NATIONAL BUREAU OF STANDARDS REPORT

5212

TESTS OF PRESTRESSED CELLULAR SLABS
(Slabs Nos. 10 through 19)

by

Arthur F. Kirstein and Michael Chi

Report to

Bureau of Yards and Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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

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

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major field laboratories in Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside back cover of this report.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

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

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metals Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Application Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships.

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

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

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT | **NBS REPORT**

1001-10-4811 April 8, 1957 5212

TESTS OF PRESTRESSED CELLULAR SLABS
(Slabs Nos. 10 through 19)

by

Arthur F. Kirstein and Michael Chi

To

Bureau of Yards and Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

TESTS OF PRESTRESSED CELLULAR SLABS
(Slabs Nos. 10 through 19)

by

Arthur F. Kirstein and Michael Chi

Abstract

In the continuing study of the properties of prestressed cellular slabs, ten additional slabs were tested under concentrated loads. All of the slabs were simply supported on two edges except Slab No. 16 which was simply supported on four edges. Deflections, strains, crack patterns, and maximum load-carrying capacities were recorded. The data reported herein substantiate the conclusions drawn in NBS Reports 4396 and 4951. Since the primary mode of failure is diagonal tension, the load-carrying capacity of the slabs can only be increased by suitable reinforcement of the webs of the concrete blocks or the use of a material for the construction of the blocks which has a higher tensile strength.

1. INTRODUCTION

As a continuation of the study of the properties of slabs composed of 6-in. cellular blocks, ten additional 5- by 5-ft slabs were 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 by either two or four supports, and the arrangement of the blocks was altered along with the use of various jointing materials.

The test results from these ten slabs substantiate the conclusions drawn in NBS Reports 4396 and 4951. A complete summary of the deflections and maximum load-carrying capacities

of all of the slabs in this testing program is presented and discussed, along with the test results from Slabs Nos. 10 through 19.

2. DESCRIPTION OF TEST SPECIMENS

2.1 Cellular blocks

The cellular concrete blocks were hollow 6-in. cubes having an opening 4.5 by 4.5 in. in cross section. There was 1- by 2-in. elliptical access hole in each web to permit the passage of the prestressing unit. The principal dimensions of the cellular blocks are shown in figure 1.

All of the blocks used in this test series were of the type designated as NBS blocks, that is, they were unreinforced and cast in three-unit gang molds. These polished steel molds were constructed to very close tolerances which produced blocks of superior quality, and the exterior dimensions of the blocks were within 0.01 in. of the nominal values.

The blocks were made of a mix proportioned of one part type III cement and three parts of sand by weight with a water-cement ratio of 0.57. This mix had a 7-day compressive strength of approximately 6000 psi as determined by tests of 2-in. cubes. However, the actual units were moist-cured continuously until they were assembled into slabs so that the compressive strength of the individual units should be expected to be somewhat greater.

Additional tests of the concrete were conducted to determine the Young's modulus and Poisson's ratio. Axial compression tests were made on columns of three blocks that were grouted together in such a fashion as to make the direction of loading coincide with the axis of the cell. Sonic modulus tests were also performed on 0.75- by 0.80- by 6-in. strips that were cut from the cellular blocks. The results obtained by both methods 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

The prestressing units in the test slabs were 5/8 in. "Stressteel" bars. The anchorage for 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 characteristic 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 the point of fracture was 35 percent.

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 arrangements of the blocks in the slabs of this test series are described as "crisscross" 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 to permit the prestressing tendons to be staggered with respect to the midplane of the slab. Thus, the resultant prestressing force produced an axial compression in two directions through the slab.

The slabs in this test series were numbered 10 through 19. All of the slabs were constructed with the unreinforced NBS blocks. The principal variables in this test series were the method of support, amount of prestressing, arrangement of blocks, and jointing material. A complete summary of these variable factors will be made later in the text along with the maximum load-carrying capacity of each slab for comparison with the first eight slabs of this testing program reported in NBS Reports 4396 and 4951.

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 2.

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 on two edges as described above except Slab No. 16 which was simply supported on 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. 16 were made with 0.001-in. micrometer dial gages that were attached to steel angles. These steel angles rested on the slab directly over the supports, thus placing the datum plane at the supports. Figure 3 shows the symmetrical arrangement of these gages. The deflection measurements of Slab No. 16 were made in a different manner to accommodate the measurement of the "curl-up" action of the corners that is typical of slabs supported on four edges. In this case

the dial gages were attached to a steel frame that was supported by the columns of the testing machine. Figure 4 shows the location of the dial gages on Slab No. 16.

The strains on the top and bottom surfaces of the slabs were measured with electrical resistance wire gages of the A-11 type. The locations of these gages are shown in figures 3 and 4.

3.3 Test procedure

The slabs were loaded at the center of the top surface through a 6- by 12- by 12-in. concrete loading block. The load was applied in increments of 1000, 2000 and 2500 pounds, 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 5 shows the observed relationship between the applied load and center deflection of Slabs No. 10 through 19. 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 (μin./lb).

Table 1 shows a comparison of the deflection sensitivities and the maximum load-carrying capacities of all of the slabs of this testing program.

The typical "curl-up" of the corners of slabs simply supported on four edges was observed for Slab No. 16 and is shown in figure 6. Slab No. 16 was the only slab reported herein that was supported on four edges.

4.2 Concrete strains

The relationship between the applied load and the strains in the concrete for Slabs Nos. 10 through 19 are shown in figures 7, 8, 9, and 10. The legends at the top of figures 7, 8, and 9 indicate the positions of the strain gages on the concrete and identify the curves as top longitudinal, top transverse, bottom longitudinal, and bottom

transverse. Figure 10 shows the load-strain relationship for Slab No. 16 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. 16 in the same locations as indicated by the legends in figures 7, 8, and 9, the average of the gages on the top and bottom are presented in figure 10.

4.3 Crack patterns

The crack patterns observed in these ten slabs are all very nearly alike as only NBS unreinforced blocks were used in the construction of the slabs. A typical crack pattern is illustrated in figure 11 for various sections through the slabs. The location and direction of the cracks indicate that the primary failure was diagonal tension, and possibly a secondary failure was due to the bursting effect of the prestressing force.

5. DISCUSSION

For the purpose of comparison, table 1 of this report includes the pertinent information obtained from the previously tested slabs (Nos. 2, 3, 4, 5, 7, 8, and 9) along with the ten additional slabs which form the subject of this report.

Upon examination of table 1 it will be seen that the slabs are grouped according to the method of support, arrangement of blocks, amount of prestress, jointing material, and the type of block used. Group I shows a great improvement in the deflection sensitivity of Slab No. 5 over that of No. 2. This is apparently due to the improved dimensional tolerances of the NBS blocks, as no jointing material was used in the fabrication of these slabs. However, attention is directed to Group II where the deflection sensitivities do not vary appreciably for the slabs constructed from Preload, NBS, and clay tile block. This, of course, is due to the fact that the grout jointing material furnishes the intimate contact necessary between individual blocks regardless of their dimensional tolerances.

The slabs having polyester resin joints exhibited values of deflection sensitivity comparable to the slabs containing grout or neat cement joints, but the slabs containing polyester

resin joints in general carried a slightly higher maximum load. This may be due to an actual tensile reinforcement of the block webs by the resin.

The relative magnitude of the deflection sensitivities of the individual slabs in Groups IV, V, and VI indicate the effect of the arrangement of blocks and the amount of prestress on the rigidity of the slabs.

In general, the slabs exhibiting high values of deflection sensitivity deviate from a linear relationship on the load-deflection curves at low loads. This can be observed for Slabs Nos. 10, 12, and 17 in figure 5.

The erratic relationship between the applied load and strain in the concrete blocks shown in figure 7 may be attributed to the lack of intimate contact between the individual blocks in the slabs. Intimate contact between the blocks in Slabs Nos. 10, 12, and 17 was not attained because no jointing material was used and the dimensional tolerance of the blocks permitted slight individual motion caused by points of stress concentration.

Figure 8 shows the relationship between applied load and strain in the concrete for Slabs Nos. 11, 13, and 18. These slabs are simply supported on two edges and have neat cement joints between the blocks. For other particulars of the slab construction, see table 1. The relationships between the applied load and strain in concrete for Slabs Nos. 14, 15, and 19, are shown in figure 9; these slabs had polyester resin joints. Attention is directed to the fact that figures 8 and 9 do not display the erratic relationship exhibited in figure 7.

The crack patterns observed throughout this series of slab tests indicate that diagonal tension is the mode of failure that limits the load-carrying capacity of the slabs. To increase the load-carrying capacity of slabs of this type, one of two things could be done--either the webs of the concrete blocks must be heavily reinforced with steel, or another material could be used in the construction of the blocks. The first alternative, while effective, would most likely entail considerable expense in producing quantities of web reinforced blocks. Therefore, a search for an existing material or the development of a new material with a more suitable tensile strength might be a more fruitful endeavor.

6. CONCLUSIONS

The foregoing discussion can be summarized in the following conclusions:

1. All of the slabs reported herein failed in diagonal tension.

2. A suitable joint material must be provided between the blocks to ensure intimate contact.

3. To improve the load-carrying capacity of these slabs, it is necessary to either heavily reinforce the webs of the blocks with steel or use a material with a more suitable tensile strength for the construction of the blocks to increase their resistance to diagonal tension failures.

Table 1. Summary of Slab Construction and Test Results

Group	Slab	Method of Support	Arrangement of Blocks	Amount of Prestress	Jointing Material	Type of Block	Deflection sensitivity μ in./lb	Maximum Load kips
I	2	4 edge	Criss-cross	1000 psi both ways	None	Preload	3.00	16.25
	5	"	" "	"	"	NBS	0.97	18.0
II	3	4 edge	Criss-cross	1000 psi both ways	Grout	Preload	0.90	35.0
	4	"	" "	"	"	"	1.10	34.25
	7	"	" "	"	"	NBS	0.70	27.28
	8	"	" "	"	"	NBS*	0.70	39.85
	9	"	" "	"	"	Clay tile	0.80	26.8
III	16	4 edge	Criss-cross	1000 psi both ways	Polyester	NBS	0.68	31.5
IV	10	2 edge	Criss-cross	1000 psi both ways	None	NBS	1.57	17.0
	11	"	" "	"	Neat cement	"	1.27	26.25
	19	"	" "	"	Polyester	"	1.39	28.0
V	17	2 edge	Criss-cross	1000 long. 500 trans.	None	NBS	2.54	11.0
	18	"	" "	"	Neat cement	"	1.40	24.3
	15	"	" "	"	Polyester	"	1.58	17.6
VI	12	2 edge	Aligned	1000 long. 500 trans.	None	NBS	2.32	13.1
	13	"	"	"	Neat cement	"	1.17	18.1
	14	"	"	"	Polyester	"	1.16	19.6

*Blocks reinforced with 1/4 in. stirrups.

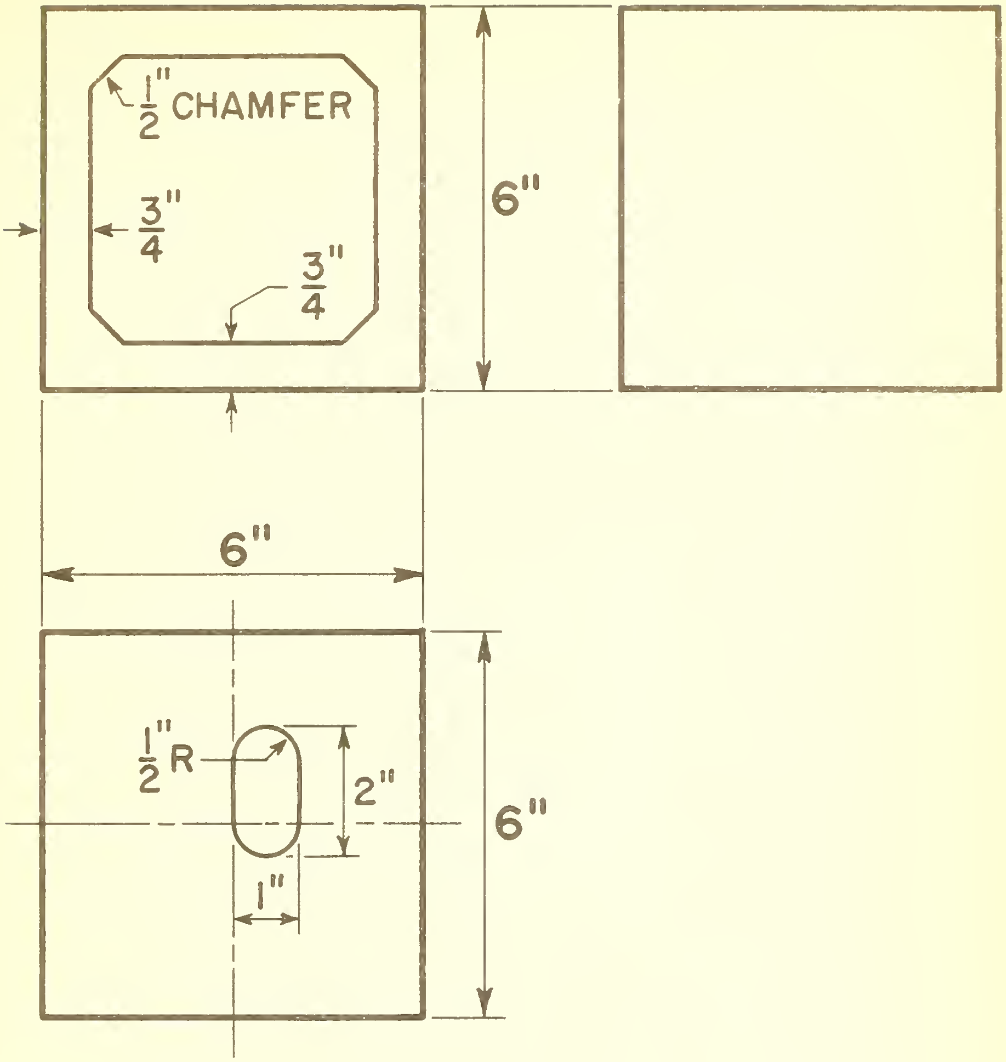


FIGURE 1. NOMINAL DIMENSIONS OF NBS UNREINFORCED BLOCKS.

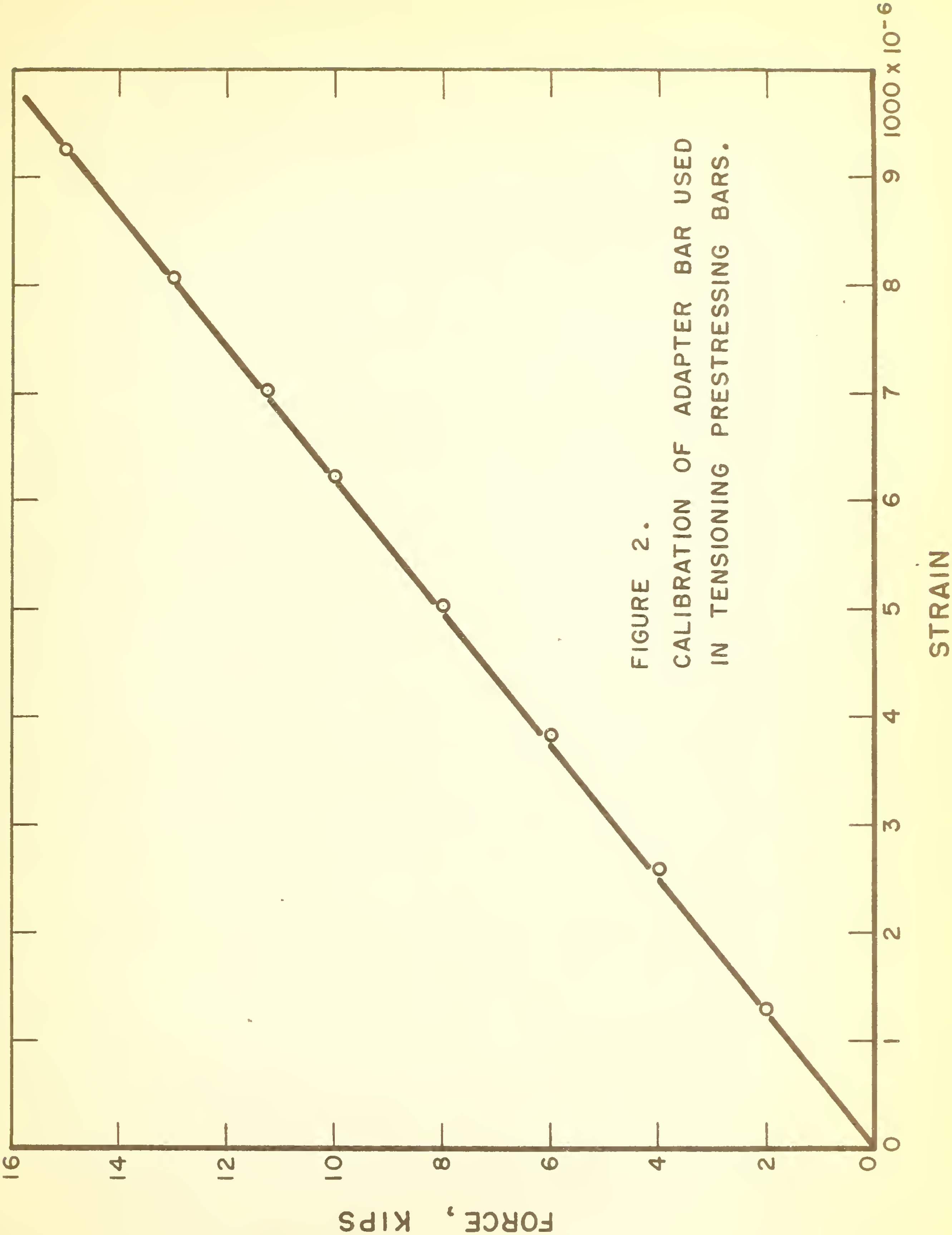
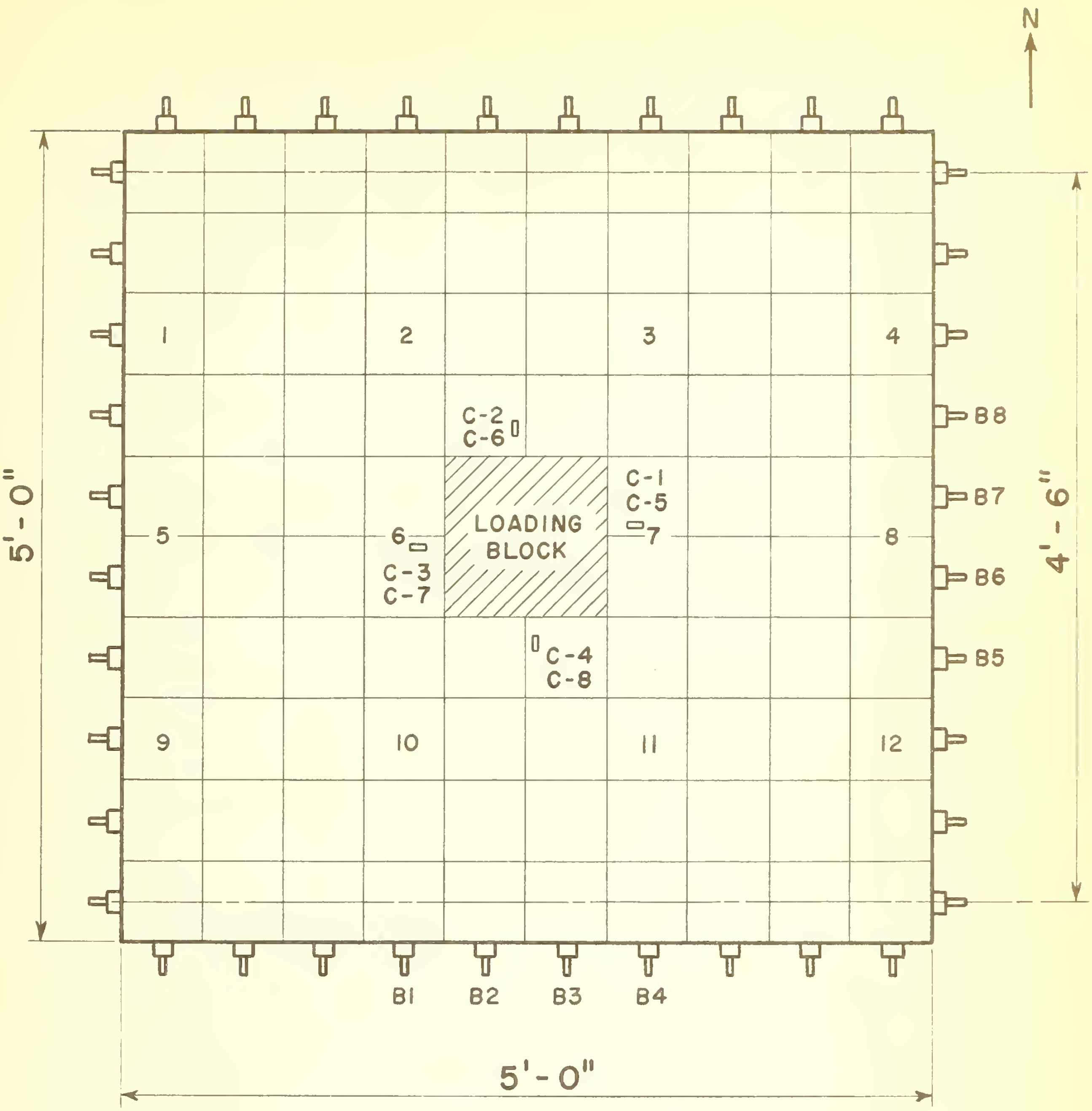


FIGURE 2.
CALIBRATION OF ADAPTER BAR USED
IN TENSIONING PRESTRESSING BARS.
STRAIN
0
1
2
3
4
5
6
7
8
9
1000 x 10-6
FORCE, KIPS
0
2
4
6
8
10
12
14
16

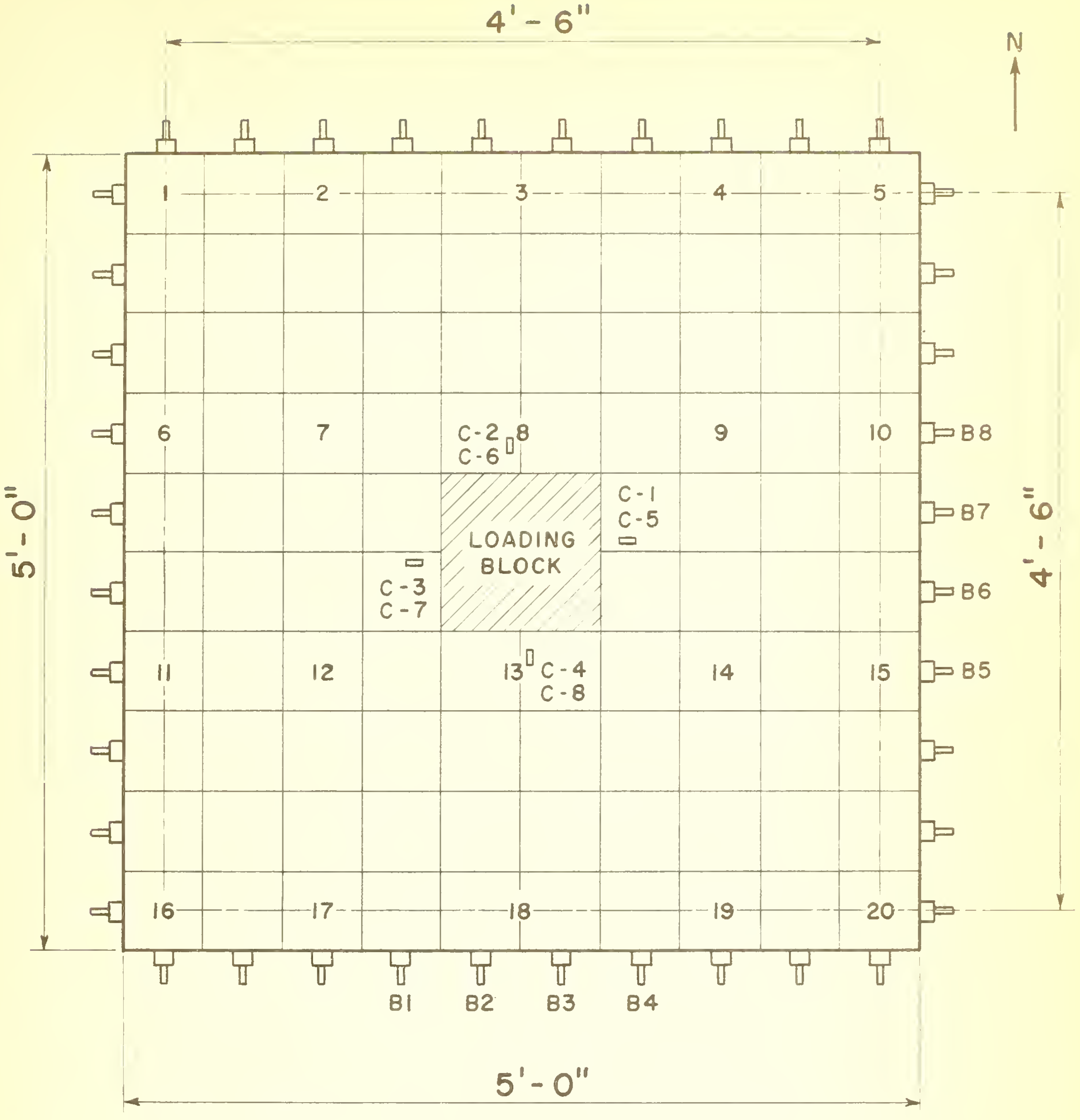
FIGURE 2.



LEGEND:

GAGES 1 THROUGH 12 INDICATE DIAL GAGES
B1 THROUGH B8 INDICATE GAGES ON BARS
C1 - C4 INDICATE SR-4 GAGES ON BOTTOM SURFACE OF SLAB
C5 - C8 " " " " TOP " " "

FIGURE 3. LOCATION OF DIAL GAGES AND STRAIN GAGES ON SLABS SIMPLY SUPPORTED ON TWO EDGES.



LEGEND:

GAGES 1 THROUGH 20 INDICATE DIAL GAGES
B1 THROUGH B8 INDICATE GAGES ON BARS
C1 - C4 INDICATE SR-4 GAGES ON BOTTOM SURFACE OF SLAB
C5 - C8 " " " " TOP " " "

FIGURE 4. LOCATION OF DIAL GAGES AND STRAIN GAGES ON SLAB NO. 16. (SIMPLY SUPPORTED ON FOUR EDGES).

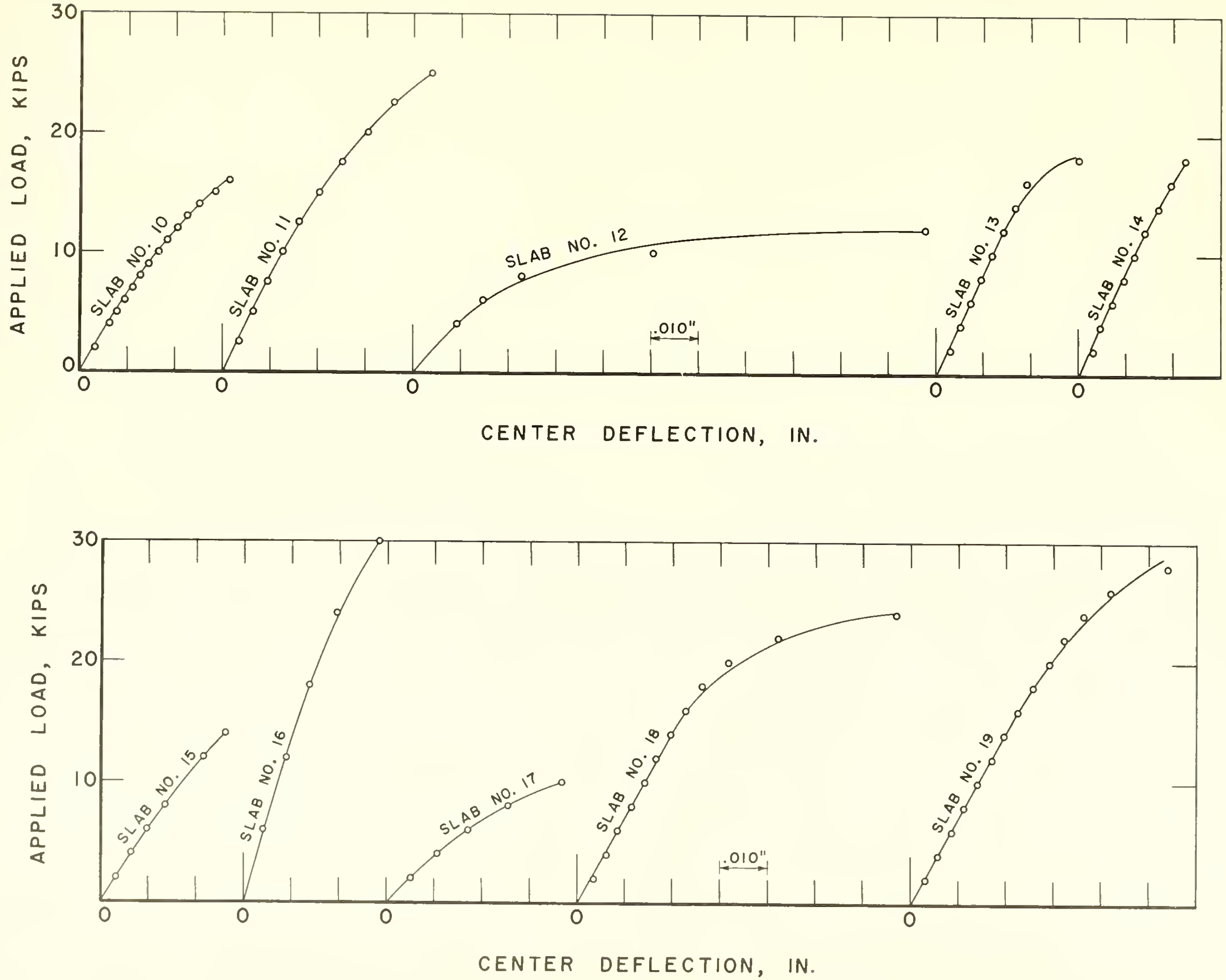


FIGURE 5. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CENTER DEFLECTION OF SLABS.

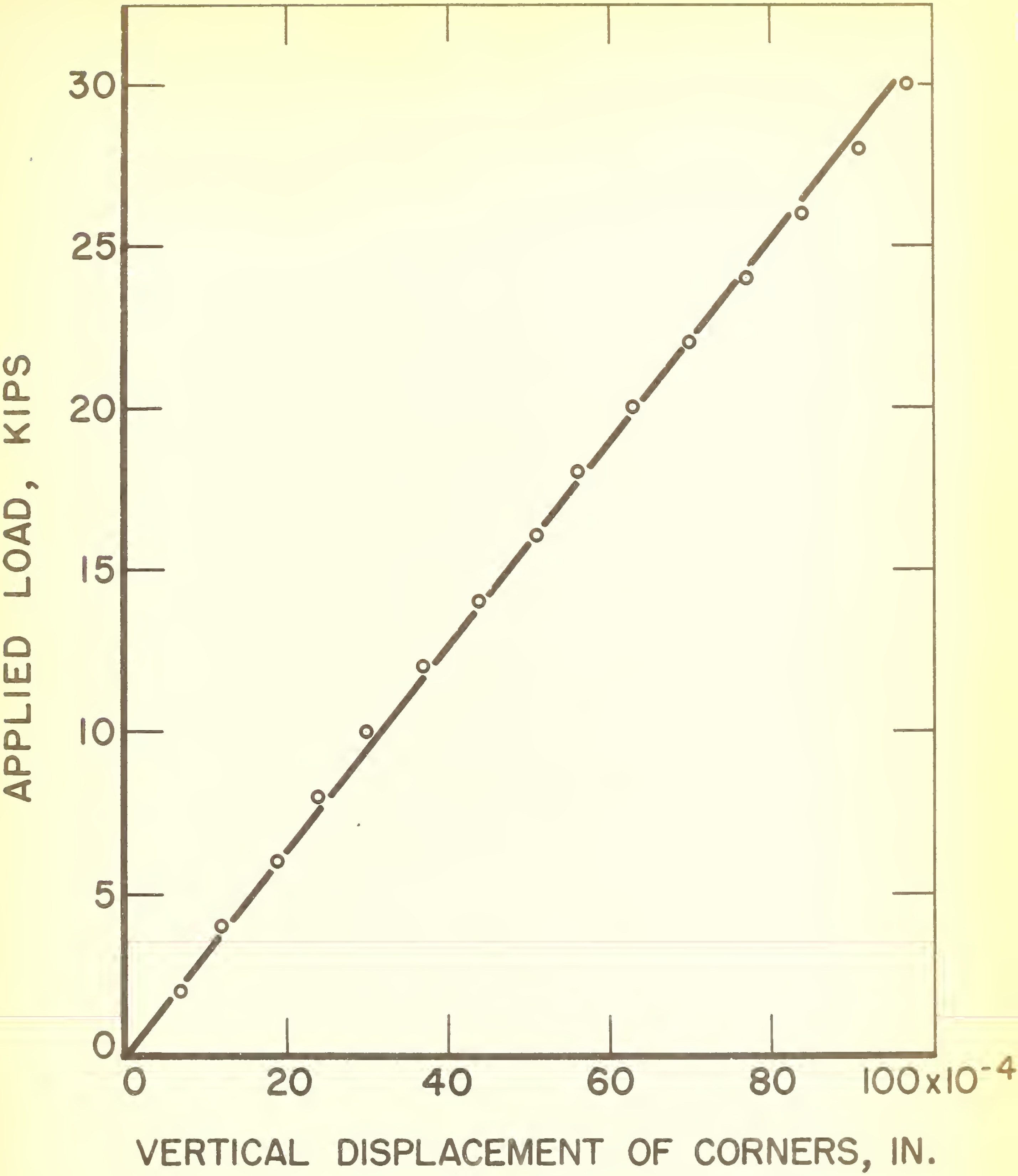


FIGURE 6. VERTICAL DISPLACEMENT OF THE CORNERS DUE TO THE "CURL UP" ACTION OF SLAB NO. 16.

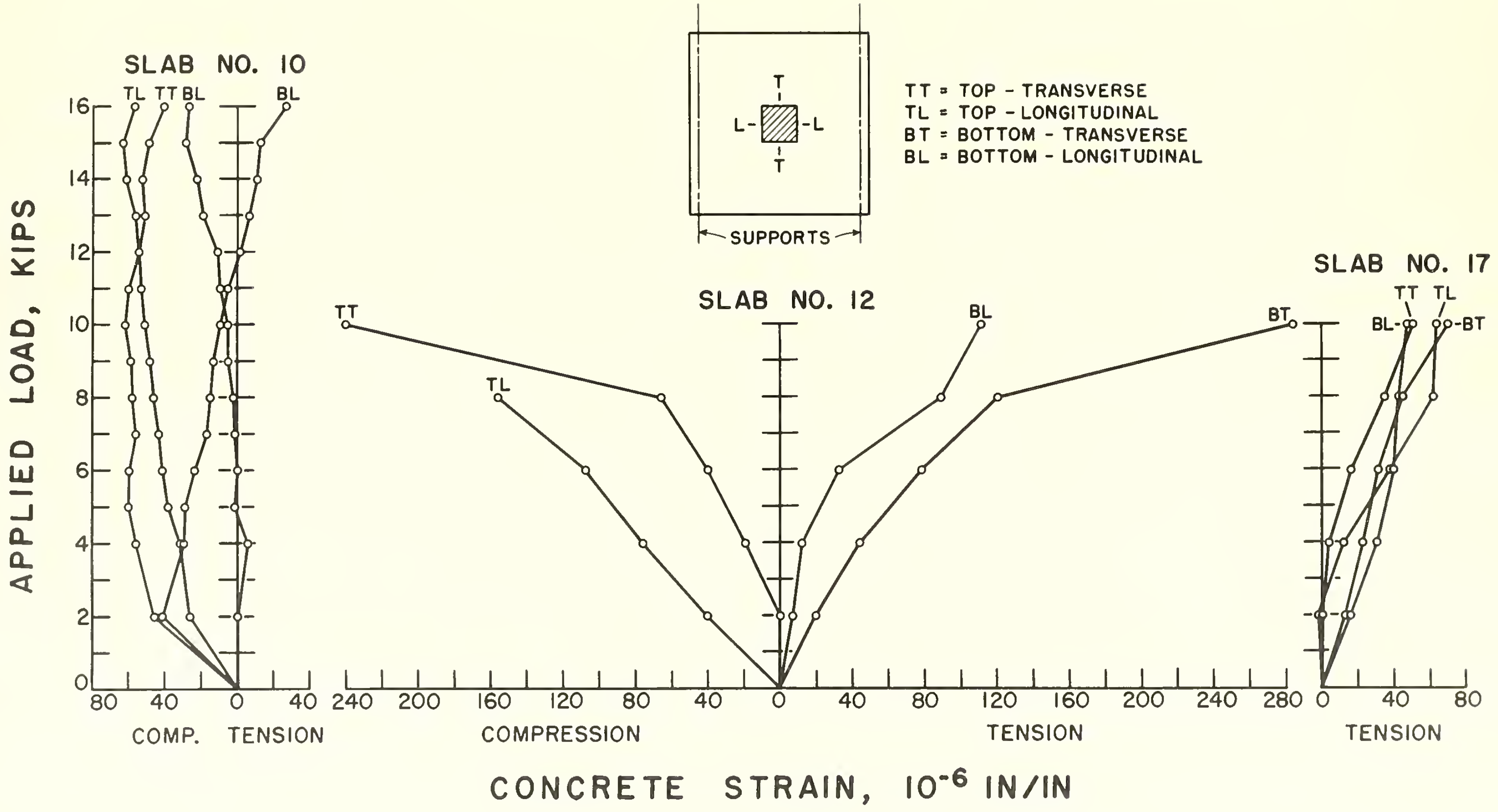


FIGURE 7. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN. (NO JOINTING MATERIAL)

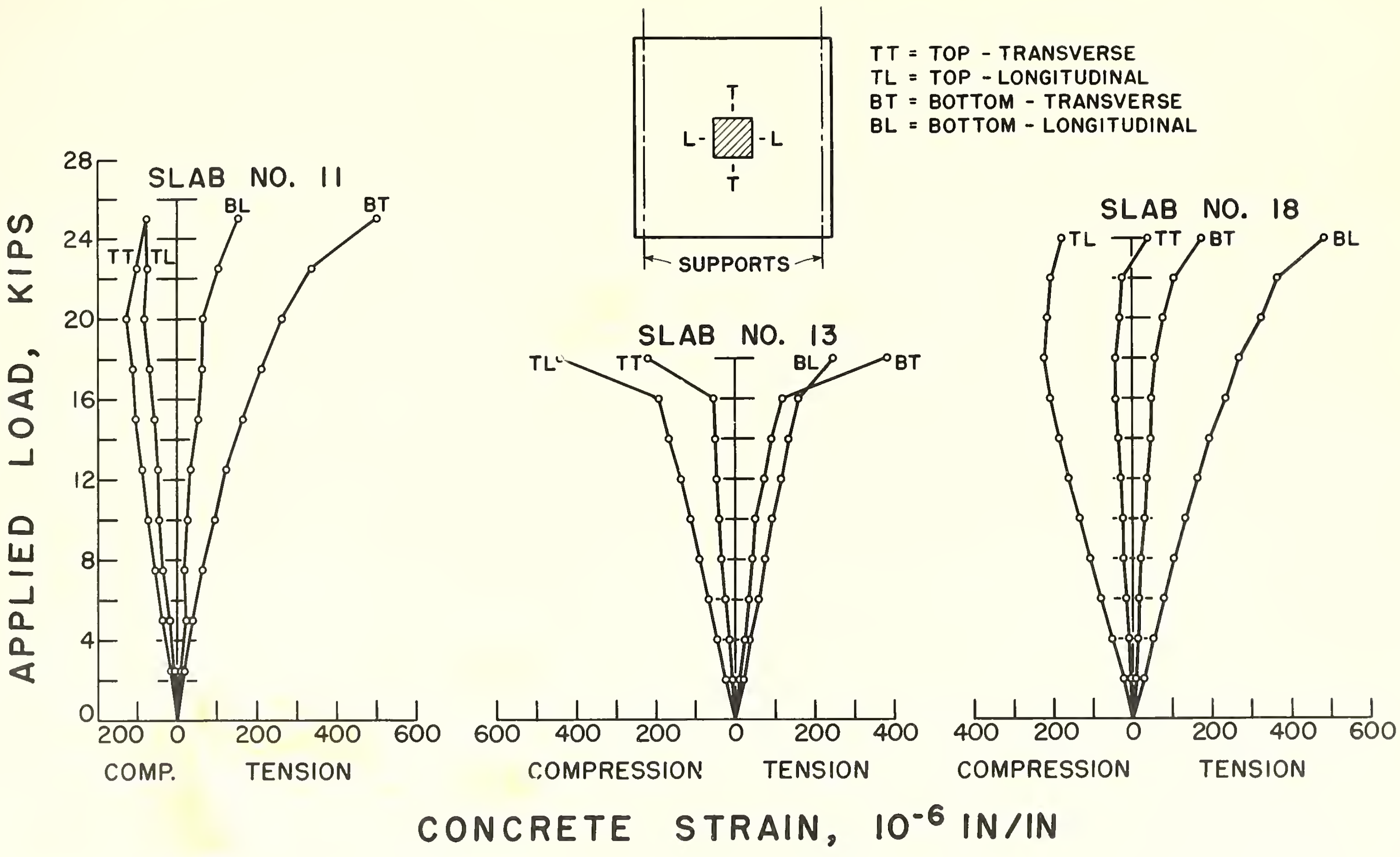


FIGURE 8. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN. (BONDED WITH NEAT CEMENT)

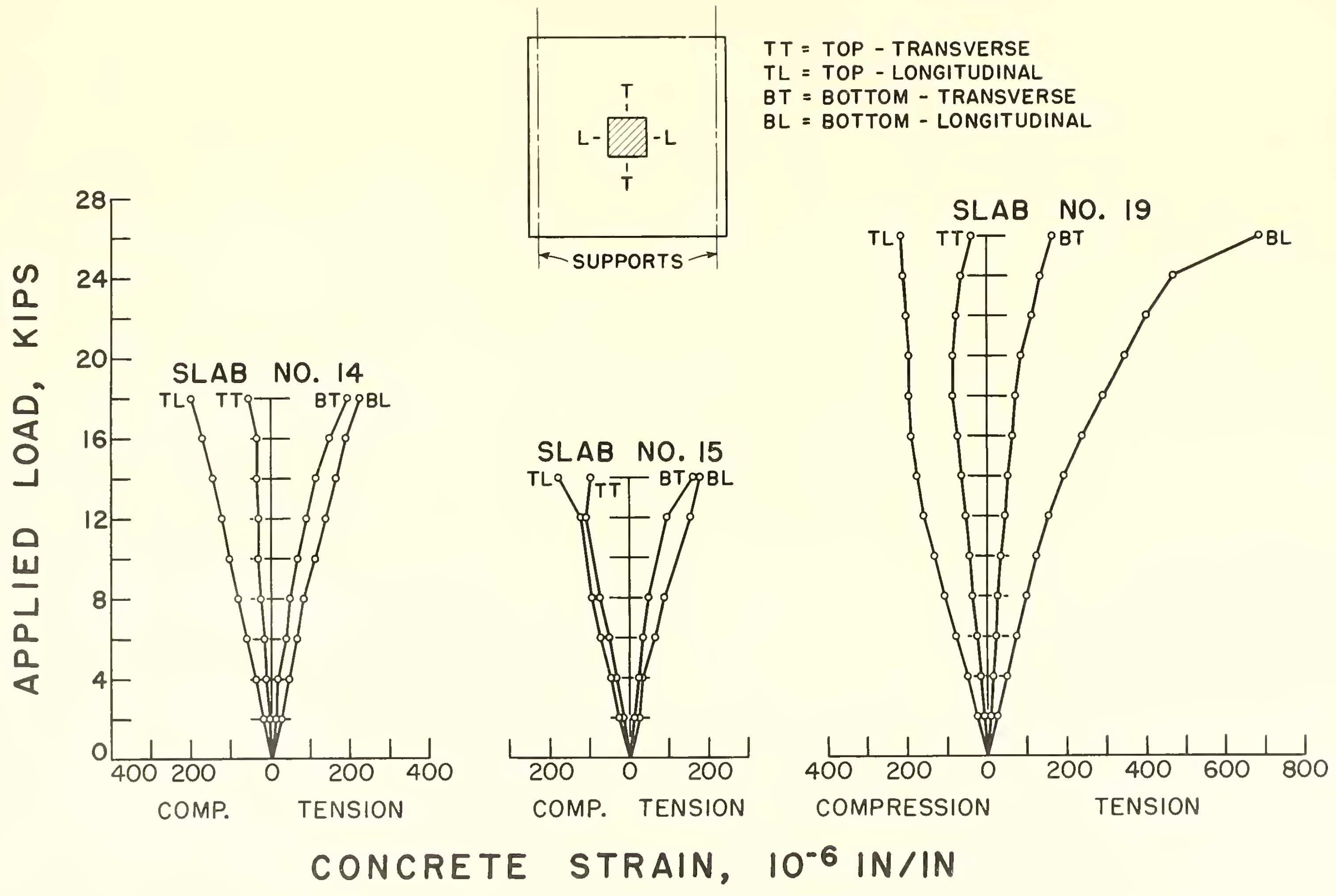


FIGURE 9. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN.
(BONDED WITH POLYESTER RESIN)

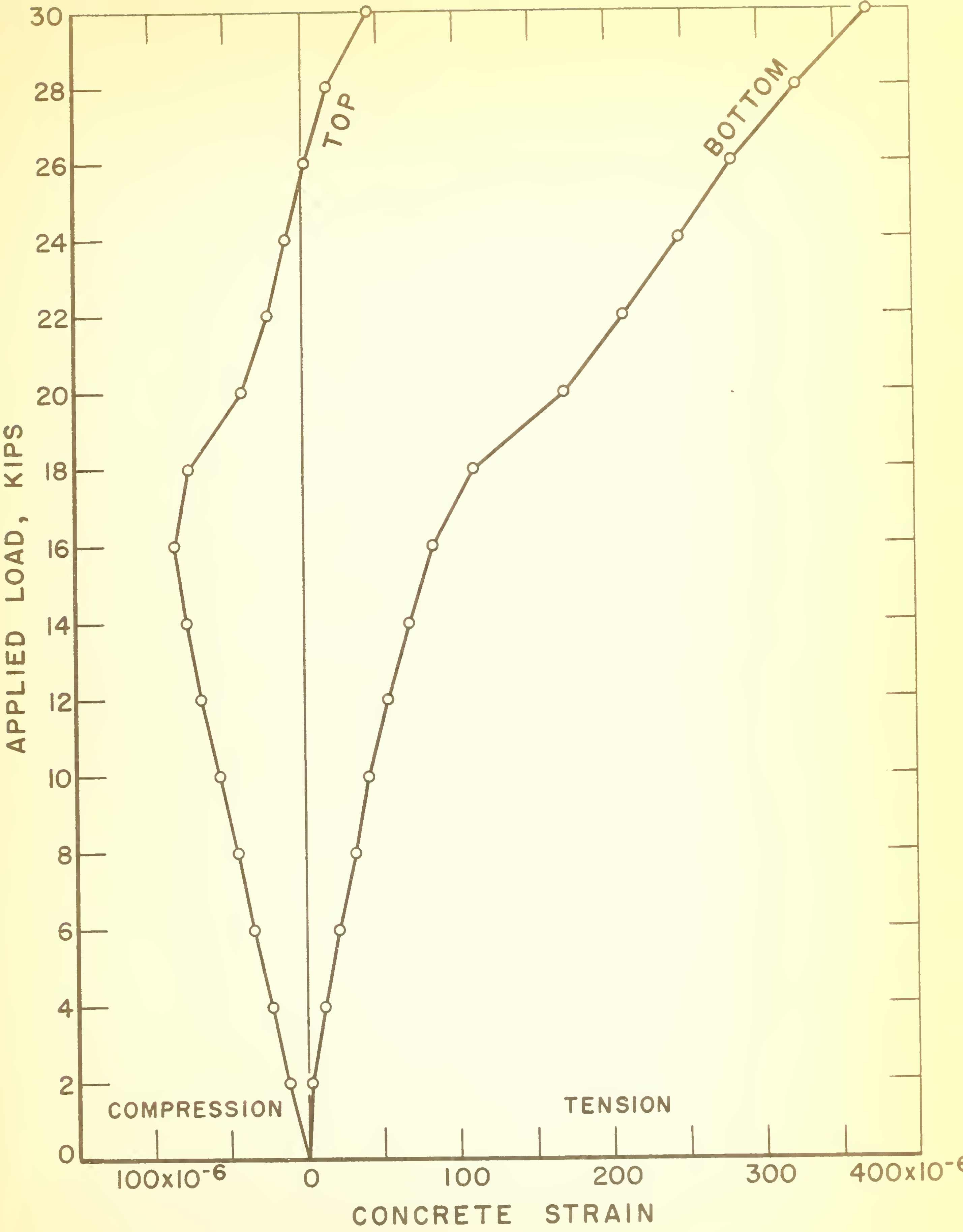


FIGURE 10. OBSERVED RELATIONSHIP BETWEEN APPLIED LOAD AND CONCRETE STRAIN. (BONDED WITH POLYESTER RESIN)

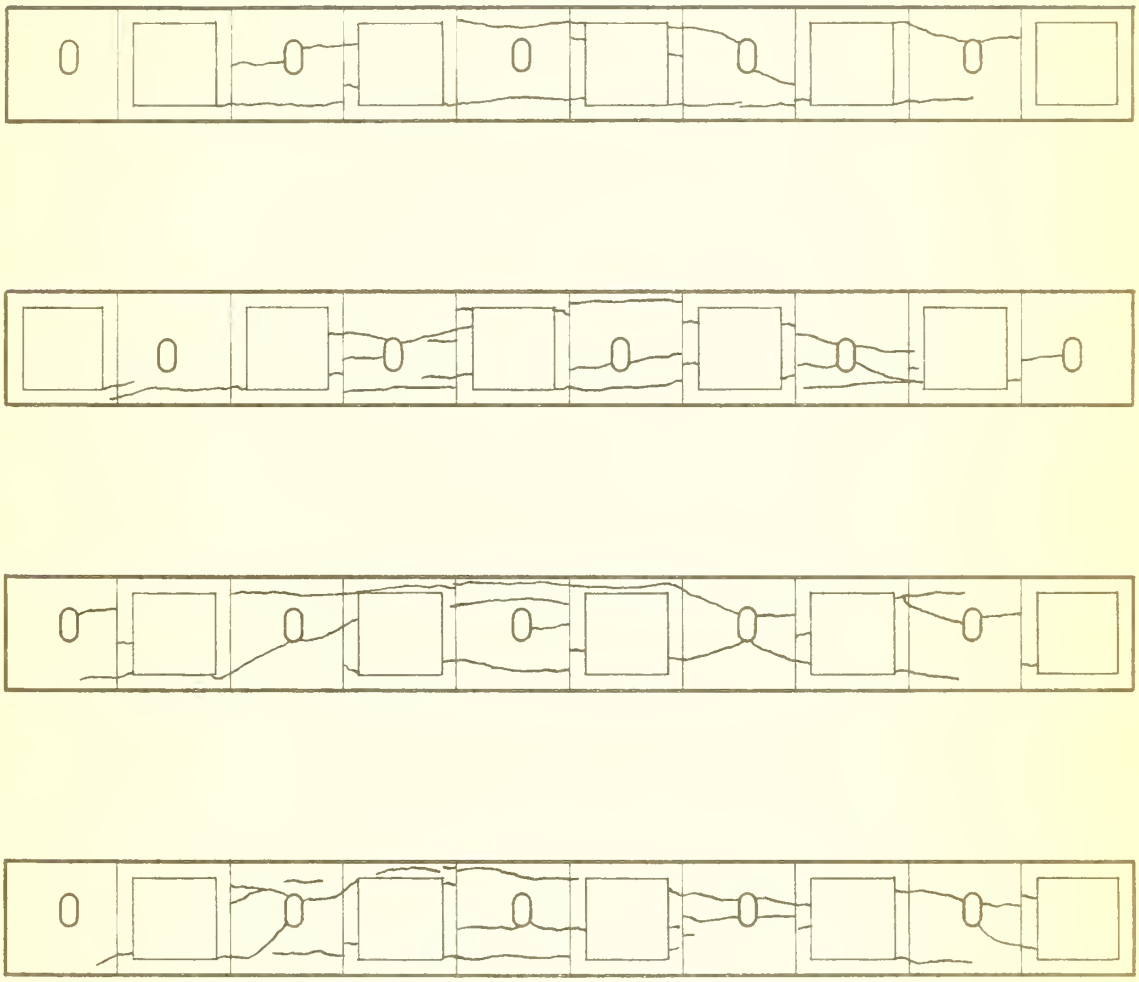


FIGURE 11. TYPICAL CRACK PATTERNS AT VARIOUS SECTIONS OF SLAB.

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. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS