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NATIONAL BUREAU OF STANDARDS REPORT

5714

TESTS OF PRESTRESSED CELLULAR SLABS
(Slabs Nos. 20 through 27)

by

Arthur F. Kirstein

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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In the continuing study of the properties of prestressed cellular slabs, eight additional slabs were tested under concentrated loads. All of the slabs were simply supported on two edges except Slab No. 20 which was simply supported on four edges. Deflections, strains, crack patterns, and maximum load-carrying capacities were recorded. Since most of the slabs in this series were made of reinforced NBS blocks which resisted premature diagonal tension failure, these slabs developed higher load-carrying capacities. These loads were sufficient to cause the four center units under the loading block to be punched into the slab before or simultaneously with the formation of the diagonal tension cracks in the webs of the units. This observation suggests that the resistance to failure by punching shear may be further increased by using stronger jointing materials and future tests will be planned to explore this possibility.

1. INTRODUCTION

This phase of the study of the properties of prestressed cellular concrete slabs was mainly concerned with the investigation of the properties of slabs containing NBS blocks that were reinforced with welded wire fabric. A portion of this investigation was devoted to evaluating the performance of unreinforced cellular pavement blocks in prestressed slabs of this type.

Seven slabs composed of 6-in. cellular blocks and one slab composed of cellular pavement blocks were fabricated and tested in the Structural Engineering Section Laboratories. These slabs were prestressed in two directions with 1000 psi in the longitudinal direction and either 500 or 1000 psi in the transverse direction. The slabs were simply supported along either two or four edges and the arrangement of the blocks was varied. Both neat cement paste and an epoxy resin were used as materials in the slabs.

2. DESCRIPTION OF TEST SPECIMENS

2.1 Cellular Blocks

Three types of cellular concrete blocks were examined in this phase of the investigation. They were the plain concrete NBS blocks, the NBS blocks reinforced with welded wire fabric, and the hollow pavement blocks.

The NBS plain and reinforced 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 the prestressing tendons. These blocks were cast in steel three-unit gang molds that were constructed to very close tolerances. The blocks made in these forms were of superior quality and the exterior dimensions of the blocks were within 0.01 in. of the nominal values. The principal dimensions of these blocks are shown in figure 1.

The pavement blocks were 6- by 15 5/8- by 7 5/8-in. concrete blocks with one oblong cell through the 6- by 15 5/8 in. face. The cell was bounded by two semicircles of 2 1/4 in. radius at the ends and straight lines between them. The shell thickness was 3/4 in. One circular hole one inch in diameter was made in each 6- by 7 5/8-in. face concentric with the center line of the 7 5/8 in. sides and tangent to the center line of the 6 in. sides. These holes accommodated the passage of the prestressing tendons. The principal dimensions of these blocks are also shown in figure 1.

All of 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 and determined by tests of 2 in. cubes. However, the actual units were moist-cured for a considerably longer period of time and then some of them were in dry storage before they were assembled into slabs. 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 ratio 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 a variation of ± 10 percent. Poisson's ratio was found to be approximately 0.15.

2.2. Prestressing Steel

"Elastuff" steel prestressing tendons were used in this series of tests. Tensile tests of this material indicated a stress-strain relationship that was essentially linear up to 95,000 psi, and exhibited a Young's modulus of approximately 30×10^6 psi. The yield strength of the bar was found to be 120,000 psi as determined by the 0.2 percent offset method and the tensile strength was found to be 133,000 psi. Although "Elastuff" bars are made of cold-worked high carbon steel, they are fairly ductile and can be machined easily.

2.3. Description of Prestressed Slabs

The nominal dimensions of each slab containing 100 cellular blocks were 5-ft by 5-ft by 6-in. The arrangement of the blocks in the slabs of this test series are described as "criss cross" and "aligned." The crisscross assemblies contained blocks that were arranged so that the axis through the open ends of one block was perpendicular to the axis of each adjacent block, while the aligned assemblies were arranged so that the axes through the open ends of all blocks were parallel. Both assembly methods arranged the holes in the webs of each block in such a fashion as to permit the prestressing tendons to be staggered with respect to the midplane of the slab in one direction, and to be placed at the midplane in the other direction. Thus, the resultant prestressing force produced an axial compression in two directions through the slab.

Slab No. 25 was made of hollow pavement blocks which were arranged as shown in figure 2 to produce a slab with the nominal dimensions of 64- by 64- by 6 in. Auxiliary tests of prestressed beam assemblies of these blocks indicated that they required more rigid end anchorage than was used with 6-in. units to obtain 1000 psi prestress in the concrete without causing distress in the individual units. To produce a more rigid end anchorage for this slab the 12 blocks bordering the slab shown in figure 2 were solid concrete. All of the bars in the transverse direction were placed one-half bar diameter above the midplane, and all of the bars in the longitudinal direction were placed one-half bar diameter below the midplane.

The principal variables in this test series were the method of support, type of block, amount of prestress, arrangement of blocks, and jointing material. A complete summary of these variable factors are shown in table 1 along with the maximum load-carrying capacity and the deflection sensitivity of each slab for comparison with similar slabs of this testing program reported in NBS Reports 4396, 4951. and 5212.

2.4. Prestressing Procedure

The tensioning force was applied to the prestressing bars by means of a hydraulic jacking rig that was equipped with a dynamometer to determine the amount of prestressing that was applied to the tendons. The calibration curve for the dynamometer is shown in figure 3.

Approximately one-half of the prestress was applied to the slab in small increments by tightening the anchorage nuts with a wrench. The remaining prestressing force was applied by means of the hydraulic jacking rig. This final stage of the prestressing operation was accomplished by using a suitable sequence of stressing the tendons so that no unduly large differences in strain would be induced in the blocks.

3. TESTING PROCEDURE

3.1. Test Setup

A 600,000-lb capacity hydraulic testing machine was used to test the slabs. The specimens were simply supported on 54-in. spans by 1-in. square aluminum bars that were attached to the steel frames resting on the testing machine platen. To ensure intimate contact between individual members, all bearing surfaces were set firmly with high-strength plaster. All of the slabs were simply supported along two edges as described above except Slab No. 20 which was simply supported along four edges. The four-edged support required additional steel frames and aluminum support bars, otherwise the setup was identical to that of the two-edged support.

3.2. Instrumentation

The deflection measurements of all the slabs except Slab No. 20 were made with 0.001-in. micrometer dial gages that were attached to steel angles. The steel angles rested on the slab directly over the supports, thus placing the datum plane at the supports.

Figure 4 shows the symmetrical arrangement of these gages. The deflection measurements of Slab No. 20 were made in a different manner to accommodate the measurement of the "curl-up" action of the corners that is typical of slabs supported along four edges. In this case the dial gages were attached to two steel frames that were supported on three points. These points were located on the top surface of the slab directly over the supports, and at the center of the support where, theoretically, no deflection takes place. Figure 5 shows the location of the dial gages and the position of the frame supports on Slab No. 20.

The strains on the top and bottom surfaces of the slabs were measured with bonded electrical resistance wire gages of the A-3 type. The location of these gages are shown in figures 4 and 5.

Slab No. 25, the slab containing pavement blocks, was instrumented in a fashion similar to the other slabs that were supported along two edges. The instrumentation diagram for Slab No. 25 is shown in figure 6.

Since it is of some interest to determine whether or not the loading block is punched into the slab before diagonal cracks form in the webs, four dial gages were arranged around the loading block on Slab No. 27 as shown in figure 7 to determine the changes in depth of slab and penetration of the loading block into the slab. Two of these gages have extensions that pass through a hole in the top flange of the block and rest in a hole in a steel plate that is cemented to the interior surface of the lower flange of the block. These gages are expected to indicate when the diagonal cracks form in the webs. The other two gages are attached to the loading block and rest on the top surface of the slab. These gages are expected to indicate when the loading block is punched into the slab. An instrumentation diagram for this slab is shown in figure 8.

3.3 Test Procedure

All of the slabs except Slab No. 25 were loaded at the center of the top surface through a 6- by 12- by 12-in. concrete loading block. Since the units in Slab No. 25 were 16 in. long, a concrete loading block 6- by 16- by 16-in. was used to apply the load to this slab. The load was applied in increments of 2000 and 5000 lb, and gage readings were made for each increment until the maximum load was reached.

4. TEST DATA

4.1. Deflection and Load-carrying Capacity of Slabs

Figure 9 shows the observed relationships between the applied load and center deflection of Slabs Nos. 20 through 27. The reciprocal of the slope of the linear or elastic portions of these curves can be considered to be a measure of the deflection sensitivity of the slabs, and is expressed in terms of micro inches of deflection per pound of applied load (μ in/lb). Table 1 shows a comparison of the deflection sensitivities and the maximum load-carrying capacities of the slabs tested during this phase of the investigation and previously tested comparable slabs.

The "curl-up" of the corners of slabs simply supported on four edges was observed for Slab No. 20 and is shown in figure 10. Slab No. 20 was the only slab reported herein that was supported on four edges.

4.2. Concrete Strains

The relationships between the applied load and the strains in the concrete for Slabs Nos. 21 through 27 are shown in figures 11 through 17. The legend on figure 11 indicates the positions of the strain gages on the concrete and identifies the curves in figures 11 through 17 as top longitudinal, top transverse, bottom longitudinal, and bottom transverse. Figure 18 shows the load-strain relationship for Slab No. 20 which was simply supported on four edges. Therefore, the direction of strain in the concrete cannot be considered longitudinal or transverse. Since the strain gages were applied to Slab No. 20 in the same positions as indicated by the legend in figure 11, the averages of the gage readings on the top and bottom surface of the slab are presented in figure 18.

4.3. Crack Patterns

The crack pattern observed in Slab No. 24, which was constructed of unreinforced NBS blocks, was typical of the diagonal tension failures reported in NBS Report No. 5212. The top view of the crack pattern in Slab No. 24 is shown in figure 19. This widespread cracking of the flanges of the blocks was accompanied by extensive crack formations in the webs of the blocks. In contrast to this widespread cracking of reinforced blocks a typical top view of the crack pattern in the NBS blocks reinforced with welded wire fabric of Slab No. 27 is shown in figure 20. This localized punching failure around the loading block was accompanied by only minor cracks in the webs of a few blocks immediately surrounding the loaded area of the slab.

As mentioned previously in the text and indicated in figures 7 and 8, measurements were made on Slab No. 27 to determine the punching action of the loading block and the vertical component of the extension of the webs in the blocks around the loaded area. The results of these observations are shown in figure 21. Attention is directed to the fact that the dial gages measuring the extension of the block webs did not indicate a sudden extension in the web associated with the formation of large cracks until the ultimate load was reached and the loading block punched into the top surface of the slab. It is realized that the measurements made with the dial gages mounted on the loading block contain minor errors due to the local deformation around the loaded area. However, no attempt was made to correct these errors as they were considered to be quite small.

Comparison of the two curves in figure 21 indicates that an increase in the rate of penetration of the loading block into the slab is associated with the first measurable change in the depth of the web of the cells adjoining the loaded area. Although these displacements appeared to develop simultaneously, it is worth noting that the large values of penetration by the loading block at loads approaching the maximum cannot be accounted for by the much smaller value of extension of the block web. It is probable, therefore, that punching shear was the primary cause of failure in slabs of the type exemplified by Slab No. 27.

5. DISCUSSION

For the purpose of comparison table 1 of this report includes the pertinent information obtained from the previously tested Slabs (Nos. 3, 4, 8, 11, 14, 15, 16, 18, and 19) along with the eight additional slabs which form the subject of this report.

Upon examination of table 1 it can be seen that the data points to the load-carrying superiority of the slabs made with reinforced blocks. Direct comparisons between Slabs Nos. 11 and 26 and Slabs Nos. 18 and 27 show that there is a large difference in the load-carrying capacities of the slabs containing reinforced and unreinforced NBS blocks. Additional comparisons can be made which appear to indicate the superiority of the reinforced blocks. These comparisons are those of Slabs No. 16 to 20, No. 19 to 21, No. 15 to 22, and No. 14 to 23. However, judgment of these data must be tempered with the fact that these slabs contained two variables. These variables were the use of reinforced and unreinforced blocks and the use of different jointing materials in the various slabs.

In the attempt to ascertain the difference in the load-carrying capacities of slabs having polyester resin and the stronger epoxy resin joints, Slab No. 24 was made to be identical to Slab No. 19 except that Slab No. 24 had the stronger epoxy resin joints. The load-carrying capacity of both slabs was 28,000 lb., and the failure was caused by the formation of diagonal tension cracks in the blocks. Since the webs of the unreinforced NBS blocks failed, no advantage was gained by using the stronger jointing material. However, comparisons of the test results for Slabs Nos. 21 and 26, and Slabs Nos. 22 and 27 containing reinforced blocks lead to a different conclusion. These data indicate that an increase in load-carrying capacity can be realized through the use of stronger jointing materials. This conclusion can be verified by comparing the results of Slabs Nos. 3, 4, 8, and 20 if the differences between the various reinforced blocks are not considered to be vital factors.

The above discussion considered only the strength factor of the jointing material. However, there are other factors to consider.Water tightness, which is probably the most important other single factor, was not considered. The grout, neat cement, polyester resin, and epoxy resin joints are all brittle and cracks may form in the joints under load. Designs may be made that limit the service load so that cracks do not form. However, it may be an advantage to use a material that has a greater extensibility, such as, an epoxy-thiokol adhesive.

As indicated in the test data, the mode of failure for the slabs containing reinforced NBS blocks appears to be different from that of slabs containing unreinforced NBS blocks. Previous tests of slabs containing unreinforced blocks indicated the diagonal tension failure of the block webs without noticeable displacement to the four blocks directly below the loading block, while tests of the slabs with reinforced NBS blocks in this series show a definite displacement of these blocks as shown in figure 21.

Slab No. 25, containing the pavement type blocks, carried a maximum load of 20,750 pounds. These units had fairly weak webs that required special end anchorages to withstand the prestressing force. This weakness was again noticed in the diagonal tension failure of the webs under load which caused most of the bottom surface of the slab to fall to the testing machine platen after the maximum load was reached.

6. CONCLUSIONS

The foregoing discussion can be summarized in the following conclusions:

1. The slabs containing NBS blocks reinforced with welded wire fabric carried considerably more load than comparable slabs containing unreinforced NBS blocks.

2. When using unreinforced NBS blocks to form a slab, no strength advantage is derived from the use of the stronger and more expensive epoxy resin over the polyester resin or neat cement paste as a jointing material.

3. The load-carrying capacity of slabs containing reinforced NBS blocks can be increased by using stronger joint fillers.

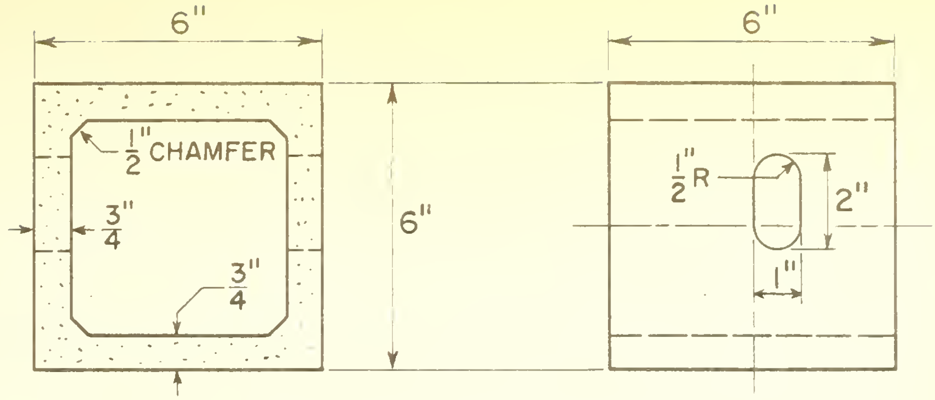
4. Slabs containing reinforced NBS blocks fail in a pure punching action as the four units directly under the loading block are punched into the slab.

5. Since the pavement blocks are prone to fail by diagonal tension at low loads and since they require special end anchorages to withstand the prestressing force, they were found to be unsuitable for use in prestressed slabs of this type.

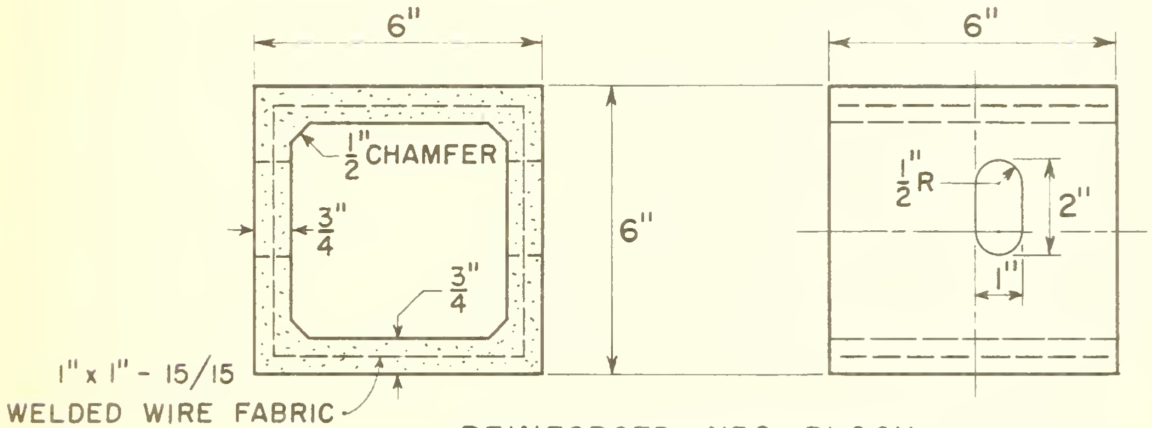
Table 1. Comparison of Test Results

Slab	Method of Support	Arrangement of Blocks	Amount of Prestress	Jointing Material	Type of Block	Deflection Sensitivity μ in./lb	Maximum Load Kips
3	4 edged	Crisscross	1000 psi both ways	Grout	Preload	0.90	35.0
4	"	"	"	"	Preload	1.10	34.25
8	"	"	"	"	NBS*	0.70	39.85
16	"	"	"	Polyester	NBS	0.68	31.5
20	"	"	"	Epoxy	NBS ⁄	0.80	50.0
11	2 edged	Crisscross	1000 psi both ways	Neat cement	NBS	1.27	26.25
19	"	"	"	Polyester	NBS	1.39	28.0
21	"	"	"	Epoxy	NBS ⁄	1.23	45.9
24	"	"	"	Epoxy	NBS	1.41	28.0
26	"	"	"	Neat cement	NBS ⁄	1.21	41.2
15	2 edged	Crisscross	1000 long. 500 trans.	Polyester	NBS	1.58	17.6
18	"	"	"	Neat cement	NBS	1.40	24.3
22	"	"	"	Epoxy	NBS ⁄	1.30	42.0
27	"	"		Neat cement	NBS ⁄	1.24	40.2
14	2 edged	Aligned	1000 long 500 trans.	Polyester	NBS	1.16	19.6
23	"	"	"	Epoxy	NBS ⁄	1.15	45.0
25	2 edged	Special ‡	1000 psi both ways	Grout	Pavement	1.41	20.75

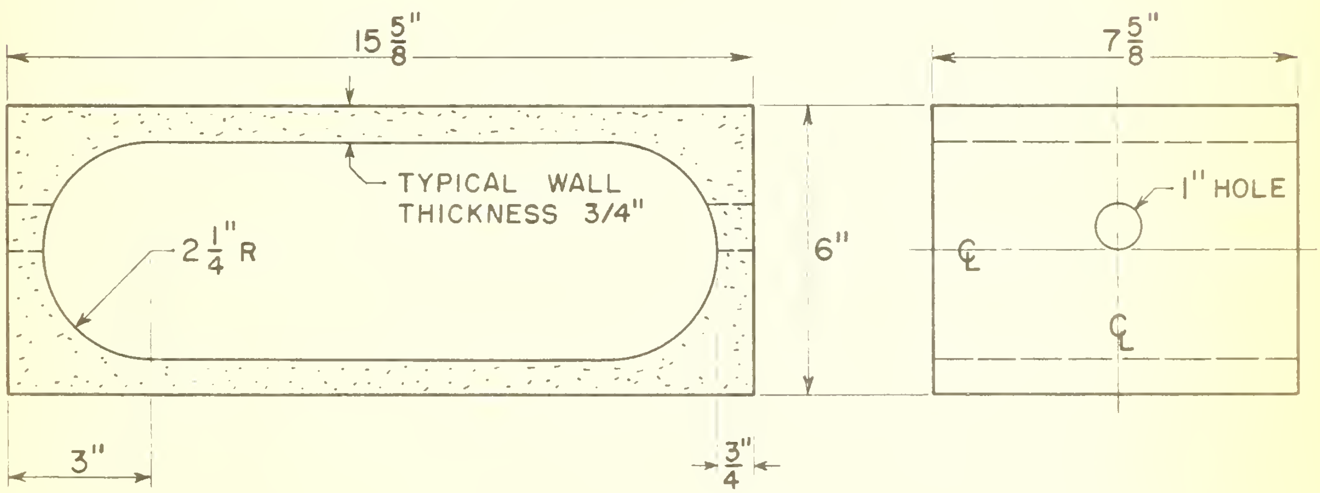
* Blocks reinforced with 1/4 in. stirrups.
⁄ Blocks reinforced with 1- by 1-in. - 15/15 welded wire fabric.
‡ See arrangement in figure 2.



REGULAR NBS BLOCK



REINFORCED NBS BLOCK



PAVEMENT BLOCK

FIGURE 1. CELLULAR BLOCKS

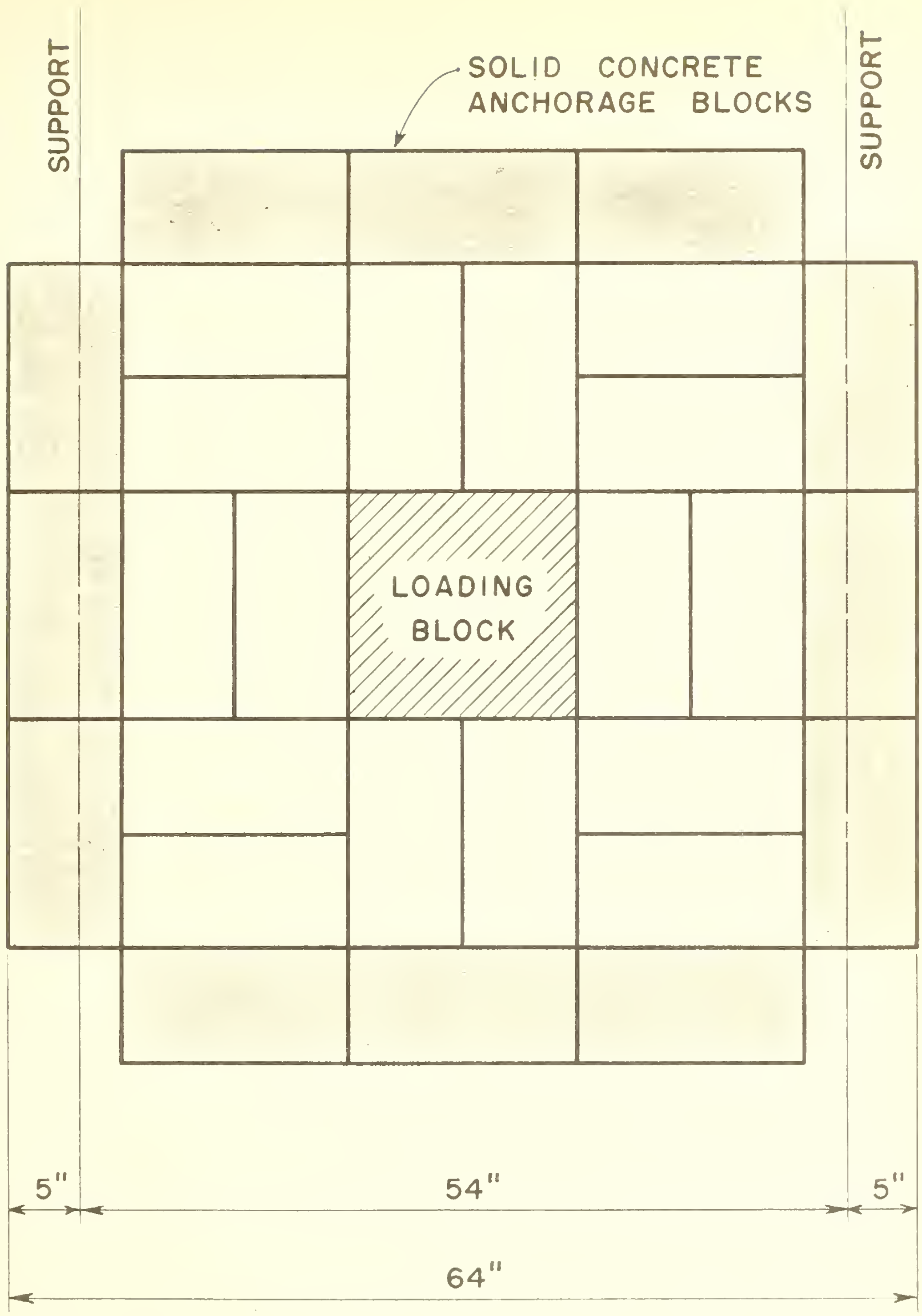


FIGURE 2. ARRANGEMENT OF PAVEMENT BLOCKS IN SLAB NO. 25

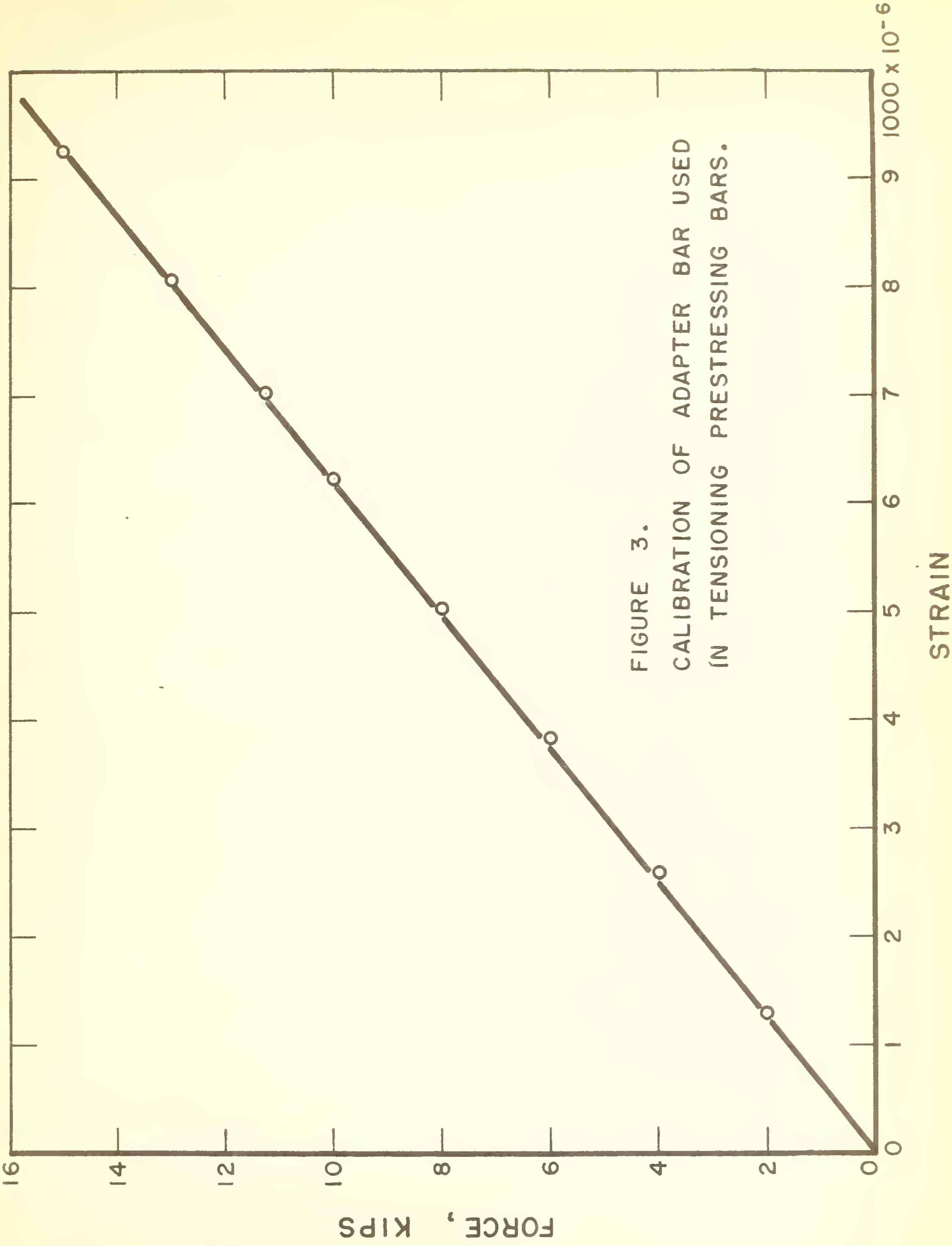
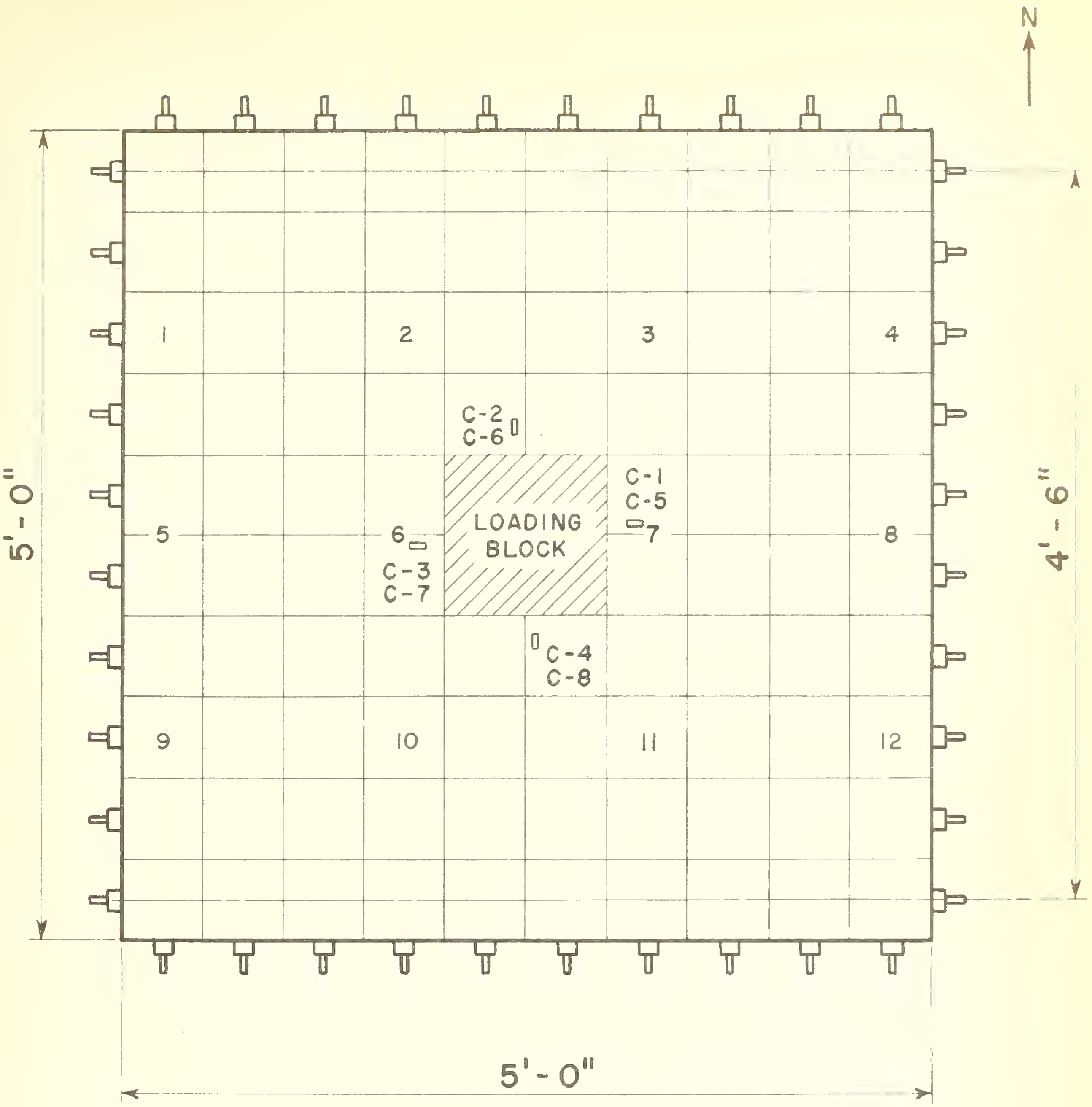


FIGURE 3.
CALIBRATION OF ADAPTER BAR USED
IN TENSIONING PRESTRESSING BARS.

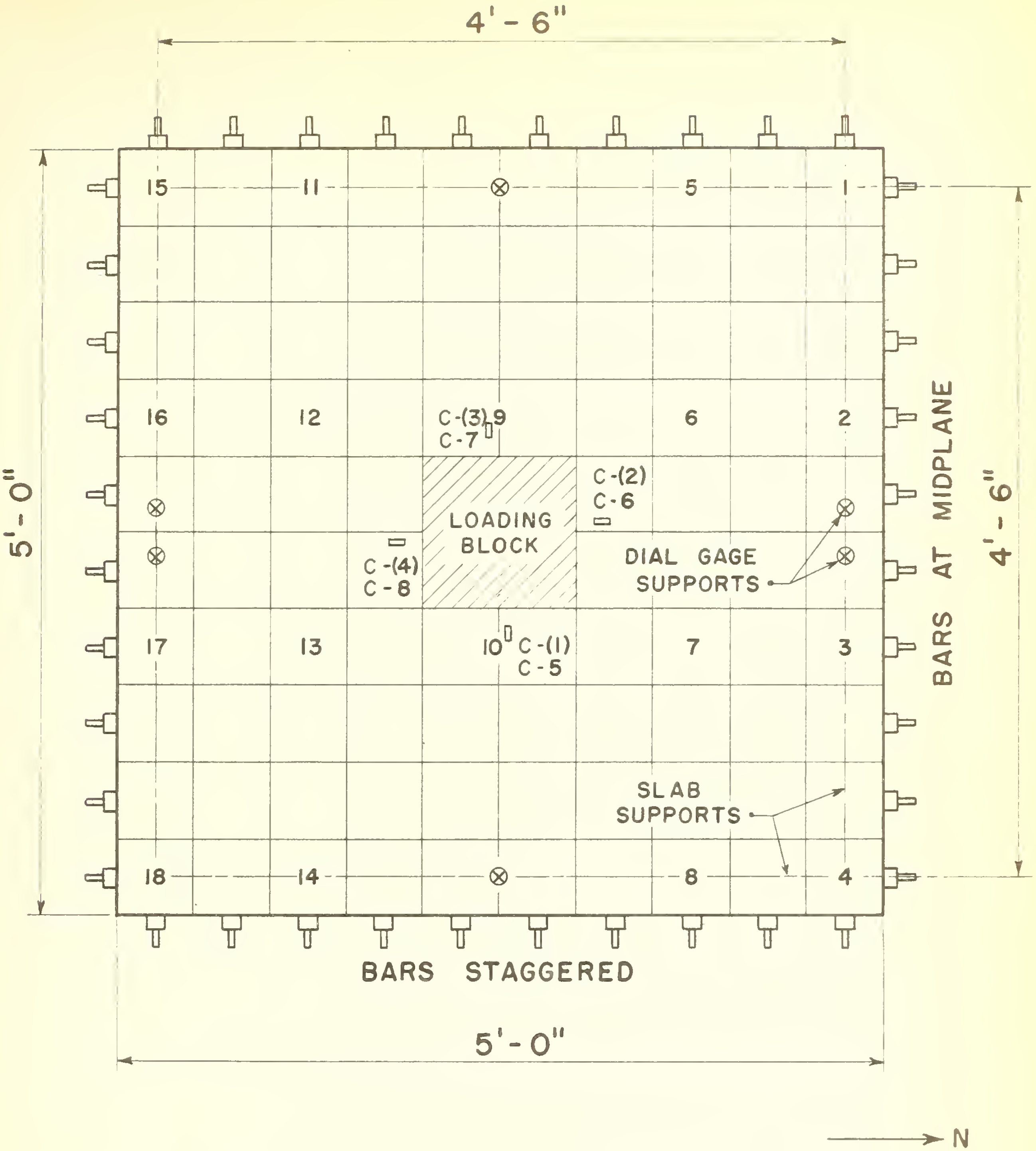
FIGURE 3.



LEGEND:

GAGES 1 THROUGH 12 INDICATE DIAL GAGES
C1 - C4 INDICATE SR-4 GAGES ON BOTTOM SURFACE OF SLAB
C5 - C8 " " " " TOP " " "

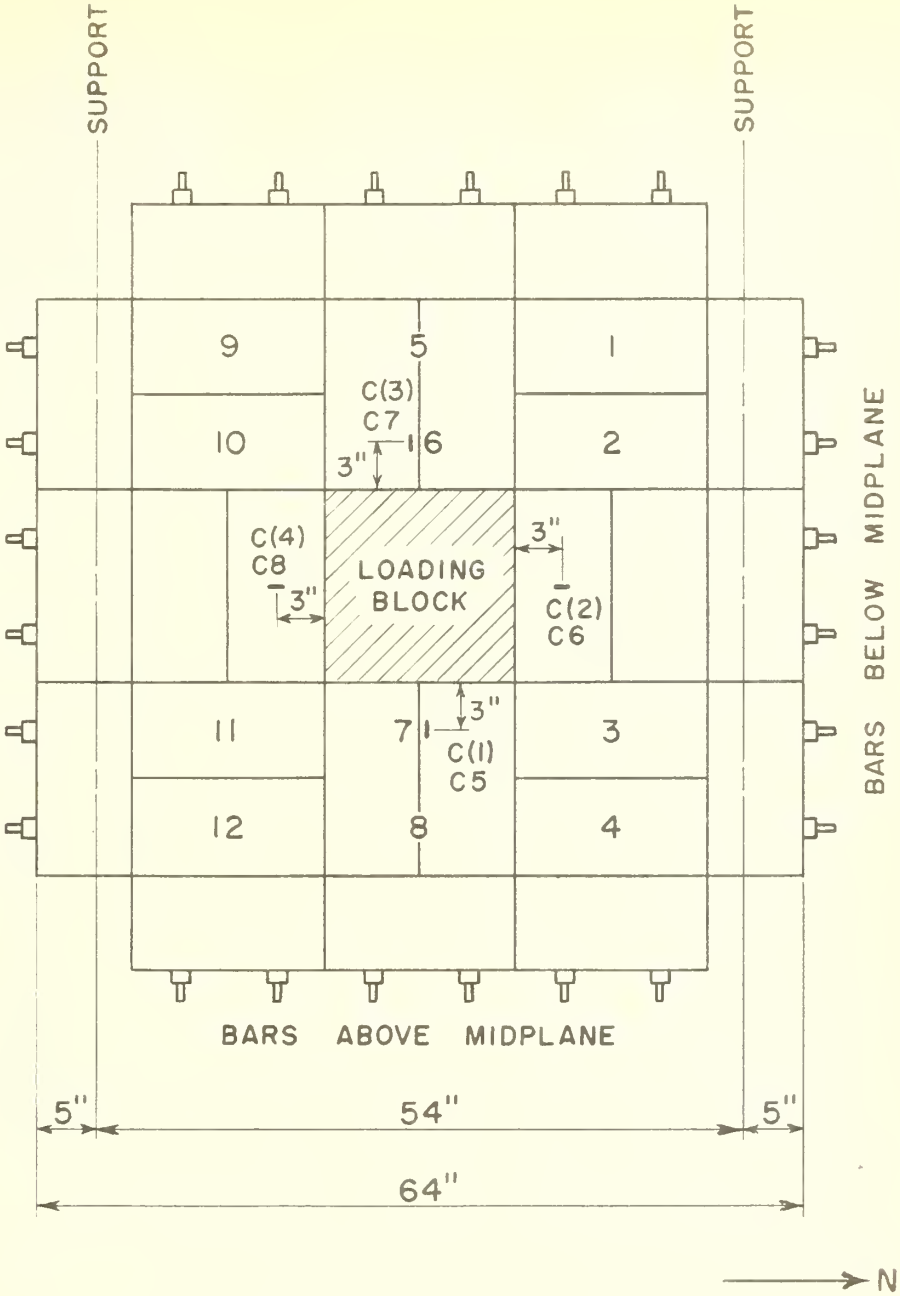
FIGURE 4. LOCATION OF DIAL GAGES AND STRAIN GAGES ON SLABS SIMPLY SUPPORTED ON TWO EDGES.



LEGEND:

GAGES 1 THROUGH 18 INDICATE DIAL GAGES
C1 - C4 INDICATE SR-4 GAGES ON BOTTOM SURFACE OF SLAB
C5 - C8 " " " " TOP " " "

FIGURE 5. LOCATION OF DIAL GAGES AND STRAIN GAGES ON SLAB NO. 20 (SIMPLY SUPPORTED ON FOUR EDGES).



LEGEND:

GAGES 1 THROUGH 12 INDICATE DIAL GAGES
C1 - C4 INDICATE SR-4 GAGES ON BOTTOM SURFACE OF SLAB
C5 - C8 " " " " TOP " " "

FIGURE 6. LOCATION OF DIAL GAGES AND STRAIN GAGES ON PAVEMENT BLOCK, SLAB NO. 25.

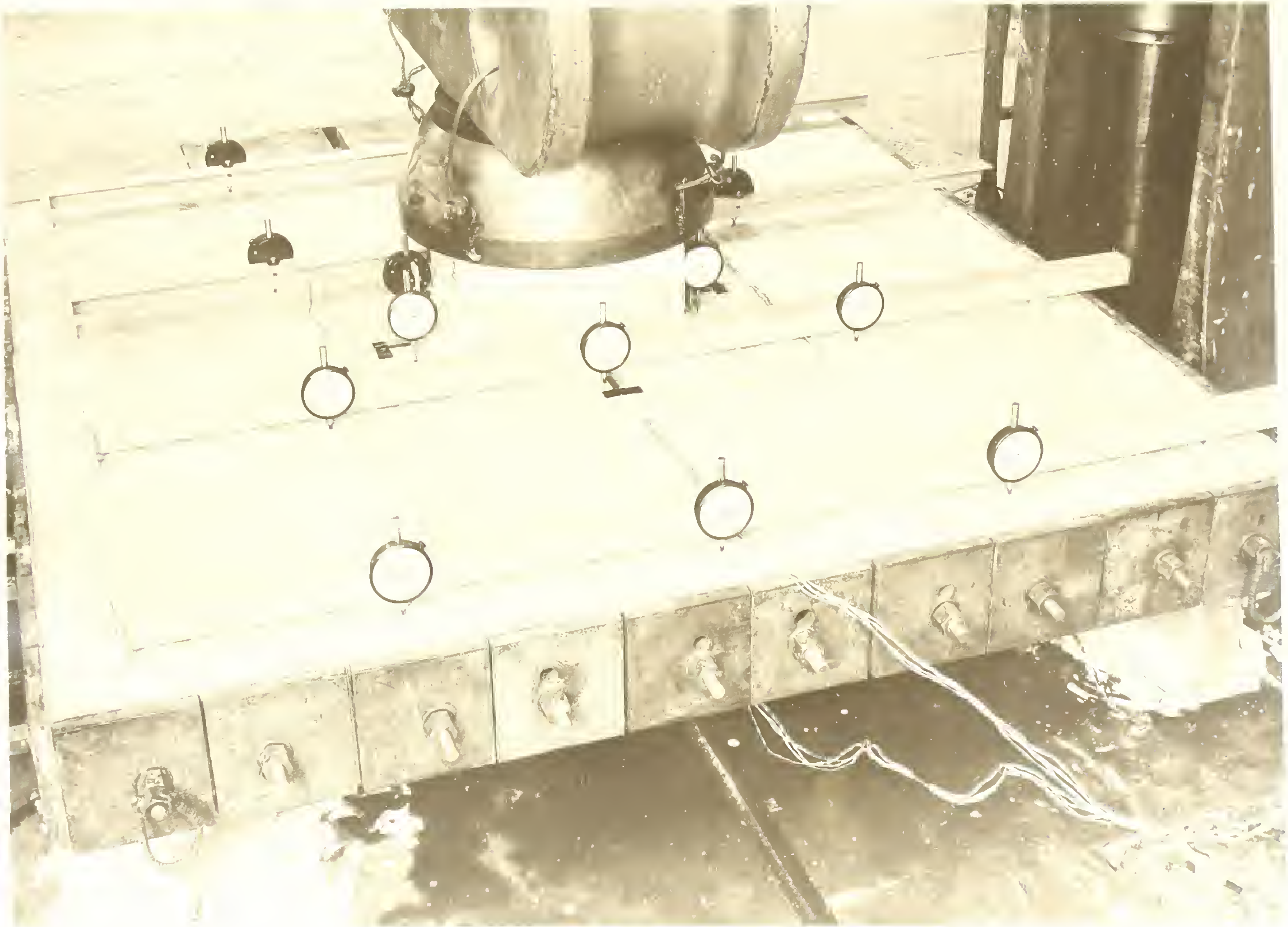
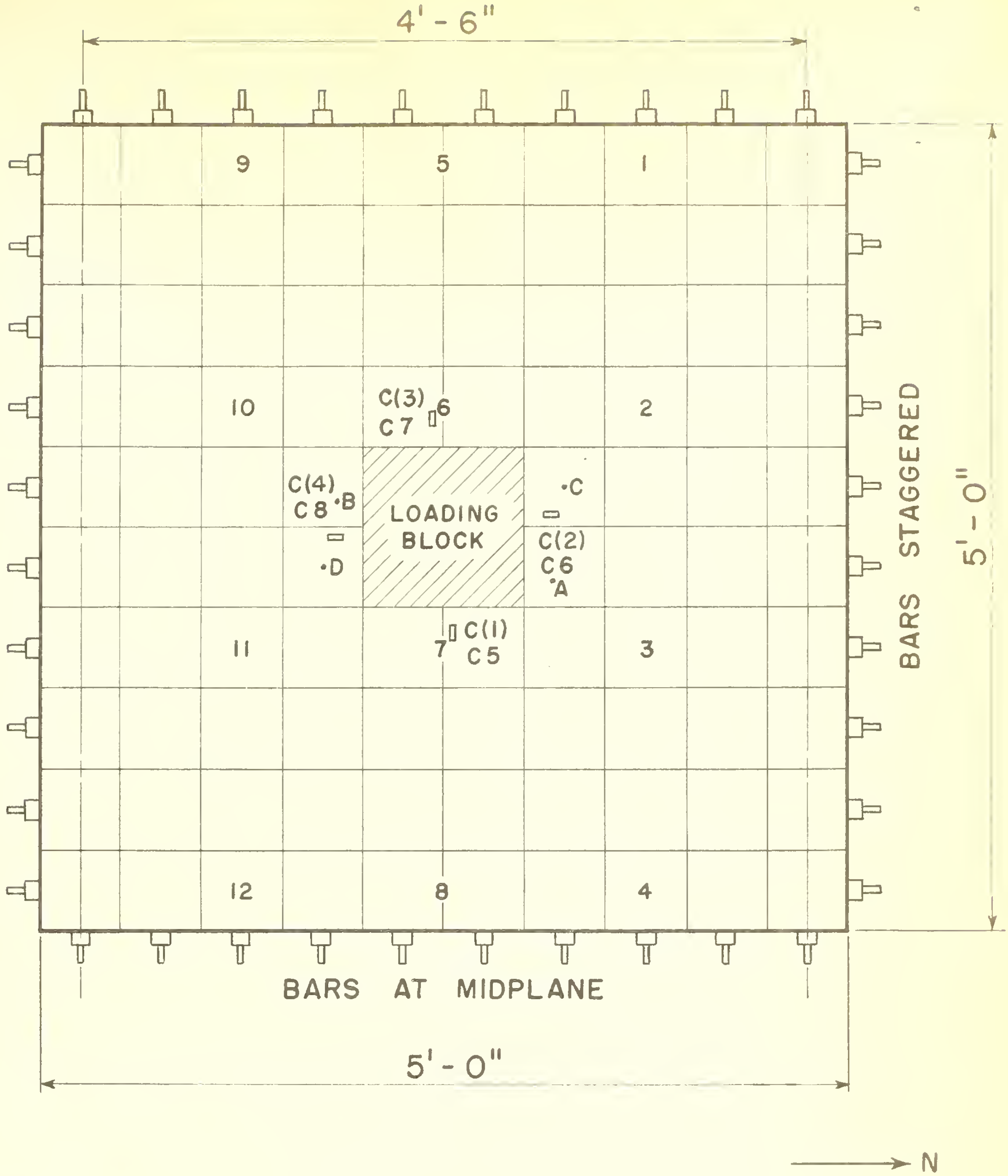


FIGURE 7. TEST SET UP OF SLAB NO. 27



LEGEND:

GAGES 1 THROUGH 12 INDICATE DIAL GAGES.

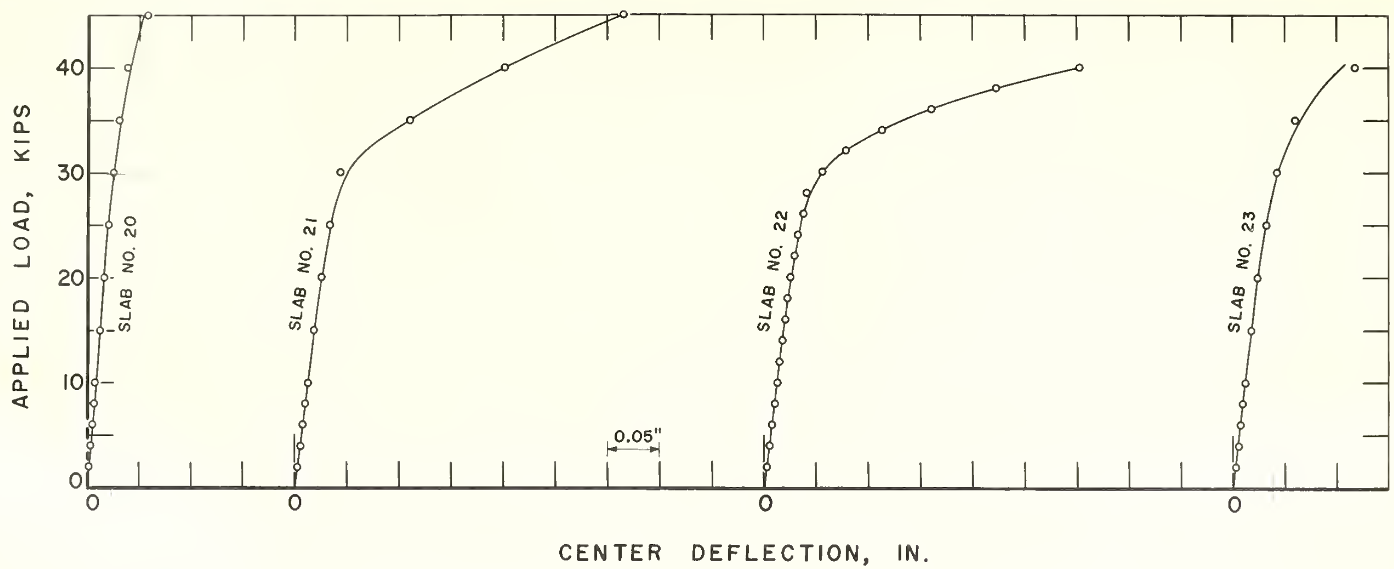
C1 - C4 INDICATE SR-4 GAGES ON BOTTOM SURFACE OF SLAB.

C5 - C8 " " " " TOP " " "

A & B ARE GAGES FOR MEASURING CHANGES IN DEPTH OF SLAB.

C & D ARE GAGES FOR MEASURING PENETRATION OF LOADING BLOCK INTO SLAB.

FIGURE 8. LOCATION OF DIAL GAGES AND STRAIN GAGES ON SLAB NO. 27



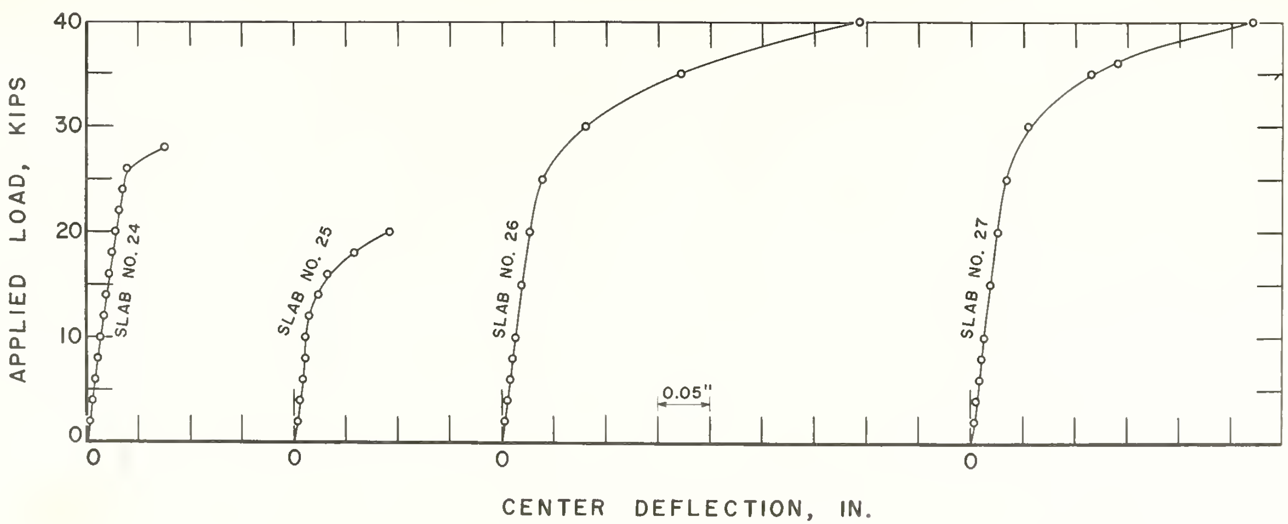


FIGURE 9. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CENTER DEFLECTION OF SLABS.

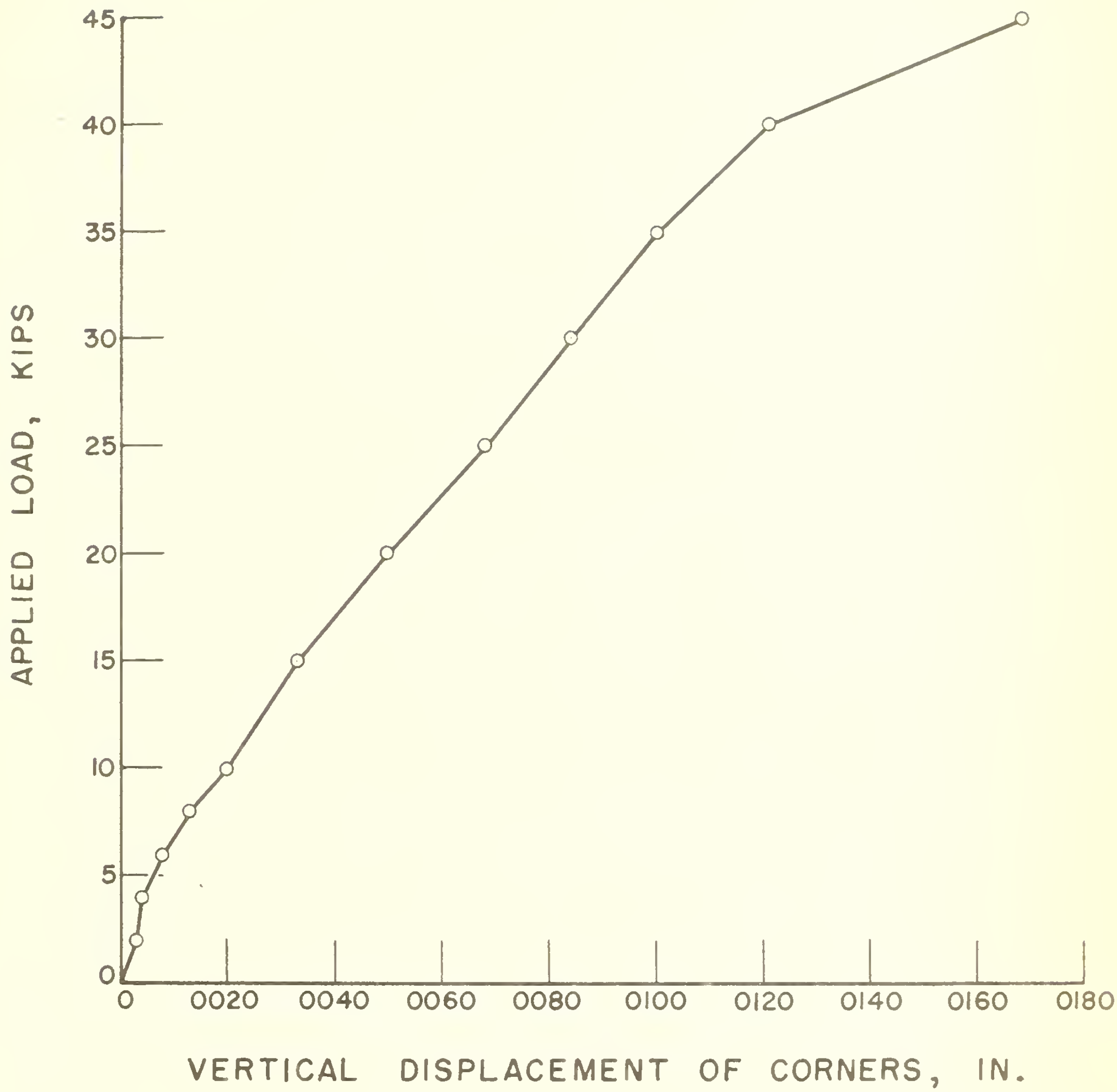


FIGURE 10. VERTICAL DISPLACEMENT OF THE CORNERS DUE TO THE "CURL UP" ACTION, SLAB NO. 20.

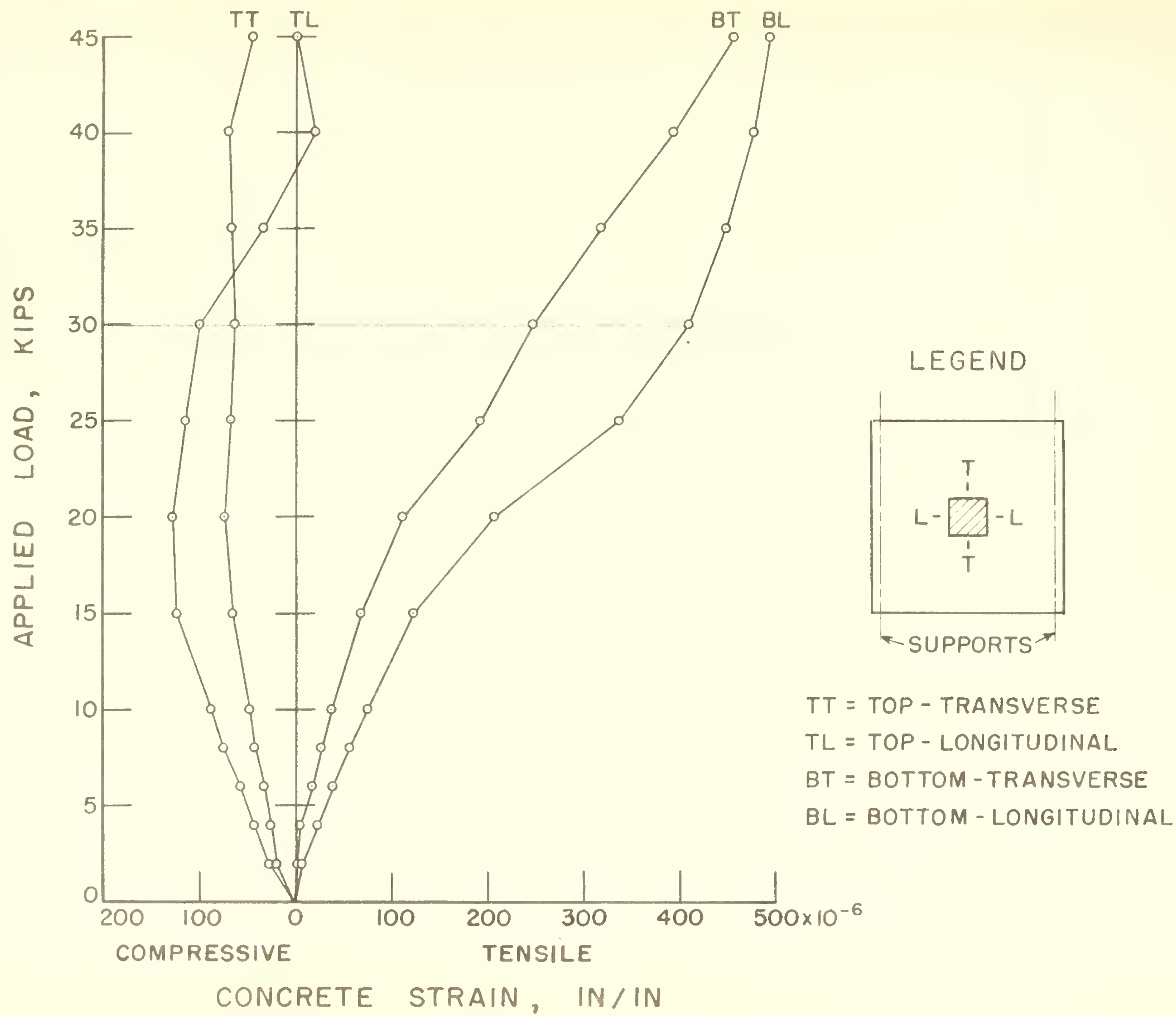


FIGURE 11. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN IN SLAB NO. 21.

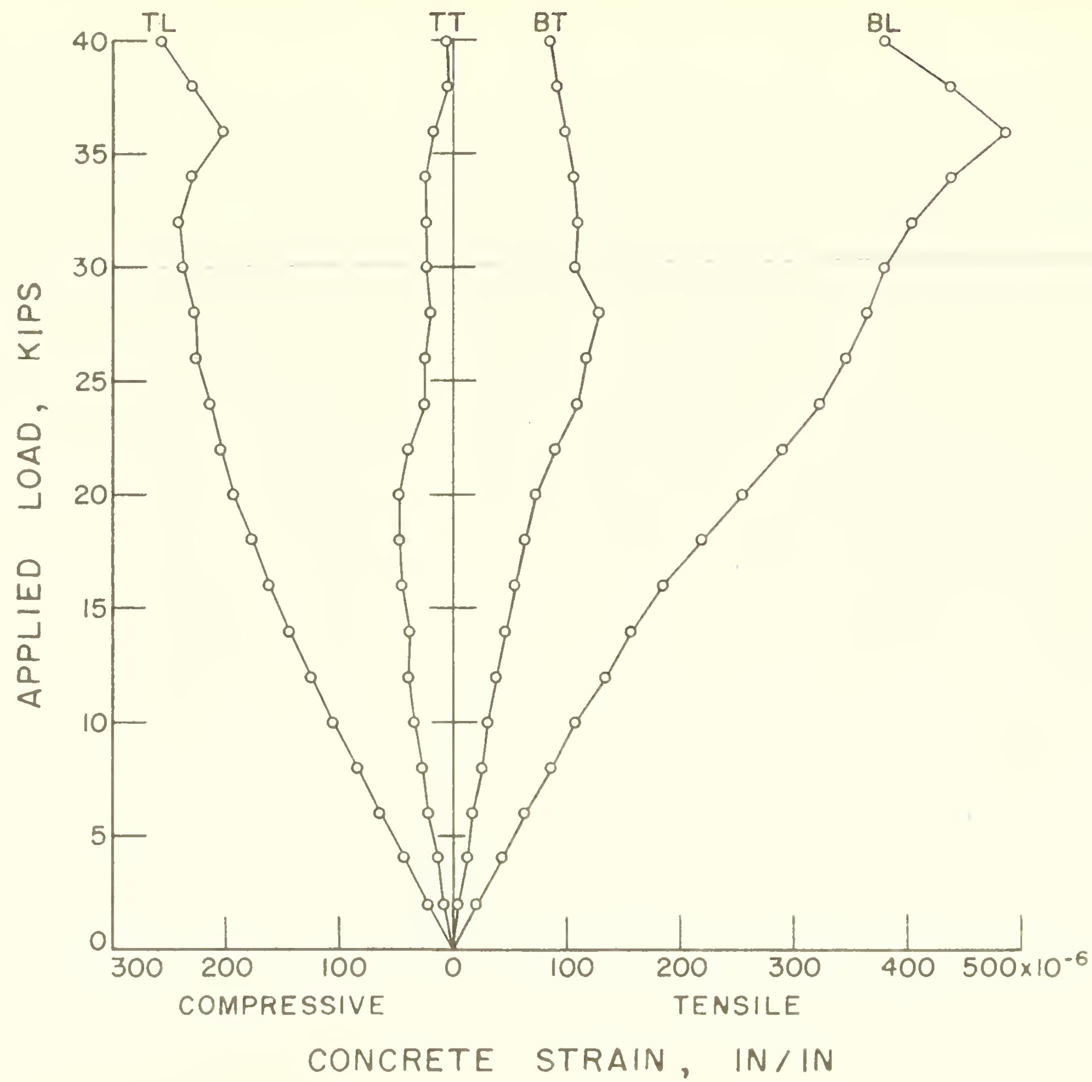


FIGURE 12. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN IN SLAB NO. 22.

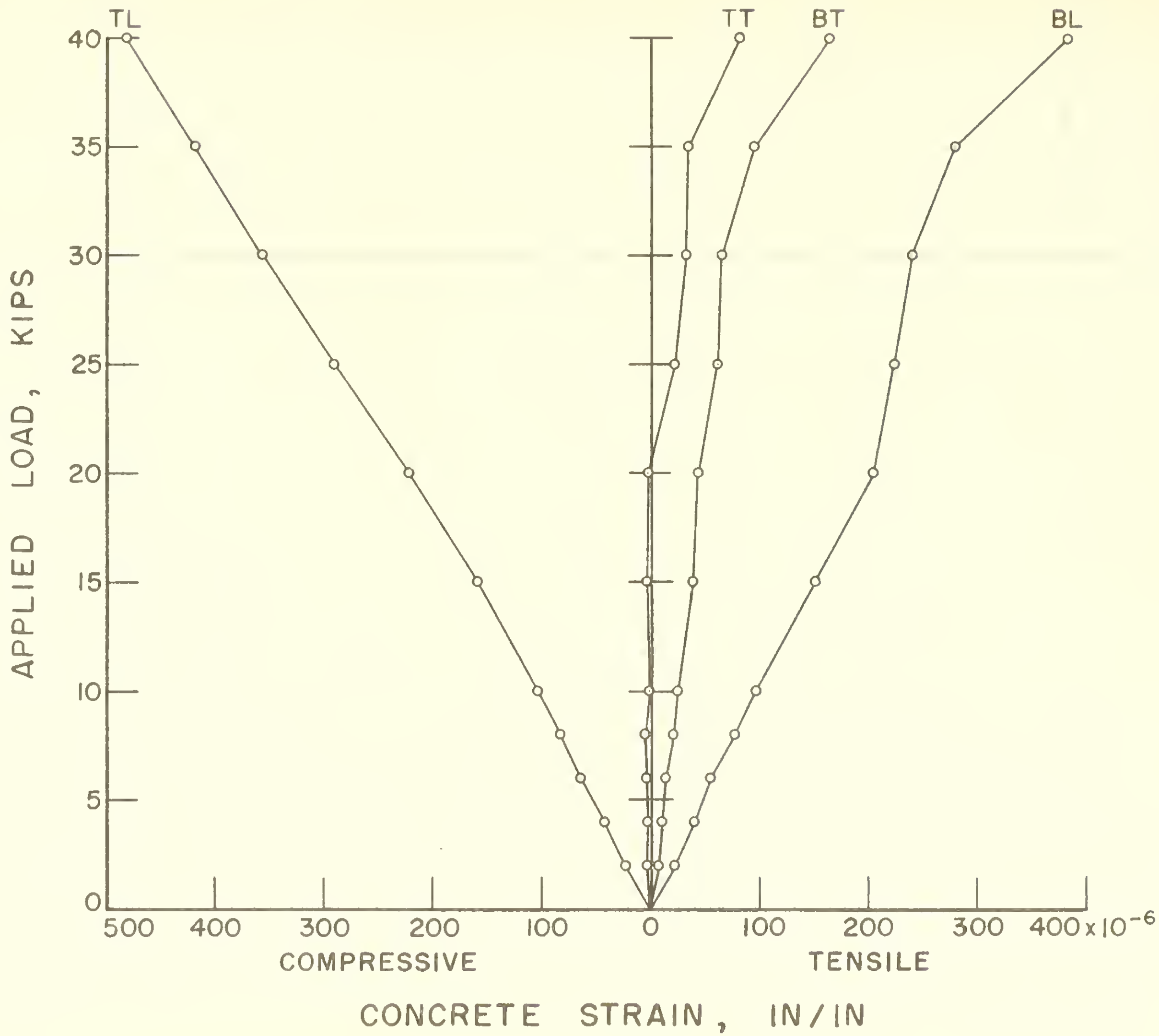


FIGURE 13. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN IN SLAB NO. 23.

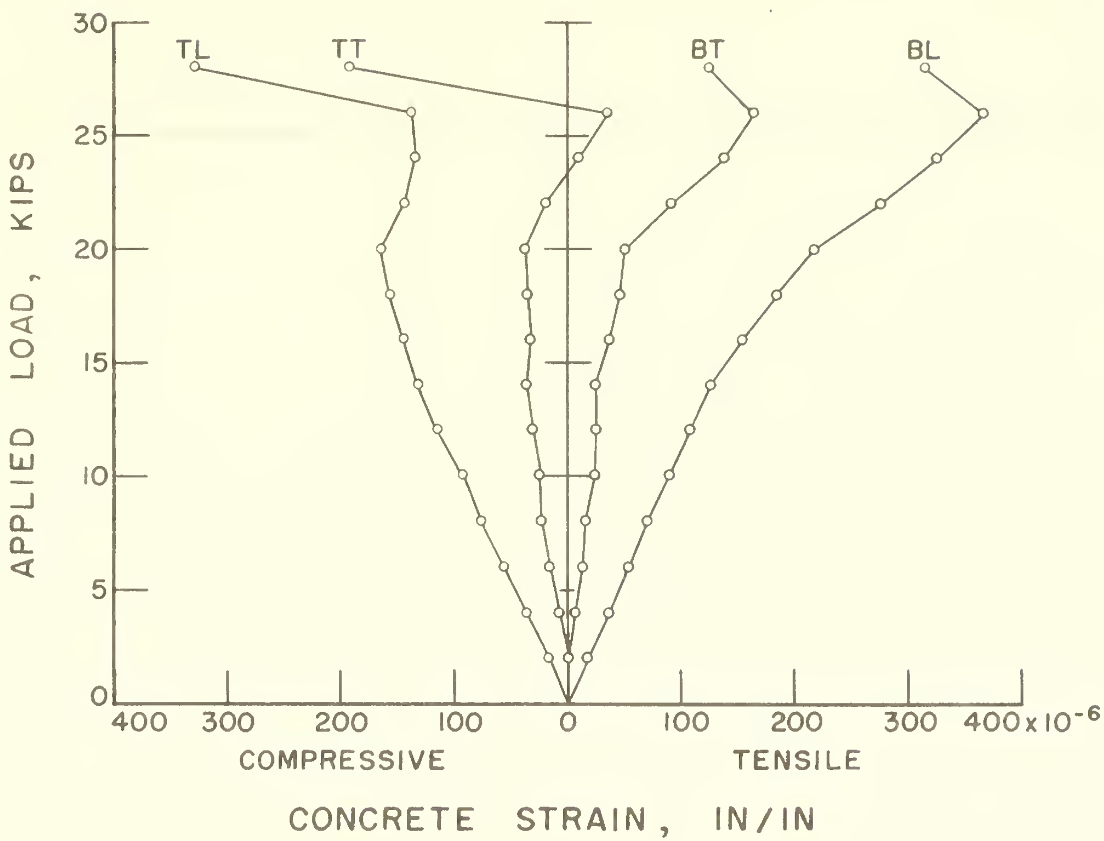


FIGURE 14. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN IN SLAB NO. 24.

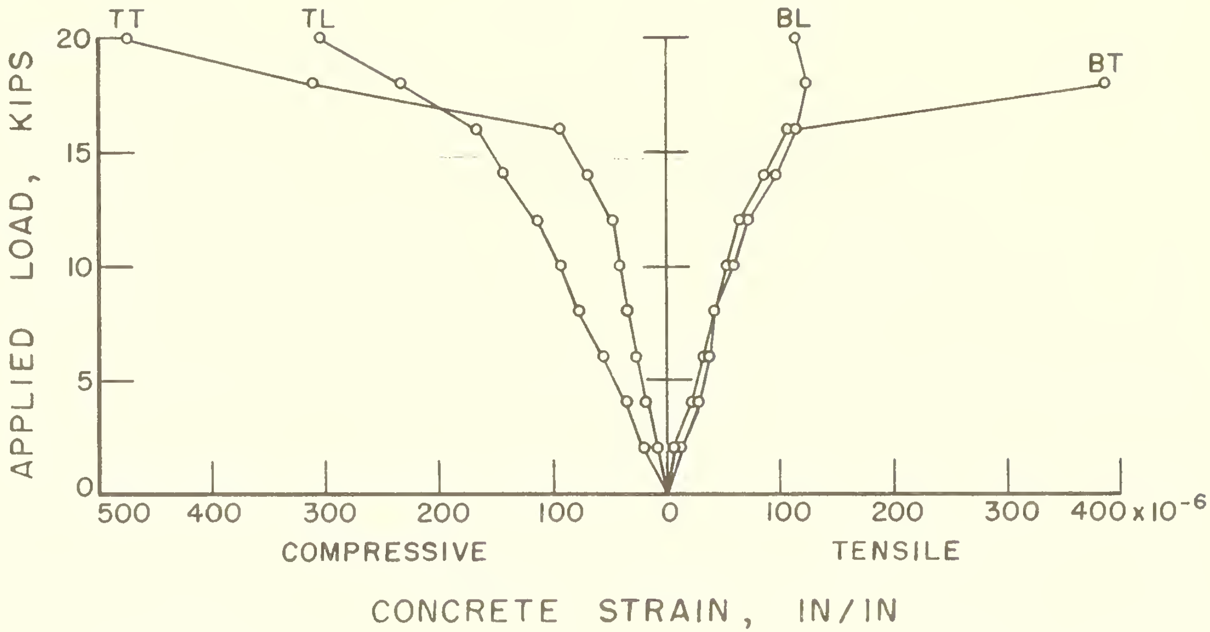


FIGURE 15. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN IN SLAB NO. 25.

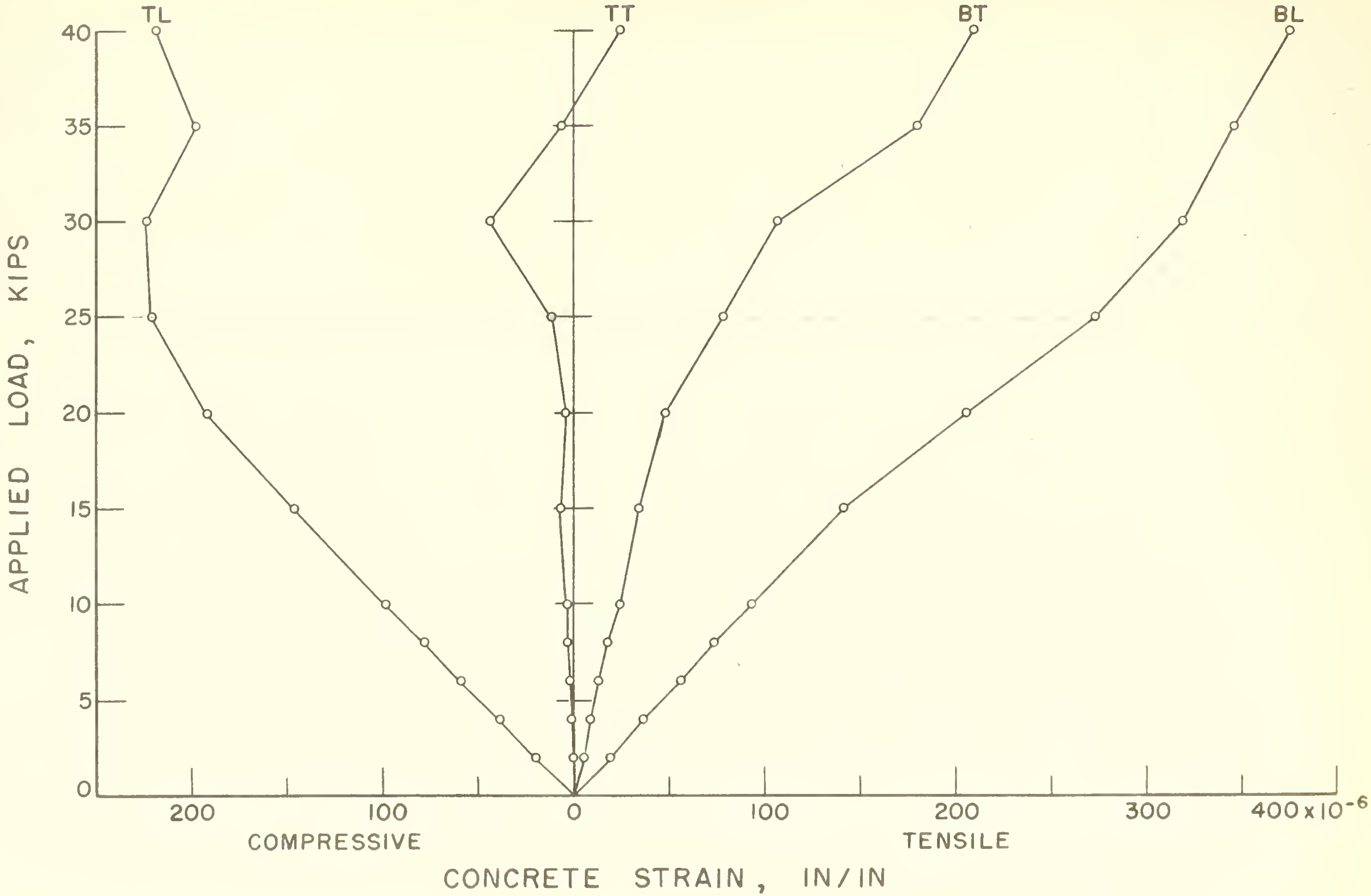


FIGURE 16. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN IN SLAB NO. 26.

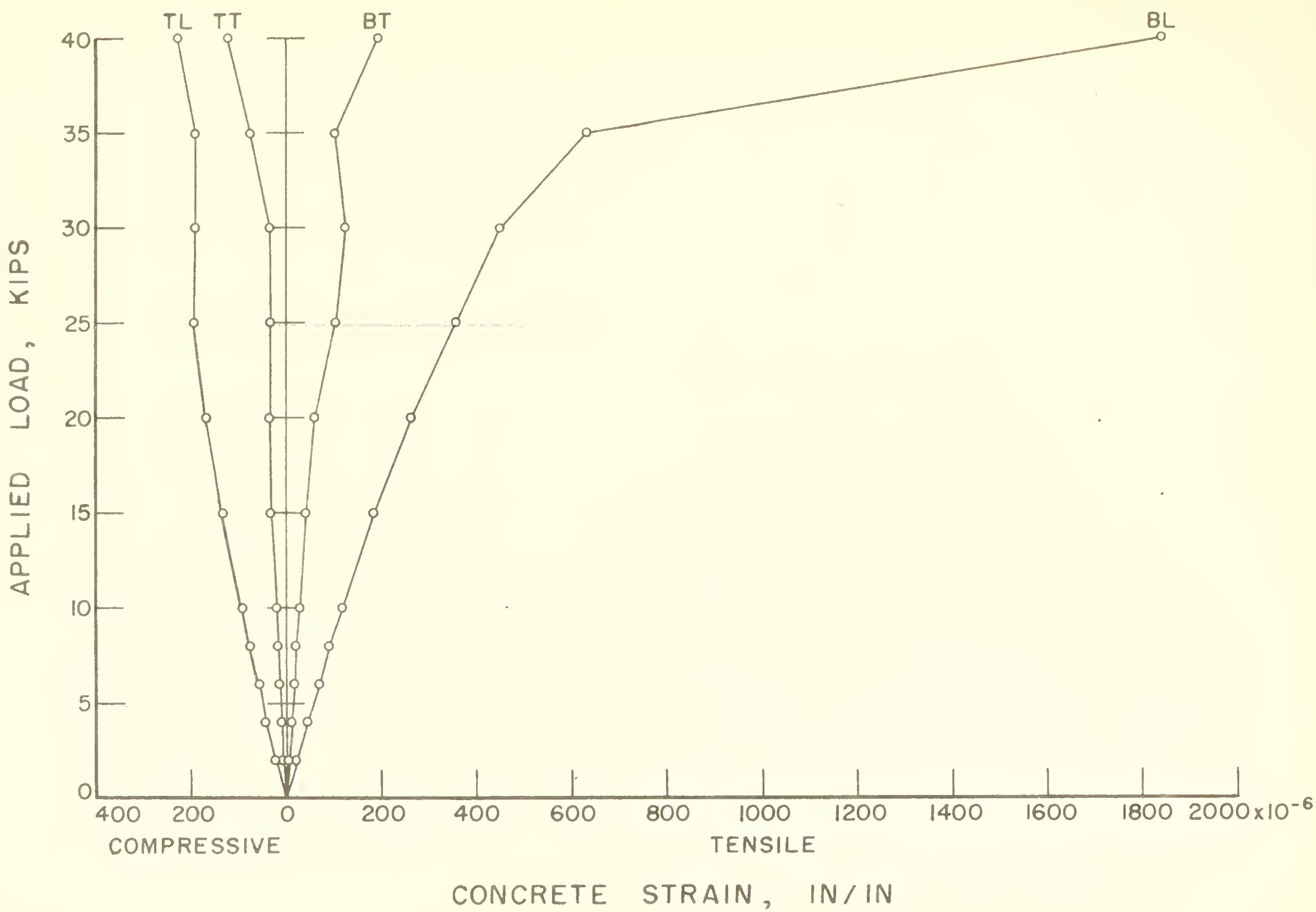


FIGURE 17. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN IN SLAB NO. 27.

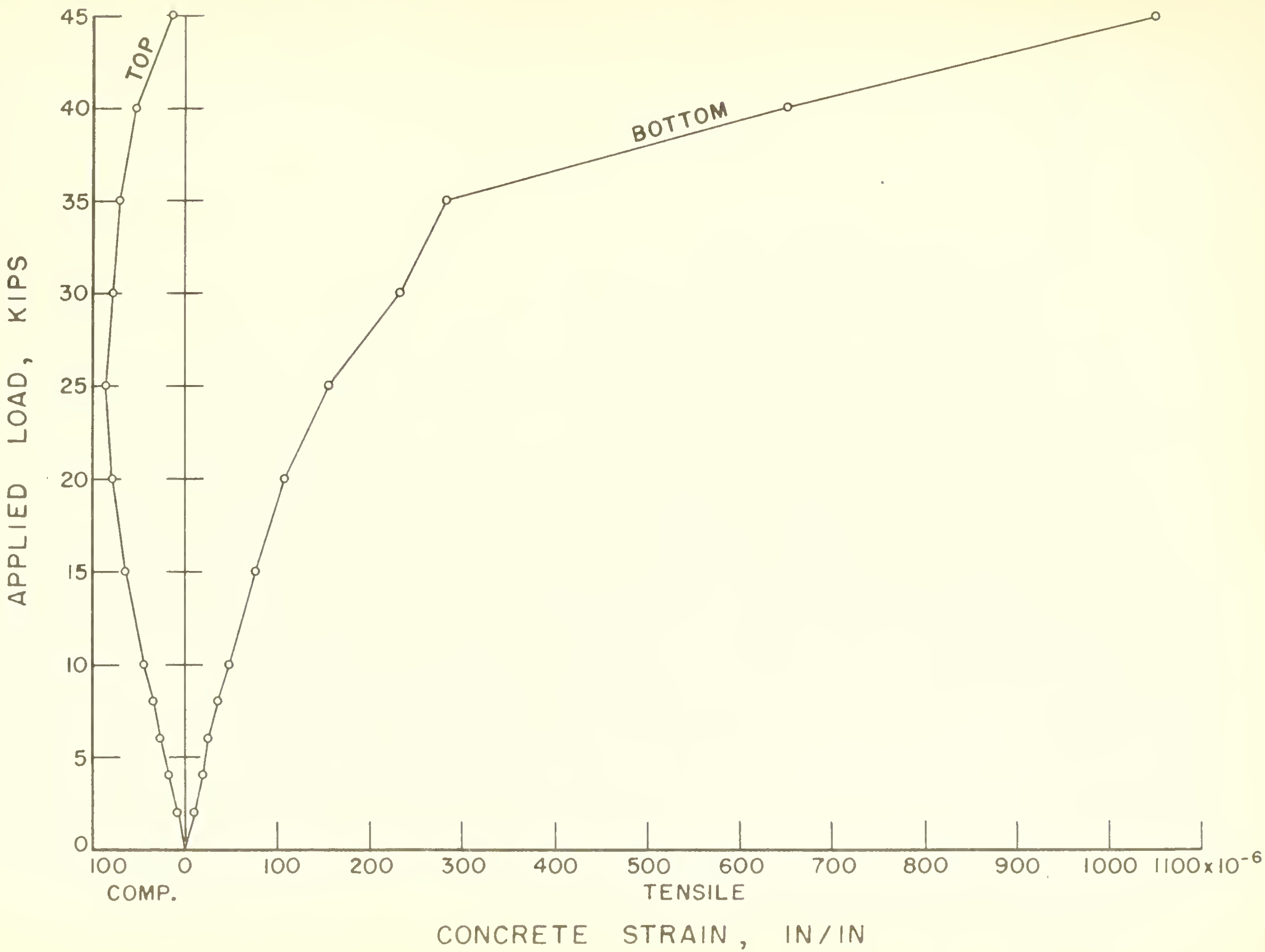


FIGURE 18. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN IN SLAB NO. 20.

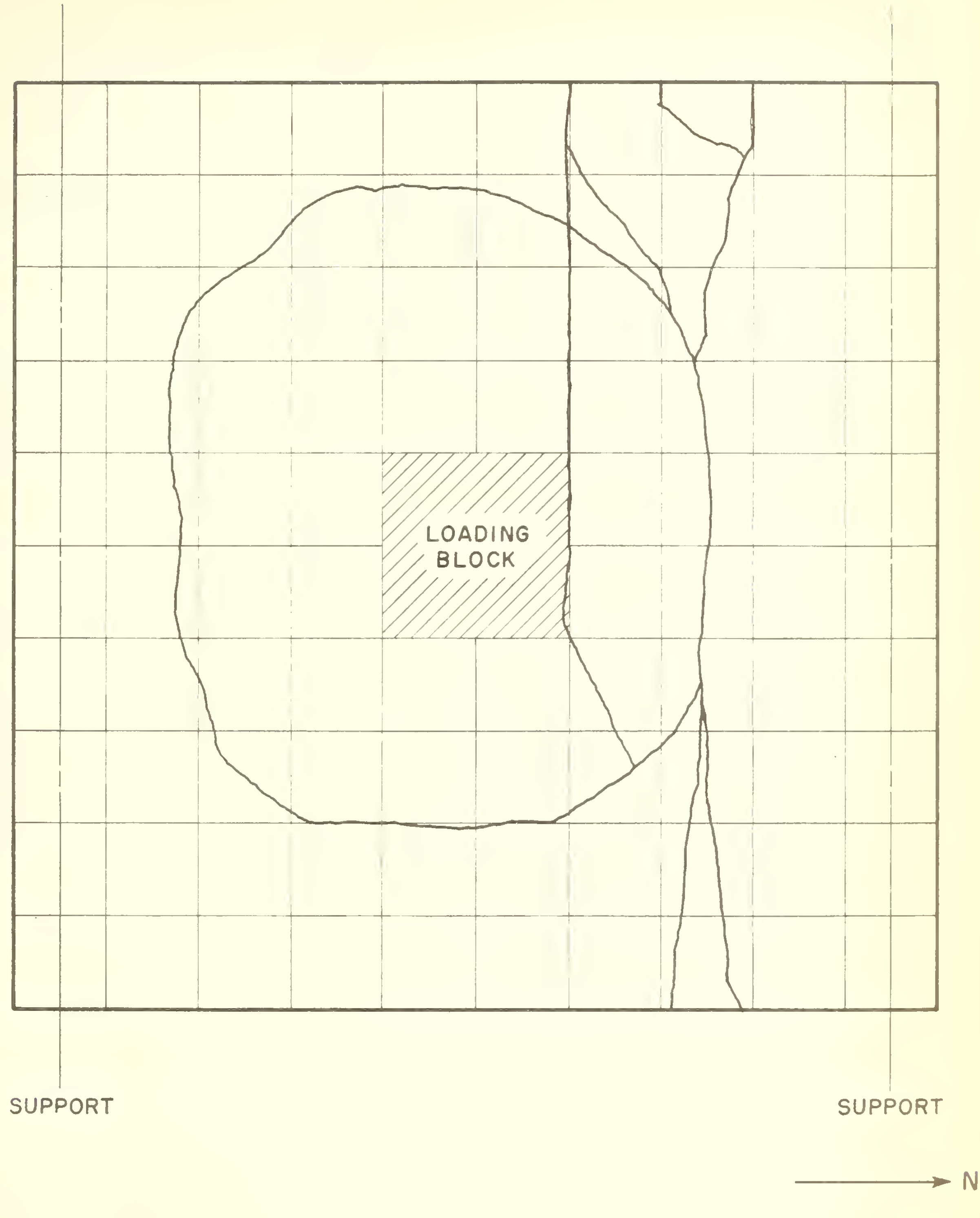


FIGURE 19. TOP VIEW OF CRACK PATTERNS IN SLAB NO. 24.

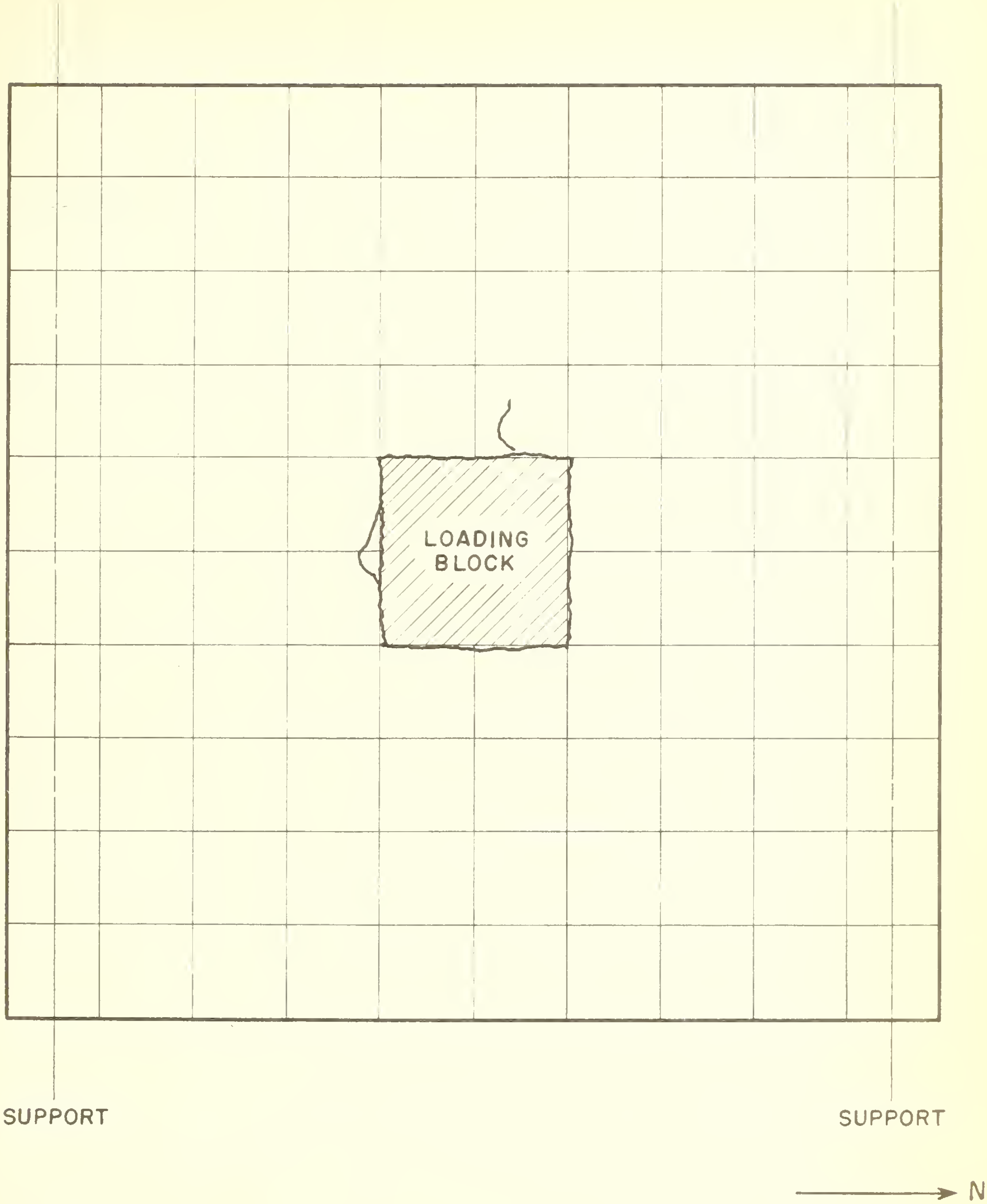


FIGURE 20. TOP VIEW OF CRACK PATTERNS IN SLAB NO. 27.

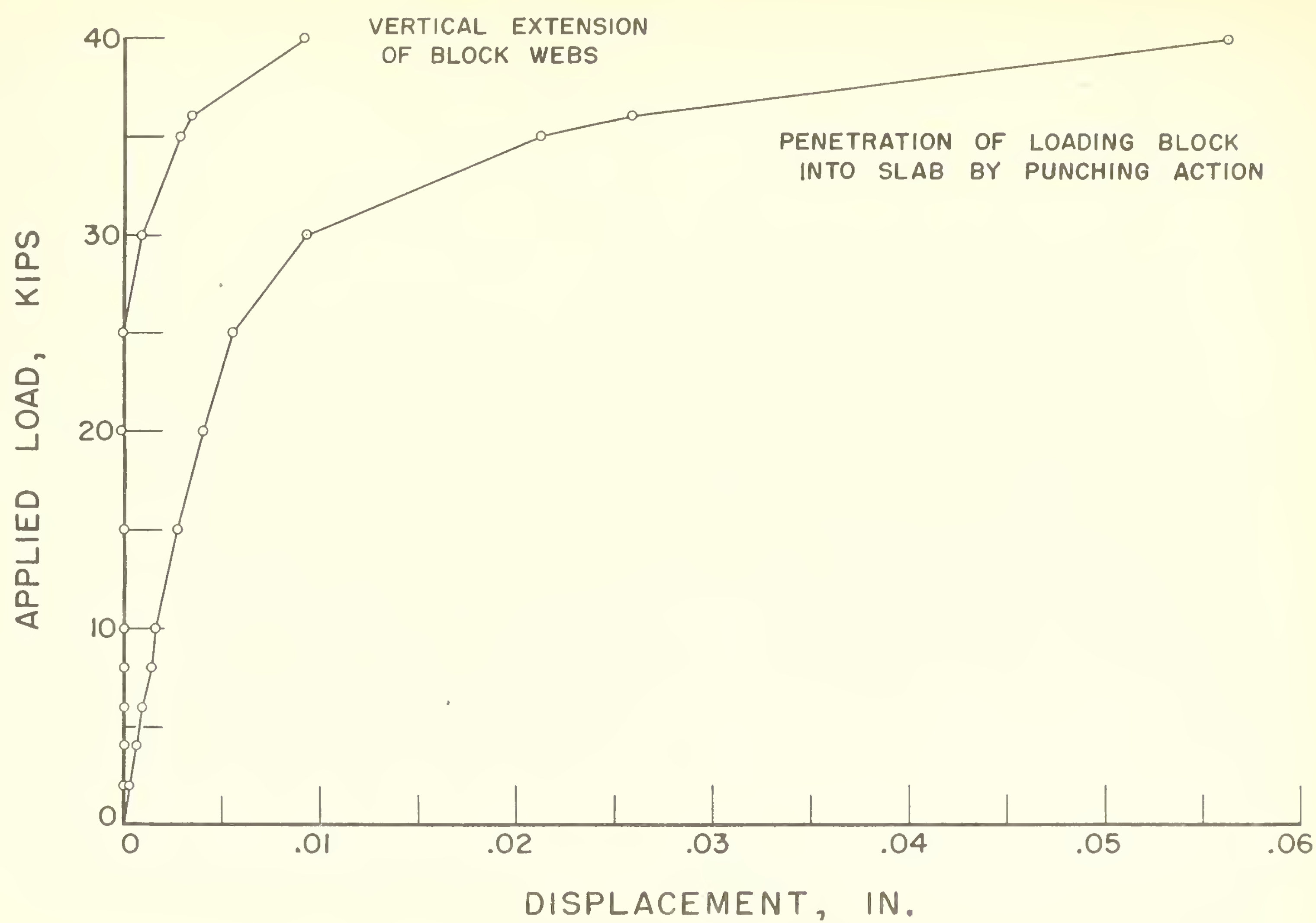


FIGURE 21. PENETRATION OF LOADING BLOCK INTO SLAB AND VERTICAL EXTENSION OF BLOCK WEBS, SLAB NO. 27.

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

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

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Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

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Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio Meteorology.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

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