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16. ABSTRACT

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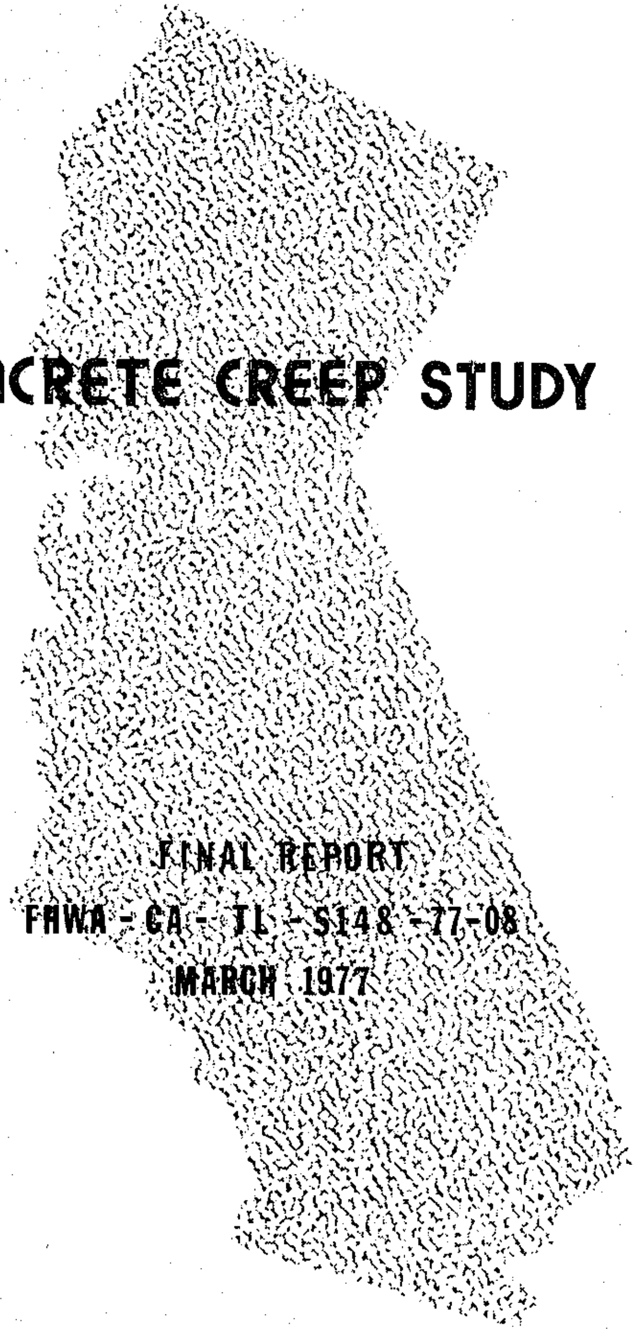

CONCRETE CREEP STUDY

FINAL REPORT

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DEPARTMENT OF TRANSPORTATION
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OFFICE OF TRANSPORTATION LABORATORY

March 1977

FHWA No. D-3-17(5)
TL No. 635148A

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

CONCRETE CREEP STUDY

Study made by . . . . Roadbed & Concrete Branch

Under the Supervision of . . . . D. L. Spellman

Principal Investigator . . . . S. N. Bailey

Co-Investigator . . . . P. E. Mason

Report Prepared by . . . . P. E. Mason

Assisted by . . . . B. F. Neal

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

SNB:lb

ACKNOWLEDGEMENTS

The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the State of California, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
CONCLUSIONS	2
IMPLEMENTATION	3
TESTING PROGRAM	4
Materials	4
Mixing and Fabricating	7
Testing	7
DISCUSSION	11
ADDITIONAL TESTING	14
SUMMARY	16
REFERENCES	17

List of Tables

Table 1,	Aggregate Petrography	5
Table 2,	Aggregate Test Results	5
Table 3,	Aggregate Gradings	6
Table 4,	Fresh Concrete Tests	6
Table 5,	Hardened Concrete Tests	9
Table 6,	Movement vs Age	10
Table 7,	Creep Relationships	12
Table 8,	Test Results - Source P	15

List of Figures

Figure 1,	Movement vs Age	10

INTRODUCTION

A matter of considerable concern to people who design and construct concrete structures is the deformation of certain concrete members which takes place with time. Two of the major contributing factors to this deformation are the shrinkage of the concrete caused by drying, and the creep caused by short term and sustained loads. The increased use of prestressed concrete in bridge construction was accentuated the problem of predicting the ultimate deflection of bridge members. Complicating the problem in California is the wide variety of aggregate types used in structural concrete.

The objective of this study was to develop techniques to assist bridge designers and construction engineers in determining factors to compensate for deflections due to shrinkage and creep.

Development, installation and initial testing of equipment was described in detail in a previous report (1). The equipment consists of frames to hold three 6 by 16 inch (150 x 400 mm) cylinders in a vertically stacked configuration. A uniform vertical load is applied by a hydraulic system. Shrinkage specimens are vertically stacked in a frame but no load other than their own weight is applied. This system is similar to that developed at the University of California (2).

Described in this report is the creep and shrinkage performance of concrete made from three different aggregate sources.

CONCLUSIONS

Based on the tests reported here and under the described conditions, the following conclusions are considered warranted:

For concrete made with a given mix design:

1. The modulus of elasticity increases with age and with increase in compressive strength.

2. Creep is less when compressive strength and the E Modulus is allowed to increase before the load is applied. Elastic deformation is also less under these conditions.

When concrete is made from different aggregate sources, but with basically the same mix design:

3. The relationships between creep, compressive strength and the E Modulus is not linear.

4. Absorption of the aggregate is an indicator of potential creep; aggregates with higher absorption values generally will have greater creep potential.

Although test data is limited, it is considered feasible to predict creep and shrinkage values for periods up to one year on the basis of tests on concrete specimens for approximately 77 days. Test concrete should be made from the ingredients and in the proportions to be used in a specific structure.

IMPLEMENTATION

The findings from this study have been transmitted to the Office of Structures and are being used to supplement a larger study of bridge deflections and movements.

TESTING PROGRAM

Materials

For the testing program three widely scattered aggregate sources were selected:

Source "A" is located about 90 miles (145 km) south of San Francisco. Coarse aggregate is crushed quarry rock, and sand is from a pit in the San Benito River Flood plain.

Source "L" is located in the Livermore Valley east of Oakland. Coarse and fine aggregates are obtained from the ancestral alluvial fan built up deposits of the Arroyo Del Valle and Arroyo Del Mocho streams and tributaries.

Source "O" is located about 60 miles (97 km) northwest of Los Angeles. Material is taken from old stream beds of the Santa Clara River, and Santa Paula and Sespe Creeks. Coarse aggregate is processed through a heavy media plant to remove lightweight unsound particles.

Tables 1 and 2 show the petrography and physical properties of the aggregates. Table 3 shows the aggregate gradings used in all concrete mixes.

Cement used in all concrete was Type II Modified, with fineness by the Blaine method of 3715cm^2/gram. Compressive strength of 2x2-inch (50x50mm) mortar cubes at 7 days by Test Method No. Calif. 515 was 3440 psi (24Mpa). Shrinkage of 1x1x11-1/4-inch (25x25x285mm) mortar bars at 3 days was 0.038% (Test Method No. Calif. 527).

The design cement content of the concrete was 7 sacks per cubic yard (0.76m^3). No admixtures were used.

TABLE 1

AGGREGATE PETROGRAPHY

SOURCE	COARSE	FINE
A	Quartz diorite 100%	Quartz 48% Quartzite 11% Feldspar 11% Sandstone 6% Granitic 6% Ultra basic 5% Volcanic 4% Vein quartz 3% Chert 2% Carbonate 2%
L	Sandstone & meta sandstone 48% Vein quartz 20% Quartz and quartzitic meta sediments 13% Volcanic & meta volcanic 8% Chert 7% Ultra basic 2% Shist 1% Granitic 1%	Sandstone 40% Quartz 18% Vein quarts 15% Granitic 11% Quartzite 5% Volcanic and meta volcanic 4% Ultra basic 3% Chert 2% Shist 1% trace of siltstone
O	Sandstone 64% Granitic & meta granitic 23% Gneiss 6% Quartzite 4% Fossiliferous sandstone 2%	Quartz 40% Sandstone 18% Granitic 12% Quartzite 10% Feldspar 9% Volcanic 7% Shale 3% Trace of mica

TABLE 2

AGGREGATE TEST RESULTS

	COARSE		FINE	
Source	Sp.G., SSD	Abs., %	Sp.G., SSD	Abs., %
A	2.88	0.7	2.61	1.4
L	2.70	1.3	2.65	1.6
O	2.60	1.7	2.57	1.6

TABLE 3

AGGREGATE GRADING, % PASSING

SIEVE SIZE		COARSE, 52% A	L	O	FINE, 48% A	L	O	COMBINED A	L	O
1-1/2"	(37.5mm)	100	100	100				100	100	100
1"	(25.0mm)	100	100	96				100	100	98
3/4"	(19.0mm)	98	96	49				99	98	73
3/8"	(9.5mm)	62	33	4	100	100	100	80	65	50
#4	(4.75mm)	9	6	1	98	100	100	52	51	48
#8	(2.36mm)	3	1	1	91	92	95	46	44	46
#16	(1.18mm)				72	65	78	35	31	37
#30	(600µm)				44	39	51	21	19	24
#50	(300µm)				16	15	18	8	7	9
#100	(150µm)				3	5	7	1	2	3
#200	(75µm)				1	2	5	0	1	2

TABLE 4

FRESH CONCRETE TESTS
(Average of 18 Tests)

Source	Slump, Inches	W/C Ratio	Cement Sks./cy	Unit wt. Lbs./CF
A	3.75	0.50	7.0	152
L	4.0	0.49	7.0	149
O	3.5	0.50	7.0	145

Note: 1" = 25.4mm
7Sk/cy = 390Kg/m^3
1 lb. = 453.6gm
1 CF = 0.0283m^3

Mixing and Fabricating

Approximately 2 cubic ft. ($0.23m^3$) batches of concrete were mixed in a laboratory tub-type mixer, following standard laboratory procedures. Water was added to produce approximately 4 inches (100 mm) of slump. Tests were made on the fresh concrete prior to molding of specimens. A total of 18 batches were made for the testing of each source. A summary of the fresh concrete tests is shown in Table 4.

Two 6" diam. x 16-inch (150x400mm) cylindrical specimens, (1 each for creep and shrinkage) and six 6x12-inch (150x300mm) cylinders, for compressive strength, and modulus of elasticity were fabricated from each batch. In the creep and shrinkage specimens, three sets of gauge pins were placed 10 inches (254 mm) apart vertically and at intervals of 120° around the circumference for measuring length changes. The gauge points were located equidistant from the ends to eliminate any variation that might be caused by end reactions. The three evenly spaced measuring lines were to eliminate the effects of any eccentricity in loading. Also, the cylinder ends were lapped to assure planeness.

Following demolding, all specimens were placed in the moist curing room until testing was started.

Testing

Specimens of the concrete made from each aggregate source were divided into 6 groups. Groups 1 and 2 were scheduled for beginning of tests when the concrete was 10 days of age, groups 3 and 4 at 28 days, and groups 5 and 6 at 60 days. For each group there were 3 creep specimens, 3 for shrinkage, and 18 for compressive strength and other tests.

On the beginning test date, creep and shrinkage specimens were removed from the moist room and placed in a drying room maintained at 50% RH and 73°F (23°C). Since each creep testing frame holds 3 specimens, one cylinder from each of the three aggregate sources was placed in the same frame. In succeeding frames, the stacking sequence of cylinders representing each aggregate source was varied to eliminate any local effects of environment or load. Both creep and shinkage specimens were placed in frames according to this procedure but the specimens for shrinkage measurement were not loaded.

Initial length measurements of all specimens were obtained and a 1200 psi (8 Mpa) load was applied to the creep test cylinders. Measurements were again made to determine the elastic deformation due to the initial load and then periodically thereafter. The 1200 psi (8 Mpa) load was maintained until the end of the testing period.

Testing of corresponding 6x12 (150x300mm) cylinders for each group was done on the day loading began. Table 5 shows a summary of the test results. It also lists the ratio of the 1200 psi (8 Mpa) load to the strength of the concrete at the time creep testing began.

Length measurements of the creep and shrinkage specimens were made periodically for 77 days for the first 3 groups and 98 days for the last 3. After the last measurements, the load was released from the creep specimens and additional measurements made to determine elastic recovery. A summary of the length changes with time is given in Table 6 and shown in generalized form in Figure 1. The average shrinkage and elastic deformation have been removed from the total length change so that only that

TABLE 5

HARDENED CONCRETE TESTS

Source	Comp. Str., PSI Age in Days			Creep Load/ Compressive Strength Ratio @ Age, in Days			Chord Mod. "E" PSIx10^6 (ASTM C-469) Age in Days		
	10	28	60	10	28	60	10	28	60
A	4530	6385	7130	.26	.19	.17	3.93	4.40	4.61
L	4290	5805	6400	.28	.21	.19	3.19	3.64	4.06
O	4020	5190	5885	.30	.23	.20	2.88	3.30	3.52

Note: 1 PSI = 6.89 kPa

TABLE 6

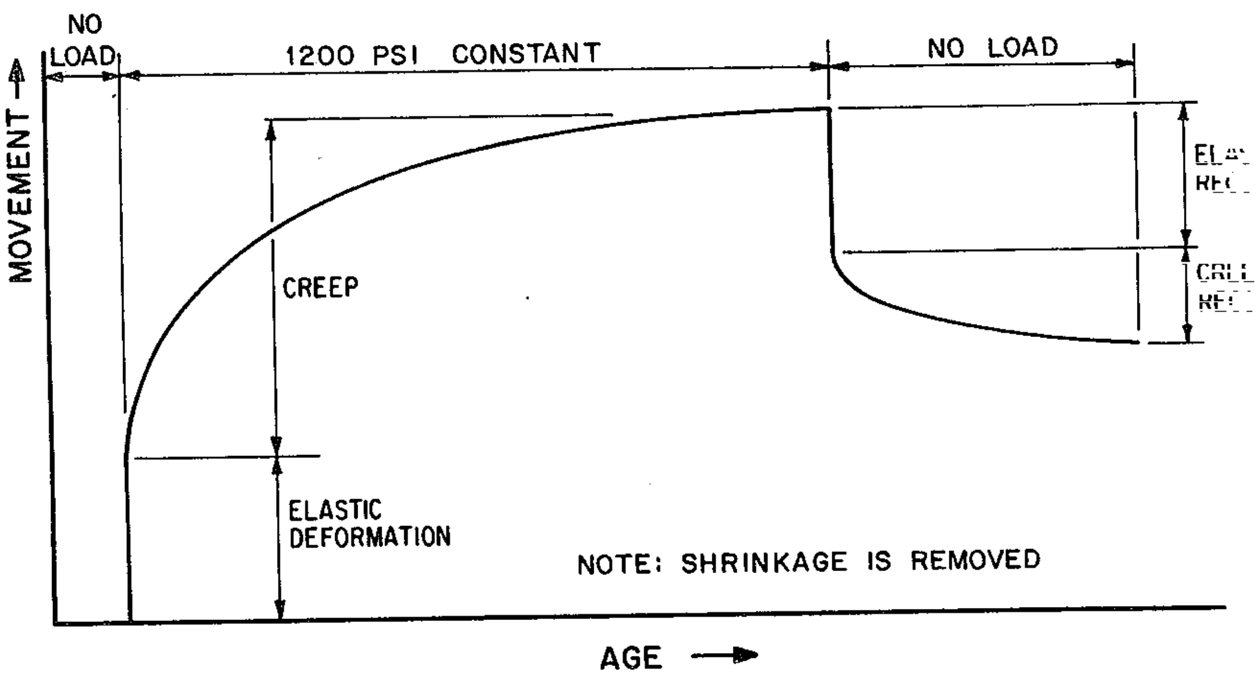
MOVEMENT VS. AGE (Inches per Inch x 10^{-5})

Test Group	Age at Load, Days	Days of Load	Elastic Defor-mation	Creep	Elastic Recovery	Creep Recovery*	Shrinkage During Cure
1 A	10	77	32	53	25	23	42
2 A	10	77	33	49	24	18	43
3 A	28	77	27	32	22	19	43
4 A	28	98	27	37	22	15	46
5 A	60	98	25	34	22	13	46
6 A	60	98	26	32	24	13	47
1 L	10	77	39	65	28	25	66
2 L	10	77	39	59	27	24	68
3 L	28	77	32	46	24	22	62
4 L	28	98	35	51	25	22	72
5 L	60	98	29	46	23	18	69
6 L	60	98	29	43	25	19	69
1-0	10	77	43	60	30	28	61
2-0	10	77	38	57	29	25	65
3-0	28	77	39	56	29	24	56
4-0	28	98	39	52	29	21	65
5-0	60	98	35	56	28	26	62
6-0	60	98	35	46	28	21	60

*After 29 weeks

Note: 1 in. = 25.4 mm

FIGURE 1



Note: 1200 PSI = 8 MPa

portion of change attributable to creep alone is shown under that heading. The creep recovery after 29 weeks is shown in the table, but approximately 90% of the change occurred in the first 15 weeks.

DISCUSSION

Other researchers (3)(4) have reported relationships between creep and (1) total amount of aggregate in a concrete mix; (2) absorption of the aggregate; (3) w/c ratio; (4) compressive strength; (5) modulus of elasticity (E); and (6) shrinkage. Since the amounts of aggregate and water were practically the same for all the test concrete, the potential influences of these factors on the creep and shinkage of the three concretes tested should be negligible. A summary of the aggregate absorption, modulus of elasticity, creep and shrinkage measurements is shown in Table 7.

Based on data from Table 6 (77 and 98 days of loading), Average Elastic Deformation (all 3 sources) when loaded @:

10 days	28days	60 days
100%	89%	80%

Average Creep Deformation (all 3 sources) when loaded @:

10 days	28 days	60 days
100%	81%	75%

The age at time of loading (compressive strength gain) has a slightly greater effect on creep deformation than an elastic deformation. The expected total deformation when load at 60 days is about 75 to 80% of that occurring when loaded at 28 days.

TABLE 7

CREEP RELATIONSHIPS

Source	Combined Agg. Absorp.,%	Modulus E PSIx10^6 Test Age, Days 10	28	60	Creep @ 77 days load, In./In.x10^{-5} Age at Loading 10	28	60	Shrinkage @ 77 days In./In.x10^{-5} Days Wet Cure 10	28	60
A	1.04	3.93	4.40	4.61	51	34	30	42	44	44
L	1.44	3.19	3.64	4.06	62	47	41	67	65	64
O	1.65	2.88	3.30	3.52	59	53	47	63	58	56

Note: 1 PSI = 6.89 kPa

1 in. = 25.4 mm

From Table 7, the relative creep after 77 days of load was as follows:

Age at load	10 days	28 days	60 days
Relative Creep	100%	78%	67%

Since the modulus of elasticity is greater at later ages and the ratio of load to strength is lower at later ages, a reduction in measured creep was to be expected.

It is apparent that creep was significantly greater for concrete loaded at 10 days of age, even though compressive strength was over 4000 psi (28 Mpa). For the cylinders loaded at 28 and 60 days, however, there is a relationship between creep and the parameters of aggregate absorption, compressive strength, and the E modulus. The same degree of relationship was not found for shrinkage, at least for aggregate sources L and O. This is most likely explained by the petrography of the aggregate as shown in Table 1. Quartz and granitic materials have low shrinkage characteristics and sandstones cause higher shrinkage. The combined aggregate from source L has about 2% more sandstone than source O.

Creep and shrinkage strains with time were analyzed to determine best fit curve equations. Since the movements are quite rapid during the first few days of drying, the analyses were based on the period from 10 days to 77 or 88 days after loading. For shinkage the best fit equation was:

$$S = At^B \qquad (1)$$

where A and B are constants, and t is time from 10 to 77 to 98 days.

For creep, the equation was:

$$C = B + A\ (\text{Log}_{10} t) \qquad (2)$$

The Index of Determination used for evaluating the equations ranged from 0.97 to 0.99, indicating a very good fit.

ADDITIONAL TESTING

Following these tests and discussions with bridge personnel, the Laboratory was requested to perform similar tests on concrete being used in an on-going bridge construction project. Although not done as part of this project, the results were compared to those already analyzed. Information on the aggregate and test results are shown in Table 8.

One of the major differences in this concrete was the addition of a water-reducing, set-retarding admixture. This may partly explain why the relationships between creep and aggregate absorption, modulus E, and compressive strength are not the same as those used for this project as shown in Table 7 for the other 3 sources. However, the best fit equations previously developed also fit the new data for loading periods up to 98 days. When shrinkage and creep measurements up to 365 days were analyzed, different methods were needed to provide more accurate predictions. The most accurate procedure was found by using equation (2) for combined shrinkage and creep, then subtracting out shrinkage determined by another equation to establish predicted creep. The new equation is:

$$S = \frac{t}{A + Bt} \qquad (3)$$

The results of these latter tests indicate that the relationship of creep to other parameters, such as aggregate absorption, compressive strength, and modulus of elasticity, changes with different mix designs. While this finding was not unexpected, it does emphasize the need for individual mix design testing to determine predictive concrete movement values. Knowledge of other related parameters may give indications of relative movement when different sources are being considered.

TABLE 8

TEST RESULTS - SOURCE P

Age at Load, Days	10	28	57
Elastic Deformations, In./In.x10^{-5}	35	29	21
Creep @ 365 days load In./In.x10^{-5}	75	51	44
Creep @ 77 days load	57	36	25
Modulus E @ Loading PSIx10^{6}	4.81	5.72	5.90*
Shrinkage @ 365 days In./In.x10^{-5}	56	60	53
Compressive strength PSI @ Loading Age	5960	6640	7380*
Creep Load/Strength Percent	20	18	16

*90 day tests

Source P is an ancestral flood plain deposit of the American River located east of Sacramento. Aggregate is predominantly basic metaigneous and quartzitic metasediments. Sp.Gr., SSD and percent absorption for coarse and fines is 2.73 and 0.7, and 2.66 and 2.2, respectively. Combined aggregate absorption is 1.25 percent.

Note: 1 in. = 25.4 mm

1 PSI = 6.89 kPa

SUMMARY

The general practice has been to estimate the four-year deflection by calculating initial deflection due to dead loads, then multiply it by a factor. (A factor of 3 has been frequently used.) This practice has been used with a fair degree of success in deciding what camber to build into a structure, but it has been varied at times when it became apparent a change was needed. The information gained about the creep and shrinkage of various aggregates indicate that a single factor should not be expected to yield the best results. The differences of mechanical properties of concretes made with different aggregates does appear to be significant and, therefore, it would be helpful to determine these properties of the concrete actually going into the work.

Using the techniques and procedures developed in this research, the effects of a 1200 pound (8 Mpa) load on the creep of concrete can be estimated after approximately 11 weeks of testing. It is hoped that observations and measurements of actual movements by the construction engineer can now be correlated to the predictive movements so that more satisfactory allowances for deflections of concrete members will be attained.

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