HIGHWAY RESEARCH REPORT

INVESTIGATION OF RESISTANCE OF CONCRETE TO CRACKING

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DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 635155

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February, 1968
M&R Report No. 635155

Mr. J. A. Legarra
State Highway Engineer
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Sacramento, California

Dear Sir:

Submitted herewith, is a research report entitled:

INVESTIGATION OF RESISTANCE

OF CONCRETE TO CRACKING

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Very truly yours,

JOHN L. BEATON
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REFERENCE: Spellman, D.L., Stoker, J.R., and Woodstrom, J.H. "Investigation of Resistance of Concrete to Cracking", State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report No. 635155, February, 1968

ABSTRACT: Concrete mixes containing water-reducing admixtures were compared to plain concrete with respect to cracking resistance. The shrinkage of concrete was restrained by an internal steel bar. The measured strain in the bar was used to compute the stresses in the concrete up to the point of cracking. The tension induced by the restraint of drying shrinkage of the concrete ultimately caused failure by tensile cracking. Corresponding shrinkage measurements were made on unrestrained shrinkage specimens.

The test procedure originally developed for this study was changed during the course of the project to overcome some apparent failure to achieve adequate bond to steel. Although the changes eliminated further bond failures, additional modifications would have to be made to improve repeatability and sensitivity of the test. A large number of tests would be required to produce statistically significant results.

KEY WORDS: Concrete, portland cement, admixtures, restrained shrinkage, cracking, testing, test methods.

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The opinions, findings, and conclusions expressed in this report are those of the authors and are not necessarily those held by the Bureau of Public Roads.

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INVESTIGATION OF RESISTANCE OF CONCRETE TO CRACKING

INTRODUCTION

Since some water-reducing admixtures increase drying shrinkage, their use in concrete in California highway and bridge construction is restricted. In an effort to minimize cracking and other problems associated with drying shrinkage, specifications have been written to prohibit the indiscriminate use of admixtures and to limit the dosage of any admixture approved for use.

Although some suppliers of water-reducing admixtures claim that their products reduce the cracking tendencies of concrete, nothing could be found in available literature to either substantiate or refute their claims. The research reported here was initiated to investigate the cracking resistance of concrete containing such admixtures compared to that of similar concrete without admixtures.

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CONCLUSIONS

While there were some inconsistencies in the test results, the following limited conclusions can be drawn.

The addition of a water-reducer increased drying shrinkage and shortened the time to concrete failure in tension. The effect of the two water-reducing retarders on shrinkage and time to cracking was not significant.

The test procedure as used lacks sufficient sensitivity for comparing concretes having small differences in shrinkage caused by admixtures.

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TESTING PROGRAM

This cracking resistance study involved fabricating concrete beams with internal restraint, allowing them to dry and shrink, then calculating the stress in the concrete at the time of cracking. Specimens fabricated for restrained shrinkage tests contained a 1-1/4-inch diameter steel rod, the ends of which were threaded to achieve bond. The central portion of the rod was prevented from bonding to the concrete by a rubber sleeve (see Figure 1).

Unrestrained shrinkage specimens were also fabricated to determine drying shrinkage of the concrete after 14 days of drying and at the time cracking occurred in the restrained specimens.

Three series of tests were made during this study. Aggregates for the first two series were of 1-inch maximum size from a source that exhibits comparatively high shrinkage characteristics. Aggregates for the third series were also of 1-inch maximum size, but were from the American River near Sacramento and have considerably lower shrinkage characteristics. All mixes contained 52% coarse aggregate and 48% sand, and Type II modified cement conforming to California Highway Specifications, except for one mix in Series 3 which was made with commercially available compensated shrinkage cement. Physical properties of the mixes are shown in Table 1.

Three different water-reducing admixtures were used in the tests. The manufacturer's normal recommended dosage was used for the mixes containing admixtures. The admixture designations and descriptions are:

Admixture	Description
A	Water Reducer (Lignosulfonate)
B	Water Reducing Set Retarder (Hydroxylated Carboxylic Acid)
C	Water Reducing Set Retarder (Lignosulfonate)

All batches with the same batch designation in each series were mixed on the same day and subsequent batches were

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mixed on a different day, usually a week or more later than the preceding batch.

Test Series No. 1

Two concrete mixes were used in this series - a control mix with no admixture and one with admixture A. Two rounds of each concrete were mixed. A 5x5x40-inch restrained specimen and an unrestrained 4x5x18-inch shrinkage specimen was fabricated from each batch. The 1-1/4-inch diameter restraining rod was threaded for 3 inches on each end. These mixes were designated 1 and 2 respectively (see tables).

Test Series No. 2

In this series, three batches of each of three concrete mixes were made. These mixes consisted of a control; one containing admixture B and one admixture C. Three 5x5x40-inch restrained specimens and three 4x5x18-inch shrinkage specimens were fabricated from each concrete mix. One restrained specimen and one unrestrained shrinkage specimen was fabricated from each batch of concrete. The restraining rods were threaded for 3 inches on each end. These mixes were designated 3, 4, and 5 respectively.

Test Series No. 3

For this series of tests, the restraining system was altered to reduce the possibility of bond failure. The length of threads on each end of the steel rods was increased from 3 inches to 4 inches. The cross-section of the beam was reduced from 5x5 inches to 4.5 inches. A 3-inch diameter hoop made from a No. 3 reinforcing bar was placed around the approximate center of the threaded portion of the steel rod as the concrete was placed.

Two rounds of each of four concrete mixes were made; a control, and mixes containing admixtures A, B, and C. These mixes were designated Nos. 6, 7, 8, and 9 respectively. One batch of a concrete mix, designated No. 10, was made using compensated shrinkage cement. One 4x5x40-inch restrained specimen and one 4x5x18-inch shrinkage specimen was fabricated from each batch of concrete. To compare flexural strength to calculated tensile strength, a 6x6x20-inch beam was also fabricated from each batch.

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Restrained Shrinkage Tests

All of the 40-inch restrained shrinkage specimens were cured for 7 days in the moist room (73°F and 100% relative humidity), then placed in laboratory air at 73°F ± and 50% ± relative humidity. Initial length measurements were made upon removal from the moist room followed by measurements taken at least three times weekly until the concrete cracked.

In Test Series No. 1, length changes of the steel were determined from three SR4 strain gages placed under the rubber sleeve at a distance of 12 inches from one end and at points 120° apart on the circumference. For the other two series, measurements were made with a length comparator (see Figure 2).

Tensile stresses in the concrete were calculated from the length measurements by determining the change in length of the steel rod and using the equation:

$$S_c = \left(\frac{\Delta L}{L}\right)\left(\frac{A_s}{A_c}\right) E_s$$

Where S_c = Stress in concrete

ΔL = change in length of restraining steel rod (difference between initial length and length at time of measurement)

L = Gage length of steel rod (unbonded length plus one-half bonded length), 37 inches for Series 1 and 2, and 36 inches for Series 3.

A_s = Cross-sectional area of steel in square inches

A_c = Net cross-sectional area of concrete in square inches

E_s = Modulus of elasticity of steel, 30×10^6 psi

After the concrete in the restrained beam had cracked, the stress at failure was computed using the length measured on the preceding reading. The actual forces present at the instant of cracking therefore, are probably slightly higher than indicated. Also, accuracy of the calculated stress is dependent upon the strain of the steel and concrete being equal. If any bond

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DISCUSSION

Restrained Specimens

The test results as tabulated in Table 2, show that the concrete in Series 1 failed in tension at a very early age. The concrete containing Admixture A, a water-reducer, failed at an average of 17 days compared to 24 days for the control concrete, although the indicated concrete tensile stress at failure was almost 100 psi greater in the admixture concrete. The tensile stresses in the concrete of this test series were computed from strain gage readings taken on the steel.

In Series 2, five of nine specimens failed in bond rather than in tension. The specimens which failed in bond were first observed to have two or three hairline cracks on the ends. These cracks radiated outward from the steel rod through the center, and increased in length and size as failure progressed. The ultimate bond failure was detected by observing a reversal in length measurements made with a comparator. Stresses computed at concrete-to-steel bond failures were in the same range as stresses of similar concrete at concrete tensile failure. However, it was felt that more valid comparisons could be drawn if bond failures were eliminated from the analysis. The described changes were made to reduce the possibility of bond failure in future tests.

In Series 2 also, tensile failure occurred in the admixture concrete sooner than in the control concrete. The calculated tensile stresses were less for the admixture concrete than for the control concrete.

The changes made in beam size and end restrainment for Series 3 are believed to have prevented bond failures. Another problem occurred however; the second round of Series 3 of all concrete mixes (mixed about one week after the first round), required a much longer time to crack. The cause of this problem may be indicated by measurements taken at the end of the wet curing period. For some unexplainable reason, the concrete in the restrained specimens from the first round appeared to be in tension a slight amount, while that from the second round appeared to be in compression in amounts ranging from 30 to 60 psi when they were removed from the moist curing room. It appears that the specimens from the

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first round did not receive sufficient moisture to provide the slight normal expansion that occurs with wet curing. Moist room record charts for this time period do not reveal any moisture or temperature variations which could provide an explanation of the suspected moisture deficiency in some of the specimens. Again, the calculated tensile stresses at failure were less, on the average, for the admixture concrete than for the control concrete, although by only a small amount.

The restrained specimen made with compensated shrinkage cement failed in tension at a comparatively early age and at a low calculated tensile stress. It was expected that the expansion provided by the "expanding cement" would produce a considerable amount of compressive stress in the concrete by the end of the curing period and thus extend the time to failure. However, measurements made during the curing period indicated variations in stresses from 40 psi tension after one day of cure to 20 psi compression after seven days. This beam was fabricated and cured at the same time as the first batches of the other concretes in Series 3, and apparently it also did not receive sufficient moisture to produce the expected expansion.

Tables 3 and 4 have been tabulated from data shown in Table 2 to illustrate the effect of admixtures tested on time to cracking. Series 2 data has been excluded because of the bond failures that occurred. While these data are considered indicative of admixture effects, they are very limited and it would be necessary to perform additional tests, perhaps using a new or improved test procedure, to verify these results.

Unrestrained Specimens

The drying shrinkage of the unrestrained specimens are shown in Table 2. The use of admixture A, a water-reducer, resulted in an increase in drying shrinkage of approximately 30%. The other admixtures had no significant effect on unrestrained shrinkage. The lower shrinkage of the concrete made with the local aggregate used in Series 3 is readily apparent.

Flexural Strength Specimens

There does not appear to be a direct correlation between tensile strength as determined from the restrained shrinkage beams and the modulus of rupture as determined from the flexural tests. The limited data indicate a wide range of moduli of rupture for a comparatively narrow band of tensile strengths.

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TABLE 1

Physical Properties of Fresh Concrete Mixes*

Series	Mix	Type of Mix	Slump Ins.	Air %	Unit Wt. Lbs./CF	Net W/C Lbs./Sk.	Cement Factor Sk./CY
1	1	Control	3.5	1.7	148.2	53.0	5.95
	2	W.R (Water Reducer) A	3.5	2.7	149.3	47.8	6.00
2	3	Control	3.3	1.7	148.6	52.4	6.00
	4	W.R-retarder B	3.8	1.9	149.4	51.1	5.94
	5	W.R-retarder C	3.7	3.2	148.2	47.6	5.97
3	6	Control	3.3	1.3	152.3	50.8	6.06
	7	W.R. A	3.4	2.0	151.4	47.6	6.05
	8	W.R-retarder B	3.5	1.5	153.0	47.2	6.09
	9	W.R-retarder C	3.4	2.0	151.7	46.5	6.07
	10	Compensated Shrinkage Cement	3.5	2.1	150.1	50.0	5.99

*Physical properties are an average of two tests for Mixes 1, 2, and 6 through 9, and an average of three tests for Mixes 3 through 5. Mix 10 is only one test.

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TABLE 2

Series Number	Mix Designation Mix, Batch, Agent	Concrete beams restrained with 1.25" diameter x 40" steel bar*			% Drying Shrinkage 4x5x18-inch Bars		Modulus of Rupture at Concrete Failure, psi
		Failure, Days Drying	Type of Failure	Calc. Conc. Stress, psi Tension	14 days Drying	At Concrete Failure	
1	1-1 Control	22	Tensile	225	0.039	0.050	--------
	1-2 Control	26	Tensile	175	0.037	0.051	
	Average	24		200	0.038	0.051	
1	2-1 A	18	Tensile	305	0.051	0.056	
	2-2 A	16	Tensile	265	0.049	0.052	--------
	Average	17		285	0.050	0.054	
2	3-1 Control	45	Bond**	345	0.035	0.069	--------
	3-2 Control	58	Bond**	315	0.033	0.072	
	3-3 Control	51	Tensile	375	0.035	0.069	
	Average	51		375	0.034	0.070	
2	4-1 B	37	Tensile	335	0.035	0.060	--------
	4-2 B	41	Bond**	280	0.035	0.064	
	4-3 B	42	Bond**	380	0.037	0.065	
	Average	37		335	0.036	0.063	
2	5-1 C	41	Bond**	365	0.037	0.069	--------
	5-2 C	37	Tensile	315	0.037	0.062	
	5-3 C	50	Tensile	370	0.038	0.072	
	Average	44		345	0.037	0.068	
3	6-1 Control	38	Tensile	390	0.028	0.035	565
	6-2 Control	62	Tensile	410	0.023	0.049	770
	Average	50		400	0.025	0.042	
3	7-1 A	20	Tensile	360	0.031	0.037	515
	7-2 A	32	Tensile	390	0.033	0.044	660
	Average	26		375	0.032	0.040	
3	8-1 B	34	Tensile	335	0.024	0.035	515
	8-2 B	78	Tensile	395	0.025	0.045	713
	Average	56		365	0.025	0.040	
3	9-1 C	38	Tensile	410	0.028	0.041	650
	9-2 C	77	Tensile	380	0.025	0.052	743
	Average	58		395	0.027	0.047	
3	10 C.S.C***	29	Tensile	290	0.025	0.037	415

* 5x5x40-inch beams for Series 1 and 2, and 4x5x40-inch beams for Series 3.
** Beams which failed in bond are not included in the averages or comparisons of restrained shrinkage beams.
*** Compensated shrinkage cement

Note: Admixture A - Lignosulfonate - water reducer
B - Hydroxylated Carboxylic Acid - water reducer-set retarder
C - Lignosulfonate - water reducer-set retarder

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TABLE 3

Effect of Admixture A on Shrinkage and Cracking
(Each value shown is an average of two specimens)

Series Number	Mix No.	Admixture	14-day Drying Shrinkage, %	% Relative Shrinkage	Avg. Time to Cracking, Days	% Relative Time to Cracking
1	1	None	0.038	100	24	100
	2	A	0.050	131	17	71
3	6	None	0.025	100	50	100
	7	A	0.032	128	26	52

TABLE 4

Effect of Admixtures B and C on Shrinkage and Cracking
(Each value shown is an average of two specimens)

Series Number	Mix No.	Admixture	14-day Drying Shrinkage, %	% Relative Shrinkage	Avg. Time to Cracking, Days	% Relative Time to Cracking
3	6	None	0.025	100	50	100
	8	B	0.025	100	56	112
	9	C	0.027	108	58	116

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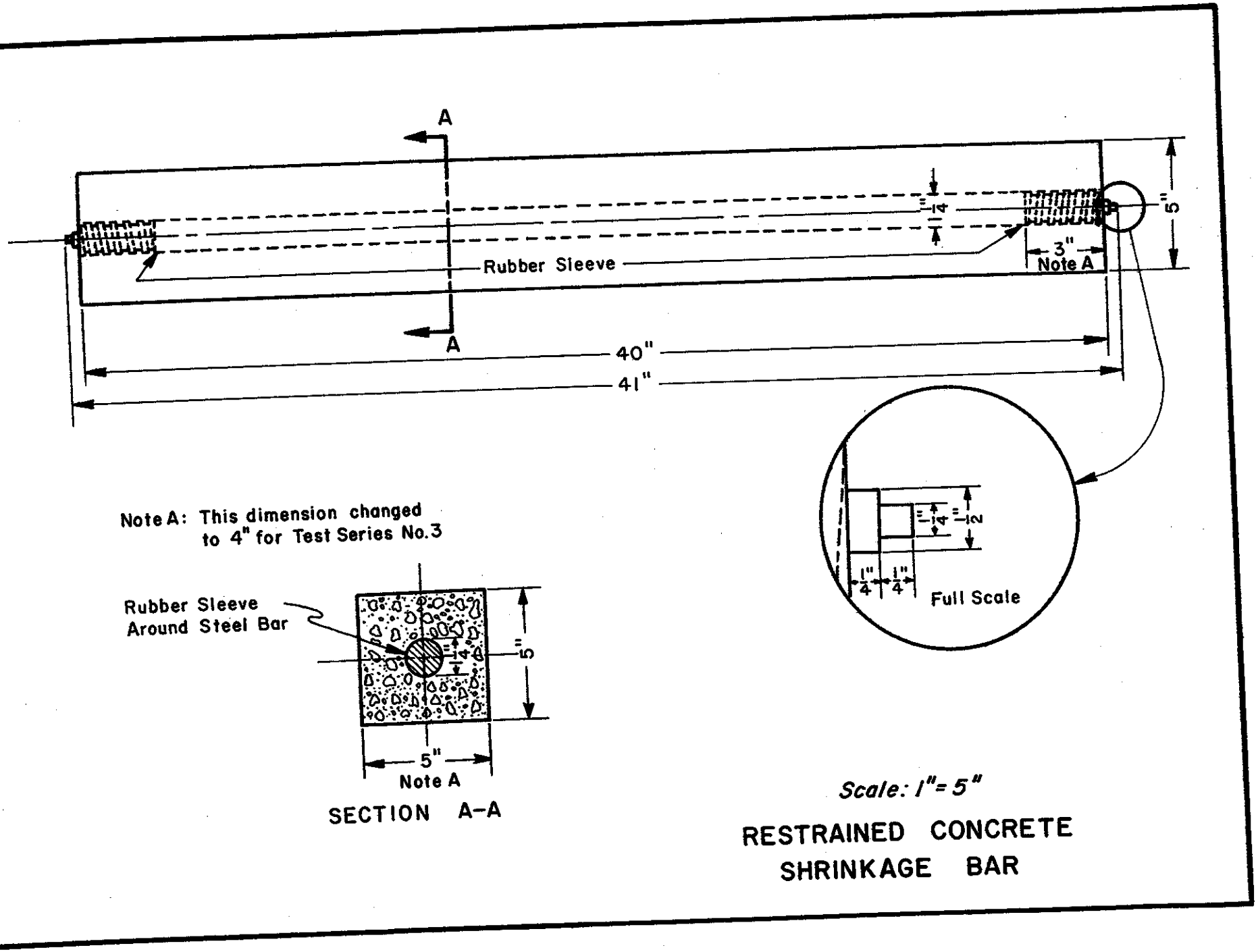

Figure 1

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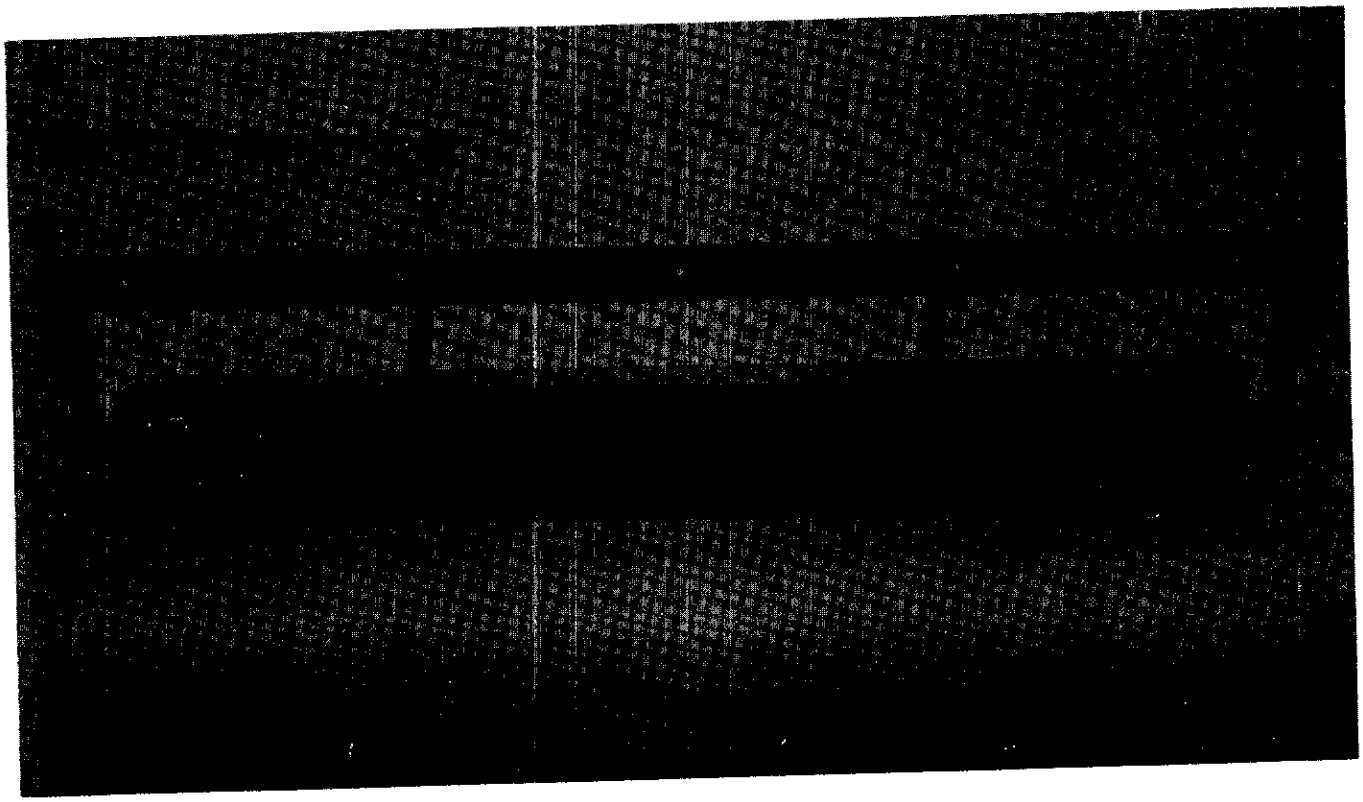

Figure 2 - Length comparator in position for length measurements

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