NATIONAL BUREAU OF STANDARDS REPORT

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Effect of Type and Arrangement of
Cellular Blocks on Strength of Prestressed Assemblies

by

M. Chi and D. Watstein

Report to

Bureau of Yards and Docks
Department of the Navy

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Abstract

Investigation was made of the mechanism of failure of two-way prestressed slabs made of cellular concrete blocks. Small columns, beams and slabs were studied and cracks in webs of blocks due to prestress were discovered. Reinforcement was found to be very effective both in minimizing the extent of these cracks and in increasing the strength of the assemblies; the shape of holes was found to have no effect on the occurrence of these cracks. The suitability of different types of blocks for use in a two-way prestressed slab can be predicted with this method of testing.

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1. INTRODUCTION

In the continuing study of the properties of the two-way prestressed cellular slabs, several slabs composed of 6-in. cellular blocks were tested. The results of the tests of slabs Nos. 1 through 4 composed of cells procured by Preload Corporation, were reported in NBS Report 4396. As will be described in detail in a forthcoming report on some of the other slabs tested, the specimens consisting of high-strength, precision cellular blocks having no reinforcement failed under smaller load than those of inferior but reinforced blocks; these slabs exhibited distinctly different crack patterns. While this finding has confirmed the Conclusion 3 in NBS Report 4396, further tests were deemed necessary to study the cause and mechanism of premature failure in slabs containing unreinforced blocks. It is for this purpose that the Structural Engineering Section initiated the auxiliary series of tests of small columns, beams and slabs described in this report.

2. DESCRIPTION OF TEST SPECIMENS

2.1 Cellular blocks

The following different types of cellular blocks were used in this test series, (see Figure 1):

Type UE - 6 in. unreinforced cells having an opening 4 1/2 in. square in cross section, with one 1- by 2-in. elliptical hole in each web.

Type UR - Same as Type UE except that it has 1-in. round holes instead of elliptical hole in each web; unreinforced.

Type UN - Same as Type UE except that it has no holes in the webs; unreinforced.

Type FE - Identical with Type UE except that it is reinforced with 1- by 1-in. 15/15 welded wire fabric.

Type SE - Identical with Type UE except that it is reinforced with stirrups of No. 4 gage mild steel wire, one in each web.

All blocks were made of mortar containing a concrete sand; the proportions of the mortar were 1:3, by weight, and the water-cement ratio was 0.57. Type I cement with 2 percent calcium chloride was used for Type UN block and Type III cement for all other types. It was assumed that the compressive strength of the mortar was essentially the same for all blocks under similar curing conditions in spite of the difference in cement types. The compressive strength of 2-in. cubes of a typical mix, after seven days of moist curing was 6200 psi. Young's modulus ranged from 3.5 to 4.5×10^6 psi with an average about 4×10^6 psi. All blocks were precision made, had excellent texture and were virtually free of shrinkage cracks. All blocks were at least six months old when incorporated into test specimens, except for blocks of Type UR which were about one month old.

2.2 Prestressing steel

The prestressing units in the test beams were 5/8 in. "Stressteel" bars. The anchorage of these bars consisted of hexagonal nuts, 1 1/4 in. long, which bore on 5 3/4- by 5 3/4- by 3/4-in. anchor plates. The tensile strength of unthreaded Stressteel bars was found to be 163,000 psi, whereas threaded bars supported by fully tightened nuts developed a tensile strength of 152,000 psi. The yield strength of the steel, determined by the "offset" method (offset = 0.2%) was 142,000 psi. The stress-strain characteristics was a straight line up to 65,000 psi, giving a Young's modulus of 30×10^6 psi; the secant modulus at 100,000 psi was 28.2×10^6 psi. The reduction in area at point of fracture was 35 percent.

2.3 Specimens

All types of blocks were so precisely made that intimate contact between them could be provided by a very thin joint. One assembly was tested with bare joints and later retested with asbestos gaskets. All others had either neat cement, neat plaster or calked joints. Cement or plaster joints were made by dipping the ends of blocks into the respective material. All cement joints were moist-cured for at least two days. Plaster joints were found to be very convenient to use since they did not need any moist curing and gained sufficient strength after a few hours of drying.

Two kinds of joint fillers were used in calked joints: "Igas No. 7," a soft bituminous material and "Kalk-Kord," a gray heavy mastic in the form of extruded bead. Because they are soft and squeezed to a very thin layer when under load, these caulking materials are applicable only to precision blocks.

Test Series 1 consisted of 20 small column specimens composed of three blocks each, the type of blocks and type of joints being as designated in table 1. In specimens Nos. 1 through 13, "Stacked" arrangement was used, i.e., the blocks were stacked like a chimney with all holes in the webs at corresponding locations. In specimens Nos. 14, 15, 16, and 17, "Crisscross" arrangement was used, i.e., the axis through the open ends of a block was perpendicular to that of adjacent one. The same "Stacked" arrangement was used in specimens Nos. 18 and 19 for Type UN blocks (no holes in the web). "Stacked" arrangement of cells is illustrated in figures 5 through 13, and "Crisscross" arrangement is shown in figures 14 and 15.

Specimen No. 20 consisted of a solid block on the top and on the bottom and a "Preload" block in the middle. The joints between these blocks were 1/8 in. mortar of one part of Type III portland cement and three parts of masonry mortar sand, by weight.

Test Series 2 consisted of 20 beams composed of five blocks each, the type of blocks and type of joints being as designated in table 2. "Stacked" arrangement was used in beams Nos. 1 through 8 and "Crisscross" arrangement was used in beams Nos. 9 through 18. Neat cement joints were used in beams Nos. 1 through 13, and subsequently neat plaster joints were used in all the others for the sake of expediency. Beams Nos. 19 and 20 were arranged with all the blocks side by side, i.e., all webs in contact. This arrangement is hereafter referred to as "Side Construction."

Prestressing of the Stressteel bars was accomplished by means of a hydraulic jack whose force was measured by a calibrated dynamometer in the adapter bar. The loss of prestress due to shrinkage and creep of concrete was not measured but believed to be negligible.

The average prestress applied to the beams is given in table 2. The maximum value of prestress given in the table is the initial prestress. In several cases the initial prestress was reduced prior to test of the beam and the reduced value is also given in the table.

In beams Nos. 1, 2, 3, 4, 5, 6, 12, and 13, the average maximum and working prestress for each beam was 600 psi. Beams Nos. 19 and 20 had no webs and therefore a correction was made to provide an average flange prestress of 600 psi and 1200 psi, respectively.

In all other beams it was intended to cause the specimens to crack prior to testing to show the effect of the web reinforcement. Accordingly, in beams Nos. 7, 8, 10, 11, 14, 15, 16, and 17 a maximum prestress of 1200 psi was applied initially; the prestress was then reduced to 600 psi in all beams except Nos. 7 and 8, in which the prestress was not disturbed. Beams Nos. 9 and 18 were prestressed to an initial maximum of 900 psi and 1500 psi, respectively, and both tested at 600 psi.

Test Series 3 consisted of determination of compressive strengths of individual blocks, two miniature slab tests and a determination of strain distribution in individual units and short columns. The blocks used in the compressive tests

were representative of the types used in Series 1 and 2 and had similar curing and age. A sufficient number of tests were made to determine the concrete compressive strengths both in the stacked and side construction positions. The miniature slabs consisted of nine blocks of Type UE with three rows of three blocks each. The blocks were arranged in a crisscross fashion and Stressteel bars were staggered to give concentric resultant prestressing just as in the 5- by 5-ft slabs described in NBS report 4396. The prestressing force applied in Slab A was enough to furnish about 1500 psi average stress in the blocks in both directions and 1000 psi in Slab B. No jointing material was used in either of these miniature slabs.

The strain distribution tests included one individual specimen each of Type UN, Type FE and Type UE block, and of a column test of three Type UE blocks, Stacked, and having cemented joints. Bonded wire strain gages were attached to individual block specimens; Tuckerman optical gages were attached to the column specimens to measure longitudinal strain and bonded wire gages were used to measure transverse strain. The locations of gages are shown in figures 2 and 3.

3. TESTING METHODS

3.1 Test series 1, column tests

All columns were tested to failure in a 300,000 lb capacity hydraulic testing machine. Irregularities in the end surfaces of the columns were taken up by placing a thin asbestos gasket on each bearing end. Cracks were traced as they developed and maximum loads were recorded. No crack pattern was available for column No. 18 because the first crack occurred at a load too close to ultimate load. Column No. 19 was loaded with bare concrete blocks in contact with each other and cracks occurred near the joints. Consequently, the load was removed, asbestos gaskets were placed at the joints and the column was loaded again until failure.

3.2 Test series 2, beam tests

All beams were tested to failure by flexure and shear in a 60,000 lb capacity hydraulic machine. The beam was supported on 6- by 5 1/2- by 3/4-in. steel plates under each end block and the plates rested on knife-edges approximately 2 ft apart as shown in figure 4. Load was applied through a 1 in. roller welded to a 6- by 6- by 3/4-in. steel plate which rested squarely on the center block in the beam. The center deflection of the beam was measured with a 0.001 in. micrometer dial

indicator placed as close to the middle as practicable. Again the crack pattern traced as it developed with load.

3.3 Test series 3, compressive strength, strain distribution and miniature slabs

All individual blocks were tested to failure in a 300,000 lb capacity hydraulic testing machine. At first all blocks in the compression tests were capped with high strength gypsum plaster on both loaded surfaces, but later on, asbestos gaskets were substituted as caps when they were found to be satisfactory in taking up small variations in dimensions of the precision cast blocks. Some blocks were tested in end construction position (with load applied in the direction of the cell) and others in side-construction position. Maximum load in each test was recorded. The cracking load for those blocks that developed cracks in early stage of the test were recorded.

In the miniature slabs the prestress was removed immediately after completion of prestressing operation, and the slabs were disassembled for inspection. No loading tests were performed.

In the strain distribution tests all specimens were tested in a 300,000 lb capacity hydraulic testing machine. Asbestos gaskets were used to transfer the load uniformly from the machine to the specimen. Readings of all gages were recorded for the 5,000 lb "flexing" load and zero readings were recorded upon removal of the load. The strain increments of all vertical gages were promptly computed and were used as a guide for centering of blocks with respect to the axis of the machine. This process was repeated until the strain increments indicated fairly uniform strain distribution. During the tests the readings of all gages were recorded for each load increment of 10,000 lb and sometimes for each 5,000 lb.

4. TEST DATA

The data for the columns in test series 1 are shown in table 1 and crack patterns are shown in figures 5 to 15. 1/ As explained in Section 3.1, column No. 19 was initially loaded with the concrete in adjacent blocks in direct contact

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1/ The numbers alongside the cracks indicate the applied loads. The encircled number indicate the order of occurrence of cracks.

and the cracking load given in table 1 corresponds to this condition. The load was then released, asbestos gaskets were placed between the blocks and the column was loaded to failure.

The test data for the specimens in beam tests are shown in table 2 and crack patterns are shown in figures 17 to 29. [1/] The relationship between center deflection and the load under different conditions is shown in figure 30.

The compressive strengths for the single blocks in series 3 are listed in table 3. No crack patterns for blocks in the end construction position were available since the cracking load was very close to failure load. No cracks were observed on the webs of blocks during the test of block of type UE in the side construction position. Type UR block in this position cracked at approximately the same load as in test of series 1, and the cracks were in the webs, usually through the holes. In the miniature slab A which had 1500 psi prestress, all nine blocks developed cracks during prestressing, while slab B, with 1000 psi prestress, six blocks developed cracks. The cracks were very narrow and irregular. They were essentially parallel to the shells and most of them passed through the elliptical holes. The strain distribution data of a three block column and three representative types of single blocks are given in table 4 and table 5, respectively.

1/ The numbers alongside the cracks indicate the applied loads. The encircled number indicate the order of occurrence of cracks.

5. DISCUSSION OF RESULTS

From the data in tables 1 and 3, the following tables can be summarized:

Average strength of column,(stacked arrangement)

Type of block	Joint material: Gement paste	Joint material: Igas	Joint material: Kalk-Kord	Average	Efficiency
	kips	kips	kips	kips	
UE	68	60	74	67.4	.69
FE	62	60	--	61	.63
SE	65	58	--	62.8	.65
UN	97	--	--	97	.79

Average cracking load of column, (stacked arrangement)

Type of block	Crack at joint: Cracking load	Crack at joint: Percent of maximum load	Crack at hole: Cracking load	Crack at hole: Percent of maximum load
	kips		kips	
UE	22	32	29	43
FE	27	44	40	65
SE	24	38	30	47

Average strength of column, (crisscross arrangement)

Type of block	Cracking load	Percent of maximum load	Maximum load	Effi-ciency
	kips		kips	
UE	15	31	48	.71
UR	10	26	39	.75
UN	12	24	50	.57 (est.

In the above tables, the efficiency of a column with stacked arrangement of cells is defined as its strength divided by the compressive strength of a single block in the end-construction position; the efficiency of a column with crisscross arrangement is defined as its strength divided by the compressive strength of a single block in the side-construction position.

As shown in the above tables, blocks of Type UN had the highest block strength, column strength and efficiency in a stacked arrangement; they had only moderate column strength and somewhat lower efficiency in crisscross arrangement. The reinforced blocks of Type FE and Type SE blocks cracked at higher loads but failed at same, or slightly lower load than the unreinforced Type UE blocks. It was also found that cracks appeared at the joints before cracking occurred near the holes. In view of the fact that most of these columns were fabricated of precision blocks with thin joints, the initial cracking could be attributed to reasons other than stress concentration near the holes.

A close examination of figures 5 to 13, revealed two important facts. The first fact was that the cracks occurred mostly in the webs and did not occur in the shells until incipient failure. The second fact was that only about 50 percent of the total number of cracks passed through the holes before failure occurred. The other 50 percent originated at the joints and did not pass through the holes at all. These two effects were particularly pronounced in crisscross arrangement as shown in figure 16. The Type UN blocks, in stacked arrangement and with cement joints, demonstrated freedom from this type of cracking as illustrated in column No. 18 but were just as vulnerable as the other types of blocks in the crisscross arrangement. Since Type UN blocks had no holes in the web, these tests had further indicated that the stress concentration at the holes was at most a secondary cause of cracks in the column tests.

In comparing the test results of columns Nos. 18 and 19, the early appearance of cracks in the latter must be attributed to the lack of joint material to take up the irregularities at the joint. These tests along with miniature slab tests indicated that longitudinal cracks would occur, even in precision blocks without jointing material, under axial compression.

Test series 2 indicated that the beams of unreinforced blocks did not crack in stacked arrangement but cracked in crisscross arrangement under nominal prestressing force. The

use of reinforcement in the webs of the other types of blocks had either reduced the width of cracks or eliminated them altogether for the same prestressing force. These cracks had reduced the load carrying capacity of all beams of crisscross arrangement, especially the unreinforced blocks. The ratio of the load carrying capacities of unreinforced to reinforced blocks decreased from 0.78 for stacked arrangement to 0.55 for crisscross arrangement. Beam No. 18 which carried 30 percent less load than other beams of the same cell arrangement indicated that excessive prestress was detrimental to reinforced blocks as well.

The strain distribution data indicated large variations of strains for different locations on the same block or for corresponding positions of different blocks. Nevertheless, the data established the following:

1. High tensile strain existed near the hole in the transverse direction.

2. The band of concrete between the holes in the webs and the bearing surfaces of the testing machine was subject to a very small compressive strain in the longitudinal direction. In other words, the stress flow by-passed not only the holes but also the concrete directly above and below them.

3. The restraining effect of the platens of the testing machine was felt near the edge of the block in contact with them. In the three block columns, the stress concentration near the hole in the top block was of a moderate amount.

4. There was no continuity of stress pattern from block to block across the joint and abrupt changes in longitudinal and transverse stresses were observed across the thin cement joints. In some cases changes from low tensile to low compressive strain was observed.

As explained above the stress concentration around the hole played a secondary role in causing cracks in the webs of the blocks. The principal cause of cracking is open to speculation. One possible explanation may be the bowing out of shells under high load as shown in figure 31 where the stress distribution is extremely complex and non-uniform. The slightest deviation of the shells of the blocks from a true plane would induce eccentric loading. Under this condition the shells would bow like a buckled column even for low slenderness ratios. Owing to the stress concentration around the holes and the inability of concrete to resist tensile forces, the webs in the middle blocks that serve as "ties"

to the twin columns, would crack at a relatively low load. Reinforcement in the web would delay the occurrence of the cracks and materially increase the cracking load. After cracking, the reinforcement holds the crack width to a minimum and resists the transverse load tending to cause diagonal tension failure. The reinforcement did not eliminate cracks but minimized the damage caused by the cracks.

Crisscross arrangement showed a much lower resistance to cracking due to prestressing and also lower resistance to transverse shear, especially if the blocks were not reinforced.

Figure 30 gives graphically the relationship between loads and deflections for the 5-cell beams. Deflection varied nearly proportionally with the load up to the point when the cracks in the web began to open up and then the deflection increased more rapidly with small increases of load, without a sharply defined transition.

As long as the shear resisting webs of the blocks were not cracked, the deflection curves for reinforced and unreinforced blocks coincided in spite of the marked differences between their load carrying capacities. In the case of reinforced block both the stacked and crisscross arrangements showed, up to a point, the same relation between the deflection and load. In the case of unreinforced blocks the effect of arrangement could not be determined because all webs in the crisscross arrangement were cracked due to prestress. It was also observed that if the shear resisting webs were cracked, the deflection curves for stacked reinforced and crisscrossed unreinforced blocks coincided, and the beams were less rigid than those with uncracked blocks. This observation indicates that the cracks in the web of a beam of this type were the largest single factor affecting the rigidity of a beam. That is, the elastic deflection equation of a beam of this type failed to predict the deflection accurately if and when the webs of the beam were cracked. This held true whether the cracks were due to transverse shear during the testing or other causes prior to testing. Beams with blocks that were cracked due to prestressing and beam No. 4 which was cracked when it was inadvertently loaded upside down, produced a load deflection curve which deviated consistently from a straight line during the early stage of loading.

6. CONCLUSIONS

1. Cracks running parallel to shells occur in the webs of all types of blocks under axial compression. Blocks in a crisscross arrangement develop cracks at lower stresses than similarly loaded blocks in stacked arrangement.

2. Suitable jointing material must be used even in most precisely made blocks in order to avoid early cracks.

3. Shape of holes in the webs of blocks is a minor factor in the formation of cracks. Cracks occurred in blocks without holes.

4. Presence of these cracks reduces the load carrying capacity and increases the deflection of beams composed of these blocks.

5. While the occurrence of these cracks is unavoidable in this type of block and arrangement, the formation of cracks can be significantly delayed by increasing the tensile resistance of the block webs either by suitable reinforcement or by improving the quality of the masonry units.

6. It was observed that a nominal prestress in beams (600 psi) with crisscross arrangement of blocks produced longitudinal cracks, while a prestress of 1000 psi in miniature slabs produced such cracks in both of the slabs examined immediately after prestressing.

Table 1. Summary of Column Tests (Test Series 1).

Specimen No.	Maximum load	Cracking load		Ratio of cracking load to maximum load		Type of blocks	Type of joint	Arrangement of blocks
		at joint	at hole	Crack at joint	Crack at hole			
	kips	kips	kips					
1	68	32	33	.47	.49	UE	Cement	Stacked
2	70.2	19	44	.27	.63	UE	do	do
3	65.5	12	32	.18	.49	UE	do	do
4	66	23	25	.35	.38	UE	Igas	do
5	54	15	20	.28	.37	UE	do	do
6	80	25	25	.31	.31	UE	Kalk-Kord	do
7	68	25	25	.37	.37	UE	do	do
8	56	24	31	.43	.55	FE	Cement	do
9	67	38	49	.57	.73	FE	do	do
10	60	20	40	.33	.67	FE	Igas	do
11	66	26	35	.39	.53	SE	Cement	do
12	64.5	--	35.5	--	.55	SE	do	do
13	58	20	20	.34	.34	SE	Igas	do
14	38.7	15	10	.26	.26	UR	Plaster	Crisscross
15	47.6	22	15	.46	.32	UE	do	do
16	50	15	--	.30	--	UN	do	do
17	50	8	--	.16	--	UN	do	do
18	92	70	--	.76	--	UN	Cement	Stacked
19	101	8	--	--	--	UN	Bare; later asbestos gaskets were added	do
20	42	--	10	--	.24	Preload	Mortar	(see page 4)

Table 2. Summary of Beam Tests (Test Series 2).

Beam No.	Maximum load, kips: Individual beams	Maximum load, kips: Average	Average maximum applied prestress	Avg. value to which prestress was reduced prior to test	Type of blocks	Type of joint	Arrangement of blocks	Remarks
			psi	psi				
1	8.0)	7.6	600	600	UE	Neat cement	Stacked	
	7.2)		600	600	UE	do	do	
3	10.1)		600	600	FE	do	do	
4	11.1)	9.8	600	600	FE	do	do	
5	9.5)		600	600	SE	do	do	1/
6	8.3)		600	600	SE	do	do	
7	9.4)	11.7	1200	1200	UE	do	do	
8	13.0)		1200	1200	UR	do	do	
9	3.4)		900	600	UE	do	Crisscross	*
10	3.3)		1200	600	UE	do	do	*
11	2.8)	3.4	1200	600	UR	do	do	*
12	3.2)		600	600	UR	do	do	*
13	4.1)		600	600	UE	do	do	*
14	5.8)		1200	600	FE	Neat plaster	do	*
15	7.0)		1200	600	FE	do	do	
16	5.9)	6.2	1200	600	SE	do	do	
17	6.3)		1200	600	SE	do	do	
18	4.2)		1500	600	SE	do	do	
19	1.2)	1.2	600	600	UE	do	Side Construction	
20	1.2)		1200	1200	UE	do	do	

1/ Diagonal tension cracks developed inadvertently during test of beam in inverted position. Beam was subsequently tested in correct position.

* Webs of beams cracked due to prestressing. These cracks are identified by "0" in figures Nos. 24 through 26.

Table 3. Compressive Strength of Individual Cellular Blocks

	Compressive strength, (kips)					
	Type UE		Type UR		Type UN	
	On end	On side	On end	On side	On end	On side
	87 94 97.4 110	64 65.1 67.8 68 70.4 73.6 60 63.5 67.2 73	60 76.3 79.8	45.9 59.2 53.8	125 120.5	--
Avg. strength	97.1	67.7	72.0	52.0	122.8	87 (est.)
Ratio of strengths (side to end)		0.70		0.72		0.71 (est.)
Maximum stress, psi	6070	7530	4500	5780	7670	9670 (est.)
Ratio of maximum stresses (side to end)		1.24		1.28		1.26

Table 4. Strain Distribution in a Column.

Strain, 10^{-6} in./in.1/

Load (kips)	SR-4 Gage No.2/									
	1	2	3	4	5	6	7	8	9	10
10	- 7	- 10	28	35	- 5	43	8	5	10	-25
20	16	12	30	55	-23	70	3	25	2	-45
30	14	45	67	180	-35	105	13	45	- 8	-62
40	- 7	125	300	432	-40	145	38	70	-30	-88
50	7	162	1683	3640	-45	185	200	75	48	30
55	30	160	2538	4250	-30	210	213	85	80	38

Load (kips)	Tuckerman Gage No.			
	E-1, W-1	E-2, W-2	E-3, W-3	E-4, W-4
10	-140	-40	-136	-105
20	-283	-90	-296	-225
30	-468	-113	-410	-338
40	-668	-120	-652	-463
50	-859	-45 390	-903	-613
55	-966	-45 500	-1025	-746

1/ Positive numbers indicate tensile strains.
Negative numbers indicate compressive strains.

2/ For location of gages see Figure 3.

Table 5. Single Block Strain Distribution

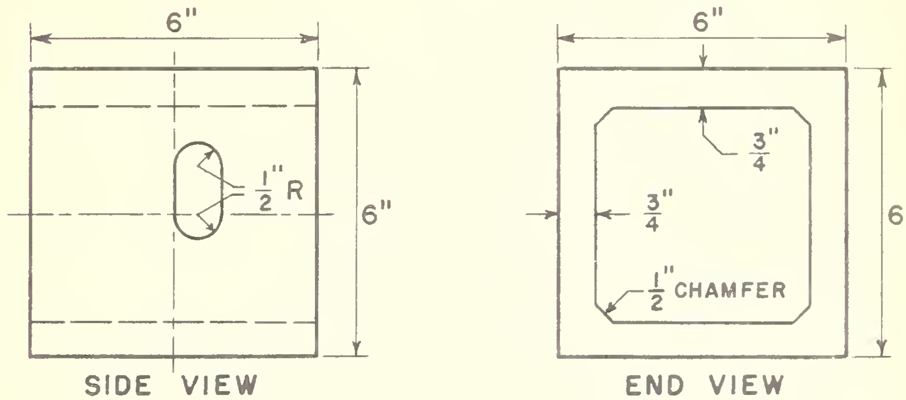
Strain, 10^{-6} in./in. 1/

Type of blocks	Load (kips)	SR-4 Gage No. 2/ 1, 2	3,4	5,6	7,8	9,10	11,12
UN	10	- 7	- 81	26	- 248		
	20	12	-208	36	- 493		
	30	66	-327	- 3	- 766		
	40	123	-475	-17	- 982		
	50	177	-634	-29	-1308		
	60	213	-778	-74	-1530		
	65	237	-871	-71	-1658		
FE	5	- 5	- 20		- 91	- 112	- 61
	10	- 4	- 51		- 181	- 221	- 131
	15	11	- 77		- 282	- 338	- 208
	20	53	-101		- 383	- 477	- 286
	25	218	-117		- 497	- 615	- 347
	30	374	-103		- 601	- 711	- 429
	35	845	- 81		- 701	- 908	- 514
	40	1236	- 81		- 798	-1065	- 606
	45	1619	- 91		- 897	-1230	- 706
UE	5	- 5	- 30		- 72	- 72	- 92
	10	1	- 56		-140	- 133	- 160
	15	20	- 74		-168	- 172	- 213
	20	22	-106		-282	- 234	- 315
	25	50	-115		-355	- 360	- 388
	30	63	-108		-423	- 439	- 473
	40	429	-156		-578	- 609	- 658
	50	836	-197		-728	- 776	- 877
	60	1586	-232		-885	- 940	-1031
	65	2186	-237		-986	-1058	-1157

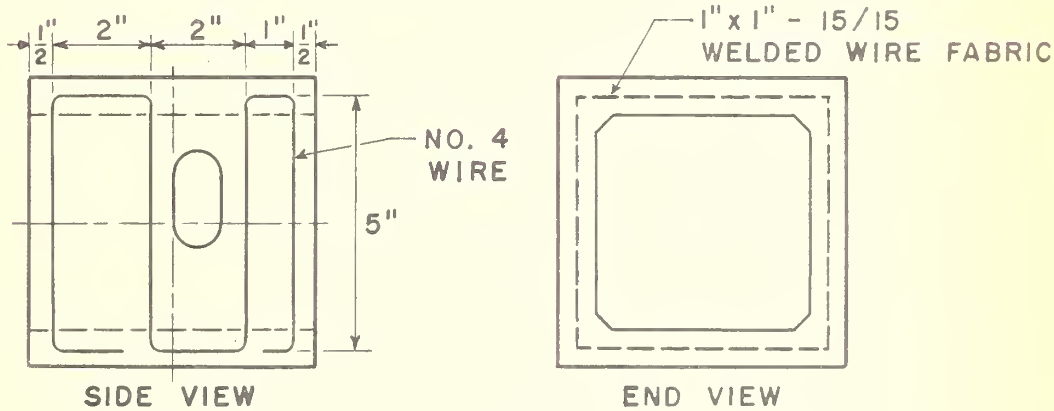
1/ Negative sign indicates compressive strain.
Positive sign indicates tensile strain.

2/ For location of gages, see figure 2.

NOTE: CELL DIMENSIONS IN END VIEW ARE SAME FOR ALL TYPES OF BLOCKS. FOR DETAILS OF SIDE VIEWS OF TYPE SE & TYPE FE SEE TYPE UE.

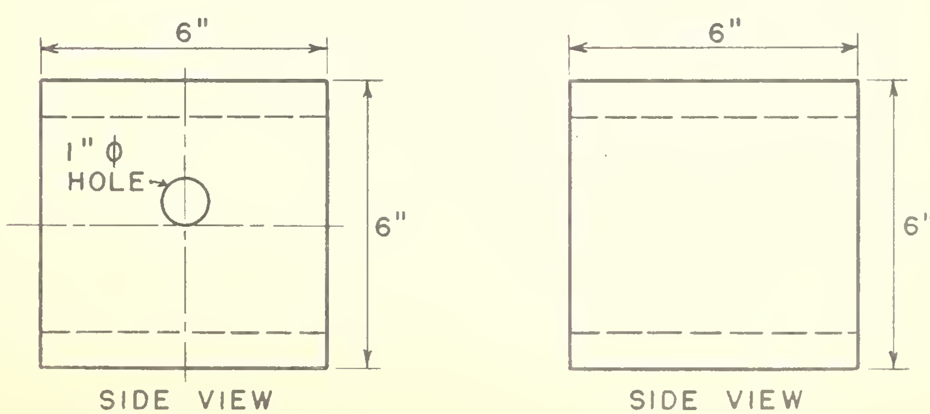


TYPE UE



TYPE SE

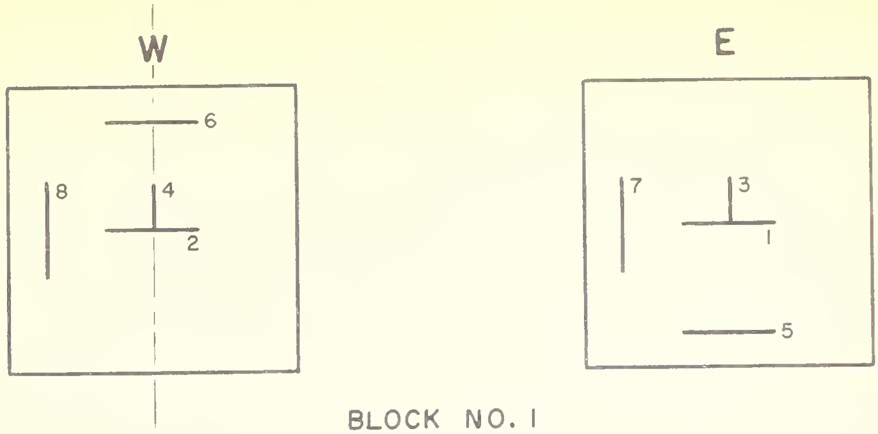
TYPE FE



TYPE UR

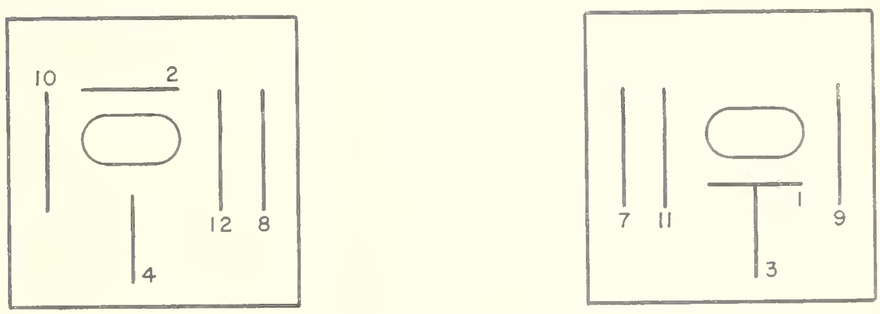
TYPE UN

FIG. I CELLULAR BLOCKS



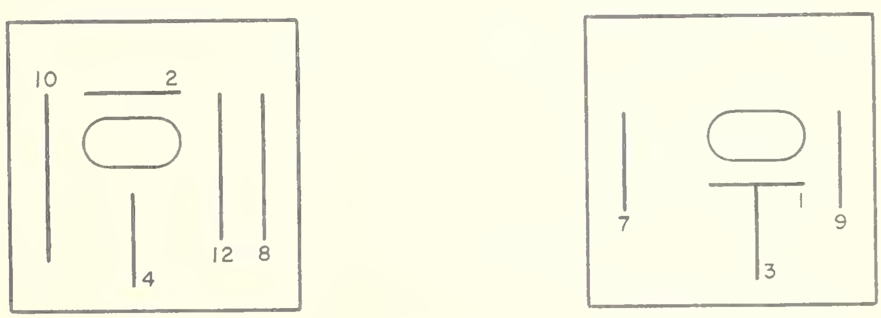
BLOCK NO. 1

TYPE UN BLOCK



BLOCK NO. 2

TYPE FE BLOCK

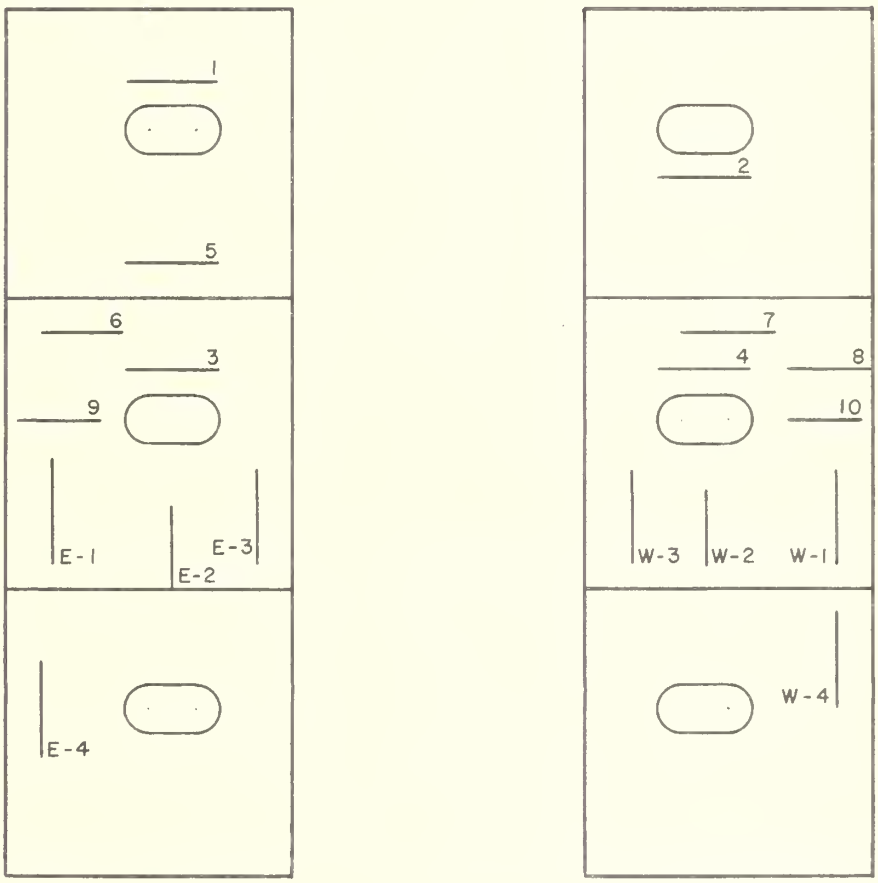


BLOCK NO. 3

TYPE UE BLOCK

FIG. 2 LOCATION OF SR 4 STRAIN GAGES IN STRAIN DISTRIBUTION TEST.

LEGEND: GAGE 1 THRU 10 - SR 4 ELECTRIC GAGES
GAGE E-1 THRU W-4 - TUCKERMAN GAGES



TYPE UE BLOCK

FIG. 3 GAGE LOCATION IN STRAIN DISTRIBUTION TEST

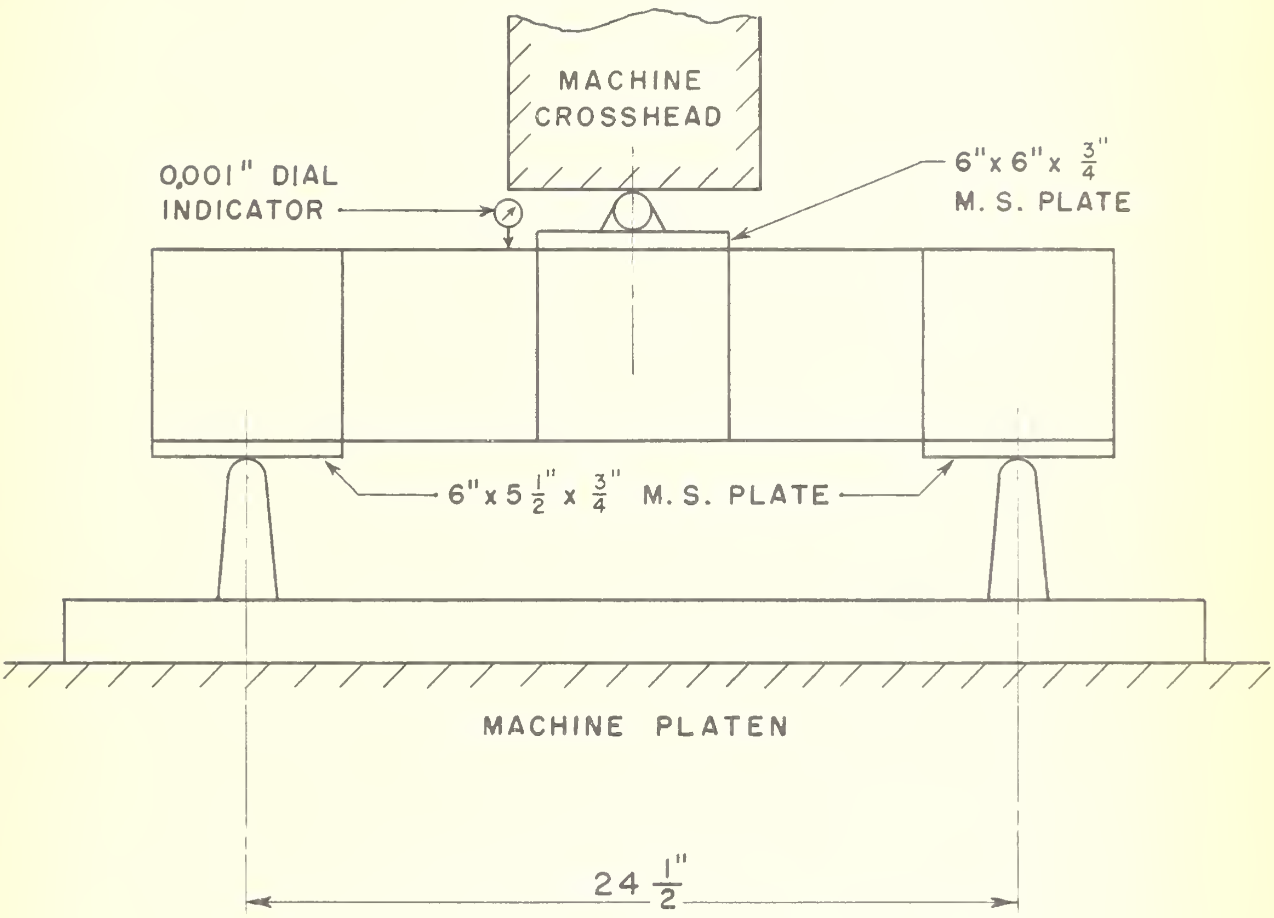


FIG. 4 SET - UP FOR BEAM TEST

TYPE UE BLOCK, STACKED,
NEAT CEMENT JOINTS.
FIRST CRACK - 32 KIPS
MAX. LOAD - 68 KIPS

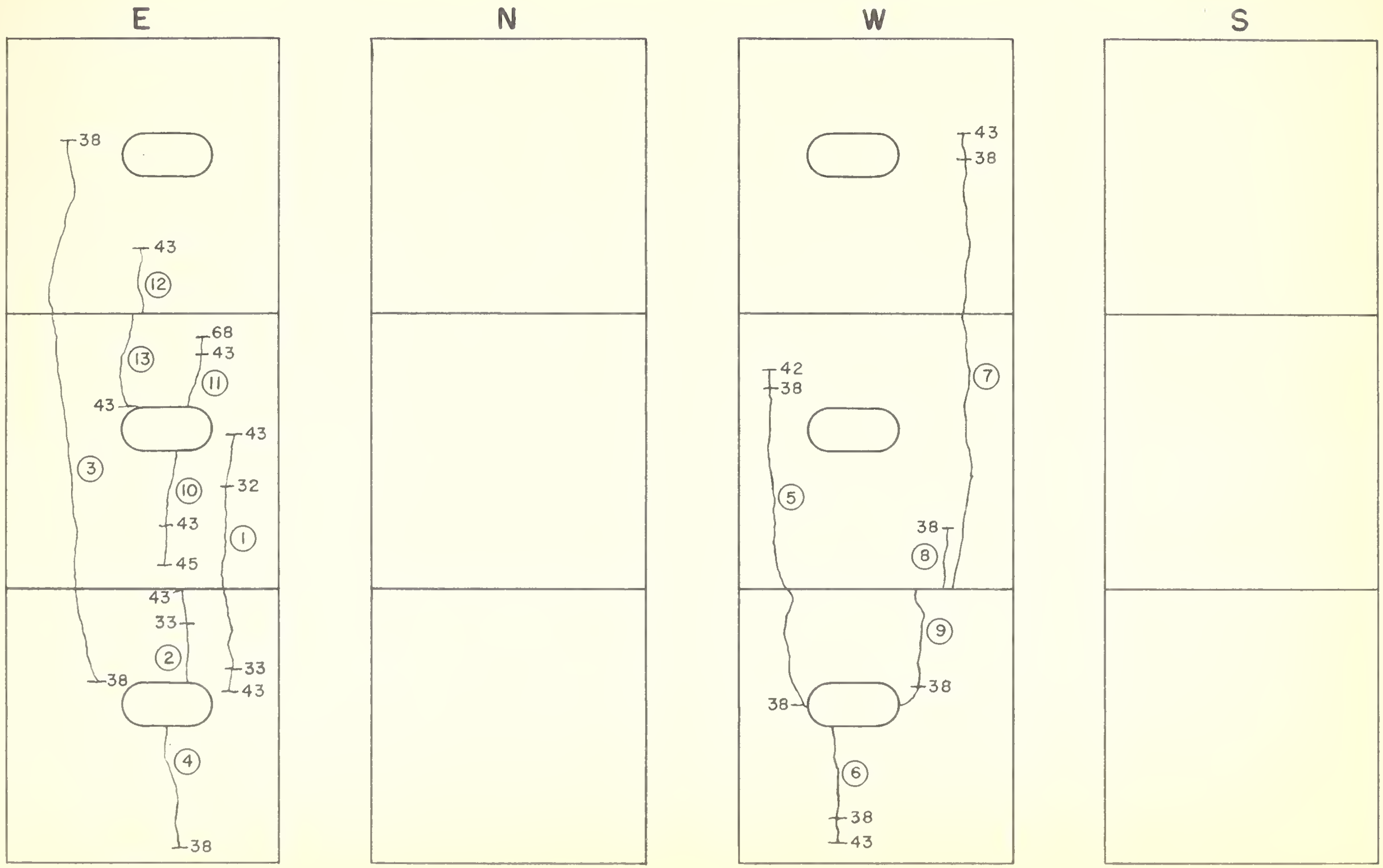


FIG. 5 CRACK PATTERN IN COLUMN NO. I

TYPE UE BLOCK, STACKED,
NEAT CEMENT JOINTS.
FIRST CRACK - 19 KIPS
MAX. LOAD - 70.2 KIPS

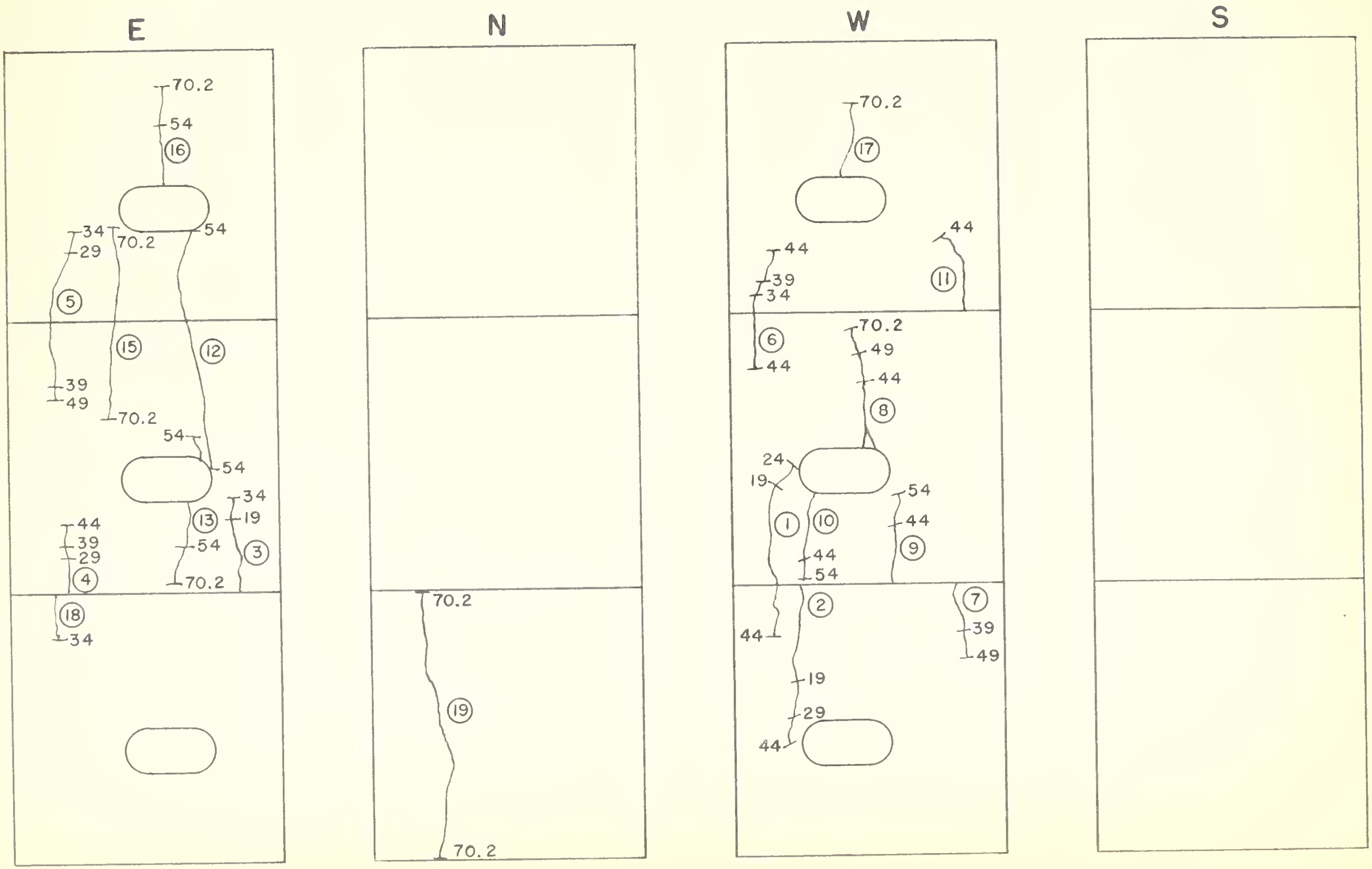


FIG. 6 CRACK PATTERN IN COLUMN NO. 2

TYPE UE BLOCK, STACKED,
NEAT CEMENT JOINTS.
FIRST CRACK - 12 KIPS
MAX. LOAD - 65.5 KIPS

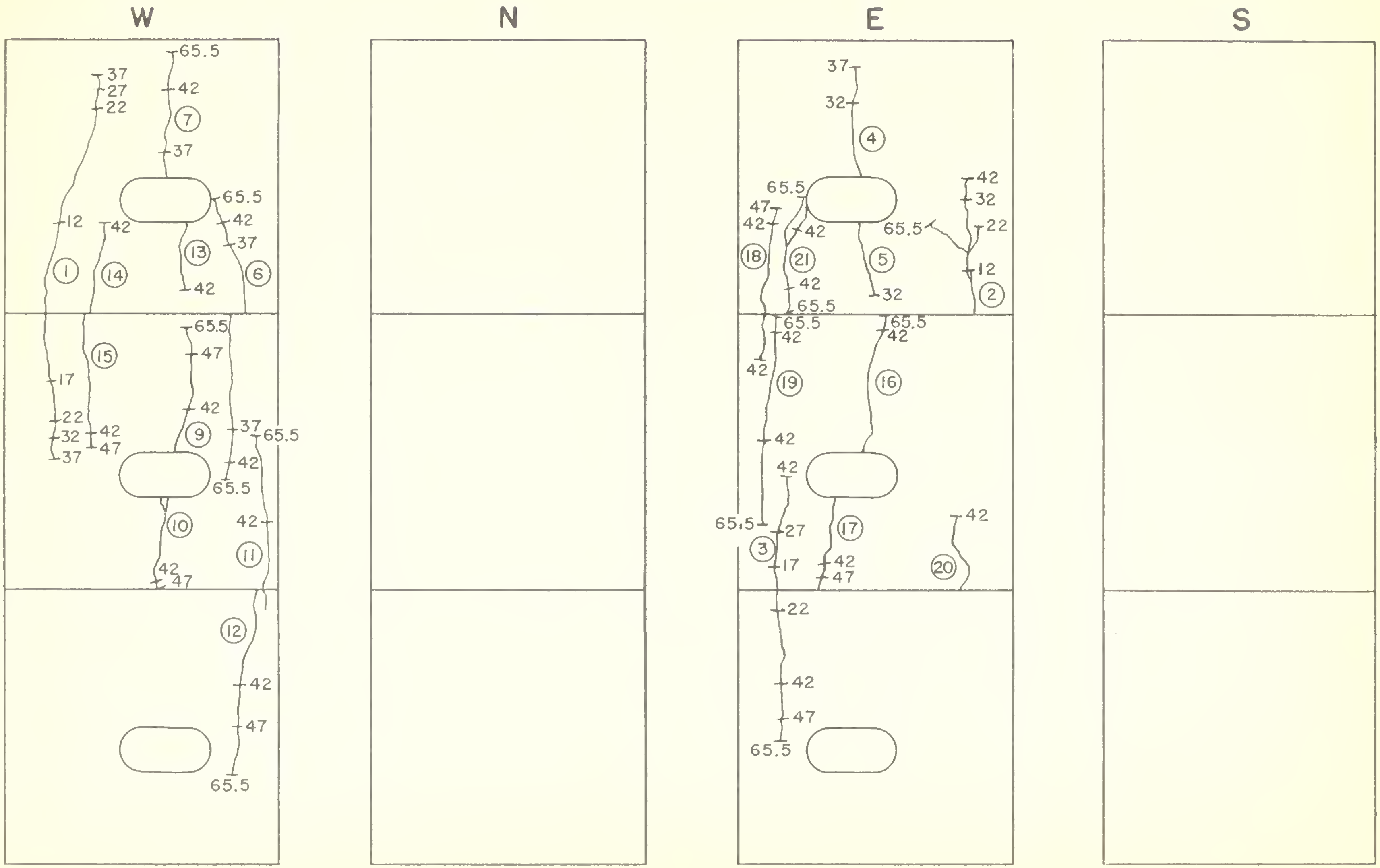


FIG. 7 CRACK PATTERN IN COLUMN NO. 3

TYPE UE BLOCK, STACKED,
IGAS JOINTS.

FIRST CRACK - 25 KIPS
MAX. LOAD - 66 KIPS

FIRST CRACK - 15 KIPS
MAX. LOAD - 54 KIPS

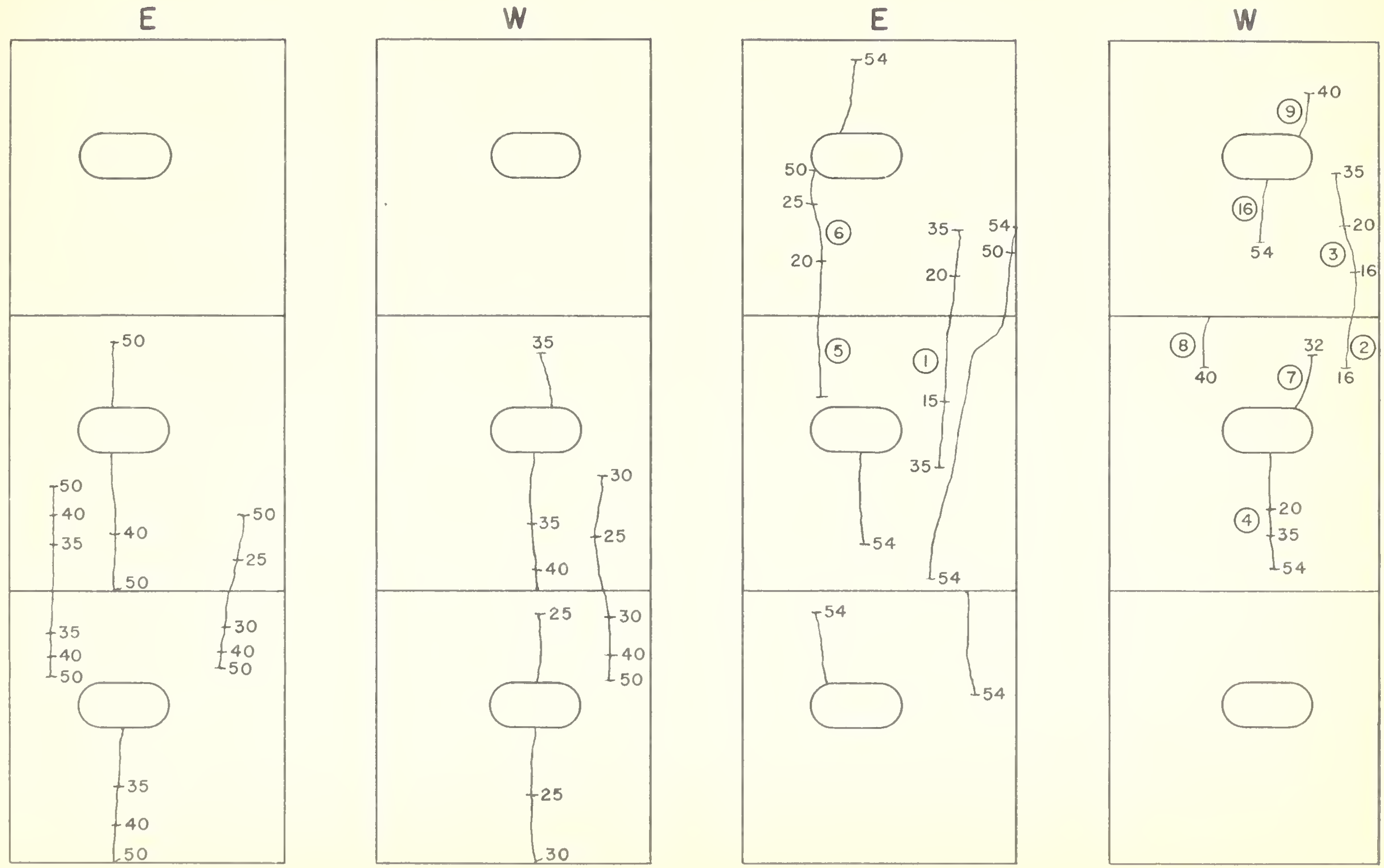


FIG. 8 CRACK PATTERN IN COLUMNS NO. 4 & 5

TYPE UE BLOCK, STACKED,
KALK-KORD JOINTS.

FIRST CRACK - 25 KIPS
MAX. LOAD - 68 KIPS

FIRST CRACK - 25 KIPS
MAX. LOAD - 80 KIPS

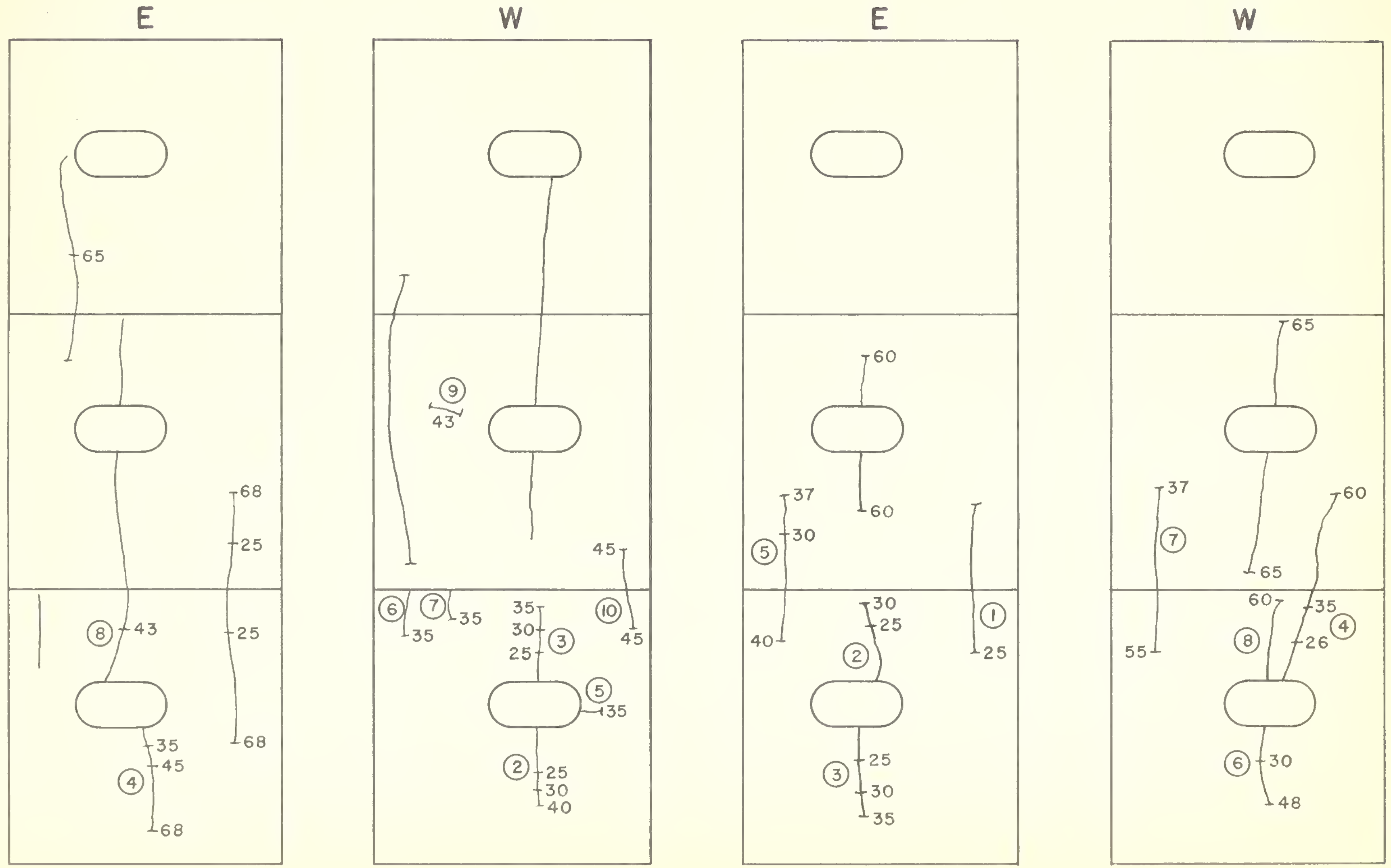


FIG. 9 CRACK PATTERN IN COLUMNS NO. 6 & 7

TYPE FE BLOCK, STACKED
NEAT CEMENT JOINTS.

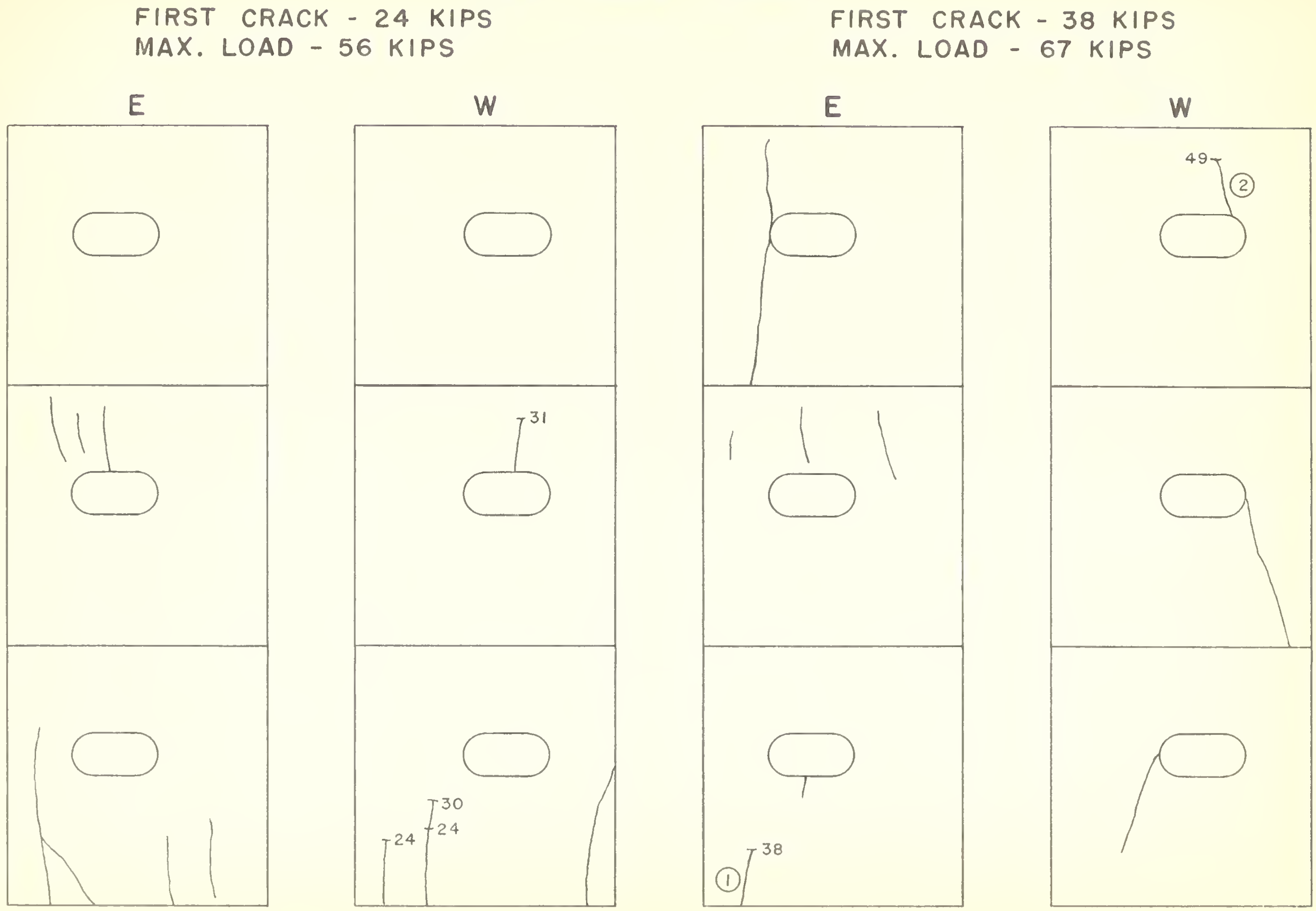


FIG. 10 CRACK PATTERN IN COLUMNS NO. 8 & 9

TYPE FE BLOCK, STACKED,
IGAS JOINTS.
FIRST CRACK - 20 KIPS
MAX. LOAD - 60 KIPS

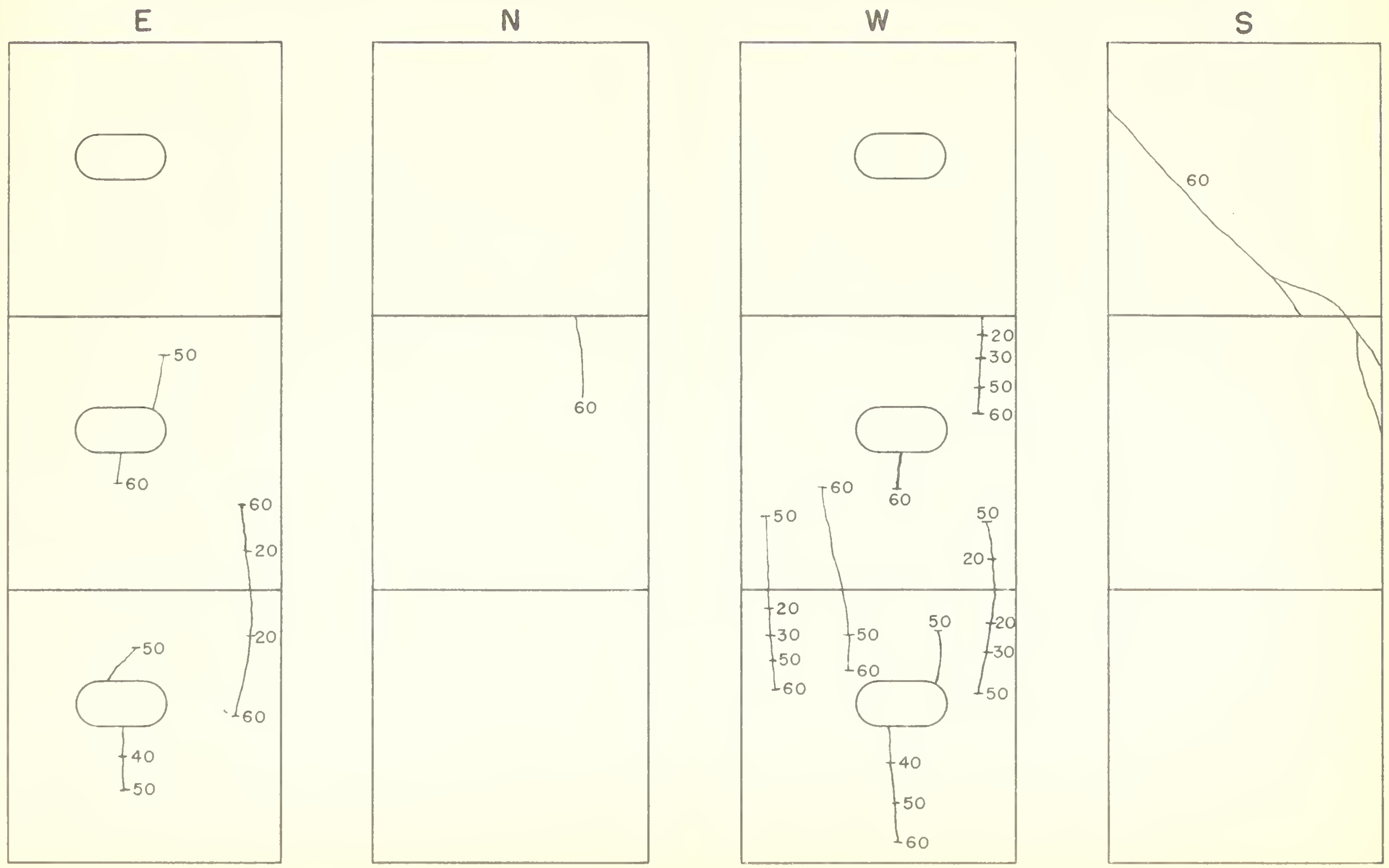


FIG. 11 CRACK PATTERN IN COLUMN NO. 10

TYPE SE BLOCK, STACKED,
NEAT CEMENT JOINTS.

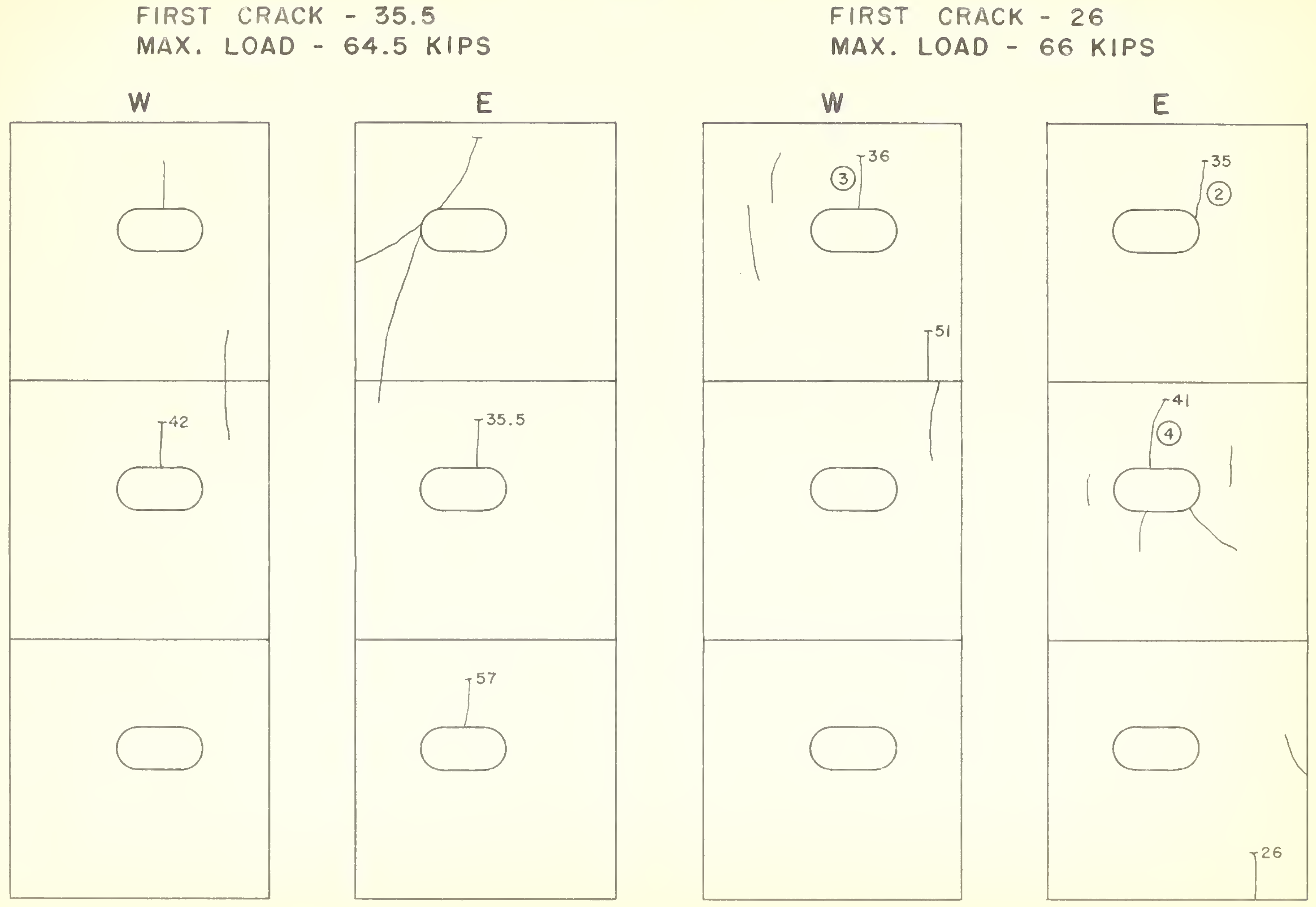


FIG. 12 CRACK PATTERN IN COLUMNS NO. 11 & 12

TYPE SE BLOCK, STACKED,
IGAS JOINTS.
FIRST CRACK - 20 KIPS
MAX. LOAD - 58 KIPS

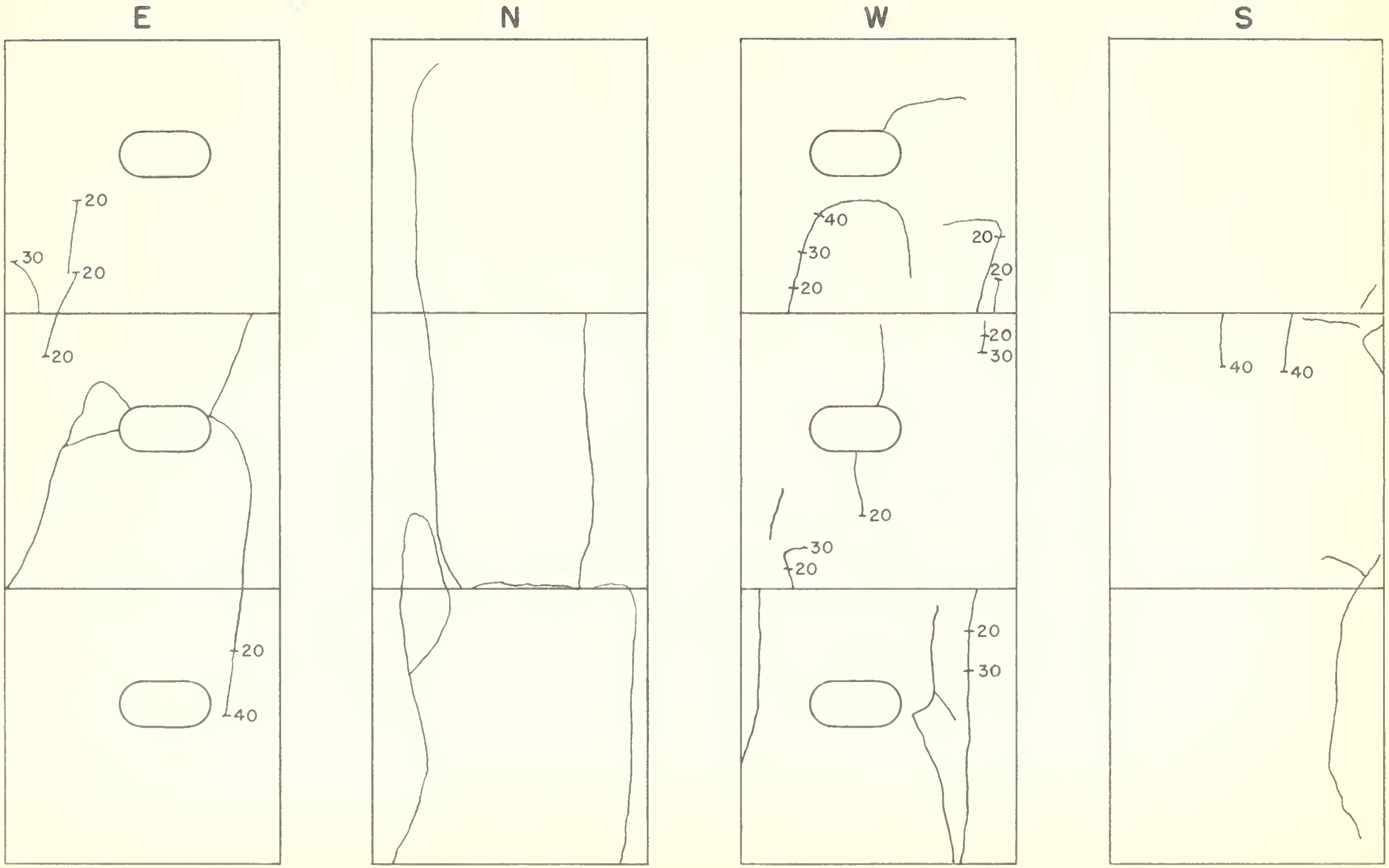


FIG. 13 CRACK PATTERN IN COLUMN NO. 13

TYPE UE BLOCK, CRISSCROSS
ARRANGEMENT, NEAT PLASTER JOINTS.

FIRST CRACK - 10 KIPS
MAX. LOAD - 38.7 KIPS

FIRST CRACK - 15 KIPS
MAX. LOAD - 47.6 KIPS

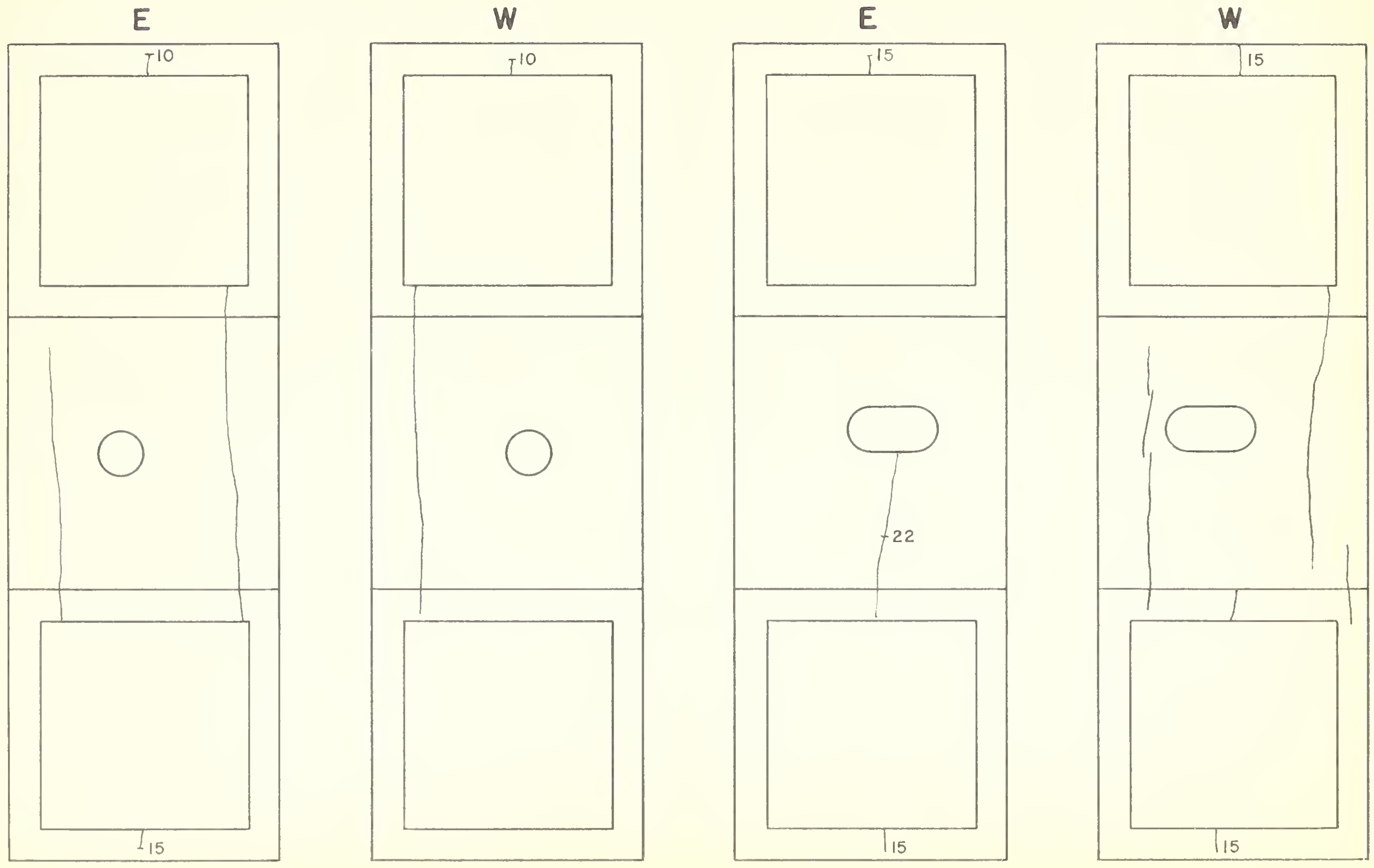


FIG. 14 CRACK PATTERN IN COLUMNS NO. 14 & 15

TYPE UN BLOCK, CRISSCROSS
ARRANGEMENT, NEAT PLASTER JOINTS.

FIRST CRACK - 15 KIPS
MAX. LOAD - 50 KIPS

FIRST CRACK - 8 KIPS
MAX. LOAD - 49 KIPS

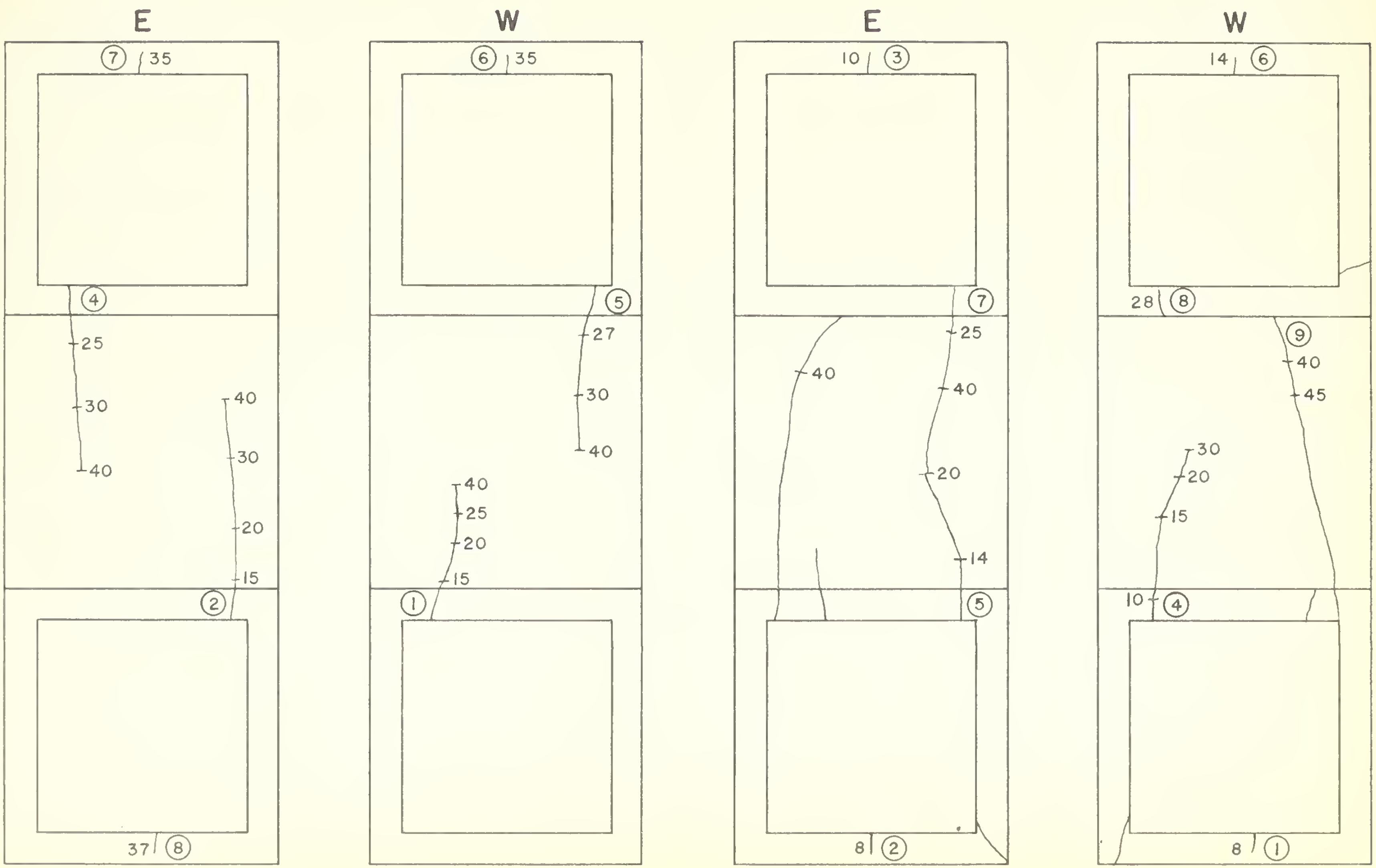


FIG. 15 CRACK PATTERN IN COLUMNS NO. 16 & 17

g. 16 - Typical crack pattern in columns with crisscross arrangement.

TYPE UE BLOCK, STACKED,
NEAT CEMENT JOINTS.
MAX. LOAD - 8.0 KIPS

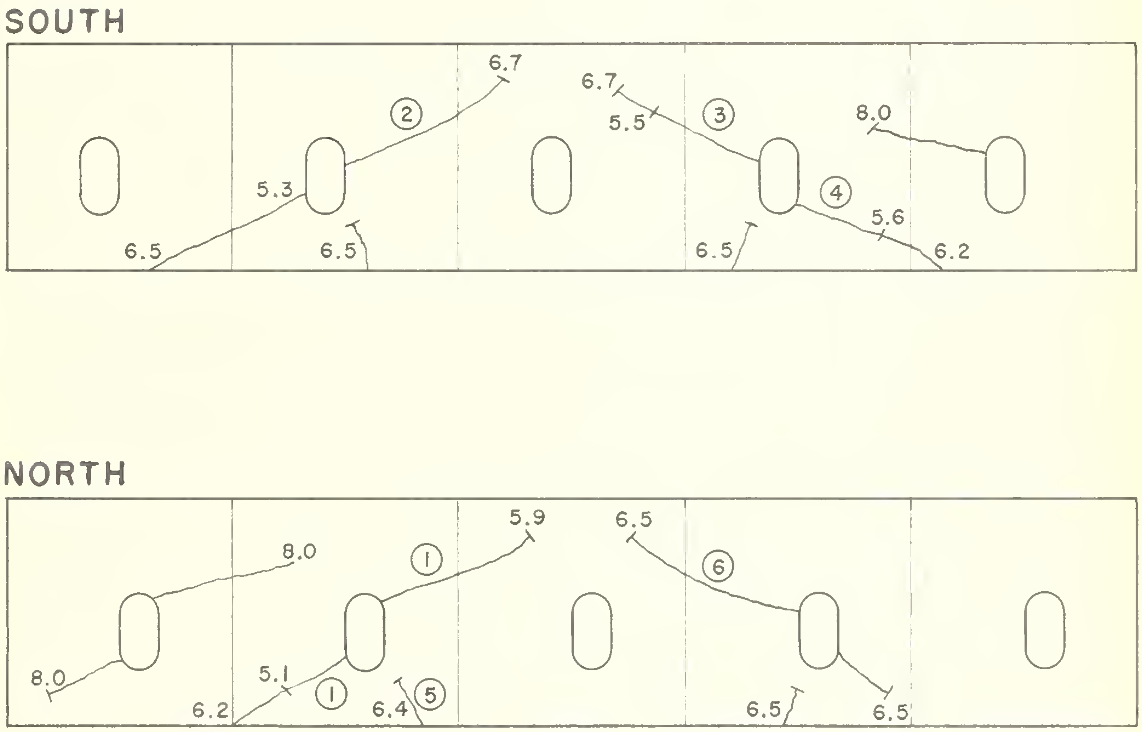


FIG. 17 CRACK PATTERN IN BEAM NO. 1

TYPE UE BLOCK, STACKED
NEAT CEMENT JOINTS.
MAX. LOAD - 7.2 KIPS

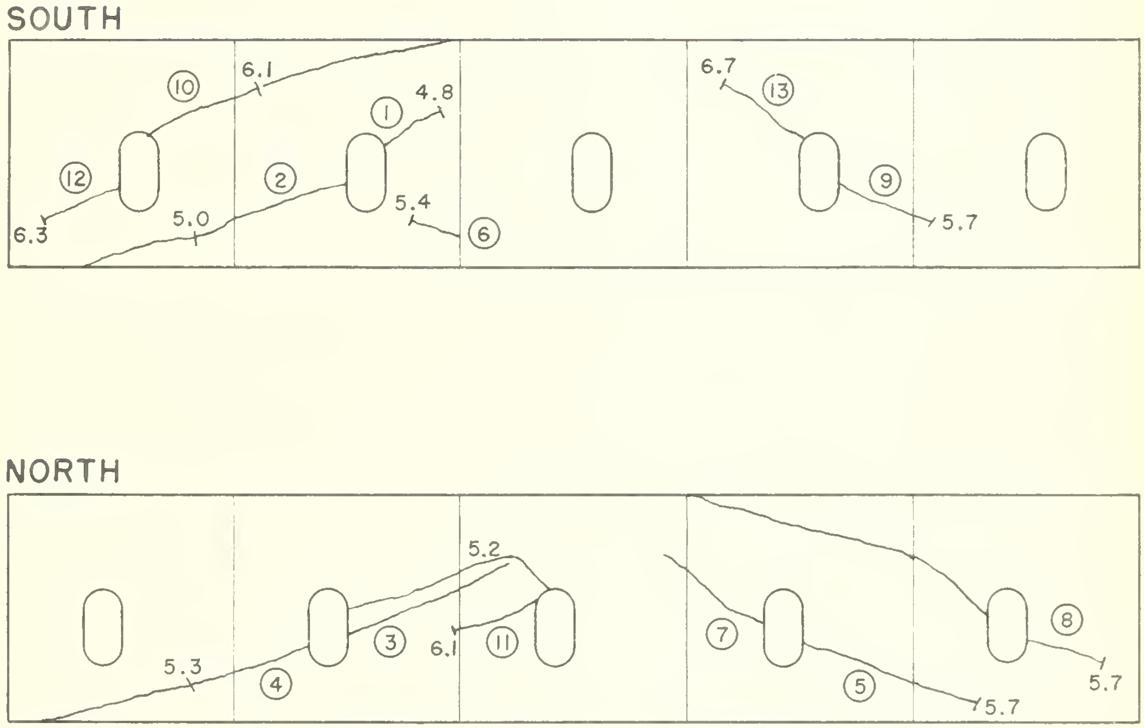


FIG. 18 CRACK PATTERN IN BEAM NO. 2

TYPE FE BLOCK, STACKED,
NEAT CEMENT JOINTS.
MAX. LOAD - 10.1 KIPS

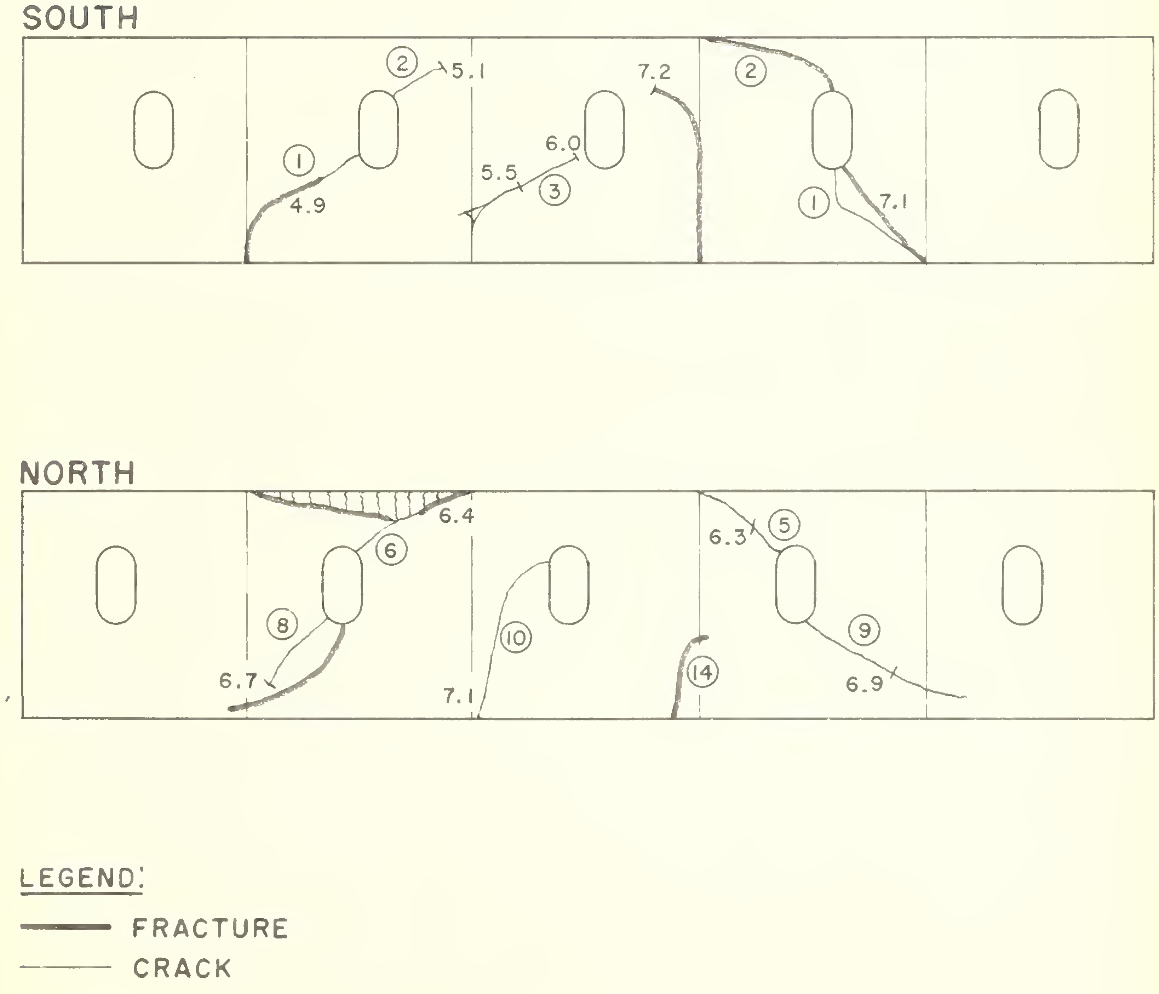


FIG. 19 CRACK PATTERN IN BEAM NO. 3

TYPE FE BLOCK, STACKED,
NEAT CEMENT JOINTS.
MAX. LOAD - 11.1 KIPS

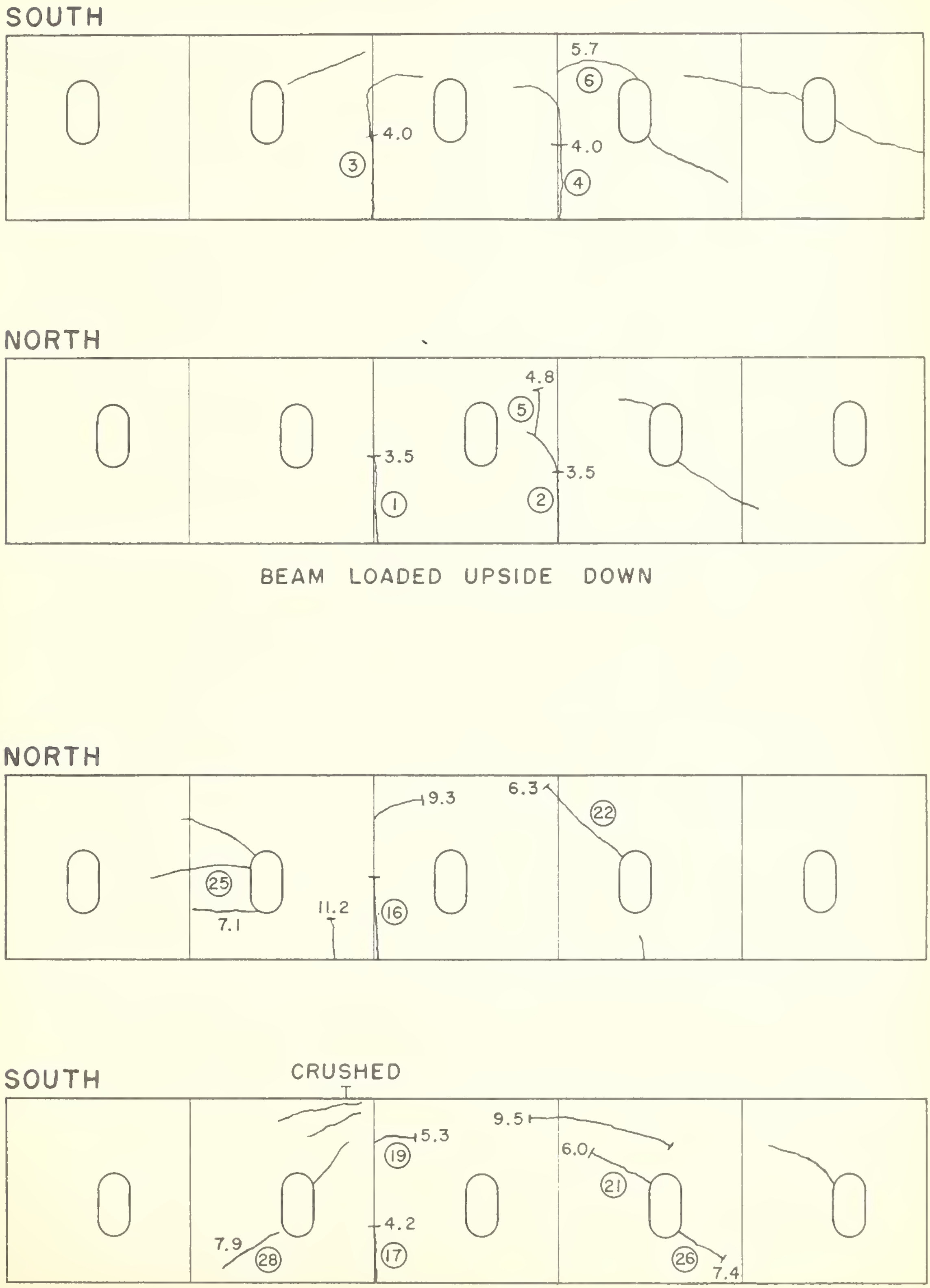


FIG. 20 CRACK PATTERN IN BEAM NO. 4

TYPE SE BLOCK, STACKED,
NEAT CEMENT JOINTS,
MAX. LOAD - 9.5 KIPS

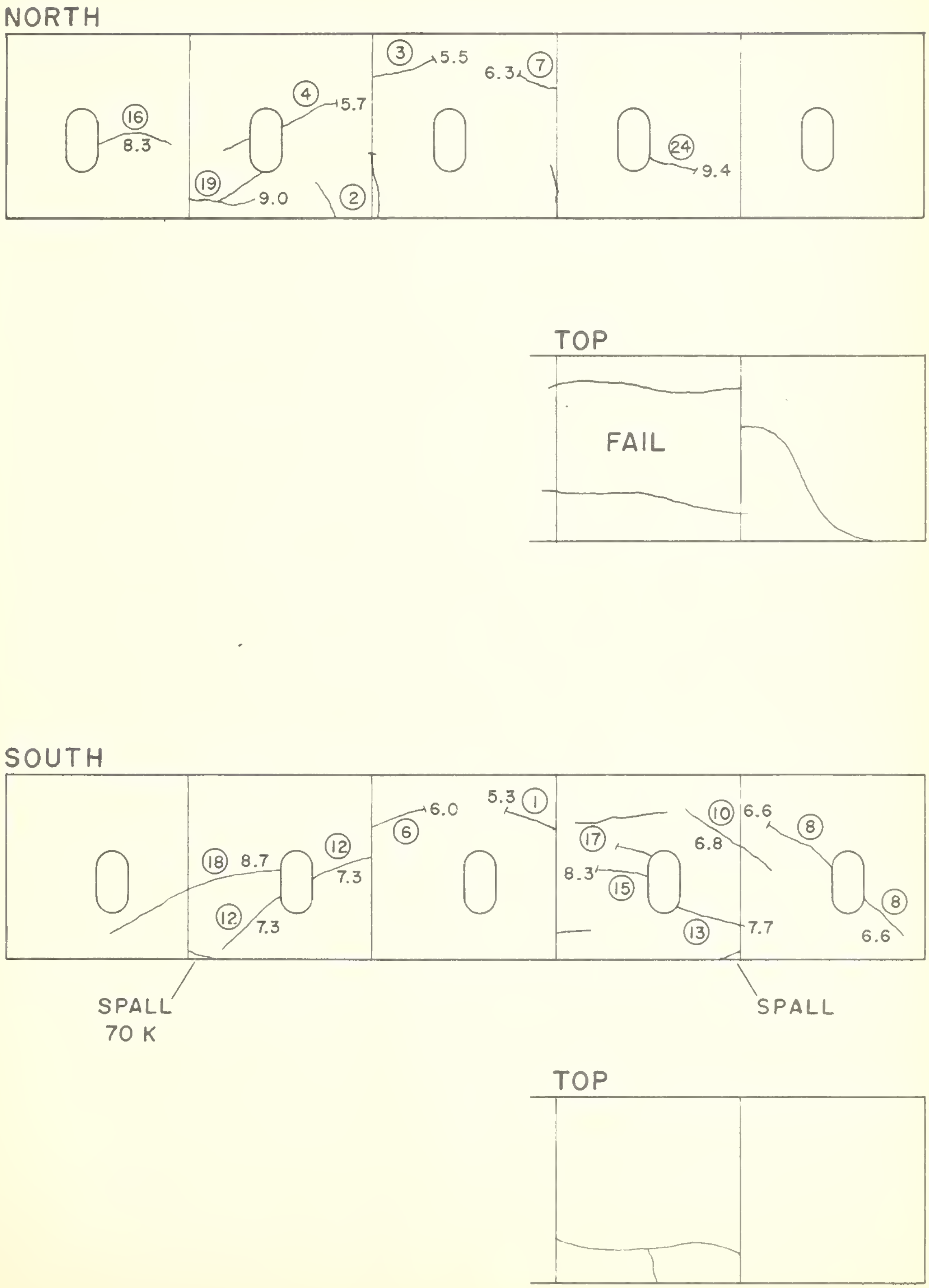


FIG. 21 CRACK PATTERN IN BEAM NO. 5

TYPE SE BLOCK, STACKED
NEAT CEMENT JOINTS.
MAX. LOAD - 8.3 KIPS

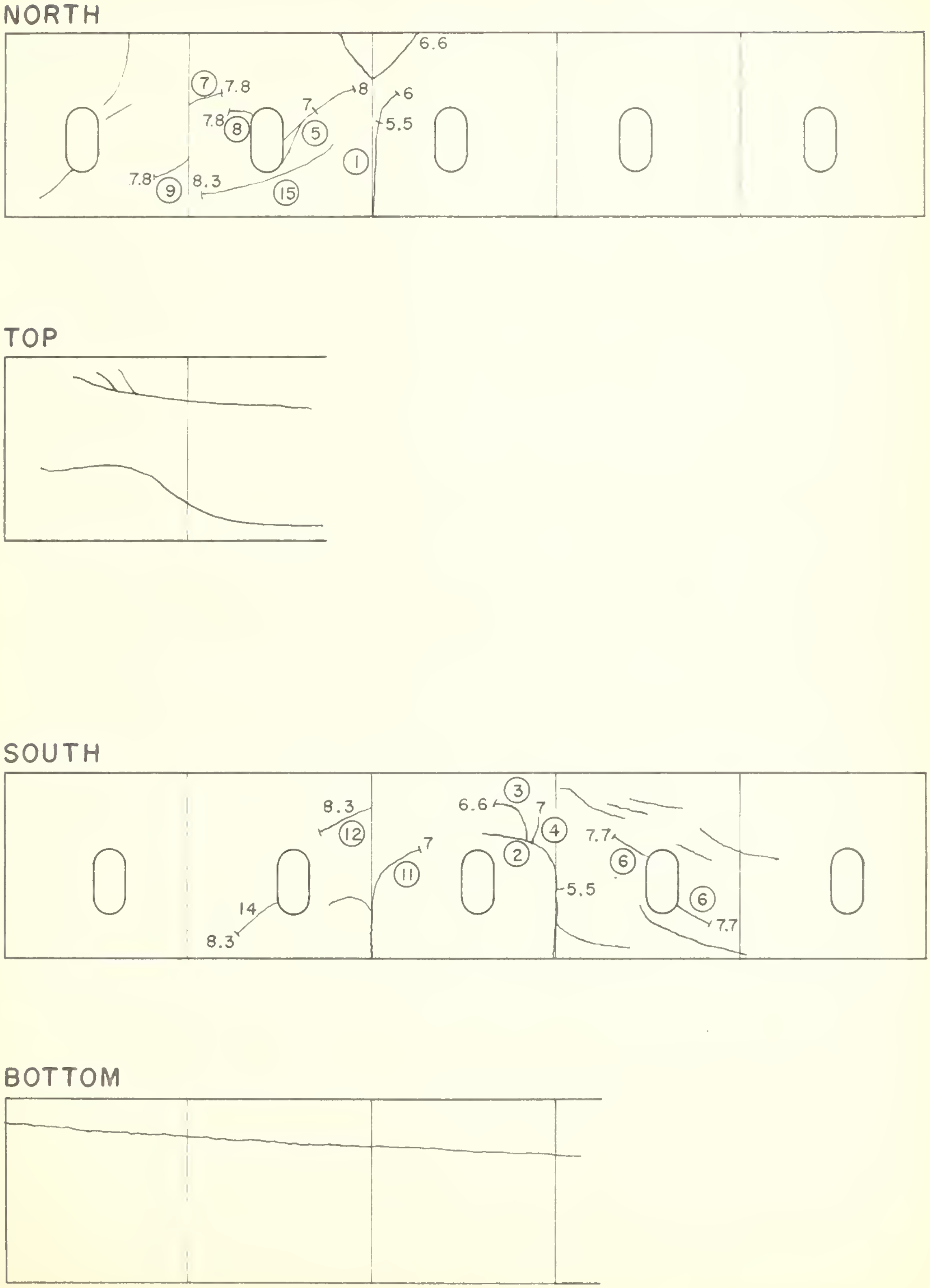
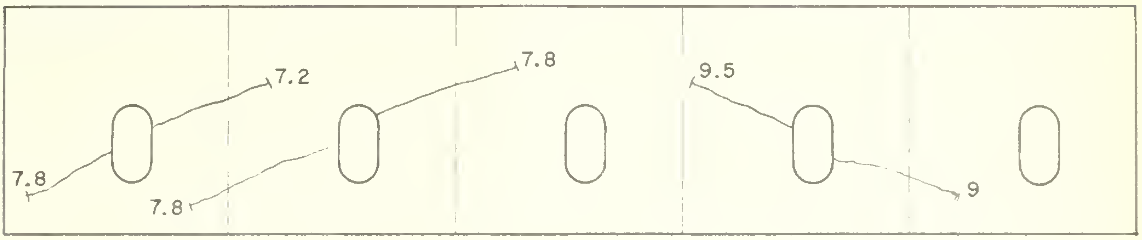


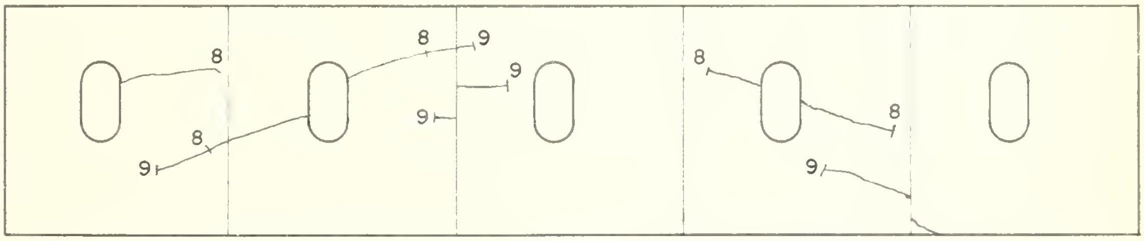
FIG. 22 CRACK PATTERN IN BEAM NO. 6

BEAM NO. 7, TYPE UE BLOCK, STACKED,
NEAT CEMENT JOINTS. MAX. LOAD - 9.4 KIPS

SOUTH

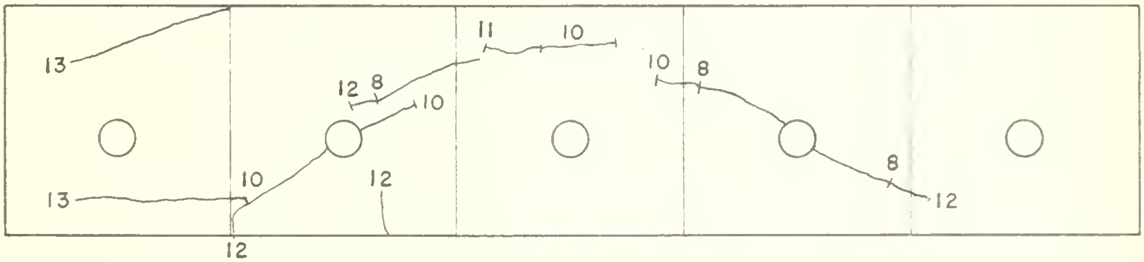


NORTH



BEAM NO. 8, TYPE UR BLOCK, STACKED,
NEAT CEMENT JOINTS. MAX. LOAD - 13.0 KIPS

SOUTH



NORTH

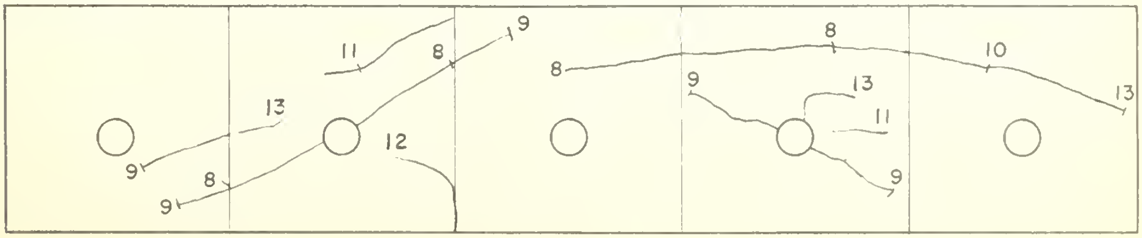
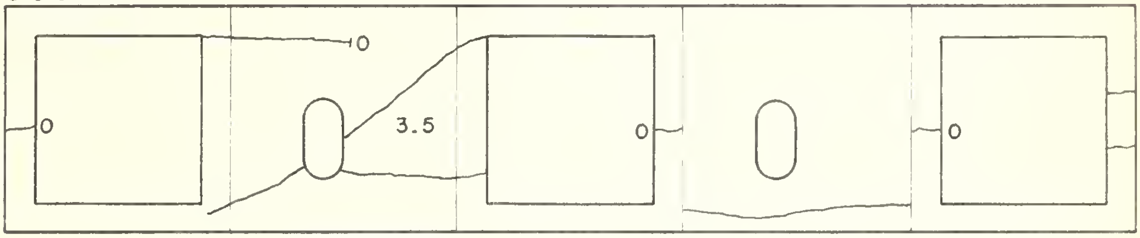


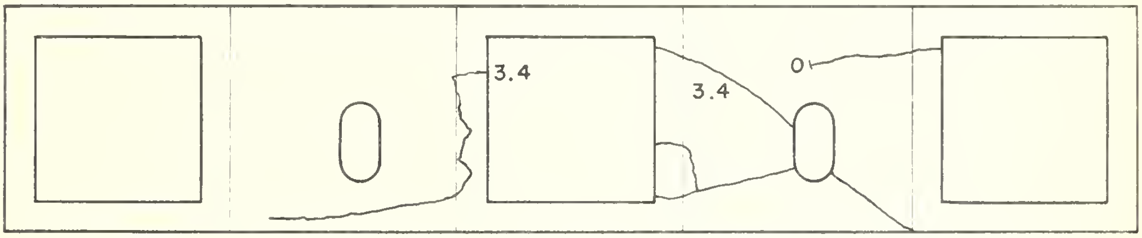
FIG. 23 CRACK PATTERN IN BEAMS NO. 7 & 8

BEAM NO. 9, TYPE UE BLOCK, CRISSCROSS ARRANGEMENT, NEAT CEMENT JOINTS. MAX. LOAD - 3.4 KIPS

SOUTH

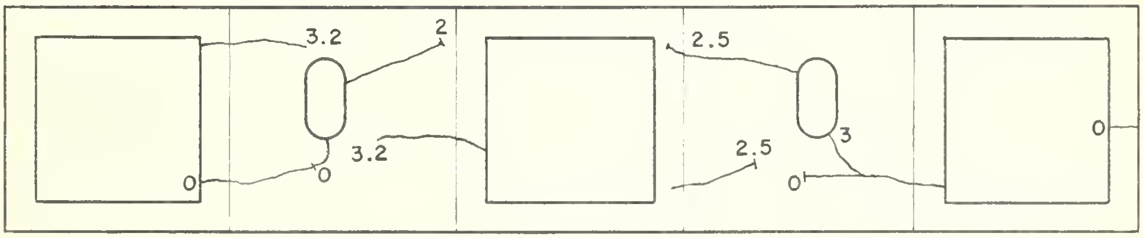


NORTH



BEAM NO. 10, TYPE UE BLOCK, CRISSCROSS ARRANGEMENT, NEAT CEMENT JOINTS. MAX. LOAD - 3.3

SOUTH



NORTH

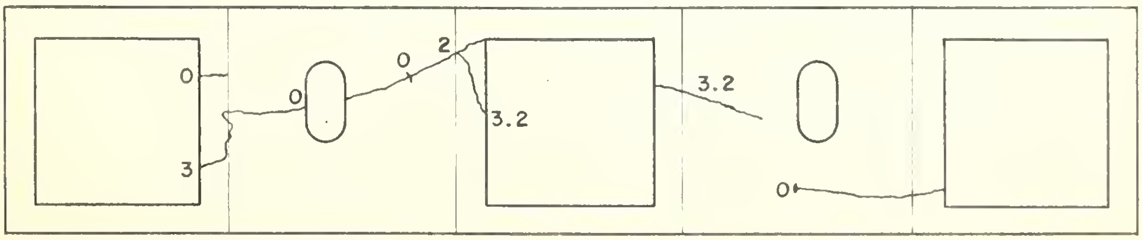
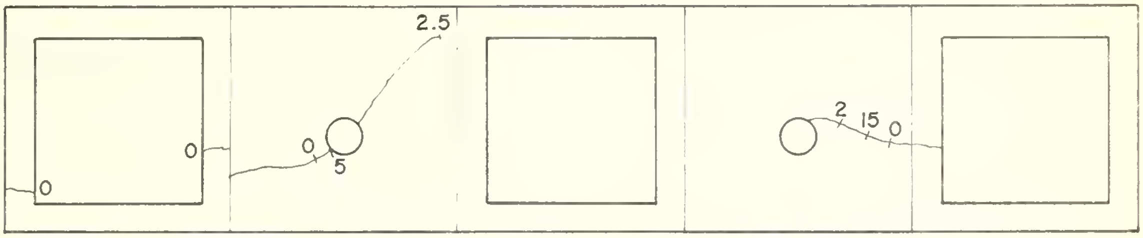


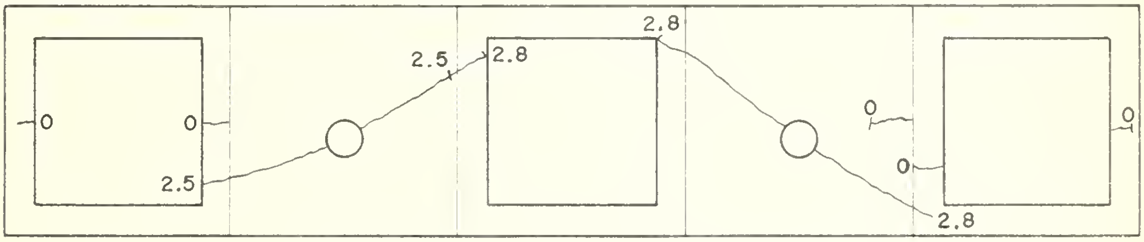
FIG. 24 CRACK PATTERN IN BEAMS NO. 9 & 10

BEAM NO. 11, TYPE UR BLOCK, CRISSCROSS ARRANGEMENT, NEAT CEMENT JOINTS. MAX. LOAD - 2.8 KIPS

SOUTH

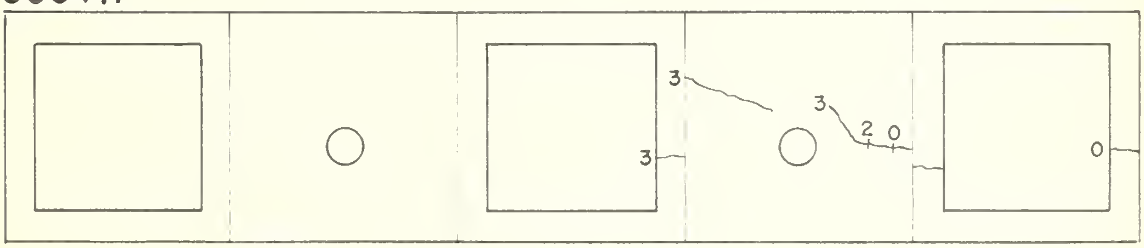


NORTH



BEAM NO. 12, TYPE UR BLOCK, CRISSCROSS ARRANGEMENT, NEAT CEMENT JOINTS. MAX. LOAD - 3.2 KIPS

SOUTH



NORTH

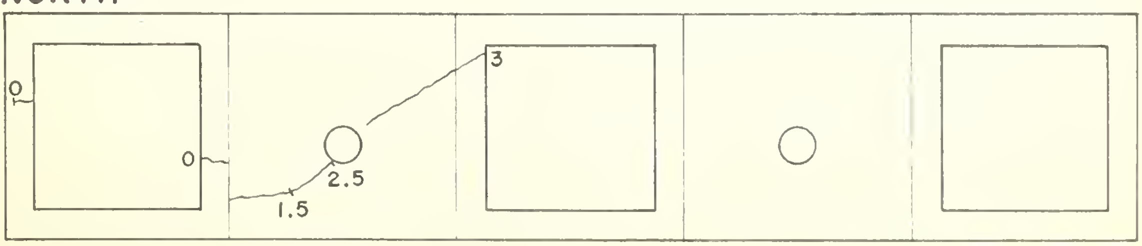
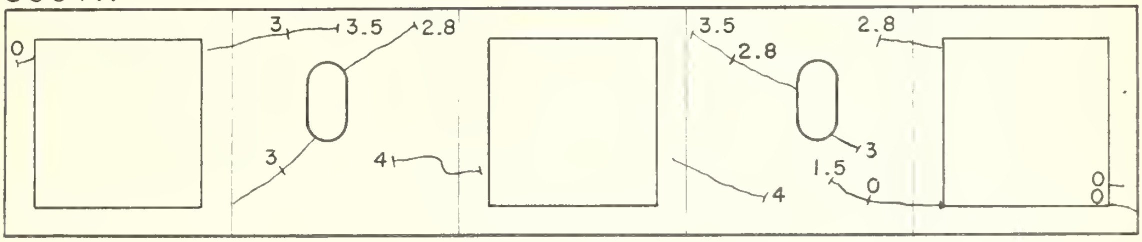


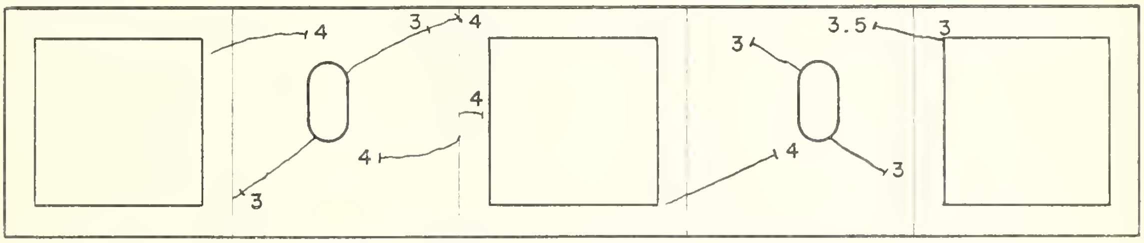
FIG. 25 CRACK PATTERN IN BEAMS NO. 11 & 12

BEAM NO. 13, TYPE UE BLOCK, CRISSCROSS ARRANGEMENT, NEAT CEMENT JOINTS. MAX. LOAD - 4.1 KIPS

SOUTH

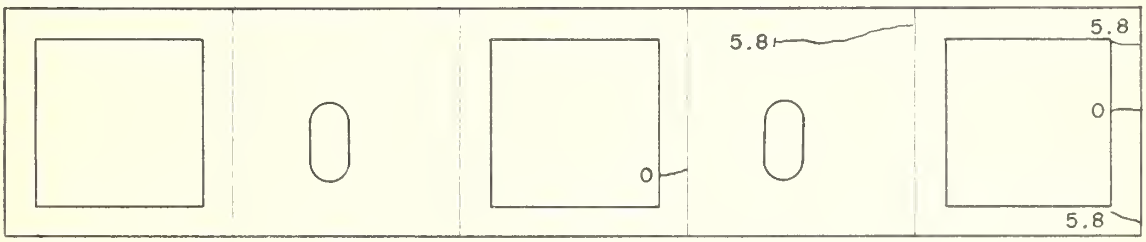


NORTH



BEAM NO. 14, TYPE FE BLOCK, CRISSCROSS ARRANGEMENT, NEAT PLASTER JOINTS. MAX. LOAD - 5.8 KIPS

SOUTH



NORTH

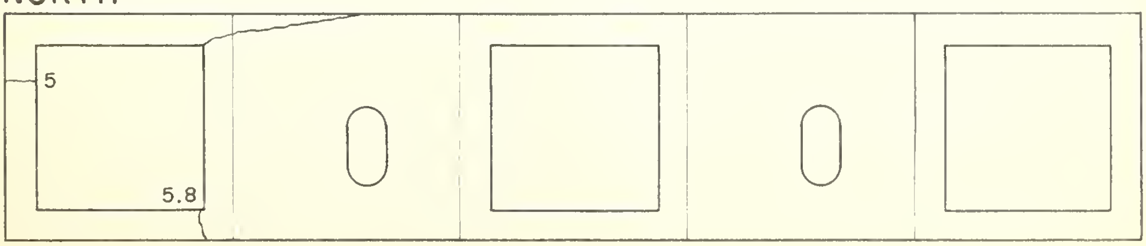
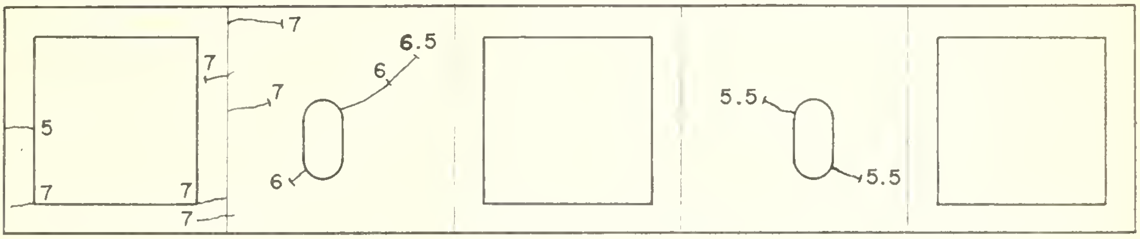


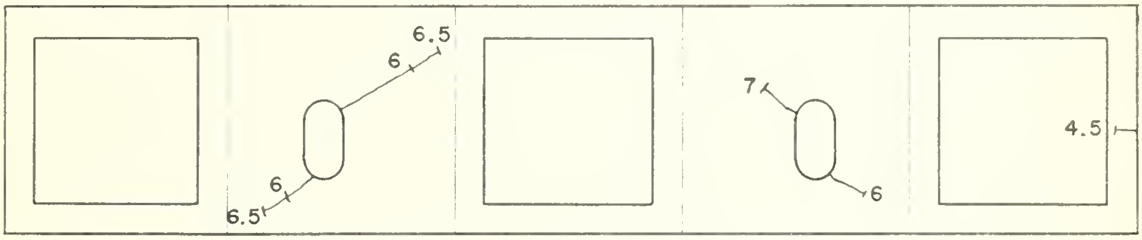
FIG. 26 CRACK PATTERN IN BEAMS NO. 13 & 14

BEAM NO. 15, TYPE FE BLOCK, CRISSCROSS ARRANGEMENT, NEAT PLASTER JOINTS. MAX. LOAD - 7.0 KIPS

SOUTH

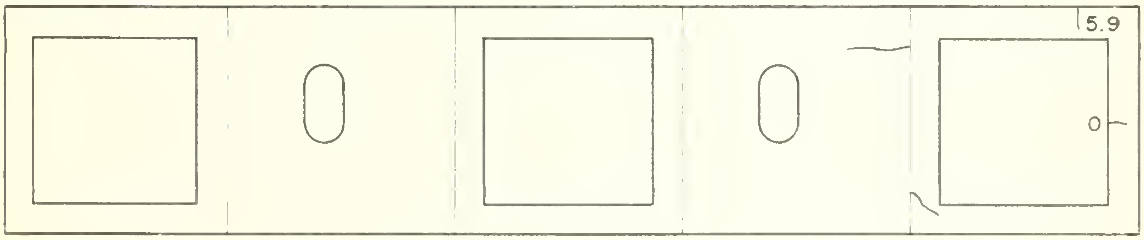


NORTH



BEAM NO. 16, TYPE SE BLOCK, CRISSCROSS ARRANGEMENT, NEAT PLASTER JOINTS. MAX. LOAD - 5.9 KIPS

SOUTH



NORTH

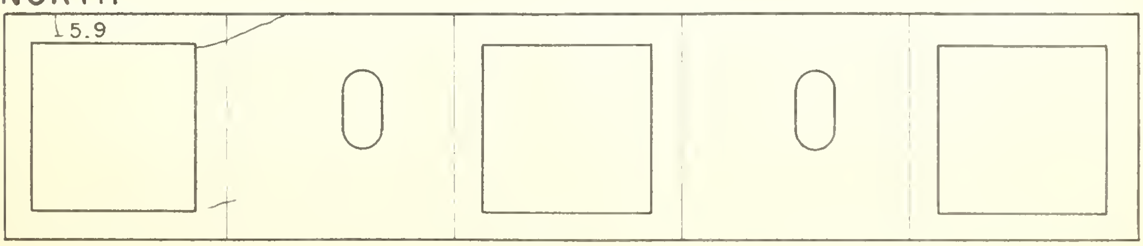
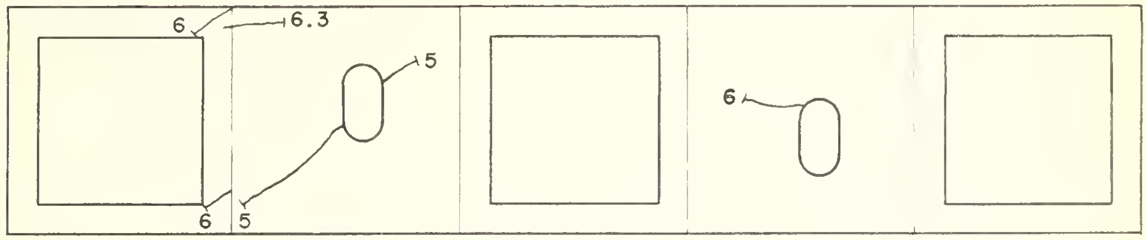


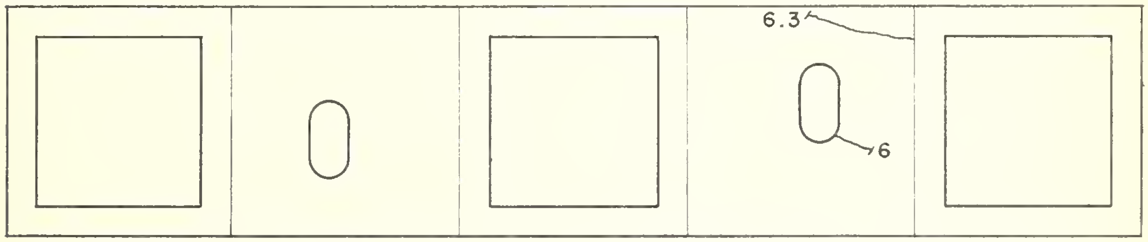
FIG. 27 CRACK PATTERN IN BEAMS NO. 15 & 16

BEAM NO. 17, TYPE SE BLOCK, CRISSCROSS ARRANGEMENT, NEAT PLASTER JOINTS. MAX. LOAD - 6.3 KIPS

SOUTH

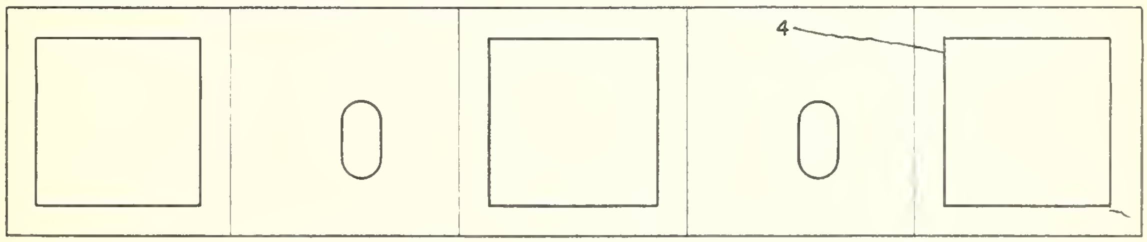


NORTH



BEAM NO. 18, TYPE SE BLOCK, CRISSCROSS ARRANGEMENT, NEAT PLASTER JOINTS. MAX. LOAD - 4.2 KIPS

SOUTH



NORTH

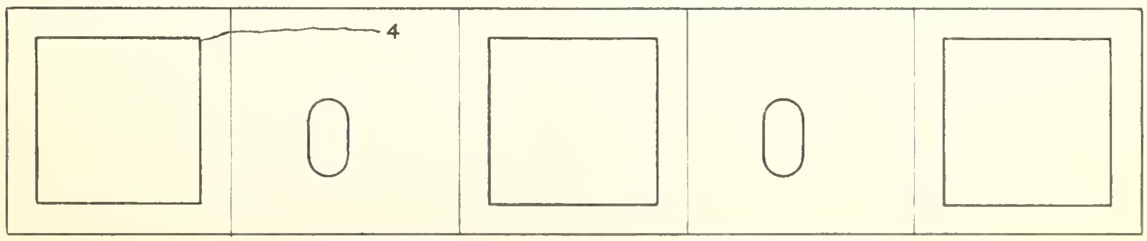
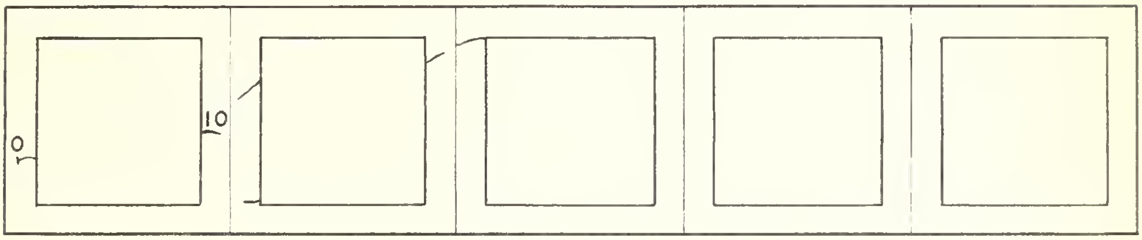


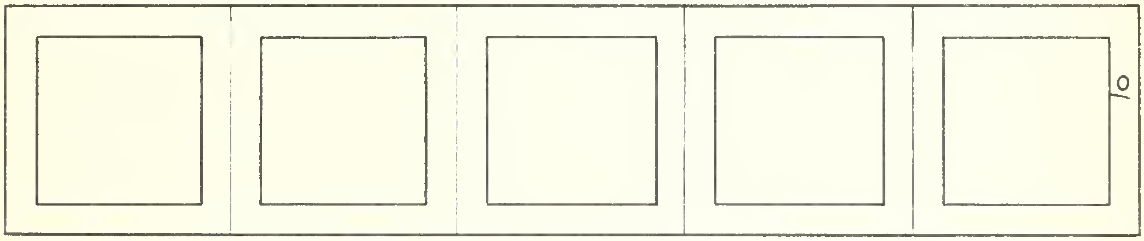
FIG. 28 CRACK PATTERN IN BEAMS NO. 17 & 18

BEAM NO. 19, TYPE UE BLOCK, SIDE CONSTRUCTION, NEAT PLASTER JOINTS. MAX. LOAD - 1.2 KIPS

SOUTH

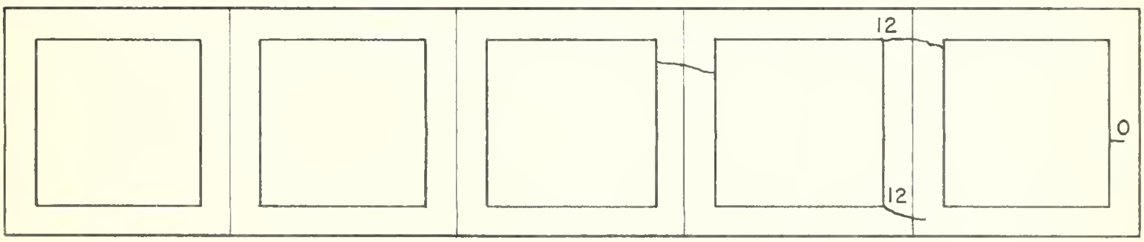


NORTH



BEAM NO. 20, TYPE UE BLOCK, SIDE CONSTRUCTION, NEAT PLASTER JOINTS. MAX. LOAD - 1.2 KIPS

SOUTH



NORTH

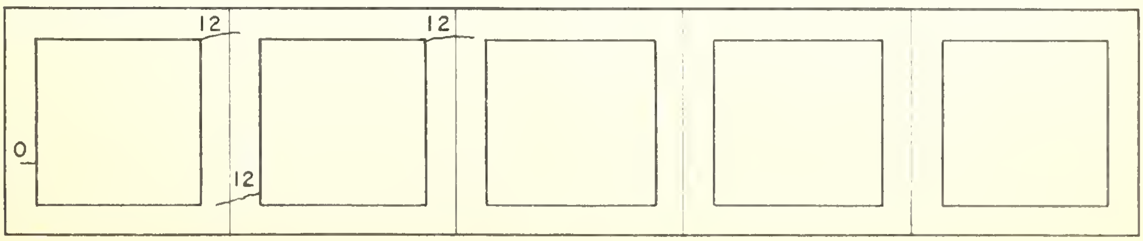


FIG. 29 CRACK PATTERN IN BEAMS NO. 19 & 20

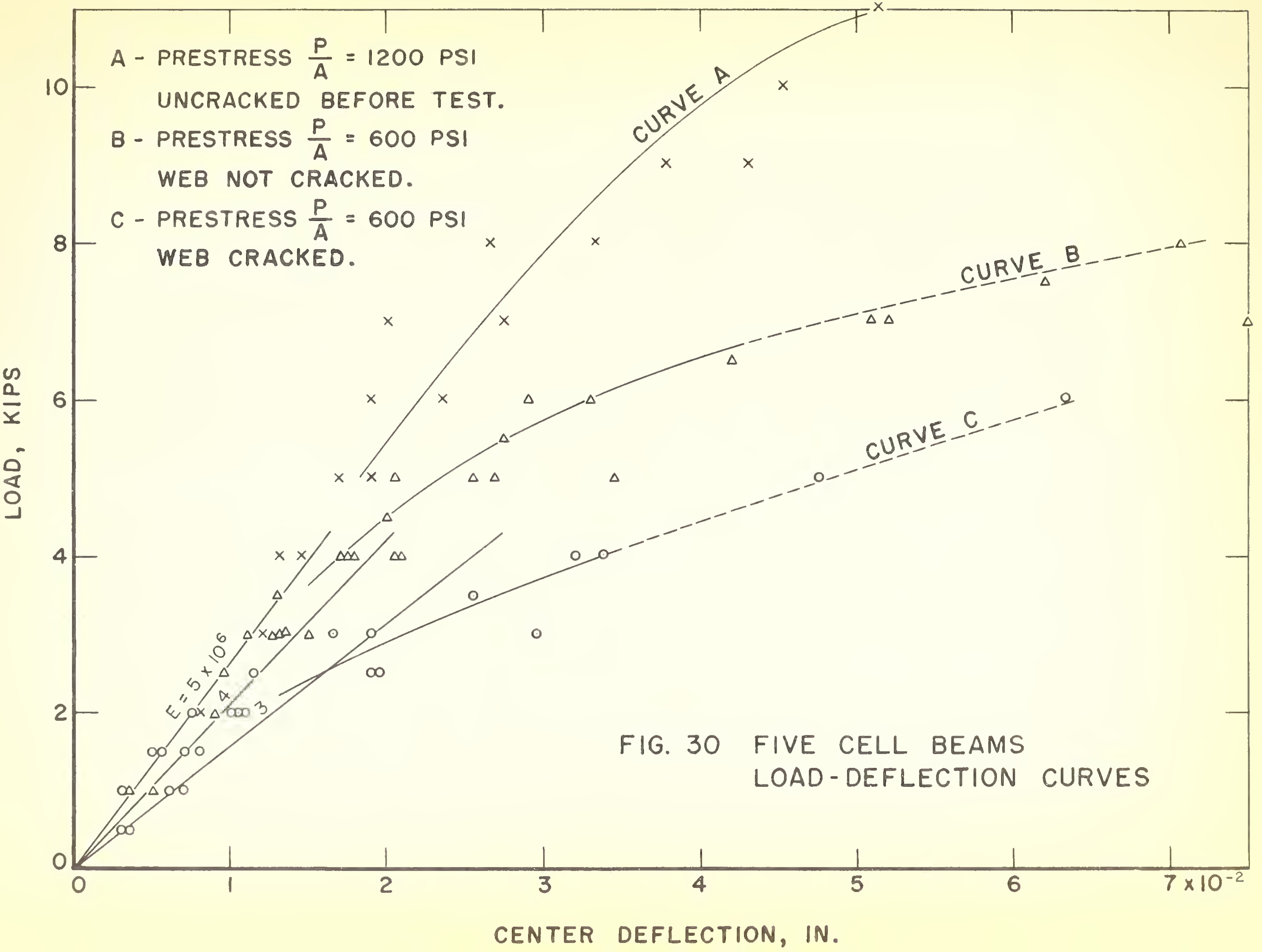
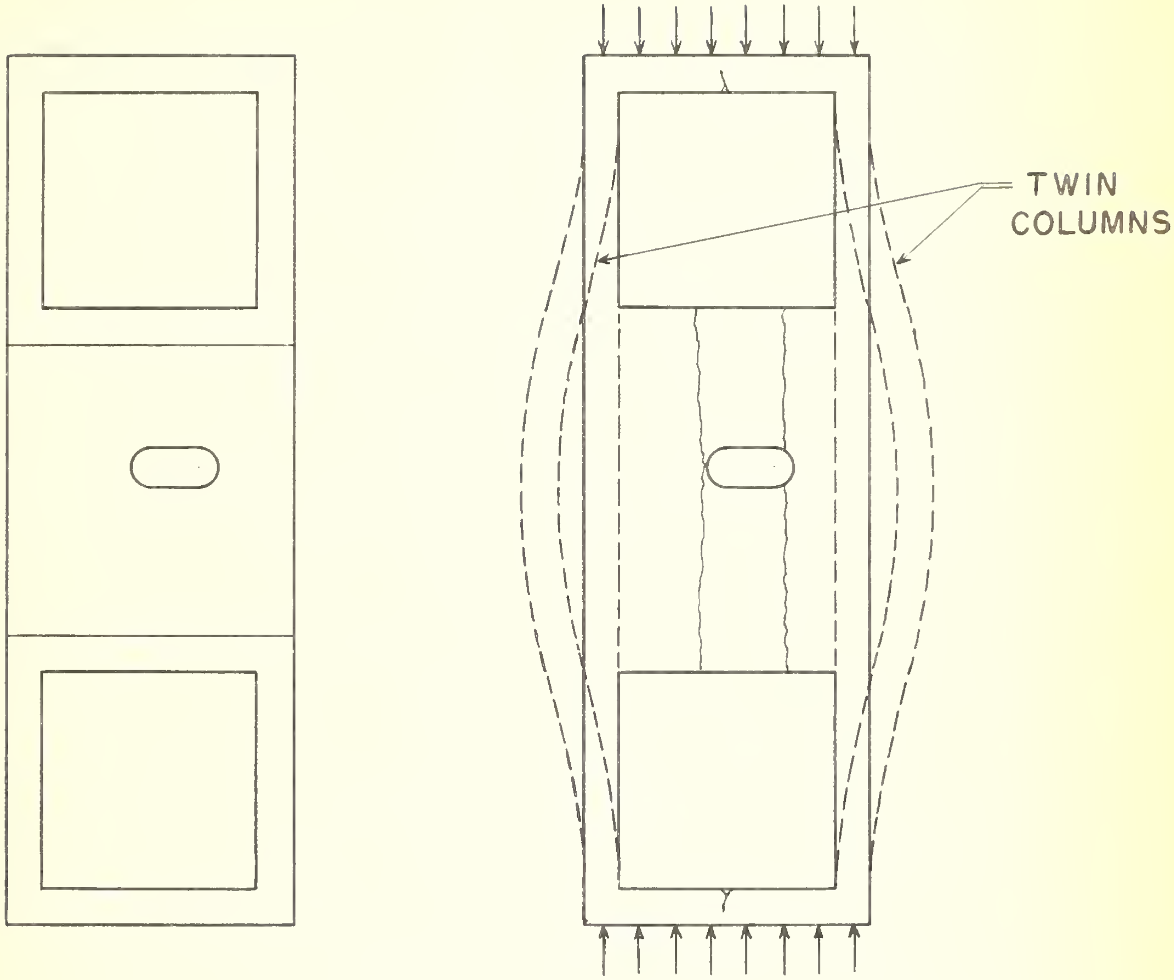


FIG. 30 FIVE CELL BEAMS
LOAD-DEFLECTION CURVES



VIEW OF COLUMN
AT ZERO LOAD

ASSUMED MECHANISM OF
FAILURE OF THE COLUMN

FIG. 31 SCHEMATIC DIAGRAM SHOWING
MECHANISM OF FAILURE OF COLUMN

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

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.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

Inquiries regarding the Bureau's reports should be addressed to the Office of Technical Information, National Bureau of Standards, Washington 25, D. C.

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