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Extensibility of Some Concrete Masonry Units

By

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EXTENSIBILITY OF SOME CONCRETE MASONRY UNITS

1. INTRODUCTION

The volume of the concrete in concrete masonry units is affected by changes in temperature and in moisture content. The units in masonry walls are more or less restrained against free shrinkage. Such restraints produce tensile stresses which may produce "shrinkage cracking" of the masonry. Cracks at vertical mortar joints usually indicate a bond failure. The concrete masonry units will crack if the tensile strains developed in them equal or exceed the extensibility of the units. (The extensibility of a material is the maximum elongation per unit of length produced by tensile stress).

2. SPECIMENS

The concrete masonry units were some of those furnished by the American Concrete Institute Committee 716 for measurement of shrinkage. The 3-cell, 8- by 8- by 16-in. units were made by the Concrete Pipe and Products Company, Richmond, Va., from expanded shale, cinders, and sand and gravel. The expanded shale aggregate units were designated as VL, the cinder aggregate units as VC, and the sand and gravel units as VS. The shrinkage and other physical properties of the units are listed in Table 1.

When tested, the units were air dry and had been stored in the laboratory for more than six months.

3. EXTENSIBILITY TESTS

The tensile strains in the concrete masonry units were observed for two different methods of loading, designated as the tensile load method and the flexure method. A considerable number of units were tested before an acceptable method of testing was devised. Despite great care in the preparation of the units for testing and in assembling the various connecting parts of the testing apparatus, observations taken during the loading indicated that many of the specimens either had not been loaded concentrically or had been subjected to conditions which caused non-uniform distribution of stress. The data from these tests are not included in the summaries; those given and discussed were obtained with seven blocks in the tensile load tests and nine others tested in flexure.

3.1 Tensile Load Method

In the tensile load method the blocks were pulled apart by applying tensile loads to the end shells. Steel plates, bedded against the inside faces of the end shells, were connected with the upper and lower heads of the testing machine by steel cables, balanced levers and shackles, as shown in Figure 1. The loading method was selected to reduce eccentricity of load application from the testing machine to the specimen and to balance, if possible, the tensile loads applied to each face shell.

Since it was desirable to have the block fail on a section passing through the center cell and since the face shells of the block were thickest at the center cell, the end cells of the block were reinforced. The reinforcement, consisting of strips of metal plaster lath embedded in calcined gypsum (Hydrocal), was applied after the blocks were painted with shellac, to reduce water absorption.

Tensile strains were measured with Baldwin Southwark SR-4 type A-11 gages of 1-in. length connected with an SR-4 strain indicator. The gages were placed on the surfaces of the face shells parallel with the long dimension of the block and on a section passing through the center cell, as shown in Figure 2. The gages were similarly located and numbered on all of the tensile load specimens. Gages 1 and 5 were on the outside faces of the face shells, gages 2 and 6 on the inside faces, and gages 3, 4, 7, and 8 were on the edges of the face shells.

The load was applied at increments of about 200 lb until failure occurred and was held constant for 3 to 4 min until a reading was obtained on each gage. The average time required to complete a test was 40 minutes.

3.2 Flexure Load Method

Each block was supported as a beam with the cells vertical over a span of 13.5 in. The support lines were under the end shells and the two load lines, 4-in. apart, were centered on the cross webs. The steel bearing surfaces along the support and load lines were bedded in Hydrocal. Those portions of the face shells enclosing the end cells were reinforced on the bottom with metal lath and Hydrocal and the method of loading was as shown in Figure 3.

An SR-4, type A-11 gage was placed on the bottom edge of each face shell parallel with the length of the block and between the load lines.

The load was applied in increments of 50 to 500 lb, until failure occurred, the increments decreasing as the total load increased. The load was held constant at each increment for about 1 min, while the observations on the two gages were obtained. The average time needed to complete a test was 15 min.

4. TEST DATA

4.1 Tensile Load Data

Data obtained from the tensile load tests are listed in Table 2. It is evident from these data that unequal strains were observed in the face shells by the tensile loading. While most of the observed strains were tensile, a gradual increase in compressive strain was noted at one or more gages on each of specimens VC-10 and VS-11. The application of the tensile loads from the bearing plates to the inner faces of the end shells tended to produce bending in the face shells and rotation of the joints in the 3-cell frame of the block. It is also probable that the curing and drying of the blocks caused some warp, stress and strain in the face shells that may still have been present at the time of test. These uncertainties, combined with the effects of reinforcing the end cells, made it inadvisable to attempt an analysis of the stresses and strains in the specimens.

In the tests, the failure of the face shells occurred at the center cell and usually near one of the cross webs. The failure section passed through gage lines in only two of the seven specimens. The applied loads and the strains observed for these two specimens VC-6 and VS-12 were greater than those noted for the other specimens containing like aggregate.

It may be noted, Table 2, that the tensile strain in some gages reached a maximum at loads less than the maximum loads. There was no consistent relation between the relative strains observed for like gage locations on the specimens.

The average maximum tensile strain for all gages on all blocks was 0.0077 percent. The average maximum strain observed on the outer face (gages 1 and 5), the inner faces (gages 2 and 6), the bottom edges (gages 3 and 7), and the top edges of the blocks were, respectively, 138-, 87-, 74- and 101 percent of the average strains. The bottom edges of the face shells were slightly thicker than the top edges and with the exception of block VL-10, the face shells were subjected to bending which tended to place the outer faces in compression. The average strains observed on the sand and gravel aggregate block were considerably lower than the strains observed on blocks containing the lightweight aggregates.

4.2 Flexure Load Data

The failure section in three of the nine flexure test specimens passed through gage lines. Five specimens failed at the center cell between the gages and a cross web and one specimen, VS-14, broke at one of the end cells. It may be noted from Table 3 that the maximum flexure loads were consistent for each kind of aggregate and did not appear to be greatly affected by the location of the section of failure.

The tensile strain in some gages reached a maximum at loads considerably lower than the maximum. It is probable that the observed strains were somewhat affected by the restraints due to the cross webs, residual strains due to drying shrinkage and by shearing strains resulting from the high ratio of depth of beam to length of span. Even so, the data clearly indicate that the sand and gravel aggregate units, VS, were stronger in flexure than the units containing lightweight aggregates and the average maximum observed tensile strain for the VS units was only about 75 percent of that for the other units.

The secant modulus of elasticity was calculated for the loads corresponding to the maximum observed strain, assuming that loads were carried only by the face shells and that the stress distribution on a vertical section of a face shell was linear.

5. DISCUSSION OF THE DATA

The relation between the values for tensile strength as determined by the two types of loading are similar to those for ordinary concretes in that the modulus of rupture was considerably higher than the tensile strength developed by the tensile load method. The relations between the tensile strength and the modulus of rupture and the compressive strength of the blocks are listed in Table 4. Other investigators who measured the tensile strength of concrete by testing cylindrical specimens report higher tensile strength and higher ratios of $T/_C$ and of $^T/_R$ than those in Table 4. For example, H. F. Gonnerman and E. C. Shuman[1] report values of $^T/_C$ averaging about 0.09 and values of $^T/_R$ averaging about 0.55. The tensile strength and the tensile strength ratios in Table 4 may have been affected by residual stresses locked in the blocks and built up during curing and drying. These effects were greatest in the sand and gravel blocks, VS, which were the strongest in compression and flexure but the weakest in tension. A previous investigation on the shrinkage of the blocks, see Table 1, indicated a very large expansion of the VS blocks on heating to 110°C (Rapid Method of drying). These expansions were not observed for the VL and the VC blocks and were much greater than what would be estimated for thermal expansion.

Unpublished data obtained from tests of symmetrical specimens of heavy aggregate concrete indicate an extensibility in tension of 80 to 100 millionths whereas specimens subjected to bending yield values of 120 to 160 millionths. From Table 2 and Figure 2, it may be noted that the sand and gravel block VS-12, the only VS block that failed near the gage line, had an average maximum strain of 81 millionths. The average of the maximum strains for the VS flexure test blocks was 162 millionths. These values are within the given limits for the unpublished data referred to above. It should be noted, Table 3, that the lightweight aggregate blocks VL and VC had greater extensibility (and lower moduli of elasticity) than did the heavier VS blocks.

The data in Table 2 may be culled by arbitrarily discarding those data on blocks which did not fail near the gage lines and which failed at low loads. By comparing the average of the maximum tensile strains observed for blocks VL-10, VC-6, and VS-12, Table 2, with the average flexure strains for similar blocks, we obtain respective ratios of 0.51, 0.70, and 0.50. These ratios are in fair agreement with the stress ratio, $^T/_R$, found by other investigators.

The temperature and the moisture content of concrete masonry walls is rarely uniform and the masonry is usually subjected to thermal and shrinkage gradients. Similarly, the tensile stresses in the masonry are more likely to be highly flexural rather than uniform, as in pure tension. Since seasonal temperature changes and drying of the masonry occur more or less gradually, the resulting stresses, if any, may be somewhat relieved by plastic deformation of the concrete. Bond failures especially if continuous through vertical and horizontal joints,

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[1] "Compression, flexure and tension tests of plain concrete." Proc. A.S.T.M. 28, 527, part 2 (1928).

also tend to reduce the tensile stresses in the blocks. Furthermore, a few minor shrinkage cracks may not seriously affect the structural stability of the walls and their resistance to wind-driven rain. For these reasons, it may be assumed that concrete masonry walls will have a satisfactory resistance to shrinkage cracking if the tensile stresses do not result in strains amounting to a considerable percentage of the extensibility of the walls in flexure. For the blocks tested in this investigation the limiting tensile strains assuming an arbitrarily selected limit of 70 percent of the maximum flexural strain would be:

Sand and gravel aggregate blocks (VS)	-	110 millionths
Cinder aggregate blocks (VC)	-	140 millionths
Expanded shale aggregate blocks (VL)	-	150 millionths

It may be noted, for blocks VL-10, VC-6, and VS-12,(tested by the tensile load method, Table 2) that the limiting strains listed above are equalled or exceeded on one or more of the gage lines in each block.

Table 1. Physical Properties of the Concrete Masonry Units.[a]

Designation	Kind of aggregate	Dimensions					Weight per cu ft of concrete	Absorption	Compressive strength, gross area	Shrinkage[c]	
		Thickness	Length	Height	Face[b] shell thickness	Web thickness				Rapid[d] method	Reference[e] method
		in.	in.	in.	in.	in.	lb	percent	lb/in.^{2}	percent	percent
VL	Expanded shale	7.62	15.62	7.57	1.62	1.19	89.9	15.3	1450	0.0434	0.0204
VC	Cinders	7.69	15.64	7.58	1.58	1.15	92.9	12.9	1280	.0388	.0176
VS	Sand & gravel	7.67	15.63	7.60	1.66	1.20	129.9	6.1	2610	.0315	.0151

[a] High pressure steam-cured concrete-masonry units made by the Concrete Pipe and Products Company, Richmond, Va.

[b] At center cell. The face shells were slightly rounded and thicker at the bottom of the mold.

[c] Each value is the average for a group of three units dried from a saturated condition, by the method indicated.

[d] Dried in a ventilated oven at 110°C for 2 days.

[e] Dried to constant weight in a closed drum of 23°F over sodium hydroxide.

Table 2. Tensile Strains as Obtained by the Tensile-Load Method

Specimen No.	Maximum load	Load at which maximum strain was observed	Maximum tensile strain, Gage No.[a] 1	2	3	4	5	6	7	8	Average maximum observed tensile strain
	lb	lb	percent	percent	percent	percent	percent	percent	percent	percent	percent
VL-10	4020	3900	0.0175	0.0088	0.0091	0.0112	0.0132	0.0089	0.0057	0.0144	0.0111
VC-6	4660[b]	4500[c]	.0164	.0178	.0201	.0129	.0112	.0165[d]	.0133	.0055	.0142
VC-10	1830	1800	.0052	.0102	-.0028[e]	.0087	.0021[e]	.0114	-.0071[e]	.0129	.0046
VC-11	1710	1600[c]	.0049	.0106[f]	.0070	.0076[f]	.0046[g]	.0134	.0040[h]	.0094	.0077
VC-Avg	2730		.0088	.0129	.0081	.0097	.0046	.0138	.0034	.0093	.0088
VS-10	2200	2100[c]	.0051	.0048	.0007[j]	.0031	.0023[j]	.0036	.0020	.0032	.0031
VS-11	1450	1400	.0004	.0029	.0018	.0024	-.0029[e]	.0144	.0183	.0064	.0055
VS-12	2500[b]	2400	.0131	.0144	.0041	.0050	.0055	.0116	.0037	.0071	.0081
VS-Avg	2050		.0062	.0074	.0022	.0035	.0016	.0099	.0080	.0056	.0056
Grand Avg	2620		.0089	.0099	.0057	.0073	.0045	.0114	.0057	.0084	.0077
Percent of Avg			116	129	74	95	58	148	74	109	100

[a] Gages 1 and 5 were on outside of face shells; gages 2 and 6 on inside of face shells; gages 3, 4, 7, and 8 were on edges of face shells.

[b] Failed at one or more gage lines.

[c] Unless otherwise noted.

[d] Observed at load of 4300 lb.

[e] Indicates the max value of compressive strain.

[f] Observed at load of 1000 lb.

[g] do 200 lb.

[h] do 400 lb.

[j] do 1800 lb.

Table 3. Tensile Strains and Young's Modulus of Elasticity, Flexure-Load Method

Specimen No.	Maximum load[a]	Load at which maximum strain was observed	Maximum observed tensile strain, Gage No. 1	Maximum observed tensile strain, Gage No. 2	Average maximum observed tensile strain	Secant modulus of elasticity at maximum tensile strain
	lb	lb	percent	percent	percent	lb/in^2
VL-11[b]	4440	4300[c]	0.0188	0.0187[d]	0.0177[e]	$1.5x10^6$
VL-12	4500	4500	.0201	.0261[f]	.0231	$1.3x10^6$
VL-13	4380	4200[c]	.0307	.0187	.0247	$1.2x10^6$
VL-average	4440		.0232	.0212	.0218	$1.3x10^6$
VC-12[b]	4700	4600	.0300	.0104	.0202	$1.5x10^6$
VC-13[b]	4560	4400	.0241	.0237	.0239	$1.7x10^6$
VC-14	4500	4400[c]	.0192	.0183[g]	.0172[h]	$1.7x10^6$
VC-average	4590		.0244	.0175	.0204	$1.6x10^6$
VS-13	5520	5500[c]	.0210[j]	.0112[k]	.0159[j]	$2.3x10^6$
VS-14[ℓ]	5800	4800[c]	.0203	.0191[m]	.0188[m]	$2.1x10^6$
VS-15	5330	5330[c]	.0142[n]	.0134	.0138[n]	$2.6x10^6$
VS-average	5550		.0185	.0146	.0162	$2.3x10^6$

a Total load on two load lines on cross shells, 4 in. apart, over a space of 13.51 in.
b Failed at one or more gage lines.
c Unless otherwise noted.
d Observed at load of 3600 lb.
e do 4000
f do 3700
g Observed at load of 3400 lb.
h do 4100
j do 5100
k do 5300
ℓ Failed at one end cell near cross web.
m Observed at load of 5700 lb.
n do 5200

Table 4. Strengths and Strength Ratios for the Blocks[a]

Kind of aggregate	Block designation	Tensile Strength T	Modulus of rupture R	Compressive strength (net area) C	$\frac{T}{R}$	$\frac{T}{C}$	$\frac{R}{C}$
		lb/in^2	lb/in^2	lb/in^2			
Expanded shale	VL	155[b]	300	2400	0.52	0.065	0.013
Cinders	VC	105	310	2110	.34	.050	.015
Sand and gravel	VS	80	380	4440	.17	.018	.009

[a] Unless otherwise noted the data are the average for tests made on 3 or more blocks.

[b] Only one block was tested.

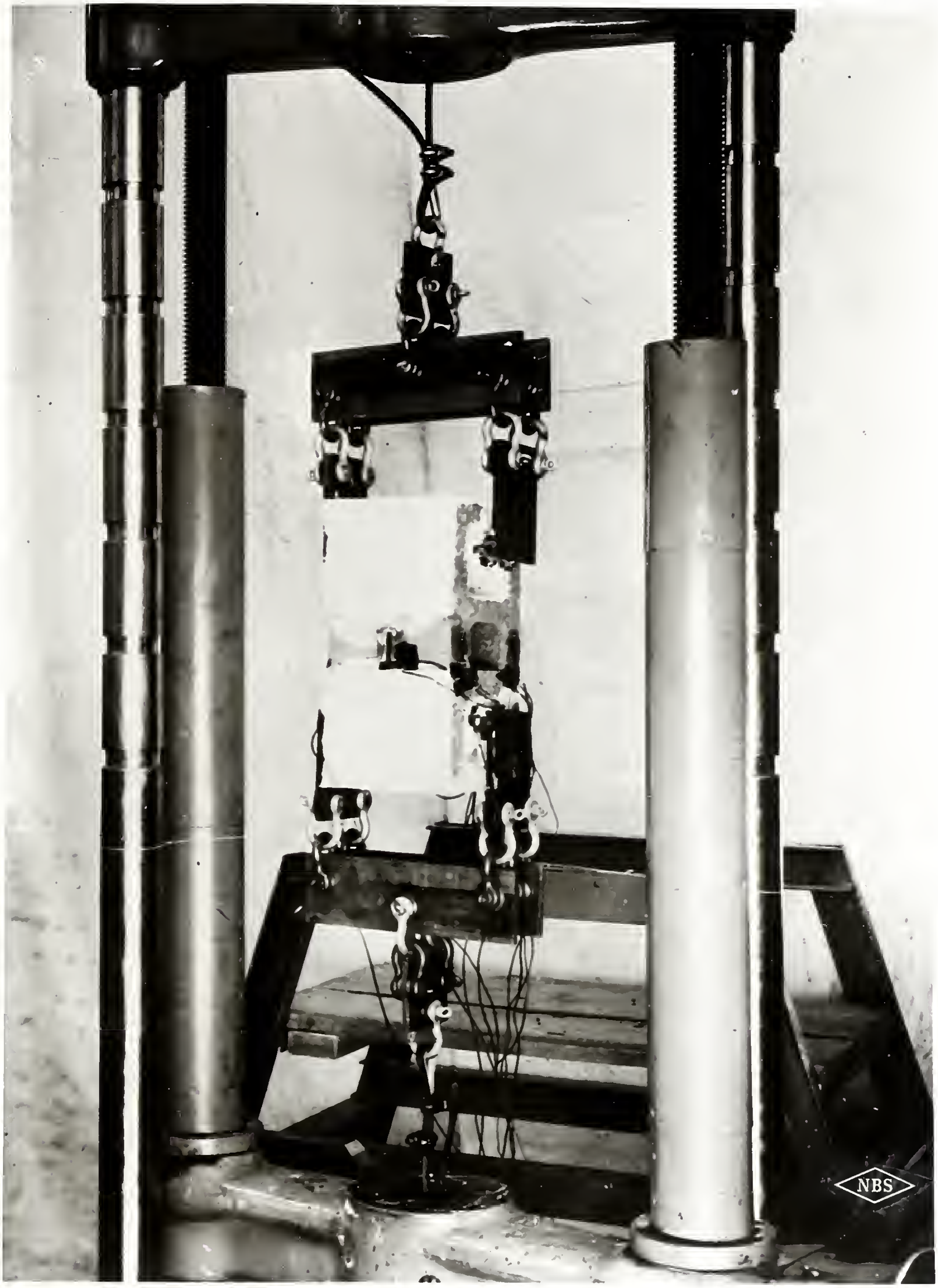

Figure 1- Tensile load specimen.

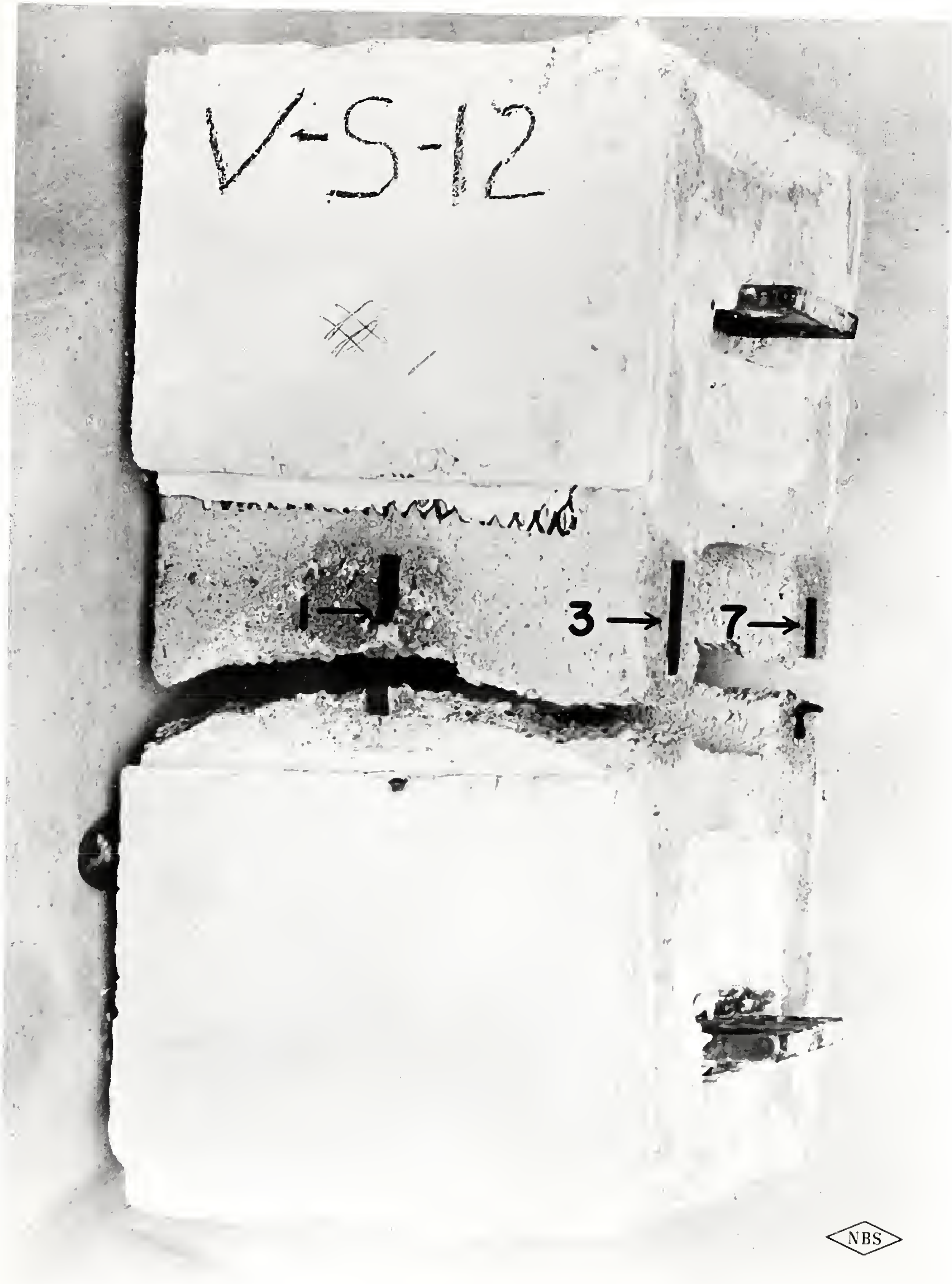

Figure 2- Tensile load specimen, after test.

Figure 3- Flexure load specimen, after test.

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