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NATIONAL BUREAU OF STANDARDS REPORT

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STRENGTH OF JOINTS IN UNREINFORCED CELLULAR CONCRETE BEAMS

by

Arthur F. Kirstein and Harvey M. Shirley

Report to

Bureau of Yards and Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NBS PROJECT | **NBS REPORT**

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STRENGTH OF JOINTS IN UNREINFORCED CELLULAR CONCRETE BEAMS

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To

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Department of the Navy

IMPORTANT NOTICE

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

STRENGTH OF JOINTS IN UNREINFORCED CELLULAR CONCRETE BEAMS

By

Arthur F. Kirstein and Harvey M. Shirley

Load tests were conducted on a number of unreinforced beams containing cellular concrete blocks to determine the strength of the joints between the cellular units. The units were reinforced and were bonded together with various mixtures of epoxy and polyester resins. Deflections, strains, and load-carrying capacities were recorded. It was found that most joint failures could be attributed to the failure of the thin layer of cement paste adjacent to the adhesive in the joint, and only a few joint failures were due to a weakness in the resin.

1. INTRODUCTION

At the request of the Bureau of Yards and Docks, the Structural Engineering Section initiated an investigation to determine the strength of adhesive in the joints of cellular concrete beams containing no longitudinal reinforcement.

The investigation was conducted to determine the cause of apparent joint failures in a series of prestressed cellular concrete slabs, and to give an indication of the amount of handling that an unstressed unit can withstand in a prestressing yard. The scope of this study was extended to include epoxy resin jointing materials that were activated by various different amines and to include a polyester resin as a jointing material.

2. DESCRIPTION OF TEST SPECIMENS

2.1 Cellular blocks

The cellular concrete blocks used in this investigation were the regular NBS blocks reinforced with welded wire fabric being used in the current investigation of the properties of prestressed cellular concrete slabs. These blocks were hollow 6-in. cubes having an opening 4.5- by 4.5-in. in cross section. There were 1- by 2-in. elliptical access holes in the webs to permit the passage of prestressing tendons when used in a prestressed assembly. These blocks were cast in steel three-unit gang molds that were constructed to very close tolerances, thus forming the blocks to exterior dimensions which were within 0.01-in. of the nominal values. The principal dimensions of these blocks are shown in figure 1.

The blocks were made of a mix proportioned of one part type III cement and three parts of sand, by weight, with a water-cement ratio of 0.57. This mix had a 7 day compressive strength of approximately 6000 psi as determined from tests of 2-in. cubes. However, the actual units were moist-cured for a considerably longer period of time, and then were placed in dry storage before being assembled into beams. Therefore, the compressive strength of the concrete in the individual units should be expected to be somewhat greater.

The Young's modulus and Poisson's ration of the concrete were determined in previous tests of the concrete units and other specimens. Axial compression tests and sonic modulus tests indicated an average Young's modulus of 4×10^6 psi with variations of ± 10 percent. Poisson's ratio was found to be approximately 0.15.

2.2 Description of beam specimens

There were nine specimens included in this investigation and each was composed of six reinforced NBS blocks. Specimens A, B, C, and D contained reinforced NBS blocks as cast, and specimens A_1, A_2, B_1, D_1 and E_1, contained similar NBS blocks that were ground to remove the layer of cement paste from the surfaces which formed the joint.

The letters in the specimen designation denote the type of resin and activator used to bond the blocks together. The subscripts indicate that the blocks used in the beams had the layer of cement paste ground from the surfaces that formed the joint. The type and mixture of the resin and the letter designation are listed below.

Type A	-	200 grams Epon 828* 13 grams Cab-o-sil* 16 grams Diethylenetriamine*
Type B	-	200 grams Epon 828 12 grams Cab-o-sil 16 grams DMP-30*

Type C	-	200 grams	Epon 828
		12 grams	Cab-o-sil
		16 grams	DMP-10*
Type D	-	200 grams	Epon 828
		12 grams	Cab-o-sil
		8 grams	DMP-30
		8 grams	DMP-10
Type E	-	200 grams	Selectron 5119*
		12 grams	Cab-o-sil
		2 grams	Lupersol DDM*

3. TESTING PROCEDURE

3.1 Test setup

All of the specimens were tested to failure in a hydraulic testing machine. They were simply supported over a 30.5-in. span and two equal concentrated load were applied as shown in figure 2. All loads and reactions were transmitted to the specimen through 1- by 2- by 6-in. steel bearing plates, and the load and reaction devices were designed to eliminate eccentric or torsional loading.

3.2 Instrumentation

The deflection measurements of the specimens were made with two 0.001-in. micrometer dial gages which were placed at midspan on both sides of the specimen. Longitudinal strain readings were made with an electrical resistance wire strain gage of type A-3 which was bonded to the center of the tensile surface of the specimen across the midspan joint.

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*List of manufacturers or sources are given in the Appendix.

3.3 Test procedure

The specimens were loaded continuously as shown in figure 2 at a rate of 600 lb per min, and simultaneous readings of strain and deflection were made at 200 lb intervals.

4. TEST DATA

4.1 Load-carrying capacity

Table 1 lists the maximum loads sustained by the specimens along with the computed maximum stresses at the extreme fibers and descriptions of the types of failure exhibited by each specimen. Figure 3 is a photograph of Beam A_1 after failure. This type of failure was also exhibited by Beam A_2 which was a companion to Beam A_1. The failure of these two beams was typified by a sudden drop of load after the maximum load was reached, and the beams continued to deflect at lower loads.

This action was due to the yielding of the No. 15-ga wires of the 1- by 1-in. welded wire fabric. All of the other specimens that failed at or near the center joint exhibited an abrupt failure that permitted the two halves to fall to the testing machine platen.

4.2 Deflection

The relationship between the computed stress in the extreme fibers at midspan and the observed deflection at midspan can be seen in figure 4 along with a theoretical relationship between these variables. The theoretical curve was computed with the assumption that the modulus of elasticity was equal to 4×10^6 psi, and that the presence of the reinforcement could be neglected in computing the moment of inertia of the cross section.

4.3 Concrete strains

The relationship between the computed stress in the extreme fiber at midspan and the observed strain in the concrete on the tensile surface of the specimen at midspan is shown in figure 5. A theoretical relationship between these variables is also shown. The theoretical curve was computed using the assumptions listed above.

5. DISCUSSION

As can be seen in Table 1, the type of failure of specimens A, B, C, and D points directly to a weakness in the cement paste that covers the surface of cast blocks of this type. Therefore, another series of specimens were fabricated and tested with blocks having the cement paste ground from surfaces that formed the joints. It should be noted that the type "C" adhesive was dropped from the second series as the DMP-10 activator was too slow. The adhesive in Beam C while partially set was still tacky after 7 days of curing. Since this slow rate of curing at room temperature was deemed unsuitable for this purpose, testing of specimens containing this resin was discontinued.

Upon comparing the test results shown in figure 4 it is noted that there is fairly good agreement between the theoretical stress-deflection curve and the test data. There is also good agreement between theory and test results indicated in figure 5 except for Specimens A_1 and A_2. The irregularity in the curves or these two specimens is probably due to the fact that the blocks rather than the center joints failed. This was quite evident in Specimen A_1, as the crack shown in figure 3 appeared simultaneously with the decrease in tensile strain indicated between 400 and 450 psi in figure 5.

It is evident from the results in Table 1 that companion Specimens A_1 and A_2 exhibited the highest load carrying capacity of the specimens tested. Furthermore, it should be noted that the epoxy resin mixture used to bond these specimens together was identical to the mixture used in the shear and flexural tests of prestressed cellular concrete slabs that were reported in NBS Reports 5714 and 5825.

The DMP-30 used to activate the epoxy resin of Specimens B and B_1 produced a resin with a pot life of only 15 min and the resin exhibited brittle characteristics under flexural tests. Therefore, epoxy resin using this activator was found to be unsuitable for bonding these concrete blocks together.

As mentioned previously, the DMP-10 used to activate the resin in Specimen C was found unsuitable because it cured too slowly. The mixture of DMP-30 and DMP-10 used to activate the epoxy resin of Specimens D and D_1 produced a resin with a fairly short pot life which took a long time to cure.

The polyester resin used in fabricating Specimen E_1 was identical to the polyester resin used to bond together some of the prestressed cellular concrete slabs that were reported in NBS Report 5212. The resin appeared to be fairly strong as it did not fail under load test as indicated in Table 1. However, it was not as workable as the epoxy resin used to bond Specimens A, A_1, and A_2,

When considering the handling and moving of unstressed bonded units similar to those bonded with the type A epoxy resin, it would appear to be desirable to limit the extreme fiber stress to 250 psi or to one half the modulus of rupture of the concrete, whichever is smaller.

6. SUMMARY

The foregoing discussion can be summarized as follows:

1. The apparent failure of the resin joints reported in NBS Report No. 5825 can be attributed to the failure of the cement paste surfaces of the concrete blocks that formed the joints in the prestressed slabs.

2. Epoxy and polyester joints can be made to resist more flexural stress than the reinforced concrete units used in this investigation.

3. Unstressed assemblies similar to those tested in this investigation can be handled and moved if the handling stresses are limited to a reasonable value.

APPENDIX

The following is a list of materials used in preparing the adhesives used in these tests and their sources:

Epon 828 - epoxy resin

Shell Chemical Corp.
380 Madison Ave.
New York 17, N. Y.

Cab-o-sil - Finely divided silica

Godfrey L. Cabot, Inc.
Mineral and Chemical Division
77 Franklin Street
Boston 10, Mass.

DMP-10)
DMP-30) Dimethylaminomethyl phenols

Rohm and Hass Co.
Washington Square
Philadelphia 5, Pa.

Diethylenetriamine

Chemical Rubber Co.
8616 Georgia Ave.
Silver Spring, Md.

Selectron 5119 - polyester resin

Pittsburg Plate Glass Co.
One Gateway Center
Pittsburgh, Pa.

Lupersol-DDM - 60% Methyl ethyl ketone peroxide in dimethyl phthalate

Novadel-Agene Corp.
Lucidol Division
1740 Military Rd.
Buffalo, N. Y.

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Table 1. Load-carrying capacity and type of failure of specimens.

Specimen	Maximum Load lb	Modulus of Rupture psi	Type of Failure
A	1890	471	Cement paste and small pieces of coarse aggregate pulled out of surface of concrete.
B	1300	324	Cement paste pulled out of surface of concrete.
C	760	189	Adhesive failure in center joint.
D	1200	299	Primary failure in adhesive in center joint; small portion of cement paste pulled out of surface of concrete.
A_1	2300	573	Crack formed in block under load-point - joints intact.
A_2	2260	563	Crack formed in block under load-point - joints intact.
B_1	2080	518	Brittle fracture of adhesive in center joint.
D_1	1980	493	Adhesive failure in center joint.
E_1	1922	479	Concrete failed at center joint.

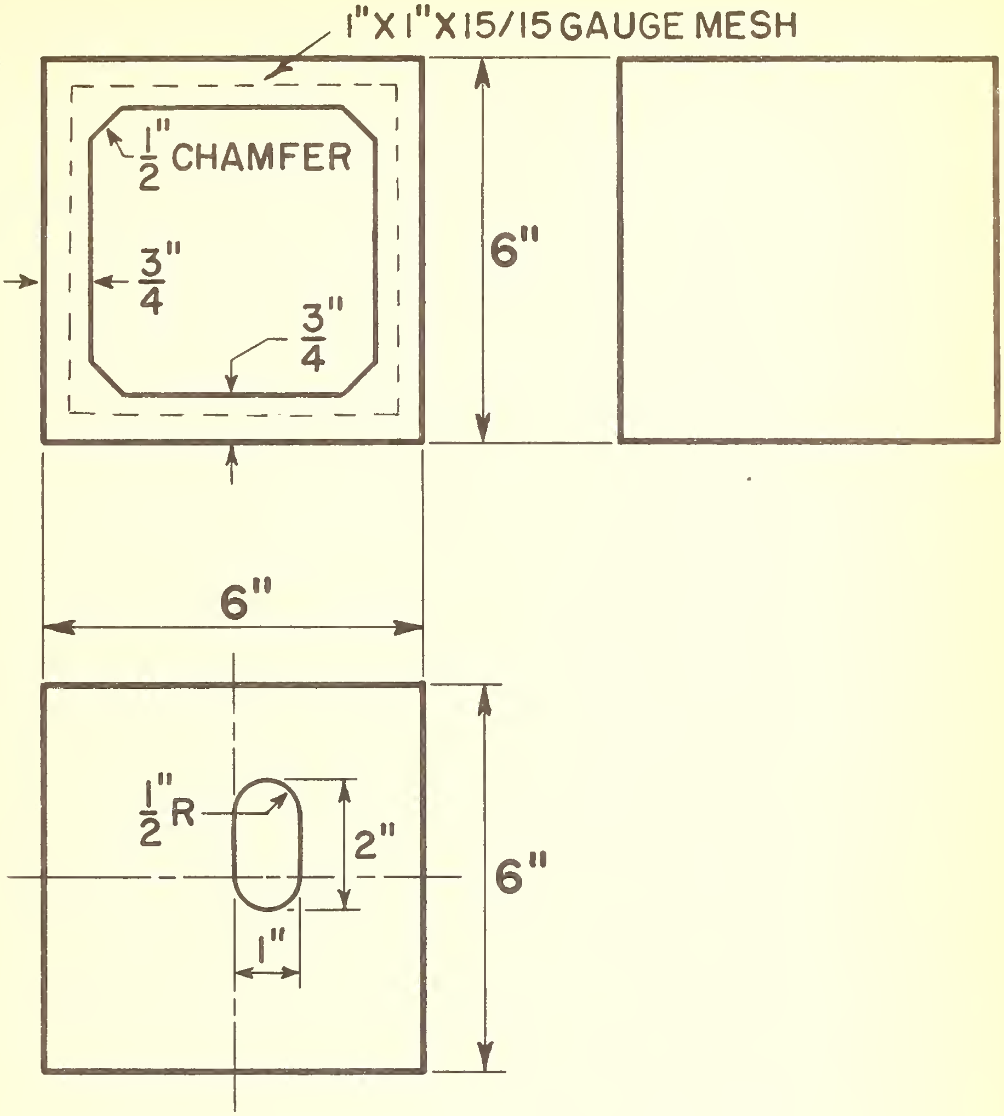

FIG. 1 - NOMINAL DIMENSIONS OF NBS REINFORCED BLOCKS.

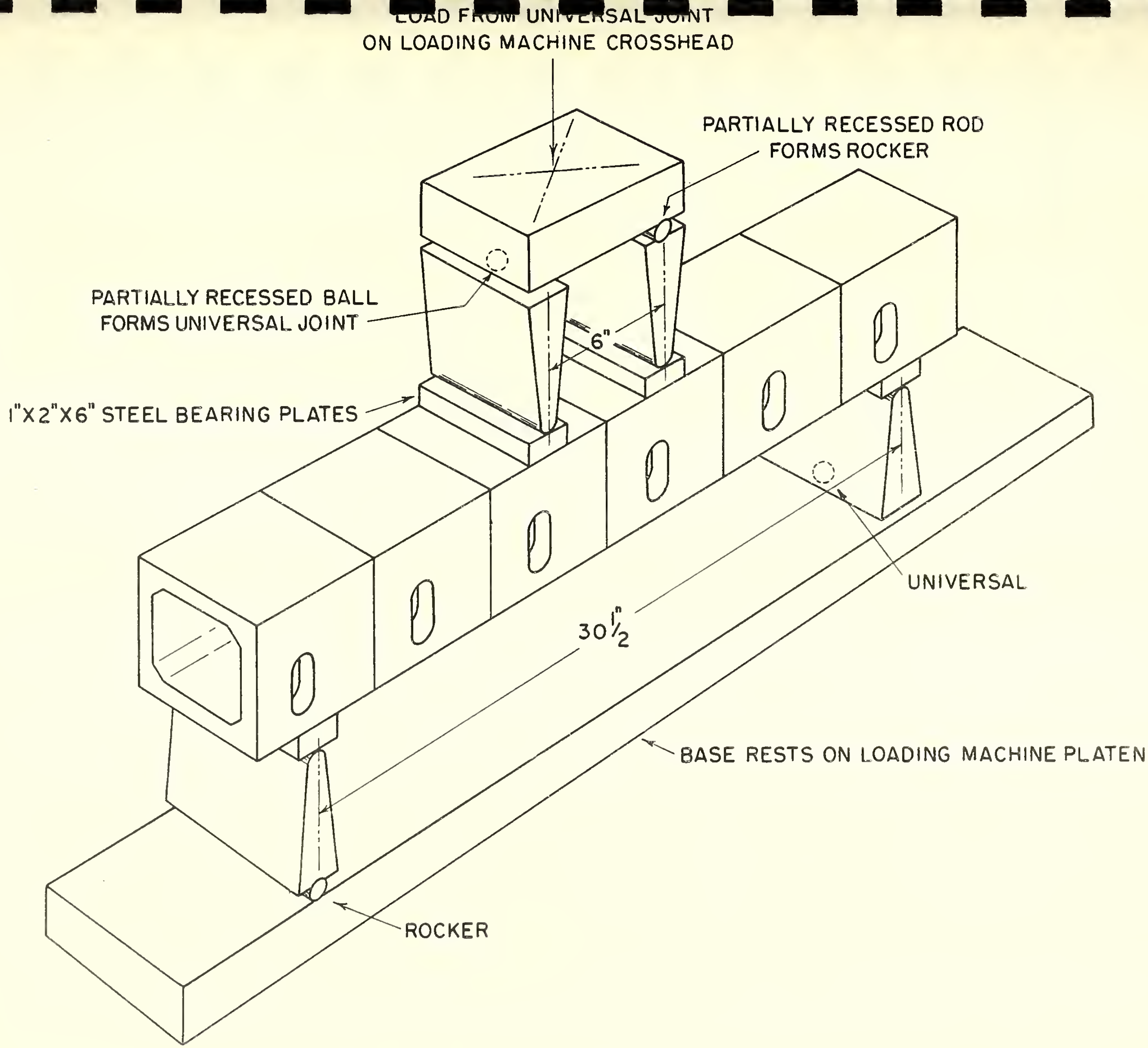

FIG. 2 – ARRANGEMENT FOR BEAM LOADING TESTS

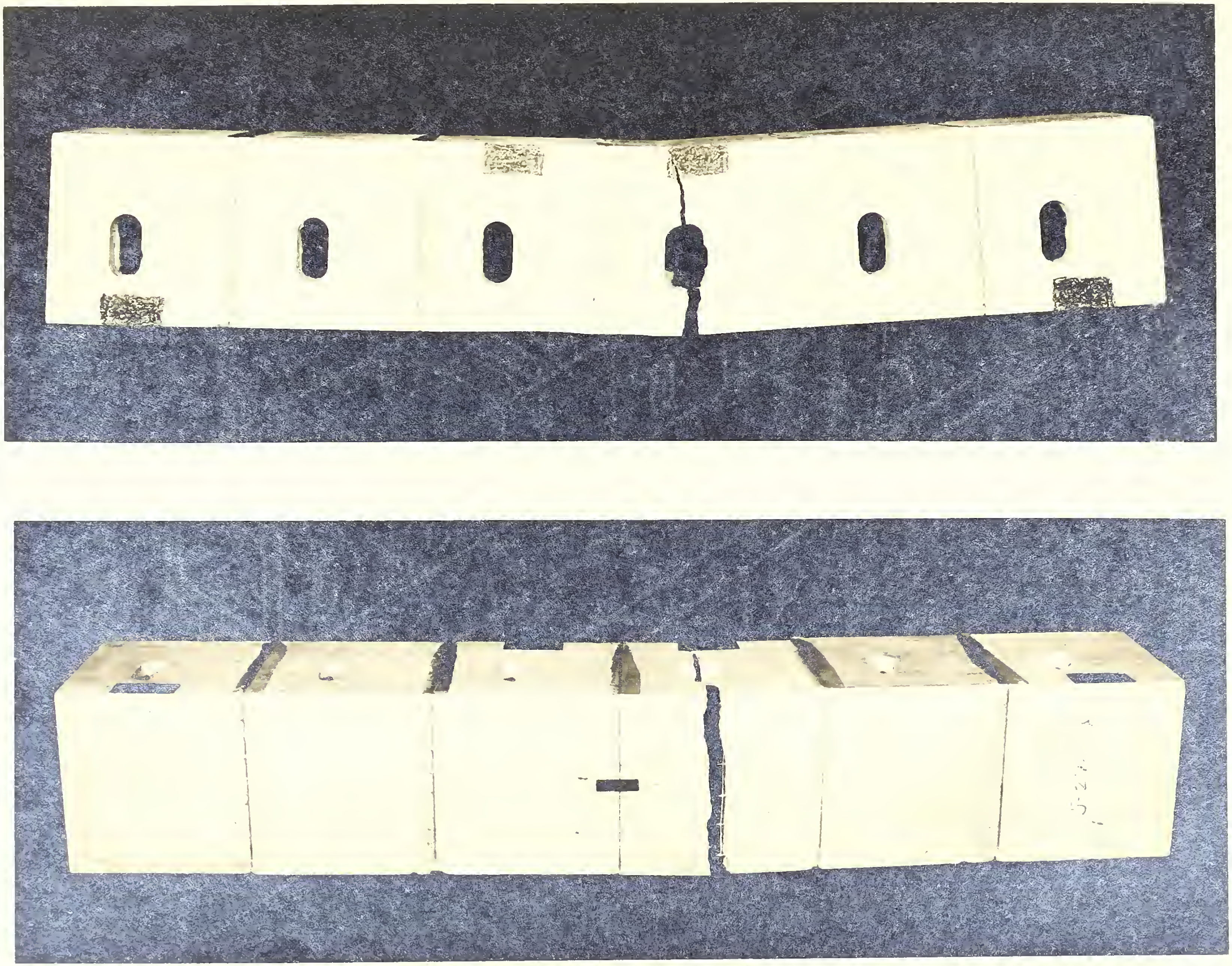

FIG. 3 – PHOTOGRAPH OF BEAM A_1 AFTER FAILURE

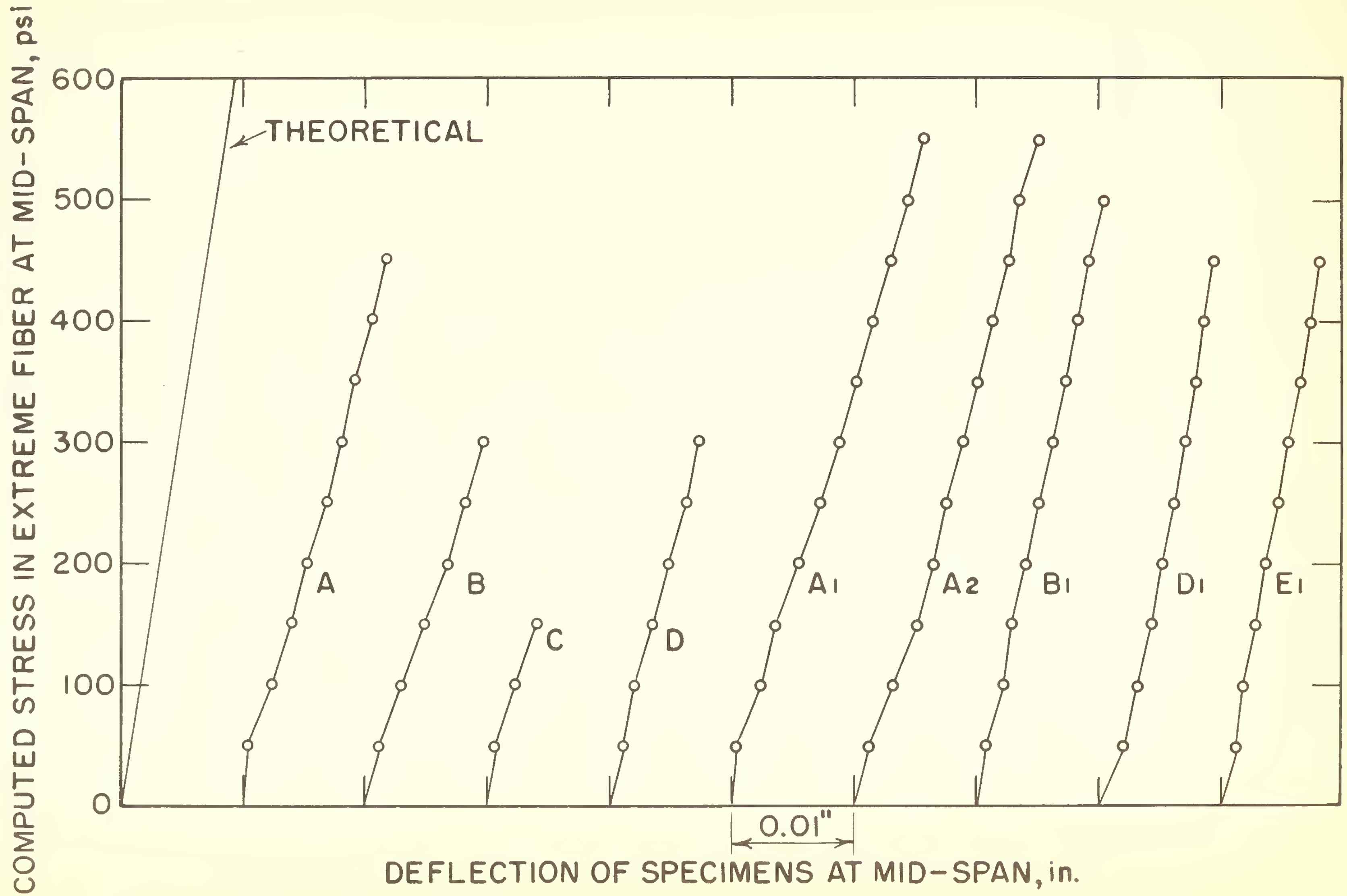

FIG. 4 - RELATIONSHIP BETWEEN COMPUTED STRESS AND DEFLECTION

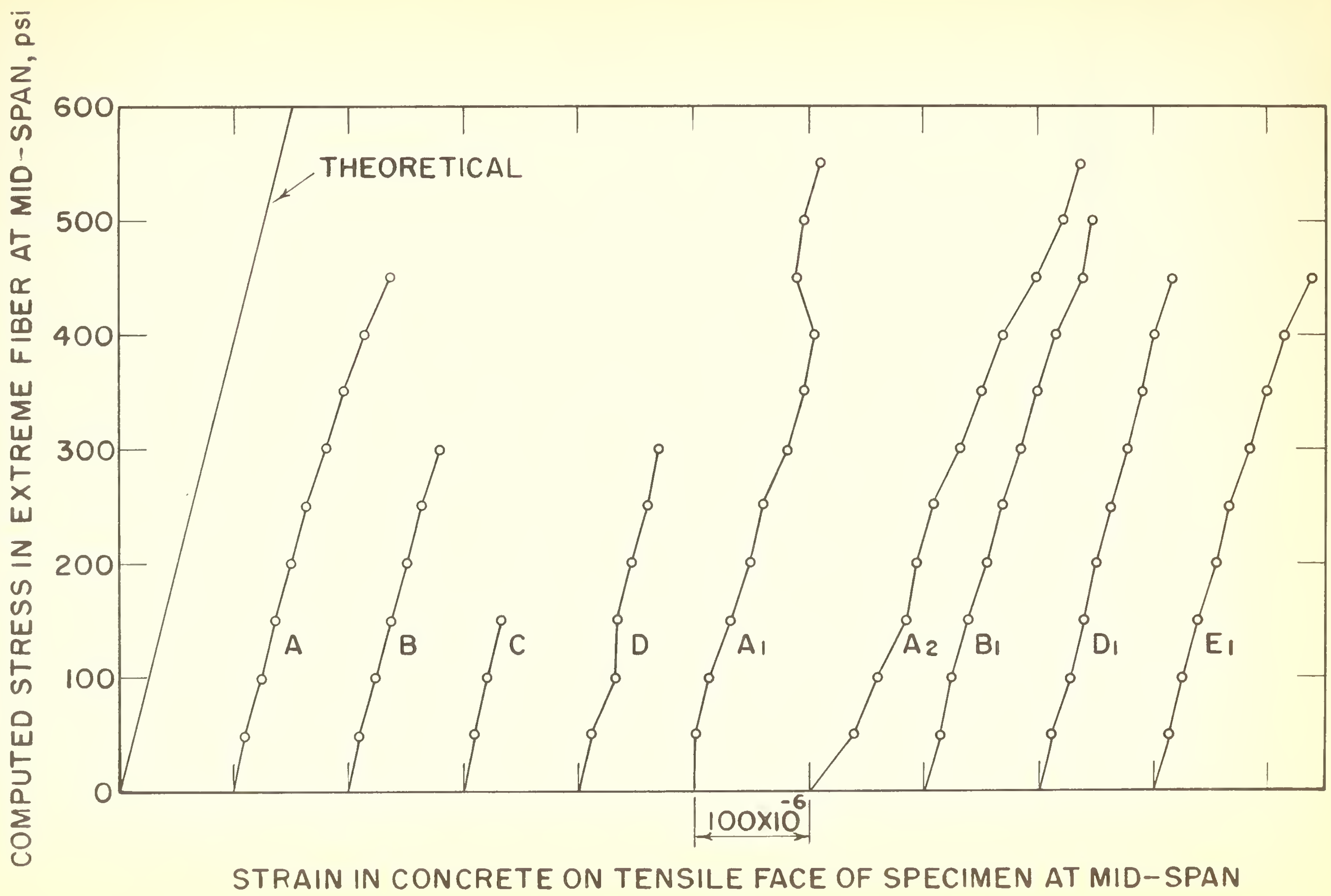

FIG. 5 - RELATIONSHIP BETWEEN COMPUTED STRESS AND STRAIN

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

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