NATIONAL BUREAU OF STANDARDS REPORT

2825

TRANSVERSE STRENGTH OF MASONRY WALLS
WITH FACINGS OF REINFORCED GUNITE

by

D. Watstein and E. J. McCamley, Jr.

Report to
Federal Civil Defense Administration

NBS

U. S. DEPARTMENT OF COMMERCE
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Abstract

The transverse strength of masonry walls having a lightly reinforced gunite facing was determined for two types of masonry construction. These were a wall of hollow concrete masonry units and a wall of brick facing backed with concrete blocks. The walls were tested as slabs having a span of 8 ft and the load was applied at quarter points. A marked increase in the transverse strength was observed for the walls faced with gunite as compared with conventional masonry construction.

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1. INTRODUCTION

The degree of protection against blast loads afforded by a masonry structure to its occupants is determined largely by the resistance of the masonry walls to transverse forces. In an effort to determine to what extent existing masonry buildings can be strengthened to resist transverse loads, the Federal Civil Defense Administration sponsored a limited number of tests of masonry walls at the Structural Engineering Section of the Division of Building Technology. Three test walls of conventional masonry construction were faced on both sides with pneumatically applied portland cement mortar, popularly known as "gunite" and the mortar facings were suitably reinforced in two directions. The walls were subjected to transverse tests in a horizontal position.

2. MATERIALS AND TEST SPECIMENS

The test walls used in this study are illustrated in figure 1. All the walls were approximately 8-in. thick, 8 ft 8-in. high and 4 ft long. Two of the walls, Nos. 1 and 3, were constructed of 8-in. hollow concrete masonry units, while wall No. 2 consisted of 4 in. of brick facing backed with 4-in. hollow concrete blocks. The walls, as shown in figure 2 and 3, were constructed within a timber frame which extended 1.5 in. beyond each face of the walls to provide a guide in applying the required thickness of gunite to the test specimens. A view of the finished walls with a gunite facing is shown in figure 4.

The physical properties of the hollow concrete masonry units and the brick are given in table 1. It will be noted that the 8-in. hollow masonry units met the requirements of Federal Specification SS-C-621 for load-bearing concrete units, while the 4-in. block failed to meet the requirement of 1000 psi for compressive strength by a slight margin. The brick met the requirements of Federal Specification SS-B-656 for clay building brick of medium grade.

The masonry mortar containing a portland masonry cement was proportioned by volume approximately in the ratio of 1:3. The compressive strength of the mortar obtained with ten 2-in. cubes was 1240 psi.

The gunite mortar consisted of portland cement of type I and concrete sand, the proportions of the mix being roughly 1:3, by volume. The average compressive strength of the gunite mortar determined with four 2-in. cubes was 5010 psi. The average flexural strength of four 1- by 6- by 18-in. slabs of gunite mortar loaded at quarter points of the 18-in. span was 1140 psi, and the sonic modulus was 4,880,000 psi. The sieve analysis of the sand used in this mortar is given in the following table:

Sieve No.	% passing
No. 4	100
8	84
16	72
30	53
50	9
100	4

As can be seen in figure 1, the gunite facing was applied to each wall surface. The thickness of the gunite facing was about 1.5 in. Each facing of gunite was reinforced with vertical and horizontal steel bars. Wall No. 1 was reinforced vertically with 1/4-in. diameter bars spaced 3 in. apart, and walls Nos. 2 and 3 had vertical bars 6 in. apart. The reinforcing bars had a yield point of 41,000 psi and a tensile strength of 68,600 psi.

Mats of 1/4-in. reinforcing bars were fabricated by wiring together the vertical and horizontal bars at the specified spacing. The mats were then wired to 1/4-in. diameter spacer bars attached to the surface of the walls with fluted hardened steel nails driven into the masonry joints. The vertical reinforcing bars were on the outside of the mats and were accurately positioned to receive a 3/4 in. cover of gunite.

The walls were constructed during the period of February 13 through February 17, 1953. The gunite was applied on April 29 when the walls were a little over 60 days old. The walls were then left outdoors to age until the last week in June, when they were transported to the laboratory. The walls were tested during the period of July 2 through July 7, when they were nearly four months old and the gunite was about two months old.

3. TESTING PROCEDURE

3.1 Transverse Tests of Masonry Walls

The walls were transported from the construction site to the testing laboratory in an upright position. A view of the wall being transported with an electric fork lift truck is shown in figure 5. The walls were tested in a horizontal position in a 600,000 lb capacity hydraulic testing machine and a view of the test wall in the machine is shown in figure 6.

The walls were tested as simply supported slabs having a span of 8 ft. Wall No. 2 was placed in the testing machine with the brick facing down. The load was applied to the walls at quarter points through two 5-in. I-beams, which received the load from two bridge beams spanning the distance between the quarter points. The two bridge beams were loaded at the center with a transverse beam which received the load from the testing machine through a spherically seated bearing block.

The bearing surfaces of the supports and the loading beams were coated with neat plaster of paris to assure uniformity of contact between the metal and the gunite facings of the test walls.

The deflection of the walls under load was measured at two points along the center line of the specimens. The dial gages measuring the center deflections were supported by tripods resting on the lower platen of the testing machine. The average of these two dial gages was corrected by the readings of another pair of dial gages which measured the movement of the supports with reference to the platen of the testing machine.

For the first wall tested, No. 2, only the compressive strain was measured at two points along the center line of the specimen. For walls Nos. 1 and 3, the compressive strain was measured at three points and the tensile strain at two points, at the mid-section of the specimens.

3.2 Tests of Auxiliary Specimens

The compressive strengths of the masonry and gunite mortars were determined with 2-in. cubes which were tested in a 60,000 lb capacity hydraulic testing machine.

The flexural strength and the modulus of elasticity of the gunite mortar were determined with 1- by 6- by 18-in. slabs. The slabs were cast in a single gang mold which was held in vertical position while the slabs were fabricated in order to obtain specimens representative of the vertical gunite facings on the test walls. The gunite slabs were tested transversely as simply supported slabs with the load applied at the quarter points. The modulus of elasticity was determined by the sonic method which employed the longitudinal resonant frequency in the long direction of the specimens.

4. RESULTS

The results of the tests are summarized in tables 2 and 3. Wall No. 1 which consisted of 8-in. concrete masonry units first started cracking at a uniformly distributed load of 635 psf and failed at a load of 1560 psf. Wall No. 3 which was identical with wall No. 1, except that No. 3 had only half as much reinforcement as No. 1, started cracking at 628 psf and failed at a load of 1094 psf. Wall No. 2 which consisted of 4-in. brick facing backed with 4-in. concrete masonry units, started cracking at 569 psf and failed at 860 psf. It is noted that walls 1 and 3 failed by tension of the longitudinal reinforcement, while wall No. 2 failed in horizontal shear. The horizontal crack in wall No. 2 developed in the plane between the brick facing and the concrete block backing, as can be seen in the view showing the crack pattern (figure 8). It is believed that the shear failure of wall No. 2 occurred prematurely and that it might have been averted had the wall terminated at the top with a course of header brick.

The load-deflection diagrams for the three walls are shown in figure 9. It is noted that walls 1 and 3 which were identical except as to the amount of reinforcement, exhibited essentially the same relationship between the load and deflection up to about 800 psf. Wall No. 2 deflected with load more rapidly than wall No. 3, although both of them contained the same amount of longitudinal reinforcement. It is believed that the greater deflection of wall No. 2 can be attributed to the imperfect bond between the brick facing and the concrete unit backing which finally resulted in shear failure in that plane.

The bending moments observed in the test walls at first crack and at failure are given in table. 3. It will be noted that the bending moments at first crack were substantially the same for all three test walls, the range of bending moments being 223,000 to 249,000 lb-in.

The resisting moments of the walls developed at the yield point and the tensile failure of the reinforcement were computed using two different methods. The method identified as "A" in table 3 was based on the assumption that the compressive stress block of a section of a wall was a rectangle having a depth equal to the thickness of gunite and that the resultant of the compressive stresses lay at the centroid of the gunite facing. The values of resisting moments listed under method "B" were computed by the conventional method of analysis of reinforced concrete, except that the value of "j" was assumed to be 0.875 and the presence of compressive reinforcement in all slabs was disregarded. The values of ultimate resisting moments, M_u, computed by both methods are given in table 3 along with the ratios of M_u to M_m, the observed bending moments at failure. The ratios of M_u to M_m were somewhat greater for method "A" than for method "B", the values for walls 1 and 3, respectively, being 0.846 and 0.620 by method "A" and 0.795 and 0.582 by method "B". It is noted that the agreement between the computed and observed values of maximum bending moments was considerably better for wall No. 1 than No. 3 which had only half as much reinforcement as wall No. 1.

The moduli of rupture of the test walls given in table 3 were computed as the tensile stresses in the gunite facing at loads causing the first crack in the specimens. It was assumed for the purpose of computations that the value of the moment of inertia of the cross-section was that of a section consisting of the two gunite facings spaced 8-in. apart. The moduli of rupture computed on this basis were 437,384 and 408 psi for walls 1, 2, and 3, respectively. It is of interest to compare these moduli of rupture with the values obtained from the transverse tests of auxiliary 1- by 6- by 18-in. slabs of gunite mortar. The tests of four auxiliary slabs gave strengths ranging from 1030 to 1260 psi, the average being 1140 psi. Thus, the ratio of the average modulus of rupture observed with the test walls to the value obtained for the auxiliary slabs was 0.36. The low value of this ratio may be attributed to two factors: a real difference in the strengths of the mortars on the faces of the test walls and in the auxiliary slabs, and the difference in the stress distribution in the two types of specimens. While an effort was made to secure thin slabs of gunite mortar representative of the facings on the walls, it is possible that the auxiliary thin slabs received more compaction both in the deposition of the mortar and the screeding operation than the mortar on the test walls. The difference between the distributions of stresses in the two types of specimens probably accounts for the greater part of the apparent difference between their strengths. It is noted that the mortar in the thin auxiliary slabs was subjected to a flexural test whereas the mortar in the facings of the walls could be regarded as undergoing a direct tensile test. The apparent difference between their strengths is corroborated by the findings of other observers. For instance, Gonnerman and Shuman[1] reported that the ratio of tensile strength to the flexural strength of concrete was about 0.55.

The load-strain diagrams for the three test walls are given in figure 10. The strains were measured at the mid-section of the walls and represent the average values given by two to three bonded wire strain gages. In specimens 1 and 3 both compressive and tensile strains were measured but in specimen 2 only the compressive strain was measured.

1/ H. F. Gonnerman and E. C. Shuman, Compression, flexure and tension tests of plain concrete, Proc. ASTM, part 2, 1928.

Comparison of the data in figures 9 and 10 reveals general similarity between the curves for like specimens. The more heavily reinforced specimen No. 1 exhibited greater rigidity than the other two walls both in regard to deflection and the flexural strain. Wall No. 2 which ultimately failed in horizontal shear showed considerably greater deflection and strain than the wall No. 3 having an equal amount of longitudinal reinforcement.

5. SUMMARY

The tests of the three masonry walls showed that the transverse strength of existing masonry may be markedly increased by the addition of lightly reinforced "gunite" to the faces of the walls. The transverse strengths of two 8-in. walls of concrete masonry units, Nos. 1 and 3, tested as simply supported slabs with an 8 ft span, were 1560 and 1094 psf for reinforcement ratios of 0.00157 and 0.00077, respectively. The third wall, No. 2, consisting of 4-in. brick facing backed with 4-in. concrete units failed in shear in the plane of bond between the facing and backing at a load of 860 psf.

The computed value of the maximum resisting moment based on the observed tensile properties of the steel, was 15 percent less than the observed value for wall No. 1 and 38 percent less for wall No. 3. It was also observed that the moduli of rupture computed as the stresses in the walls at the appearance of the first crack differed markedly from the values determined in the tests of auxiliary thin slabs of gunite mortar. On the average, the ratio of the moduli of rupture observed in the test walls to those obtained with the thin specimens, was 0.36.

The data obtained in these tests are insufficient to provide a basis for calculating the transverse strengths of masonry walls with thicknesses of gunite facing and amounts of reinforcement materially different from those used in these tests. It is felt that additional tests of masonry walls are needed in order to establish adequate criteria for strengthening existing masonry buildings.

Table 1. Physical Properties of Hollow Concrete Masonry Units and Brick.

Concrete Masonry Units

Dimensions, in.				Absorption lb/cu ft of concrete	Compressive strength lb/sq in. of gross area
Thick-ness	Height	Length	Shell thick-ness		
7.65	7.70	15.65	1.50	13.3	1360
3.65	7.70	11.65	1.05	15.5	940

Brick

Dimensions, in.	Absorption	Compressive strength	Transverse strength
	percent	psi	psi
2.30 x 3.75 x 7.90	2.3	11,910	570

Note: The data in this table are average values based on tests of 3 to 5 specimens of each kind.

Table 2. Summary of Data, Transverse Tests of Walls

Wall No.		1	2	3
Type of wall		8-in. concrete block	4-in.brick and 4-in.concrete block	8-in. concrete block
Reinforcement ratio (vertical bars, one gunite facing)		0.00157	0.000795	0.000772
Total load on wall, lb 1/	at first crack	20,730	18,570	20.500
	at failure	50,930	28,090	35,700
Uniformly distributed load, lb per sq ft of wall area 1/	at first crack	635	569	628
	at failure	1,560	860	1,094
Center deflection at maximum load, in.		1.3	0.3	1.7
Manner of failure		tension failure of reinforcement	horizontal shear	tension failure of reinforcement

1/ Dead weight of wall and loading fixtures included in these figures.

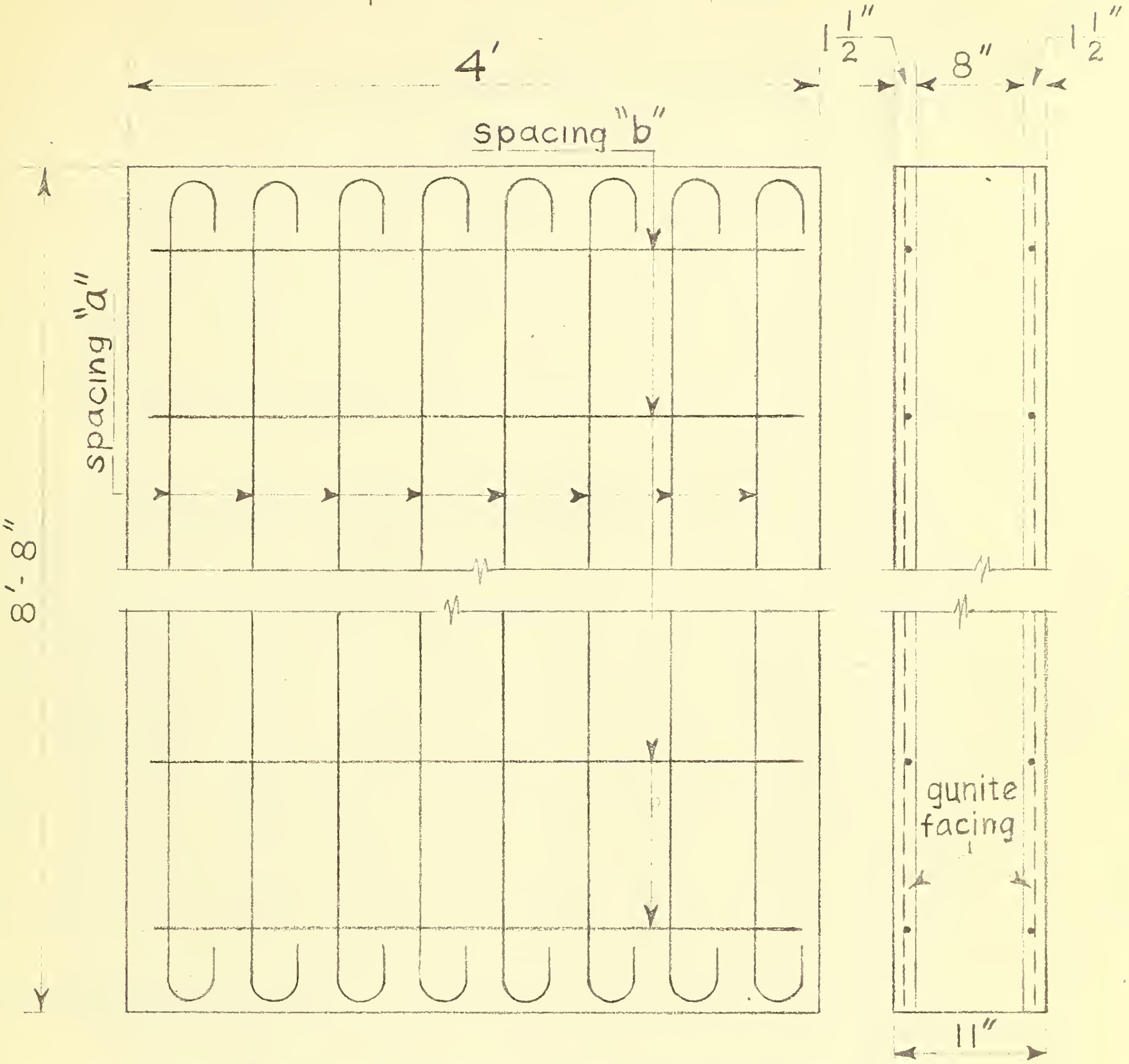
Table 3. Comparison of Observed and Calculated Properties of Test Walls.

Wall No.		1	2	3
Bending moment at center of wall lb/in. 1/	M_m, at first crack	249,000	223,000	246,000
	M_m, at failure	611,000	337,000 2/	428,000
Resisting moment computed by Method A, lb in.	M_y (yield point of steel)	309,000	153,000	158,000
	M_u (tensile failure of steel)	517,000	257,000	265,000
	M_u/M_m	0.846	0.763 2/	0.620
Resisting moment computed by Method B, lb in.	M_y (yield point of steel)	290,000	144,000	149,000
	M_u (tensile failure of steel)	485,000	241,000	249,000
	M_u/M_m	0.795	0.715 2/	0.582
Section Modulus I/c, in.^{3}		569	581	603
Modulus of Rupture, psi (stress at first crack)		437	384	408

1/ Dead weight of wall and loading fixtures included in these figures.

2/ Wall No. 2 having failed in horizontal shear did not develop the tensile strength of reinforcement.

Description of Test Walls



Designation and Type of Wall	Vertical Steel ($\frac{1}{4}''\phi$)		Horizontal Steel ($\frac{1}{4}''\phi$)	
	"a"	Steel Ratio	"b"	Steel Ratio
#1 - 8" Concrete Block	3"	0.00157	16"	0.000296
#2 - 4" Brick Backed with 4" Conc. Block	6"	0.000795	12"	0.000397
#3 - 8" Concrete Block	6"	0.000772	12"	0.000386

Figure 1

Fig. 2 - Front view of test walls.

Fig. 3 - Rear view of test walls.

Fig. 4 - Test walls with gunite facing.

Fig. 5 - Test wall in transport.

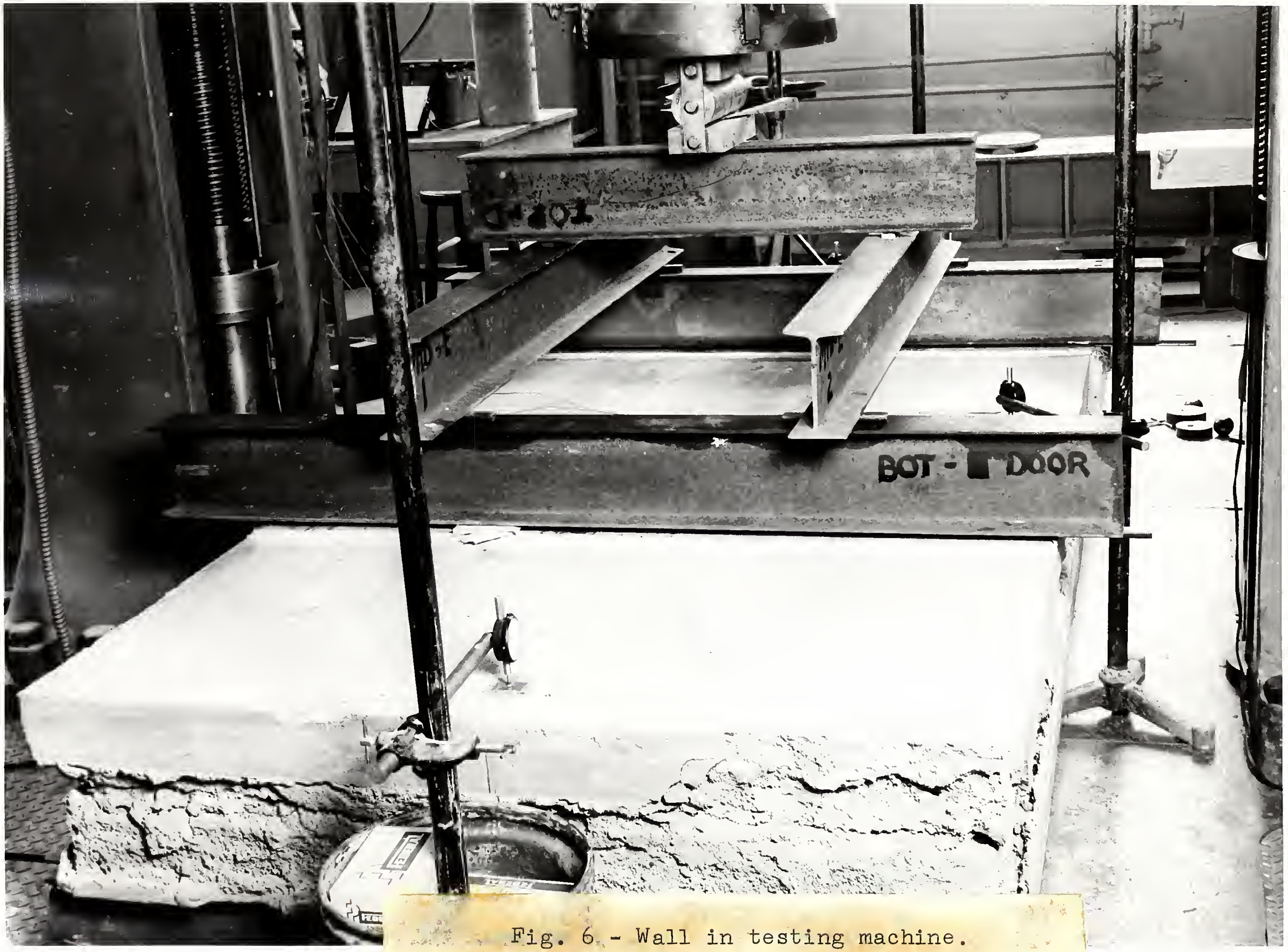


Fig. 6 - Wall in testing machine.

Fig. 7 - Wall after test.

CRACK PATTERN ON
MASONRY WALLS WITH
REINFORCED GUNITE FACINGS

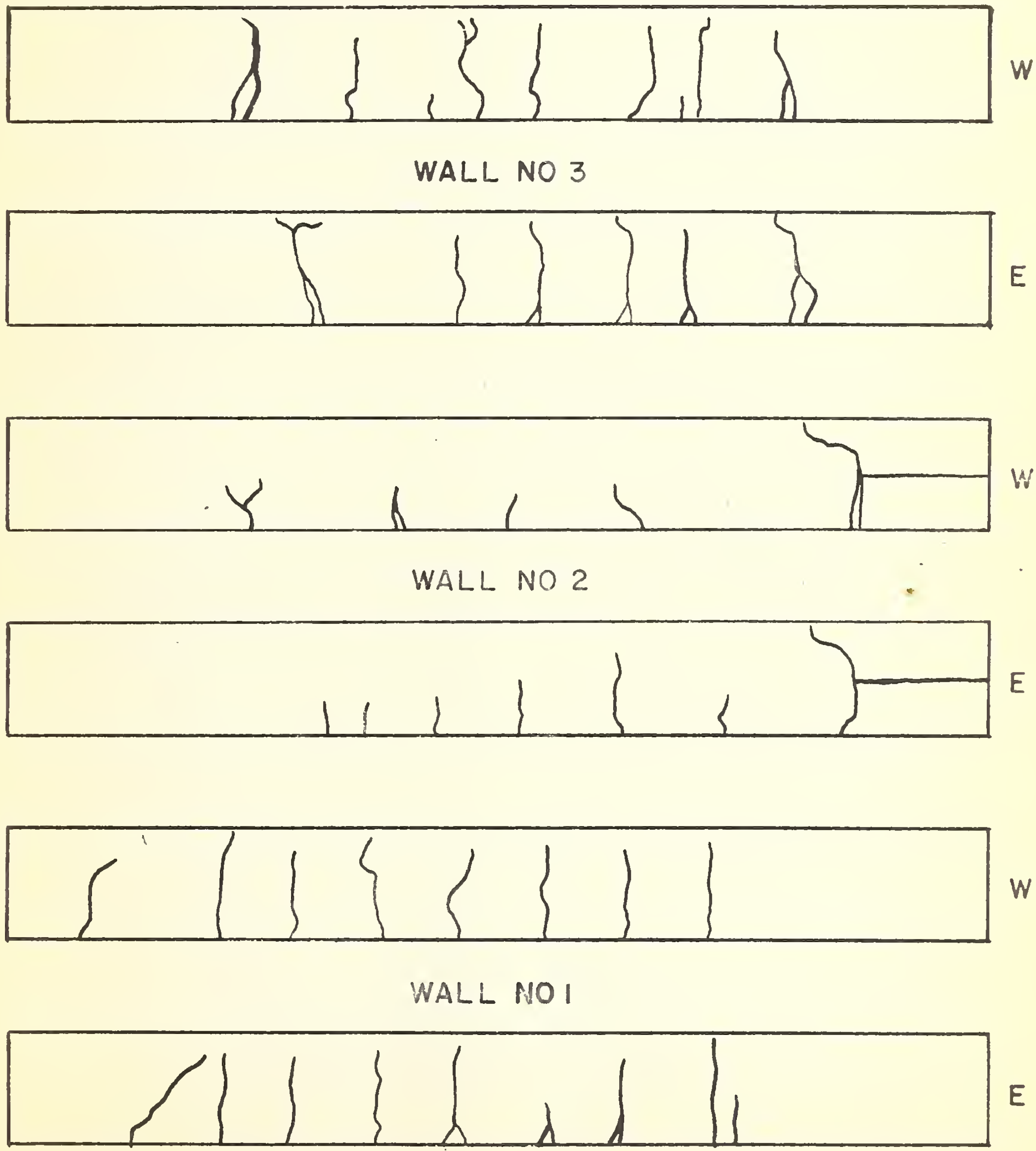
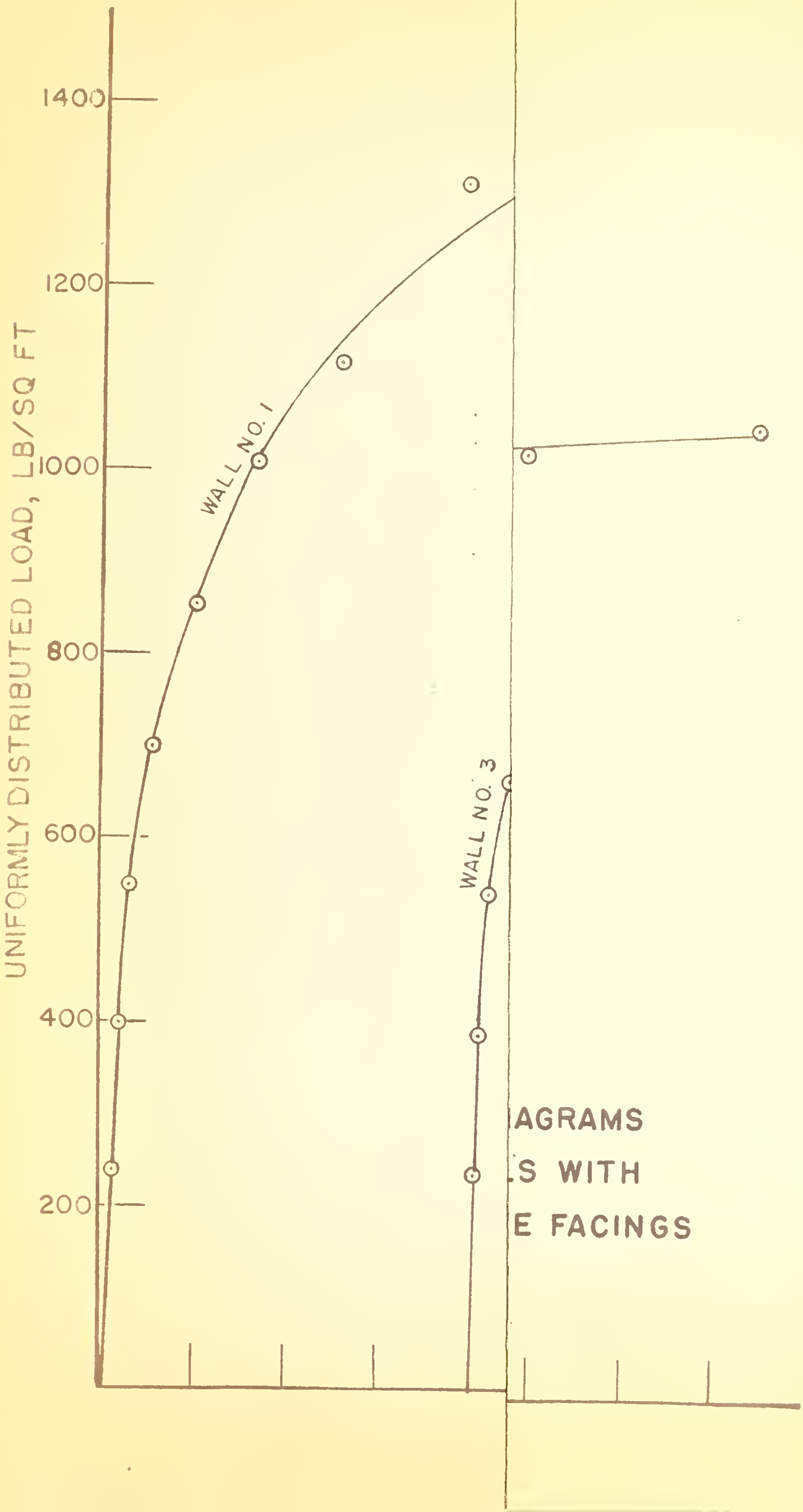
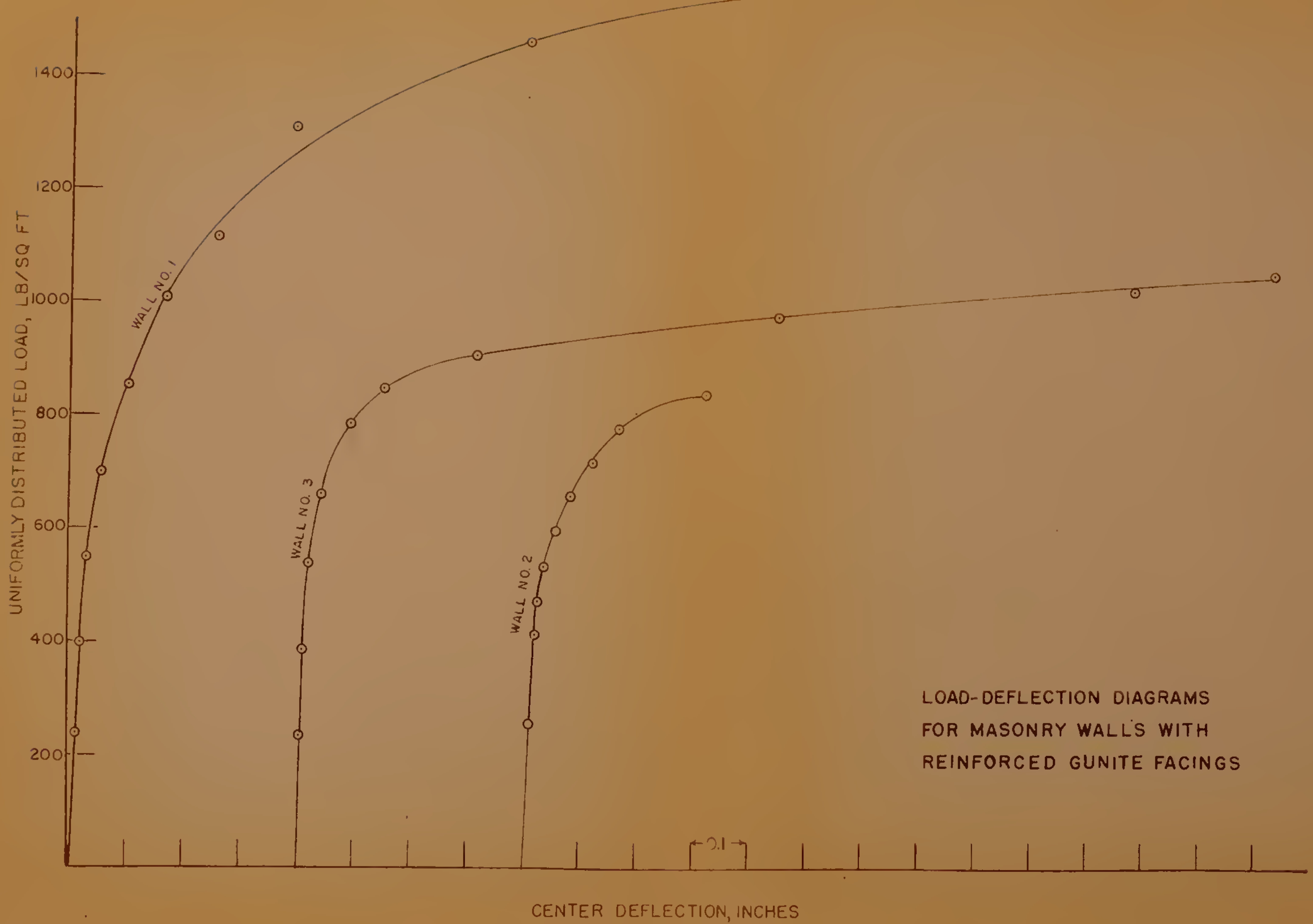


Fig. 8



AGRAMS
S WITH
E FACINGS

Fig. 9



LOAD-DEFLECTION DIAGRAMS
FOR MASONRY WALLS WITH
REINFORCED GUNITE FACINGS

Fig. 9

COMPRESSIVE & TENSILE STRAIN IN GUNITE FACINGS AT MIDSECTION

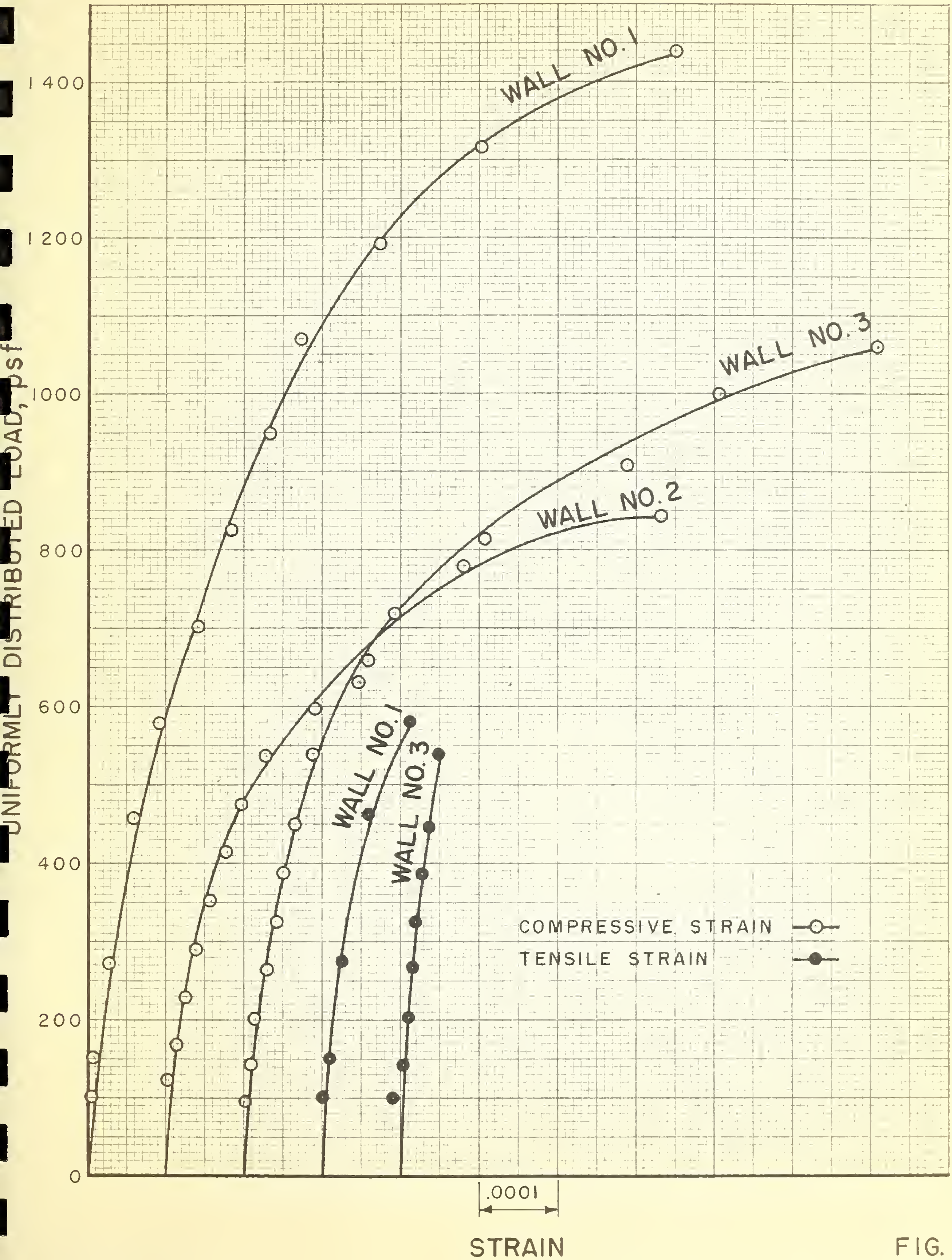


FIG. 10

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The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

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