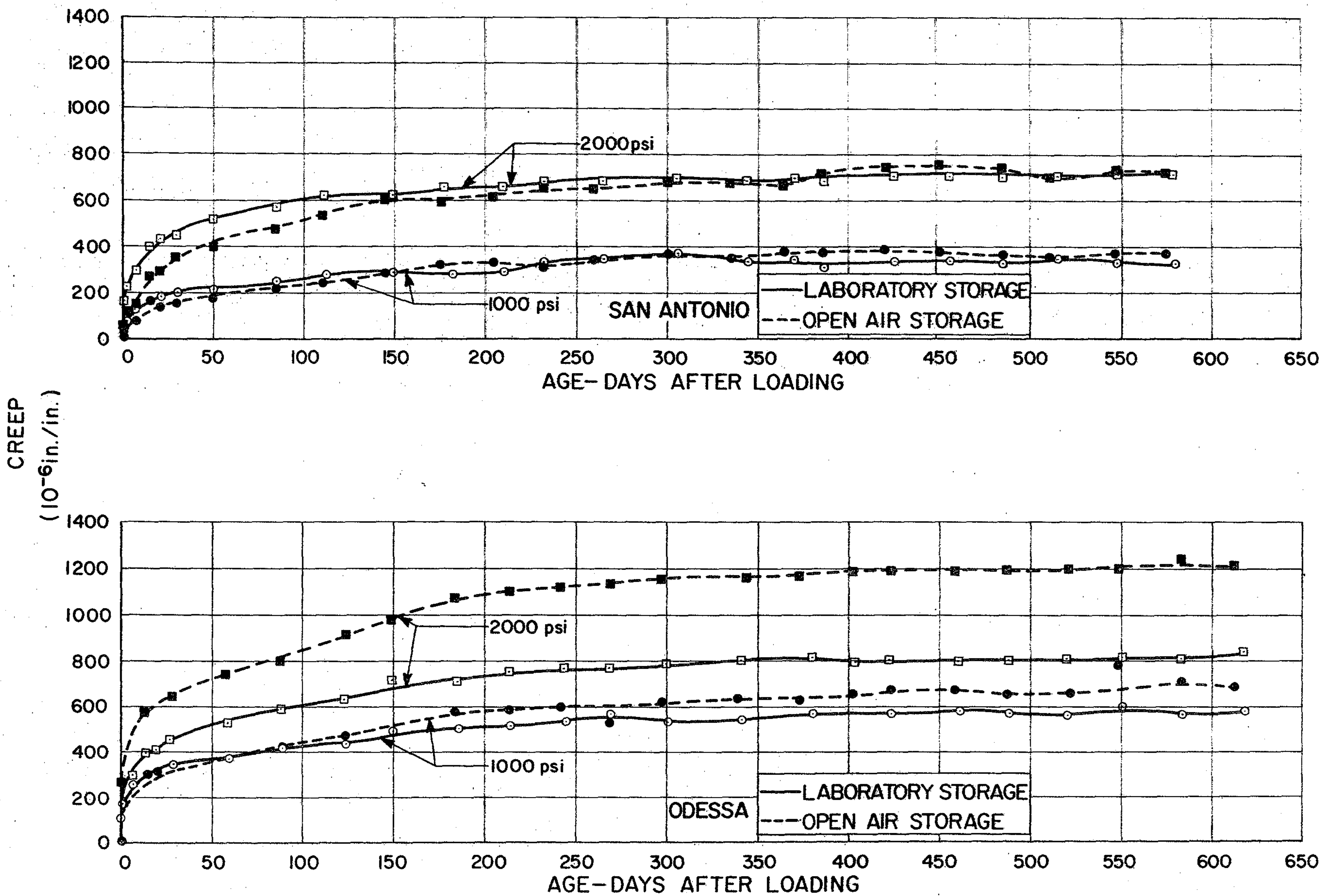

FIGURE 5 — CREEP vs. TIME

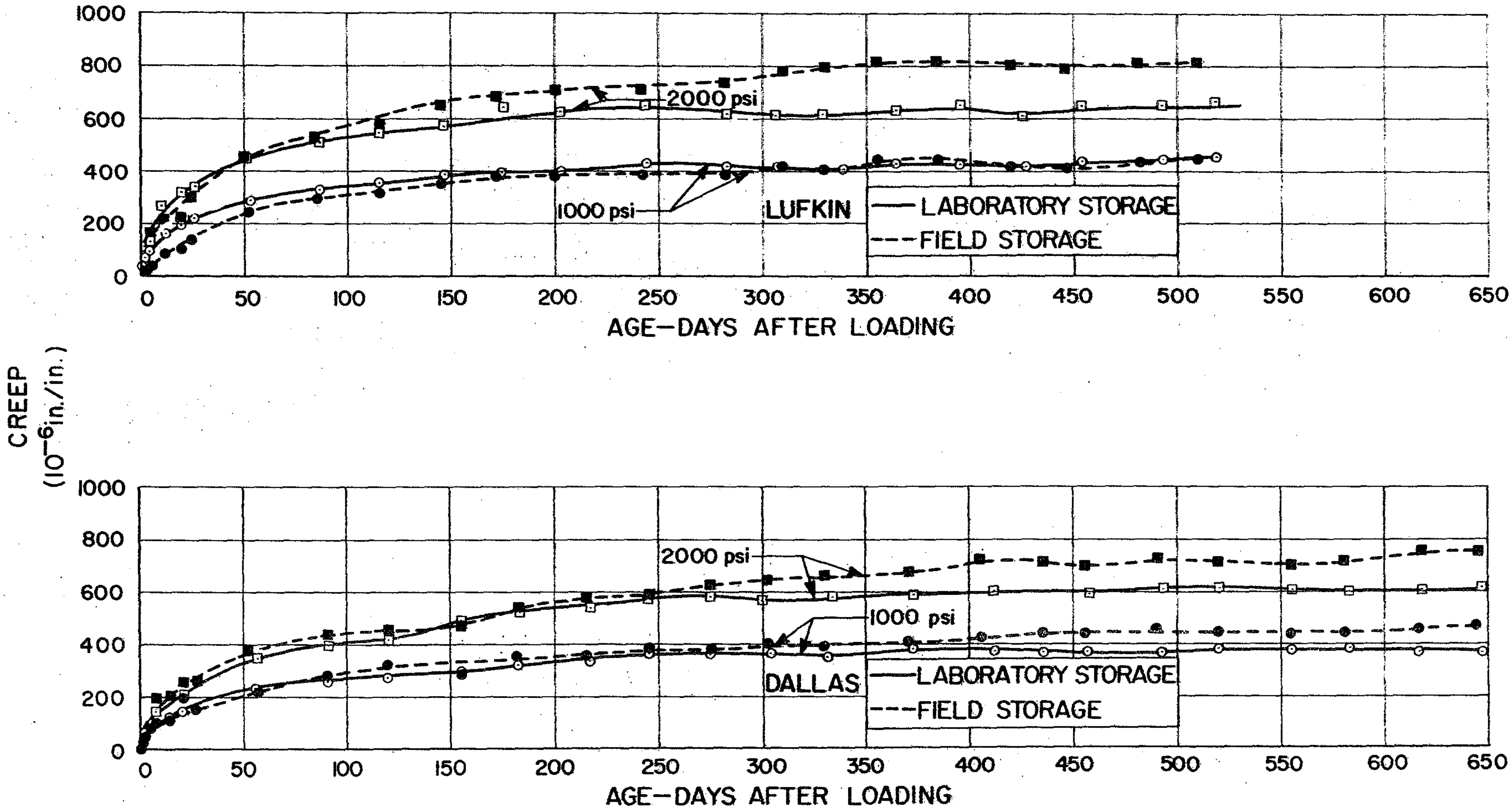

FIGURE 5 - CONTINUED

of the creep at termination had developed. The helical springs used in the loading frames have spring rates of 10,000 and 18,000 pounds per inch, respectively, for the 1000 psi and 2000 psi specimens. The computed stress loss in the 1000 psi specimens was about 2 percent of the initial and 2.2 percent in the 2000 psi specimens. The load check indicated losses of approximately 20 psi in both the 1000 psi and the 2000 psi specimens, the discrepancy being due to imprecise portable measuring equipment. Adjustments were made as nearly as possible to meet the theoretical losses.

The load adjustments discussed above fail to account for the low ratios of 2000 psi creep to 1000 psi creep for Odessa and Lufkin laboratory stored concretes. The corresponding ratios for the other specimens, both field and laboratory, approach the expected value of 2, although none reach it. All data and procedures have been studied in an effort to explain the unusual behavior of the Lufkin and Odessa laboratory materials. The possibility of friction having developed between the horizontal bearing plate, that separates the specimen from the spring, and the vertical tension ties was suggested. Test frames were inspected for that possibility, but they were not broken down because to do so would have destroyed the test. No conclusive reason has been found to explain the trouble.

The 1000 psi field values agree well with the corresponding laboratory values. On the basis of the data appearing here, one could develop creep data from 1000 psi specimens, which are relatively easy to handle, and use it for unit creep values to be used in design.

Unit creep curves, creep divided by unit stress, are shown in Figures 6 and 7. The same information is shown in both the figures; it is just arranged in a different way for comparison of values. Figure 6 shows the field stored concretes in one set of curves and the laboratory cured

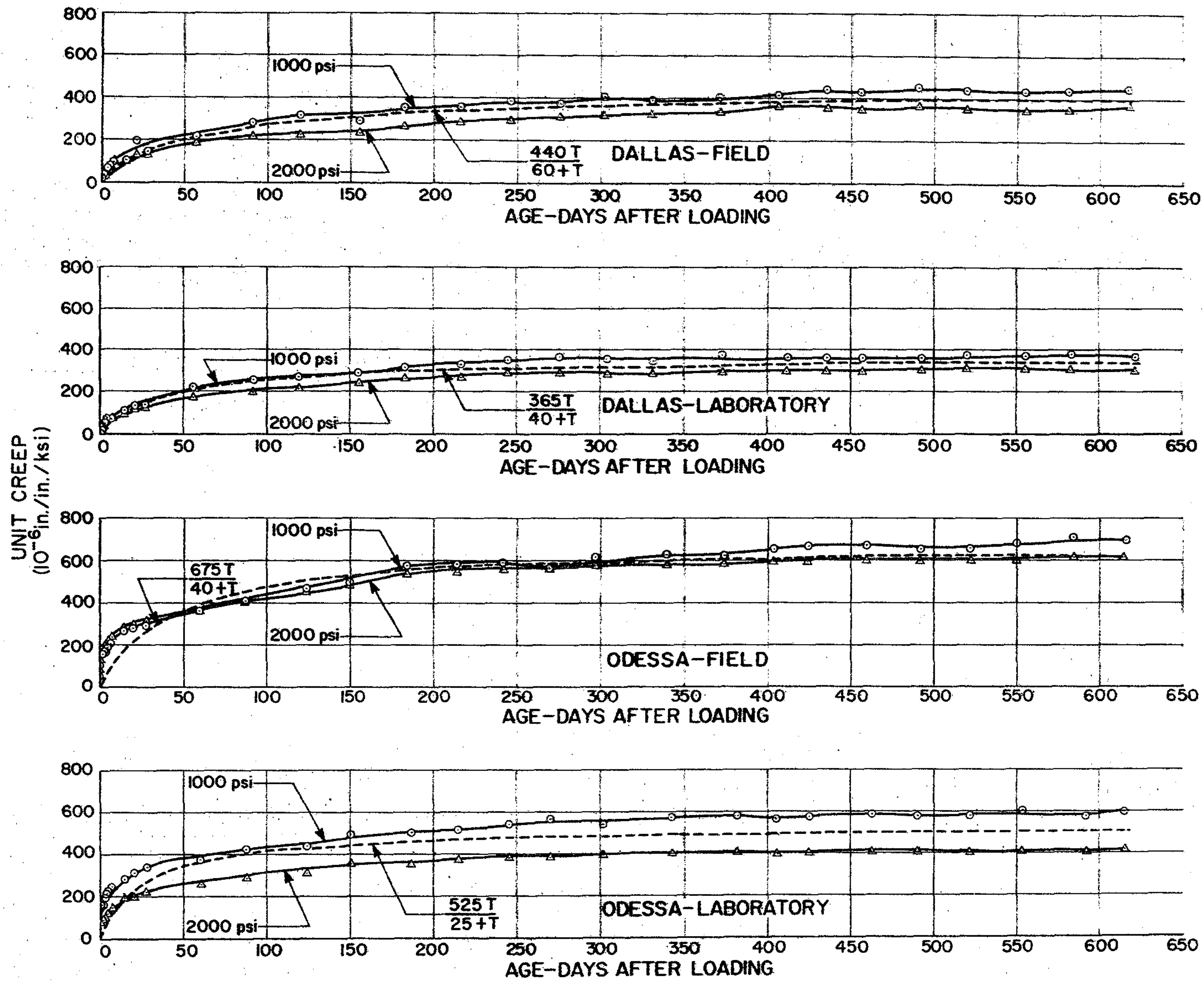

FIGURE 6 - CREEP CURVES FOR THE FOUR CONCRETES

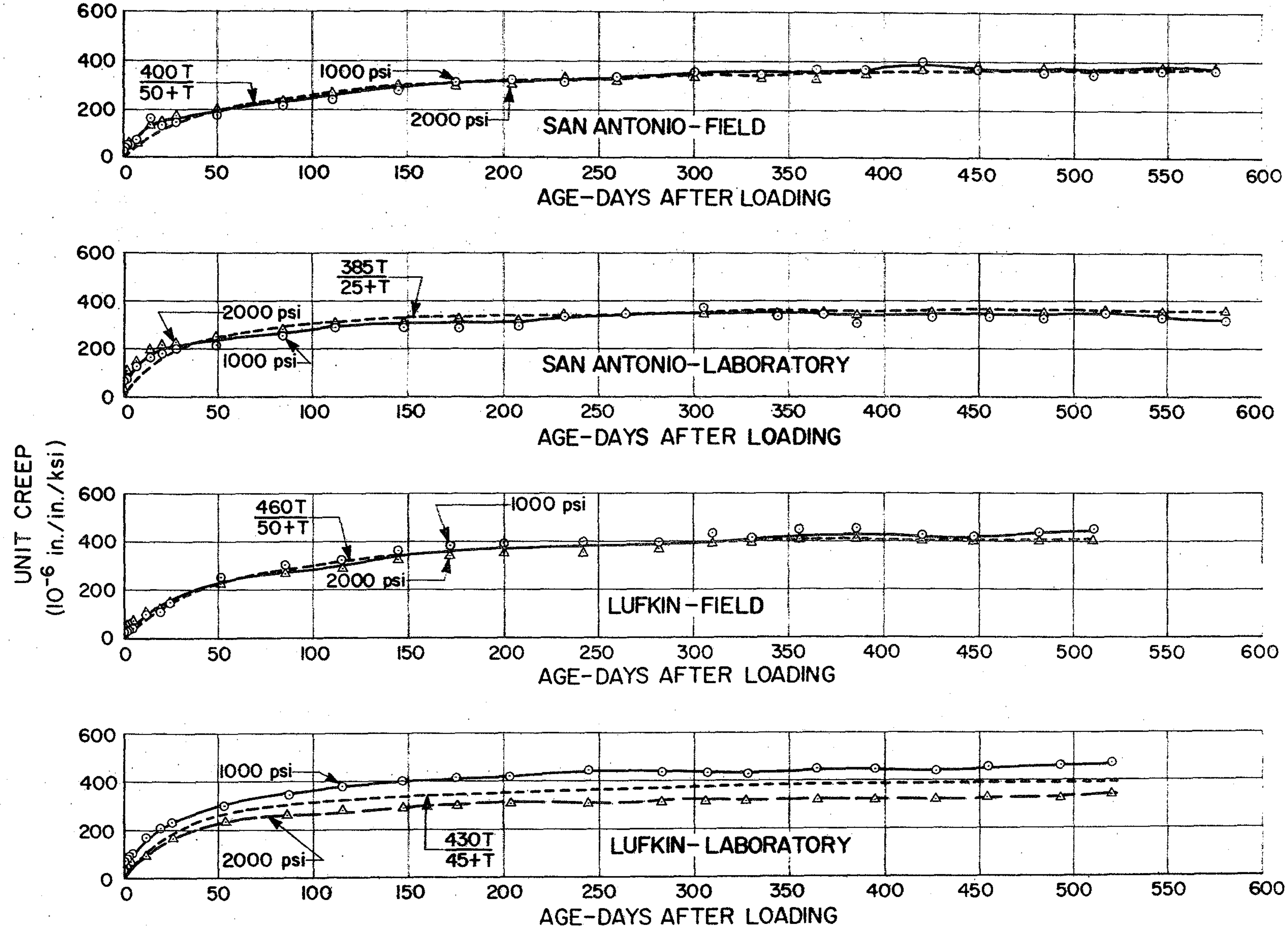

FIGURE 6 — CONTINUED

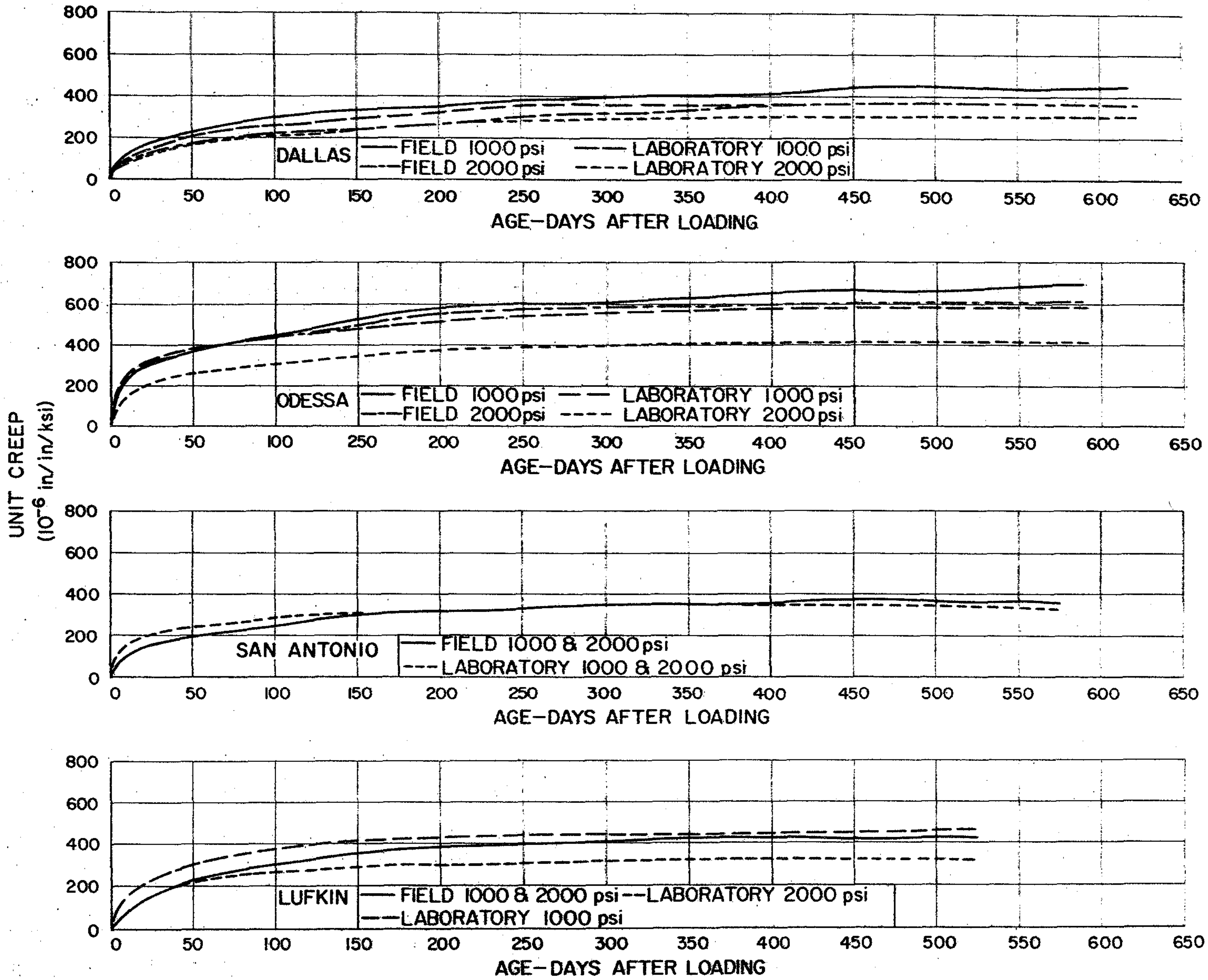

FIGURE 7— CREEP CURVES FOR 1000 AND 2000 psi STRESS

TABLE 5. Ratio at 2000 psi Creep to 1000 psi Creep at 500 Day Age

Material	2000 psi Creep ÷ 1000 psi Creep	
	Field Storage	Laboratory Storage
Dallas	1.62	1.65
Odessa	1.80	1.38
San Antonio	1.93	2.00
Lufkin	1.84	1.48
Average	1.80	1.63

concretes in another set of curves. This is done for each source of material. Figure 7 shows one set of curves for each location. That one set consists of the two field curves and two laboratory curves. The scales of the unit creep curves are reduced so much, when total creep is divided by unit stress, that the differences seen in previous curves appear to be greatly reduced. Such an effect is generally seen when data are reduced for design applications, and it has the effect of minimizing differences in measured data.

The expression of creep as a function of unit stress and of time is useful to the designer in predicting camber of beams and in estimating prestress losses. Such information can be taken from curves, such as those shown in Figure 6, or it can be expressed mathematically. The latter expression is more useful in design and it becomes especially so when designs are automated by means of the computer. The mathematical expression becomes simpler if a linear relationship between creep and stress is used. Such a relationship is assured in the San Antonio material of these tests. The average of the ratios of 2000 psi creep to 1000 psi creep is seen to be 1.80 for the four field concretes, Table 6, and the corresponding laboratory material ratio of 1.63 would be raised considerably if the Lufkin and Odessa 2000 psi laboratory values were discounted.

Figure 8 shows three of the four creep curves for laboratory stored specimens to be about the same, even though the specimens were made from different materials. It is also interesting to note from these curves that the creep curves obtained from the field stores specimens is very nearly the same as for laboratory stored specimens. Mix designs, Table 2, are similar, as would be expected because of highway specifications, and differences seen in creep and shrinkage would probably be due primarily to the different aggregates used in the different locations. The Odessa concrete contained the highest cement content, however, the paste content for the four mix designs is very nearly the same, approximately 30 percent.

Consider the average unit creep observed in the laboratory for the four different concretes. At 500 days age, values of approximately 340, 500, 370, and 395 (10^{-6} in./in./ksi) are noted from Figure 6 average curves for the respective locations, Dallas, Odessa, San Antonio, and Lufkin. For these specimens in the laboratory, the temperature and relative humidity were the same, the stress levels were essentially constant, and the paste content of the mixes was approximately the same. From these conditions then, it could be reasoned that the aggregates in the mixes would be responsible for the differences in the magnitude of creep. Neville (4) states that of

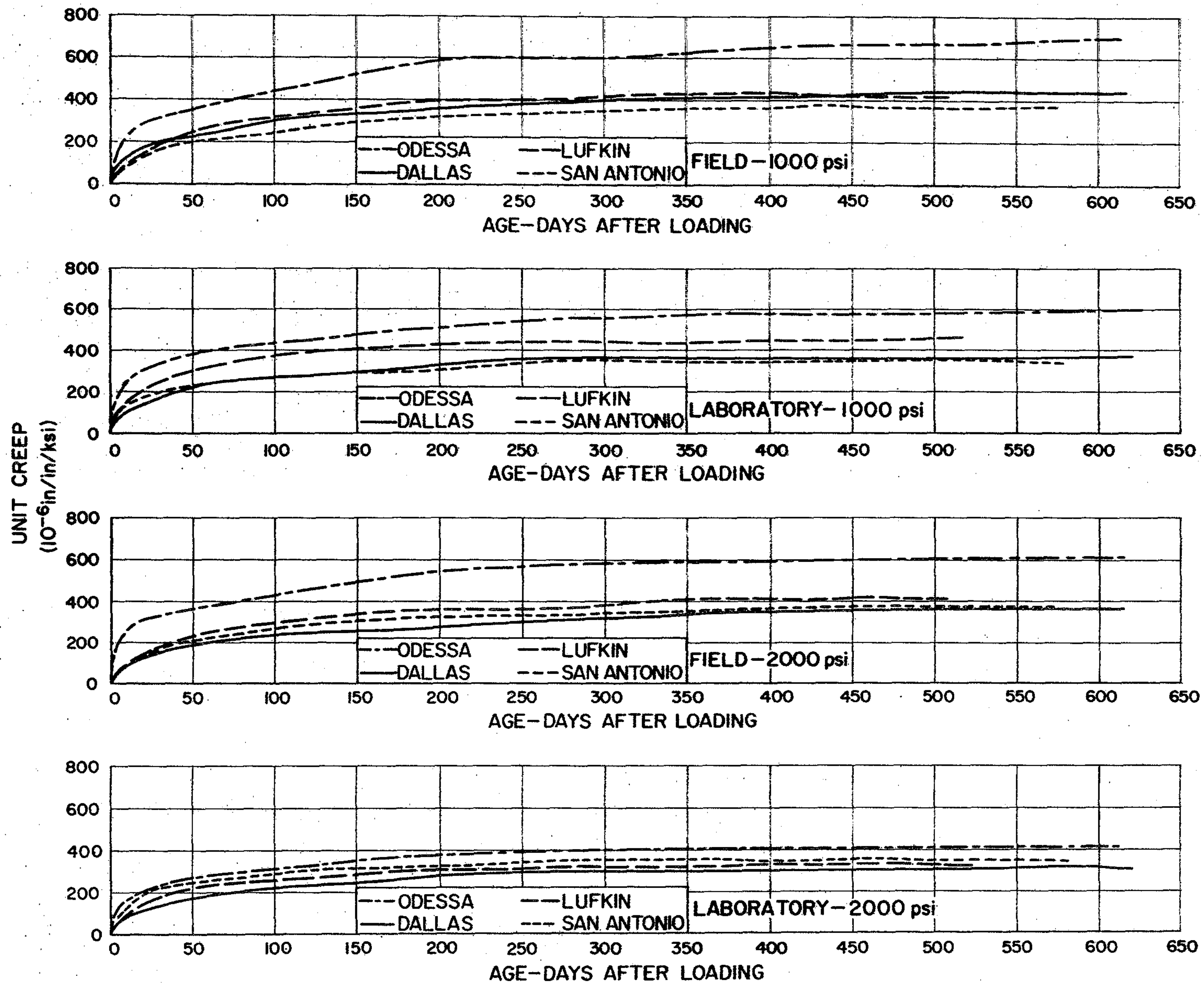

FIGURE 8 — CREEP CURVES FOR THE FOUR LOCATIONS

all the physical properties of aggregate which influence creep of concrete, the modulus of elasticity of the aggregate is probably the most important factor. The higher the modulus the greater restraint offered by the aggregate to the potential creep of the paste. It is seen in Table 3 that the Odessa concrete had a lower modulus of elasticity than the other concretes. This means that more strain, or deformation, occurred per unit of stress for the Odessa concrete than for the other concretes. It is probable that the Odessa aggregate had a lower modulus of elasticity than the other aggregates thus making it an important factor influencing the creep of that concrete.

It is not possible to distinguish separate effects of temperature or relative humidity from the limited weather data. It is noted, however, that the total effect is of primary interest. Now,if a comparison of creep values at 500 days is made between specimens from the same concrete, but different storage environments, it should be possible to see the effect of the environment on the creep of that concrete. It is seen from Table 4 that the creep values from a varying environment of the field are greater than the creep values at a constant environment of the laboratory. Storage location had little effect on creep values of the San Antonio concrete which indicates that the environment of the field storage location was about the same as the laboratory. In contrast, it is seen that the creeps from field stored concrete at Dallas, Lufkin, and Odessa locations were increased approximately 15, 19, and 26 percent respectively, over companion laboratory stored specimens. Hansen and Mattock (3) recognized that a changing humidity, as encountered in the field, will cause greater creep than will a constant condition of humidity.

The creep coefficient of a concrete, ratio of creep to elastic strain, gives the designer useful information about long term behavior of the material under load when its elastic behavior is known. The coefficients shown in Table 4 were found from data in Tables 3 and 6. The modulus of elasticity of the materials at release were used to determine elastic strains, and these strains are relatively high because of the low moduli at the very early age of release.

Functions for Creep and Shrinkage

Several methods have been proposed for the prediction of creep and shrinkage for design. Reference 5 contains an excellent discussion on prediction of creep and shrinkage.

Hyperbolic functions are easily developed to represent measured creep and shrinkage data and they readily lend themselves to computer applications. Such functions have been selected to represent the data collected for this report. The functions have the following form:

$$\varepsilon_{sh} = \frac{\varepsilon^{\infty}_{sh} T}{A + T} , \tag{1}$$

where

ε_{sh} = shrinkage strain,

$\varepsilon^{\infty}_{sh}$ = maximum shrinkage strain to which ε_{sh} approaches asymptotically,

T = time in days since measurements began,

A = constant, approximately the time required for ε_{sh} to reach one half $\varepsilon^{\infty}_{sh}$,

$$\varepsilon_{cr} = \frac{\varepsilon^{\infty}_{cr} T}{B + T} , \tag{2}$$

where

ε_{cr} = unit creep strain,

$\varepsilon^{\infty}_{cr}$ = maximum unit creep strain to which ε_{cr} approaches asymptotically,

T = time in days since application of load,

B = constant, approximately the time required for ε_{cr} to reach one half ε_{cr}.

The functions have been developed for both shrinkage and creep curves in the form of equations (1) and (2) and are summarized in Table 6. The hyperbolic functions show the similarity in creeps of the Dallas, San Antonio, and Lufkin concretes and that similarity can be seen in the curves. However, there is enough difference in the curves as to affect the results of computed camber based on these functions for shrinkage and creep. Sinno (6) stated that unit creep strains influence camber growth directly and need to be estimated within $\pm$ 35 x 10^{-6} in./in. to have an accuracy of $\pm$ 0.1 in. of maximum computed camber.

The step-by-step method used in References 1 and 6 has been used with creep and shrinkage functions of Table 6 to make predictions of maximum camber. The beam used for the predictions is a 56 ft long simply supported Texas Highway Department Type B beam with thirty-two 7/16 in. diameter prestressing strands tensioned to 18.9 kips per strand. No external load is applied to the beam. Those predicted maximum cambers are shown in Figure 9. It is seen from that figure that the camber predictions

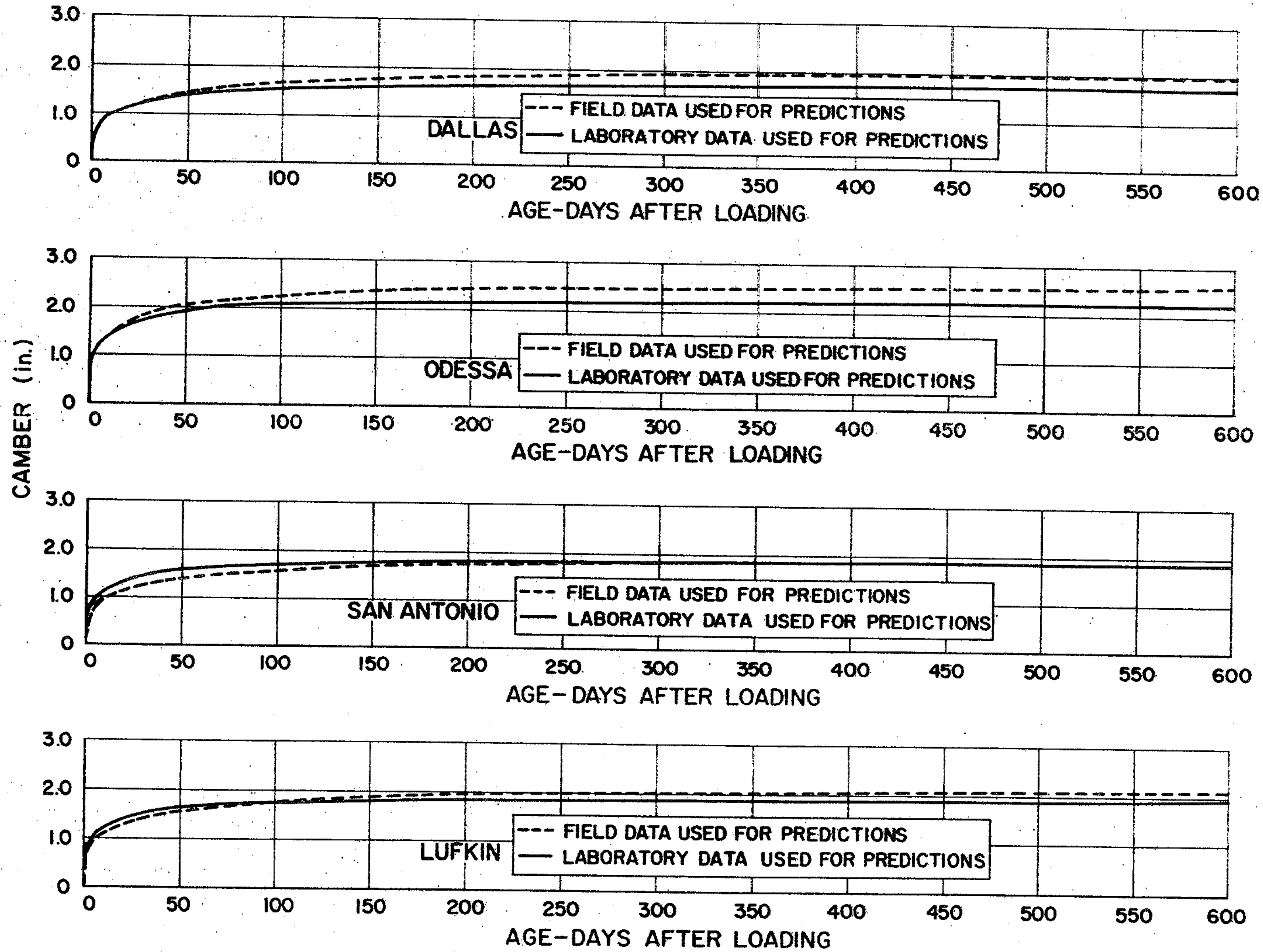

FIGURE 9 - PREDICTED CAMBER OF THD TYPE B, 56 FOOT SPAN PRE-STRESSED BEAM USING METHOD OF REFERENCE 6

will vary depending upon the creep and shrinkage functions used. Camber predictions based on laboratory data were practically the same as those based on field storage for the San Antonio concrete. Similar comparisons of predicted cambers at Odessa, Dallas, and Lufkin show that the cambers based on functions from field data are approximately 13, 12, and 10 percent respectively greater than cambers based on functions from laboratory data.

TABLE 6. Summary of Functions for Shrinkage and Creep

Concrete Producer Location	FIELD DATA Shrinkage	FIELD DATA Creep	LABORATORY DATA Shrinkage	LABORATORY DATA Creep
Dallas	$\frac{315\ T^*}{20 + T}$	$\frac{440\ T}{60 + T}$	$\frac{500\ T}{15 + T}$	$\frac{365\ T}{40 + T}$
Odessa	$\frac{525\ T}{10 + T}$	$\frac{675\ T}{40 + T}$	$\frac{650\ T}{20 + T}$	$\frac{525\ T}{25 + T}$
San Antonio	$\frac{380\ T}{25 + T}$	$\frac{400\ T}{50 + T}$	$\frac{500\ T}{20 + T}$	$\frac{385\ T}{25 + T}$
Lufkin	$\frac{290\ T}{25 + T}$	$\frac{460\ T}{50 + T}$	$\frac{450\ T}{25 + T}$	$\frac{430\ T}{45 + T}$
** Houston	$\frac{350\ T}{6 + T}$	$\frac{225\ T}{15 + T}$		

* T - Time in days

** Data from Reference 1. Beam L3-5

The difference in material and cyclic differences of relative humidity and temperature at the various locations determine values of parameters in the parabolic functions which appear in the creep and shrinkage functions used in making the camber predictions. The range, minimum to maximum values from Figure 9, of the mid-span camber presented in Figure 10 reflects those differences. Also shown in Figure 10 is the predicted and measured camber for beam L3-5 of Reference 1; a 56 ft long Texas Highway Department Type B beam. It can be seen from Figure 10 that the use of creep and shrinkage data developed in Houston, Texas to predict camber for a similar beam made and stored at any of the locations reported here could underestimate the camber by as much as 100 percent. Thus it is seen that materials and environment can have a great influence on camber prediction of prestressed concrete bridge beams. The designer should have information on the particular materials used in the design as well as the behavior of concretes in the area of installation in order to make close predictions of the service behavior of the structure.

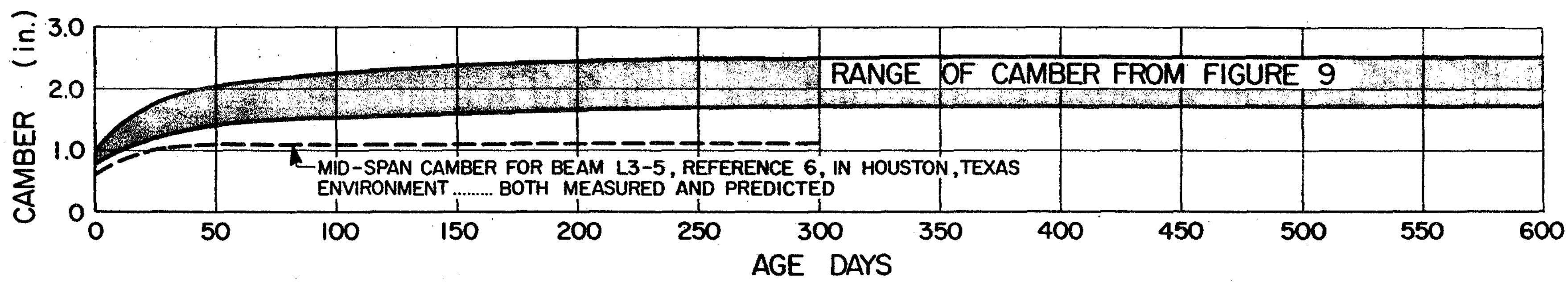

FIGURE 10 – RANGE OF CAMBERS FROM FIGURE 9

CONCLUSIONS

This research was undertaken to determine the influence of materials and environment, typical of four geographical areas of Texas, on creep and shrinkage of plain concrete. Tests on specimens designed for collection of time dependent strains of loaded and non-loaded concretes were collected to reach the objective of this research. The shrinkage strains were measured for non-loaded 3 x 3 x 16 in. prisms. The total strains, measured from prisms loaded parallel to their axis, were used to determine the creep strains by subtracting the elastic and shrinkage strains and dividing by the applied stress.

Duplicate sets of specimens cast at Dallas, Odessa, San Antonio, and Lufkin were made and cured alongside pretensioned prestressed beams fabricated for the Texas Highway Department. One set was stored near the place of fabrication and the other set stored in the laboratory at 73°F, 50 percent relative humidity for the duration of the test.

Conclusions

On the basis of test conditions and results reported herein, the following conclusions may be made:

1. Climatic conditions under which concrete is stored influences both creep and shrinkage.
    a. Shrinkage of specimens stored in open air at (or near) place of fabrication was not as great as that of companion specimens stored in the laboratory under conditions of constant temperature and relative humidity according to these ratios:

Place	Ratio: Field shrinkage/Laboratory shrinkage (at 500 day age)
Dallas	0.62
Odessa	0.82
San Antonio	0.75
Lufkin	0.65

b. Creep of specimens stored in open air at (or near) place of fabrication was greater in three out of four cases, than that of companion specimens stored in the laboratory under conditions of constant temperature and relative humidity according to these ratios:

Place	Ratio: Field creep/Laboratory creep (at 500 day age)
Dallas	1.14
Odessa	1.26
San Antonio	0.97
Lufkin	1.20

2. Computations for camber of prestressed beams, using the method discussed in this report, should be based on creep and shrinkage data from concrete made from the same materials and stored in the same area as the structure of which the beams are to be an integral part.

3. Shrinkage and unit creep may be expressed as hyperbolic functions of time.

Recommendations

In computations for prestress loss and camber of prestressed beams, creep and shrinkage should be determined as nearly as practicable for the concrete and location of the structure. Information on the materials used in the concretes of this study is contained in Tables 2 and 3 of the report, and the locations are given for sources of the materials. For those locations and materials the final (old age) shrinkage and creep values should be those found in the study, namely:

	Dallas	Odessa	San Antonio	Lufkin
Shrinkage (10^{-6} in./in.)	315	525	380	290
Unit creep (10^{-6} in./in./ksi)	440	675	400	460

The functions developed for shrinkage and creep of the materials in the locations of the field tests may be used with the prestress loss and camber computer program reported in Reference 1. Those functions are:

	Dallas	Odessa	San Antonio	Lufkin
Shrinkage (10^{-6} in./in.)	$\frac{315\ T}{20 + T}$	$\frac{525\ T}{10 + T}$	$\frac{380\ T}{25 + T}$	$\frac{290\ T}{25 + T}$
Unit creep (10^{-6} in./in./ksi)	$\frac{440\ T}{60 + T}$	$\frac{675\ T}{40 + T}$	$\frac{400\ T}{50 + T}$	$\frac{460\ T}{50 + T}$

In all cases, T is the time in days of age, assuming that measurements began at one day age at time of prestressing.

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