NATIONAL BUREAU OF STANDARDS REPORT

6529

Flexural Tests of Prestressed Cellular Slabs
(Slabs F-3 and F-4)

by

Arthur F. Kirstein and Leopold F. Skoda

Report to
Bureau of Yards and Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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FLEXURAL TESTS OF PRESTRESSED CELLULAR SLABS
(Slabs F-3 and F-4)

Arthur F. Kirstein and Leopold F. Skoda

Two additonal specially designed specimens were constructed and subjected to pure bending following the completion of the investigation in which twenty nine 5- by 5-ft prestressed cellular slabs tested under concentrated loads (see NBS Report 6321). One slab was made of reinforced blocks and the other was made of unreinforced blocks. Both slabs contained epoxy resin joints and were prestressed to 1000 psi in both directions. Deflections, strains, crack patterns, and maximum bending moments were recorded. Since the cellular portions of the slabs were not subjected to shear, both slabs developed flexural failures as the top flanges of the blocks failed in compression.

1. INTRODUCTION

In previous tests carried out in the investigation of properties of prestressed cellular slabs, the specimens were 5- by 5-ft in size supported either on two or four edges and subjected to a concentrated load at the center. The information derived from these tests served as the basis for modification of the design of the cellular blocks and the method of jointing which resulted in substantial increases in the shear resistance of these slabs.

In the current phase of the study of these slabs, the object is to determine the flexural behavior of prestressed assemblies. The test results of two prestressed slabs subjected to pure bending are presented herein as a continuation of an investigation presented in NBS Report 5825. The results of this investigation are expected to serve as a basis for further improvements in this type of construction.

2. DESCRIPTION OF TEST SPECIMENS

2.1 Cellular Blocks

The cellular concrete blocks used in this investigation were the regular reinforced and unreinforced NBS blocks. They were hollow 6-in. cubes having an opening 4.5- by 4.5-in. in cross section with a 1- by 2-in. elliptical access hole in each web to permit the passage of the prestressing tendon. Both the reinforced and unreinforced block had the same principal dimensions which are shown in figure 1.

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 for a considerably longer period of time and then placed in dry storage before they were assembled into slabs. Therefore, the compressive strength of the concrete in the individual units might have been 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 the slabs. 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 120,000 psi as determined by the 0.2 percent offset method and the tensile strength was 133,000 psi. Although "Elastuff" bars are made of the cold-worked high carbon steel, they are fairly ductile and can be machined easily.

2.3 Description of Prestressed Slabs

There were two slabs tested in this investigation. The nominal dimensions of the portion of Slab F-3 which was in pure bending were 2-ft by 5-ft by 6-in. This portion of the slab contained 40 reinforced blocks. The nominal dimensions of the similar portion of Slab F-4 were 5-ft by 5-ft by 6-in. This portion of Slab F-4 contained 100 unreinforced blocks. The blocks in both slabs were arranged in a crisscross pattern so that the axis through the open ends of one block was perpendicular to the axis of each adjacent block. The holes in the webs of the blocks were arranged to permit the longitudinal prestressing tendons to be located along the mid-plane of the slab, and the transverse tendons were staggered above and below the mid-plane. Thus, the resultant prestressing forces produced an axial compression of 1000 psi in two directions through the slabs.

Epoxy resin was used as jointing material in both slabs. This adhesive was made of a mix of 100 parts Epon 828, 8 parts diethylenetriamine, and 5 parts Cab-o-sil, by weight. 1/

1/ Epon 828 is an epoxy resin that cures at room temperature; diethylenetriamine is the curing agent for the epoxy resin, and Cab-o-sil is a finely divided silica filler.

Both slabs were equipped with solid concrete end spans in the longitudinal direction which resisted the shearing forces of the load and served as anchorage blocks. With the use of these end spans and the loading technique described later, it was possible to subject the test section of the specimen to pure flexure.

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 applied prestressing force. 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. Slab F-3 was simply supported by rockers that rested on the testing machine platen, and the loads were applied through a knife edge at one end of the test section and rollers at the other end. The loads were distributed across the ends of the concrete shear spans with stiffened I-beams. Figure 3 is a photograph of Slab F-3 and the test setup. Slab F-4 and the test setup are shown in figure 4. This slab was simply supported by I-beams that rested on the testing machine platen. In order to give the slab more freedom to rotate at the supports 1- by 1-in. aluminum bars were placed between the I-beam supports and the concrete end spans. The loads were applied through 12- by 12- by 6-in. concrete blocks which were arranged as shown (Fig. 4). All surfaces bearing on the test specimens were firmly set in high strength plaster to ensure intimate contact.

3.2 Instrumentation

The deflection measurements of Slab F-3 were made with 0.001-in. micrometer dial gages attached to steel angles resting on the slab directly over the joints between the test section and the end shear spans. Thus, the datum plane was located on the top surface of the specimen and at the ends of the test section. Figures 3 and 5 show the symmetrical arrangement of these gages. The deflections of Slab F-4 were also measured with 0.001-in. micrometer dial gages which were attached to steel angles. These angles were supported on the top surface

of the specimen directly over the supports. Thus, the datum plane for Slab F-4 was located at the supports. This method of support for the dial gages is shown in figure 4 and the symmetrical arrangement of these gages is shown in figures 4 and 6.

The strains in the concrete on the top and bottom surfaces of the slabs were measured with bonded wire strain gages of the AR-1 and A-3 types. The locations of these gages are shown in figures 5 and 6.

Bonded wire strain gages of the A-3 type were placed at the center of the two outer prestressing tendons of both slabs to measure the strains in the steel due to the applied load.

3.3 Test Procedure

Slab F-3 was loaded as shown in figure 3. The load was applied in increments of 1,000 lb, and gage readings were made for each increment until the maximum load was reached. Figure 4 shows how Slab F-4 was loaded. The load was applied in 2,000 lb increments up to 10,000 lb. Then increments of 5,000 lb were applied until failure. Gage readings were made for each increment of load.

4. TEST DATA

4.1 Deflections and Load-Carrying Capacities of Slabs

Slab F-3 carried a maximum applied load of 16,350 lb and Slab F-4 carried a maximum of 35,000 lb which correspond, respectively, to total bending moments, Mu, (including dead load) of 217.8 and 489.4 in-kips. During the tests, signs of distress were noted in both slabs at moments considerably below the maximum. At about 0.65 applied/ultimate moment, (141.6 in-kips), audible cracking took place in Slab F-3 which is indicated by the change of slope of the deflection curve in figure 7. Audible cracking in Slab F-4 occurred at a moment of 351.7 in-kips, but this is not indicated by the corresponding curve in figure 7 because the deflections exceeded the range of the dial gages.

The deflections along transveerse sections on Slab F-4 are shown in figure 8. The deflections presented in this figure are total deflections measured with respect to a datum plane through the supports.

4.2 Concrete and Steel Strains

The steel strains are plotted against the ratio of applied moment to ultimate moment for convenience in presenting the data from Slabs F-3 and F-4 on the same set of coordinate axes in figure 9. The open circles represent data from Slab F-3, and the solid circles represent data from Slab F-4.

The average concrete strains on the tensile and compressive faces of Slabs F-3 and F-4 at midspan are shown in figure 10. Again the open circle represent data from Slab F-3, and solid circle represent that of Slab F-4.

The longitudinal strains in concrete along transverse sections of Slab F-4 are presented in figure 11. A complete tabulation of the concrete strains measured in Slab F-4 is given in Table 1.

4.3 Mode of Failure

Both slabs failed in compression as did Slabs F-1 and F-2 (NBS Report 5825). The crack patterns in Slab F-3 are shown in figure 12. The shaded and missing portions of the blocks indicate the location of the compression failure. When Slab F-4 was dismantled after testing, most of the block fell apart. Therefore, no crack patterns could be presented for this slab. However, a photograph of the compression failure of Slab F-4 is presented in figure 13.

5. DISCUSSION

When considering a slab subjected to concentrated loads, such as Slab F-4, it is expected that the slab will bend in the transverse direction as well as the longitudinal direction. Furthermore, it is expected that local depressions will be formed around the loaded area. The deflections presented in figure 8 and the strains presented in figure 11 do not appear to bear this out. However, when the rigidity of the solid concrete end spans is considered, these findings are not unexpected.

Audible cracking, having occurred at 24,200 lb, can explain the erratic behavior of this slab at higher loads. The photograph of the compression failure in the area of sections 3-3 and c-c will also explain these erratic deflections and strains. Figures 9 and 10 show marked changes in the slopes of the curves representing steel and concrete strains, respectively, after the cracking occurred. As pointed out before, figure 7 also indicates this change of slope in the deflection curve for Slab F-3.

The crack patterns of Slabs F-1 and F-2 (presented in NBS Report 5825) were more widespread than the crack patterns of Slab F-3. Limited crack formation in Slab F-3 is due to the use of welded wire fabric as web reinforcement. Since the unreinforced blocks of Slab F-4 fell apart when the slab was dismantled, no crack patterns could be presented.

6. SUMMARY

The preceding work can be summarized as follows:

1. Both slabs exhibited abrupt compression failures of the compressive flanges of the concrete blocks.

2. Since the solid concrete end spans of Slab F-4 were very rigid compared to the test span, no measurable transverse bending due to the concentrated loading technique was observed.

3. Both slabs showed signs of distress in the form of cracking prior to the final compression failure. The formation of cracks in the slabs caused large increases in steel strains, concrete strains, and deflections at approximately two thirds of the ultimate moment for Slab F-3 and three fourths of the ultimate moment for Slab F-4.

Table 1. Concrete Strain in Slab F-4

Gage	Load, lb 2,000	4,000	6,000	8,000	10,000	15,000	20,000	25,000	30,000
101	2	5	9	14	19	27	36	47	99
201	-3	-7	-8	-12	-15	-27	-37	-44	-27
102	-10	-19	-27	-39	-49	-71	-100	-147	-215
202	5	10	20	30	38	57	69	68	97
103	-24	-46	-64	-86	-106	-153	-209	-282	-441
203	22	44	64	79	106	148	196	217	236
104	2	2	2	2	7	7	11	23	40
204	0	- 3	- 3	- 6	- 10	- 20	- 46	- 93	- 78
105	- 6	-15	-22	-35	- 45	- 70	- 99	-153	-224
205	6	13	20	31	41	61	78	56	61
106	-19	-38	-60	-80	-100	-146	-205	-285	-430
206	21	41	63	82	104	160	218	249	258
107	5	7	9	9	11	17	20	27	49
207	-3	- 9	-10	-10	- 14	- 21	- 29	- 31	- 37
108	-10	-22	-30	-43	- 53	- 83	-119	-155	-263
208	9	13	24	36	42	61	83	99	93
109	-21	-45	-67	-90	-113	-172	-236	-301	-543
209	22	41	64	86	108	158	212	253	258
110	- 2	- 2	- 3	- 4	- 4	- 10	- 10	- 9	- 17
210	1	- 4	- 3	- 1	- 4	- 6	- 14	- 24	- 36
111	-10	-20	-29	-47	- 57	-93	-132	-180	-294
211	9	15	23	40	52	77	104	125	122
112	-24	-45	-67	-90	-114	-171	-232	-294	-504
212	22	41	63	89	112	165	223	266	269
113	- 3	- 6	- 7	-11	- 15	- 22	- 31	- 39	- 46
213	4	4	8	14	16	22	24	21	19
114	-10	-24	-35	-54	- 72	-112	-158	-202	-323
214	12	19	31	50	66	99	134	137	153
115	-23	-50	-74	-96	-125	-191	-253	-310	-513
215	24	42	66	91	114	169	227	226	243

Table 1. Concrete Strain in Slab F-4 (Continued)

	Load, lb								
Gage	2,000	4,000	6,000	8,000	10,000	15,000	20,000	25,000	30,000
116	-16	-38	-53	-72	- 93	-141	-196	-270	-377
216	23	37	58	85	106	158	204	213	263
117	-18	-39	-55	-75	- 98	-140	-201	-273	-428
217	14	28	46	66	81	116	139	140	152
118	-29	-44	-62	-84	-106	-164	-223	-286	-533
218	22	41	65	91	113	173	235	274	265
119	-19	-41	-58	-79	-100	-151	-211	-281	-512
219	21	38	60	83	105	161	223	270	269
120	-24	-48	-70	-98	-118	-179	-246	-315	-587
220	20	45	64	91	110	170	236	288	329
121	-19	-44	-65	-86	-106	-165	-226	-292	-506
221	21	41	61	88	107	163	221	264	260
122	-21	-42	-69	-91	-115	-176	-238	-300	-480
222	27	54	73	100	127	187	250	279	309
123	-21	-45	-65	-89	-111	-165	-221	-282	-500
223	28	44	66	88	112	166	226	265	279
124	-21	-44	-67	-90	-111	-169	-228	-289	-524
224	22	40	62	84	108	159	220	261	286
125	-21	-43	-64	-88	-110	-167	-221	-281	-916
225	20	40	61	89	110	165	227	275	256
126	-21	-47	-70	-91	-119	-179	-247	-321	-1059
226	28	49	71	99	124	184	251	300	216
127	-18	-40	-60	-74	- 98	-147	-203	-262	-682
227	20	45	60	87	112	165	227	262	196
128	-21	-41	-62	-82	-107	-162	-227	-290	-741
228	20	41	63	91	117	173	240	290	158
129	-22	-45	-68	-92	-116	-180	-244	-303	-953
229	20	39	59	81	102	153	209	250	123
Avg. Top	-21	-43	-65	-85	-110	-167	-228	-291	-870
Avg. Bottom	22	43	63	89	113	168	231	275	190

Compressive strain indicated by minus sign (-).

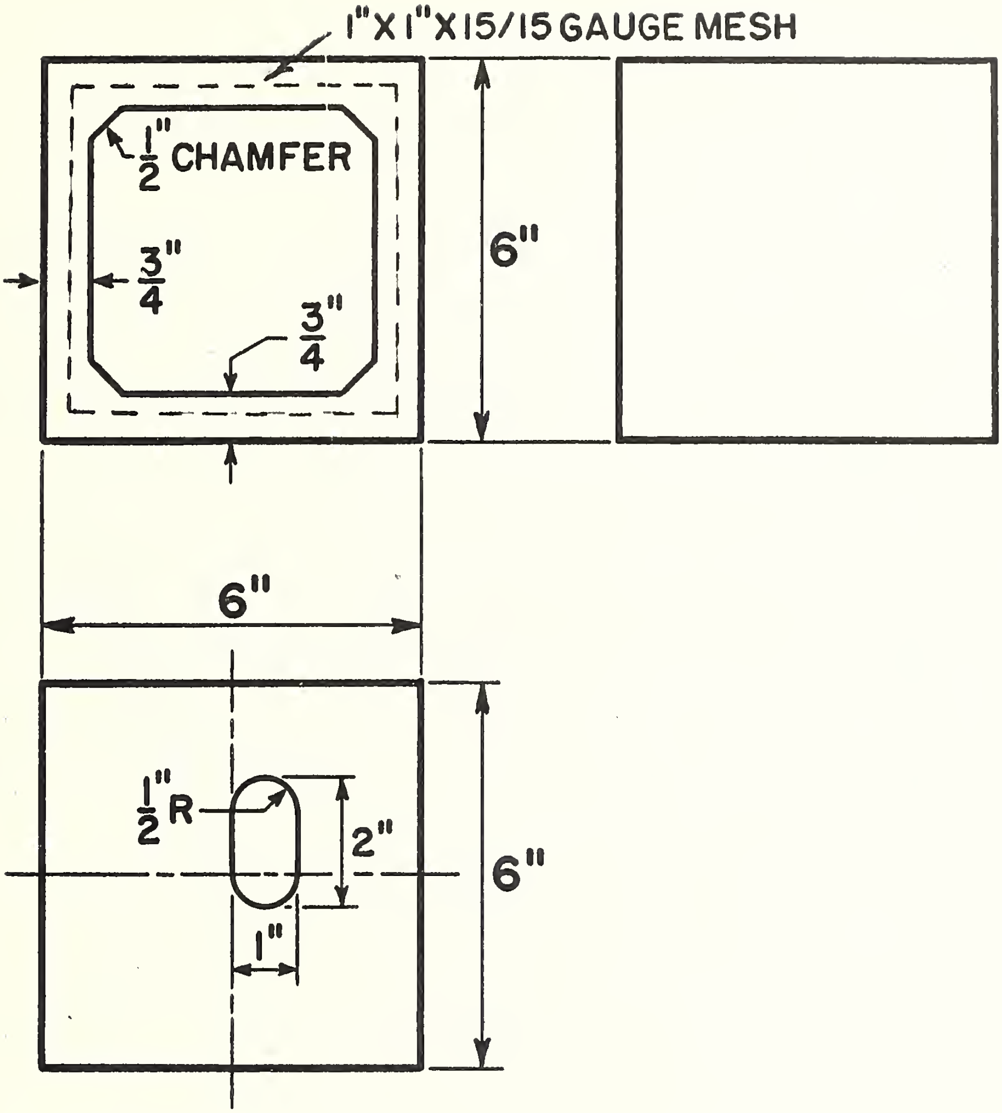


FIG. 1 - NOMINAL DIMENSIONS OF NBS REINFORCED BLOCKS.

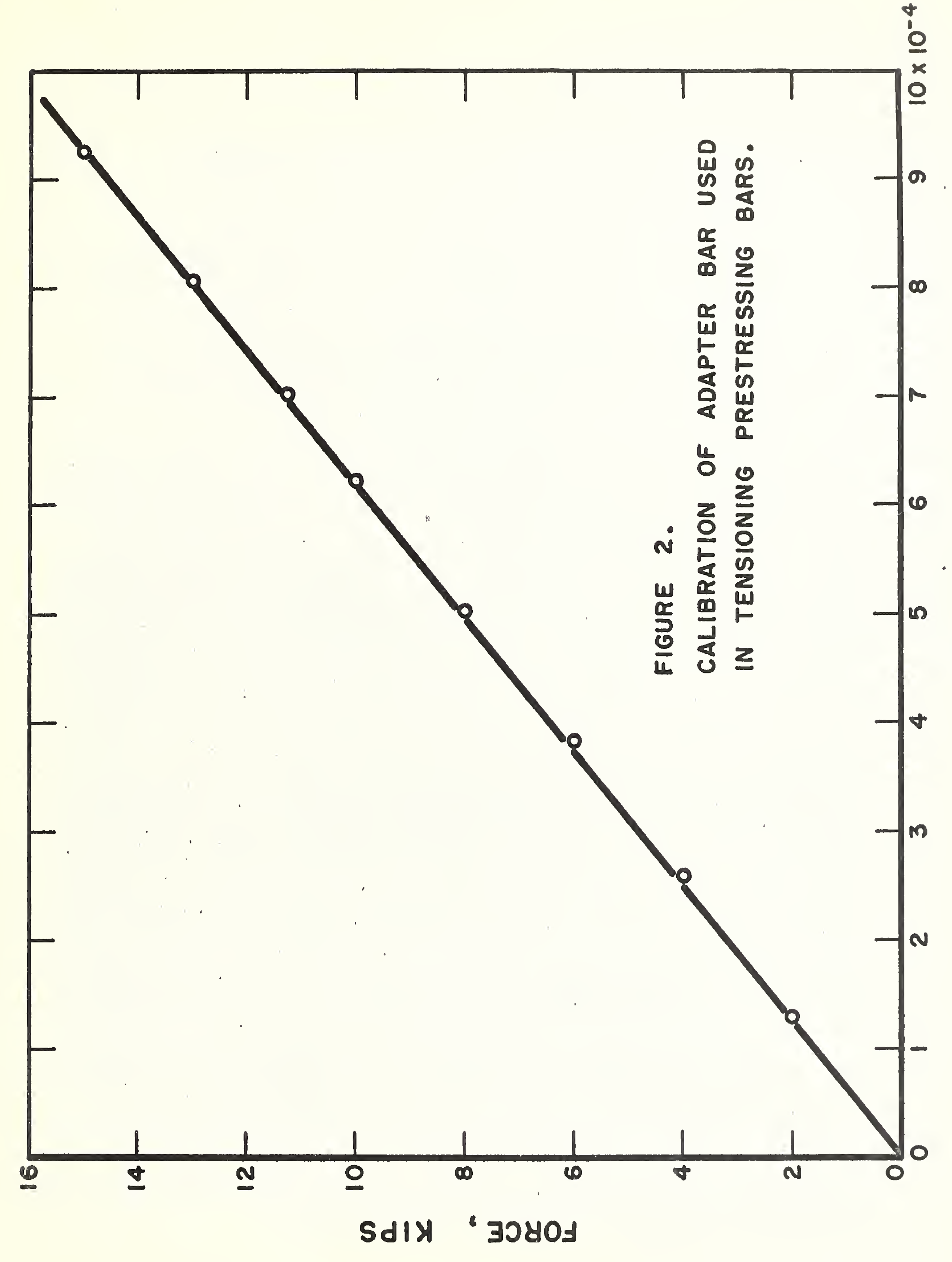
 FIGURE 2.
CALIBRATION OF ADAPTER BAR USED
IN TENSIONING PRESTRESSING BARS.

FIGURE 2.

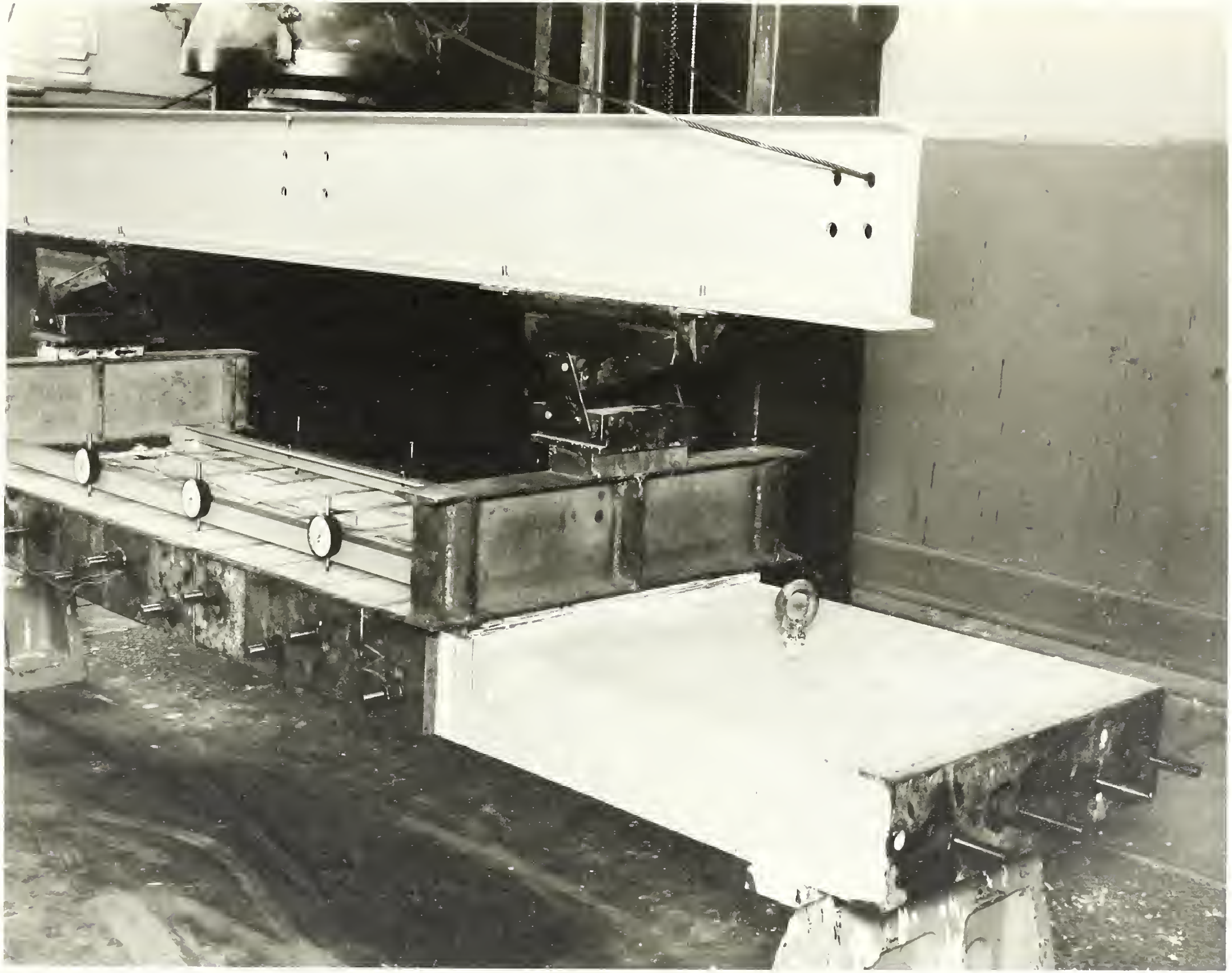


FIGURE 3. PHOTOGRAPH OF SPECIMEN AND TEST SETUP. (SLAB F-3)

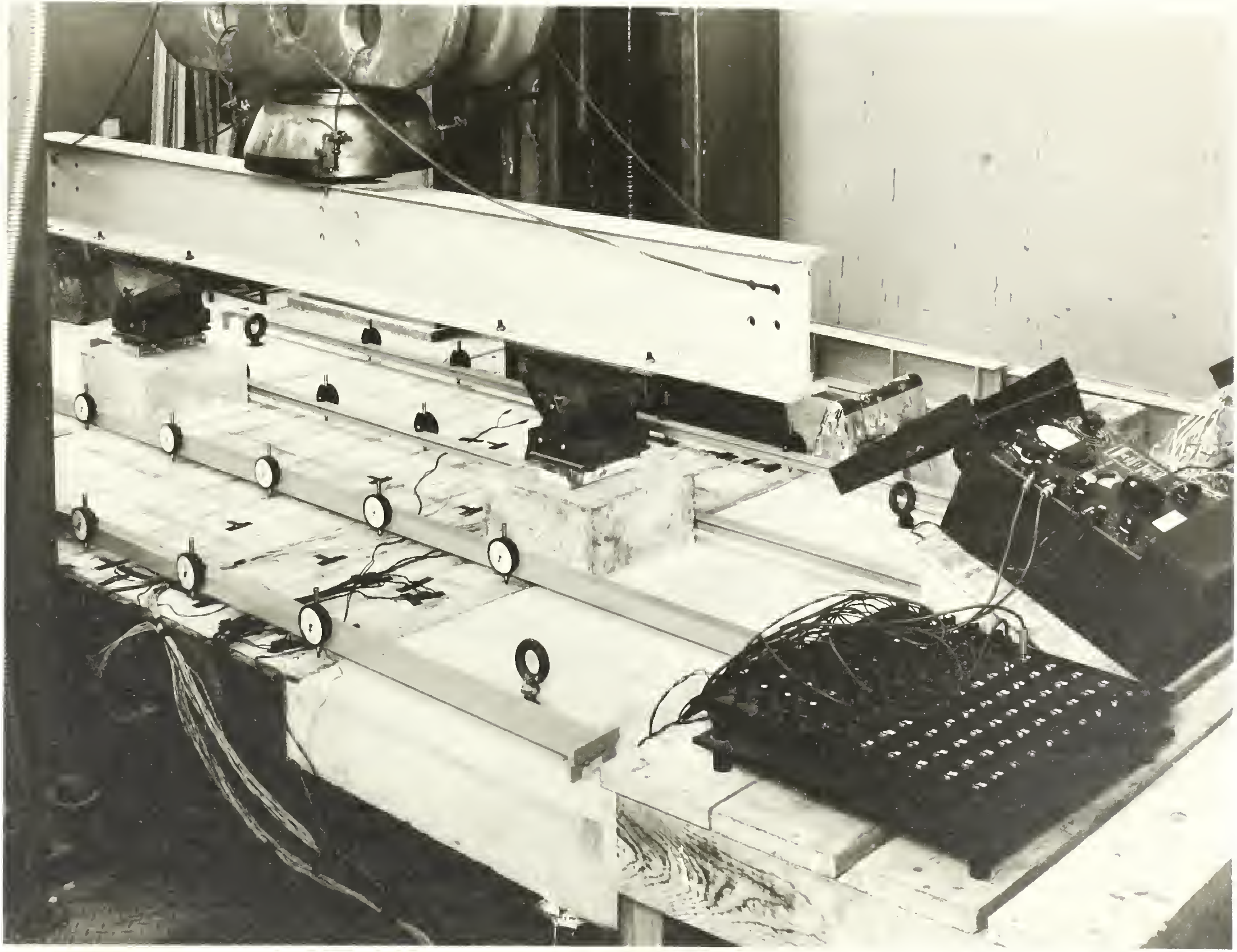
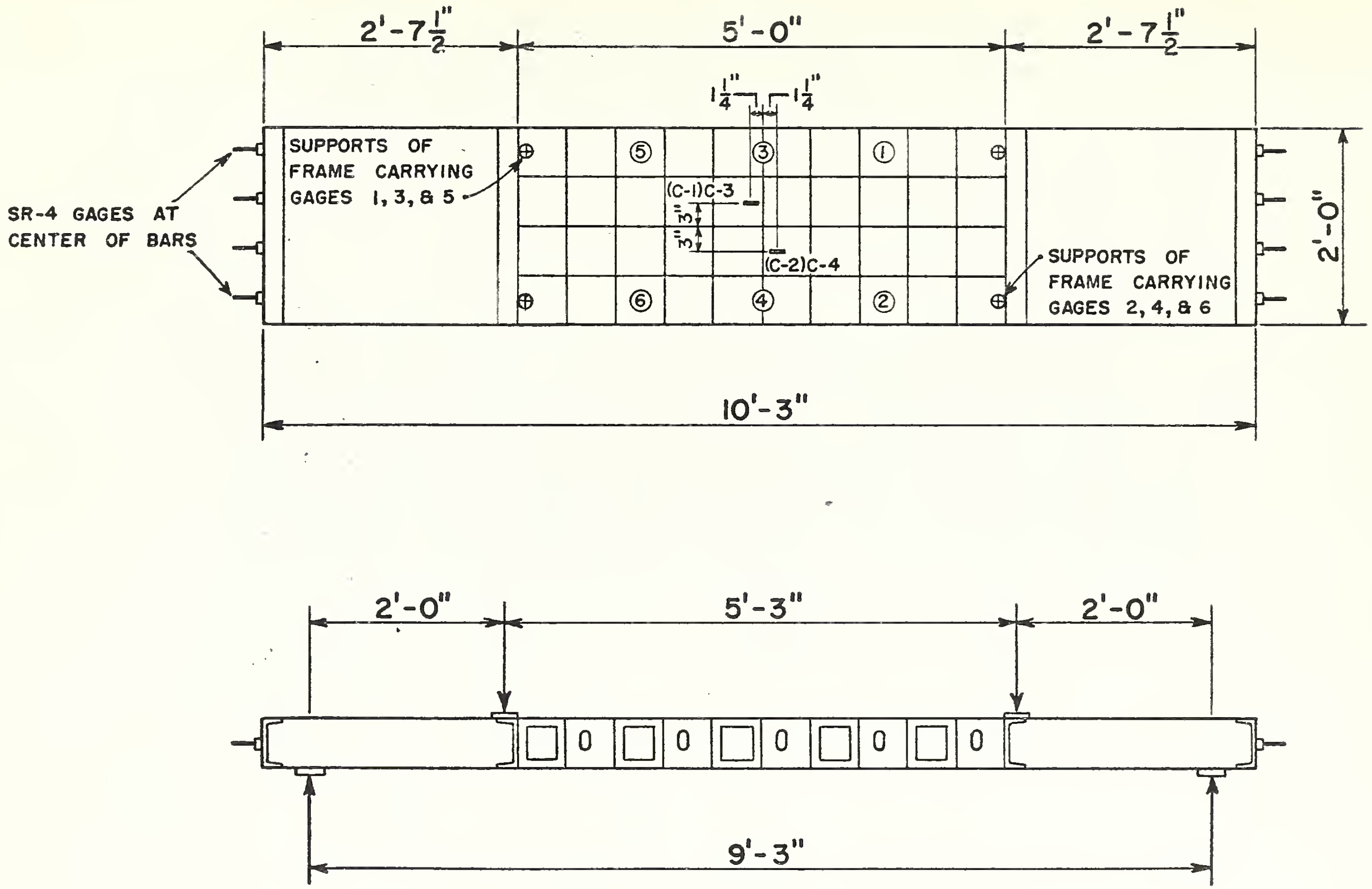
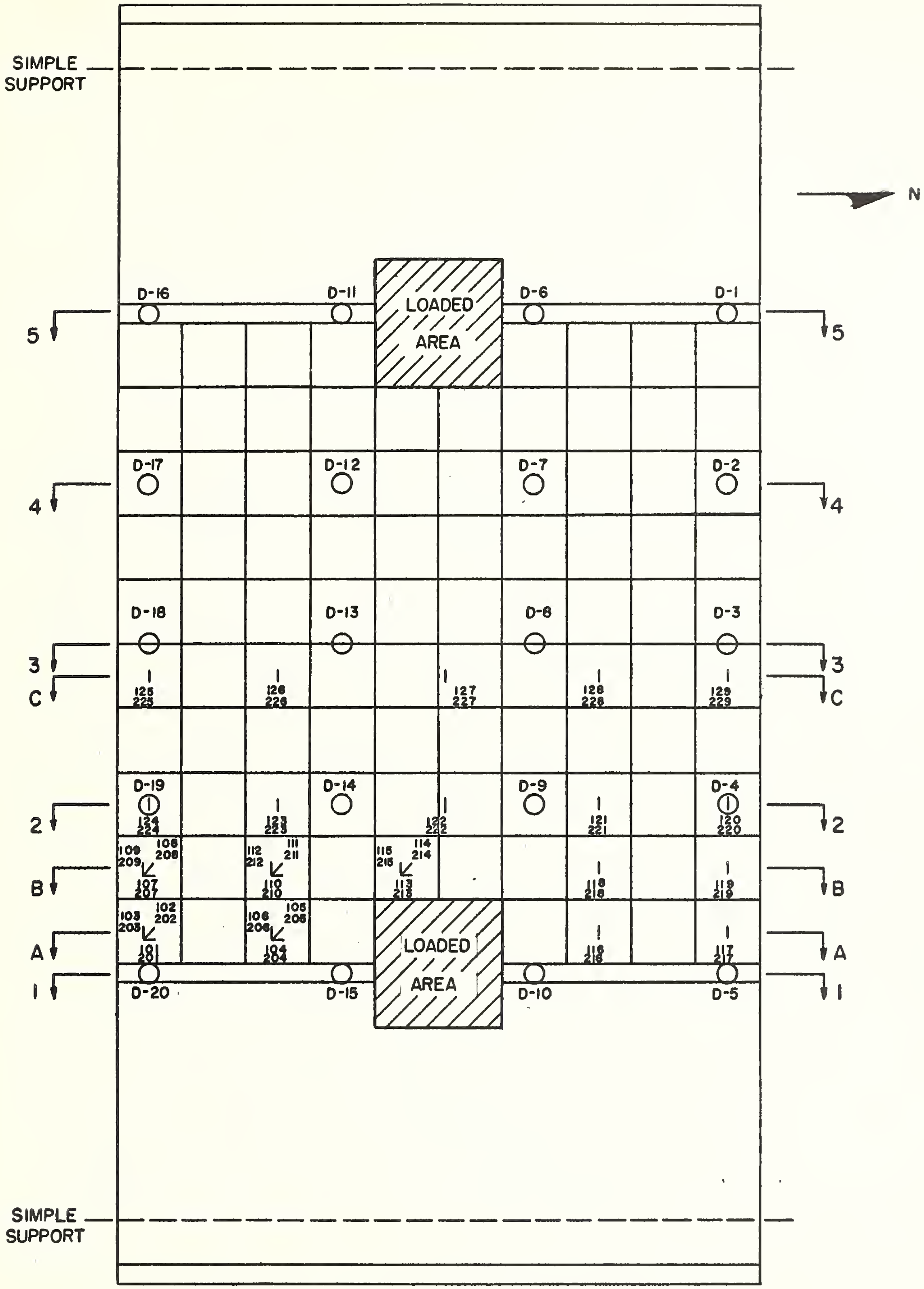


FIGURE 4. TEST SETUP FOR SLAB F-4.



DIAL GAGES 1 THRU 6 (DEFLECTION)
SR-4 GAGES C-1 AND 2 CONCRETE STRAIN (BOTTOM)
SR-4 GAGES C-3 AND 4 CONCRETE STRAIN (TOP)

FIGURE 5. INSTRUMENTATION AND LOADING DIAGRAM OF SLAB F-3.



No. 100 SERIES STRAIN GAGES TOP SURFACE
No. 200 SERIES STRAIN GAGES BOTTOM SURFACE
GAGES D-1 THRU D-20 DEFLECTION

FIGURE 6 INSTRUMENTATION DIAGRAM OF SLAB F-4

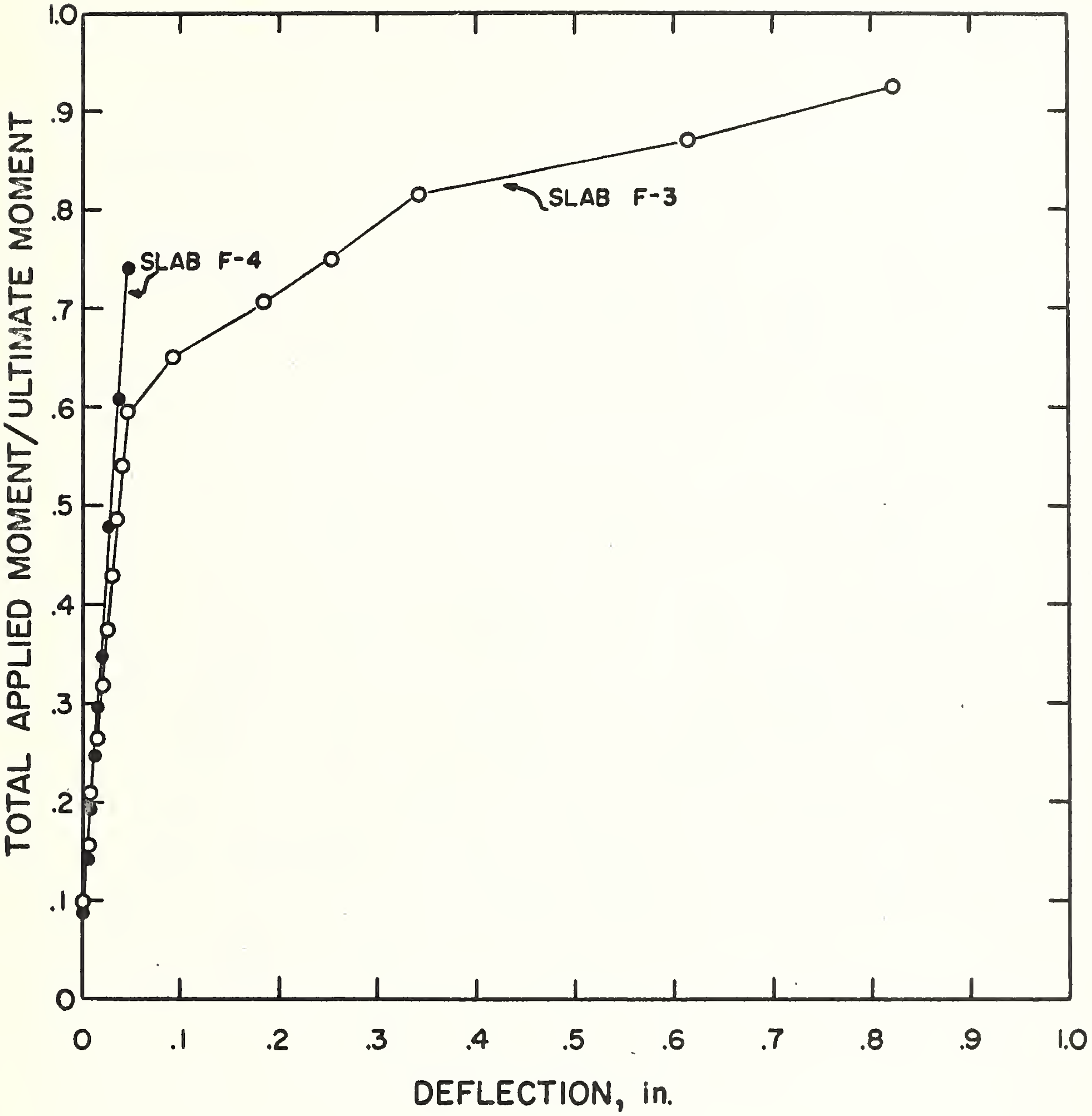
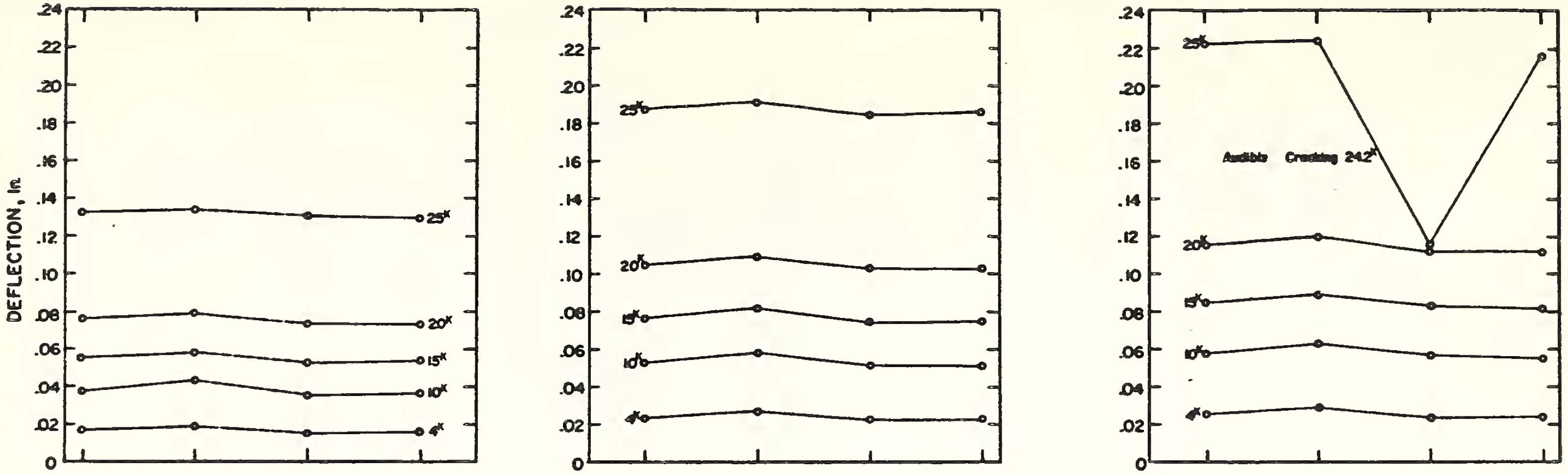


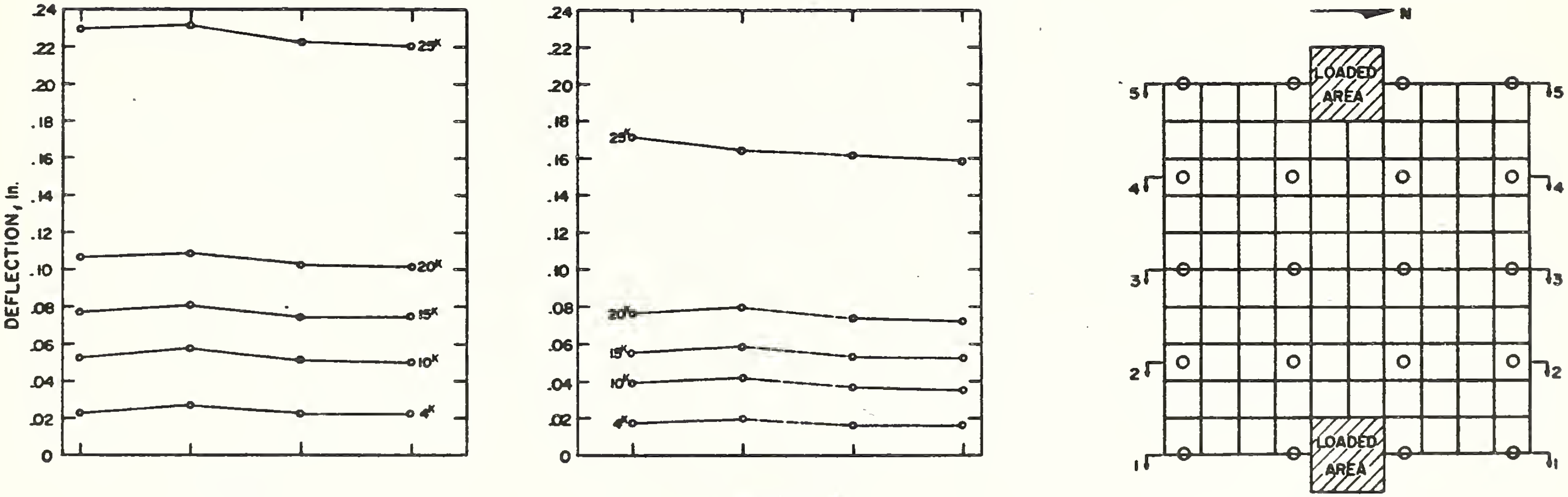
FIGURE 7. CENTERLINE DEFLECTIONS OF SLABS F-3 AND F-4 IN CONSTANT MOMENT SPAN.



SECTION 1-1

SECTION 2-2

SECTION 3-3



SECTION 4-4

SECTION 5-5

GAGE POSITIONS

FIGURE 8. DEFLECTIONS ALONG TRANSVERSE SECTIONS ON SLAB F-4

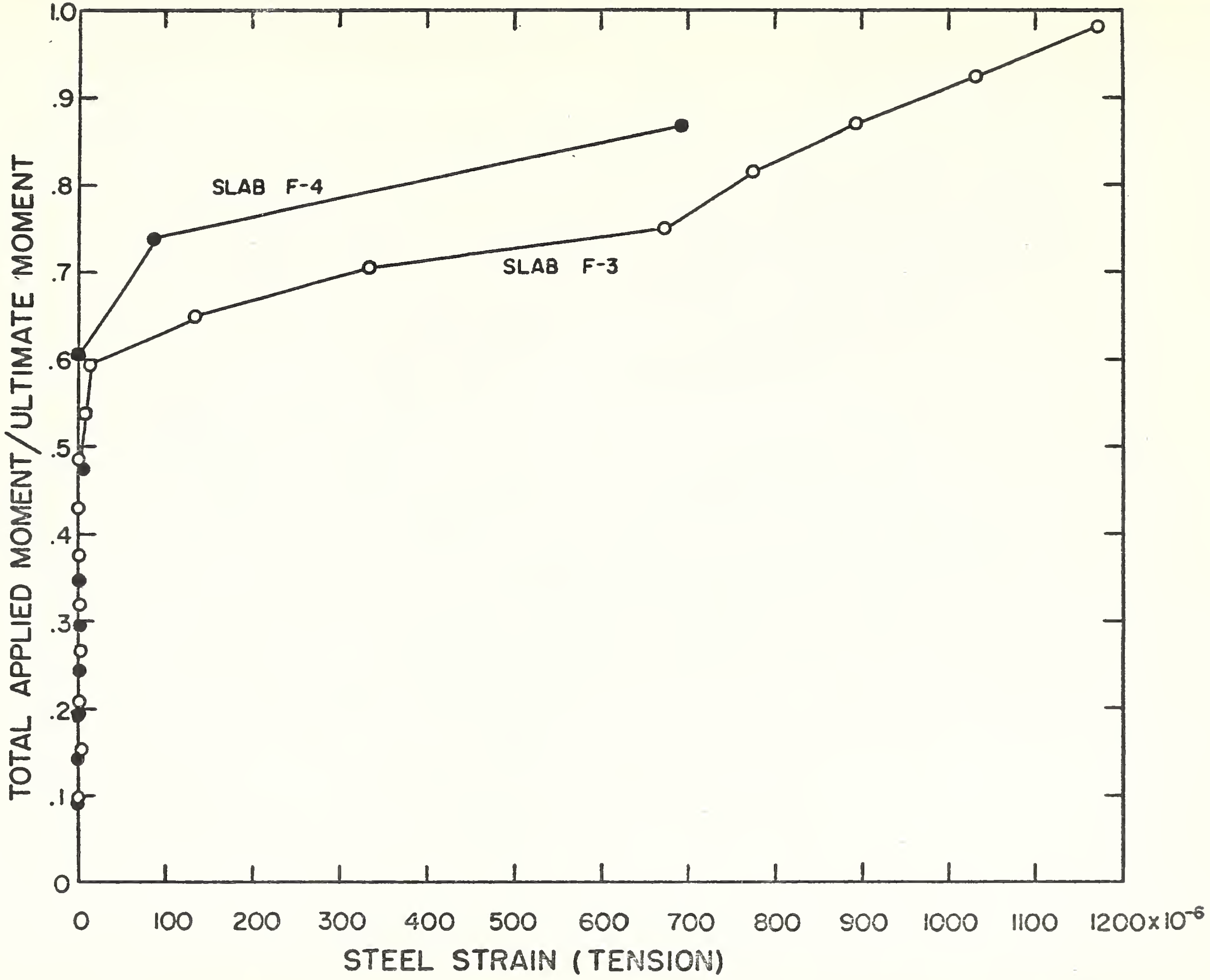


FIGURE 9. LOAD INDUCED STRAIN IN STEEL OF SLABS F-3 AND F-4

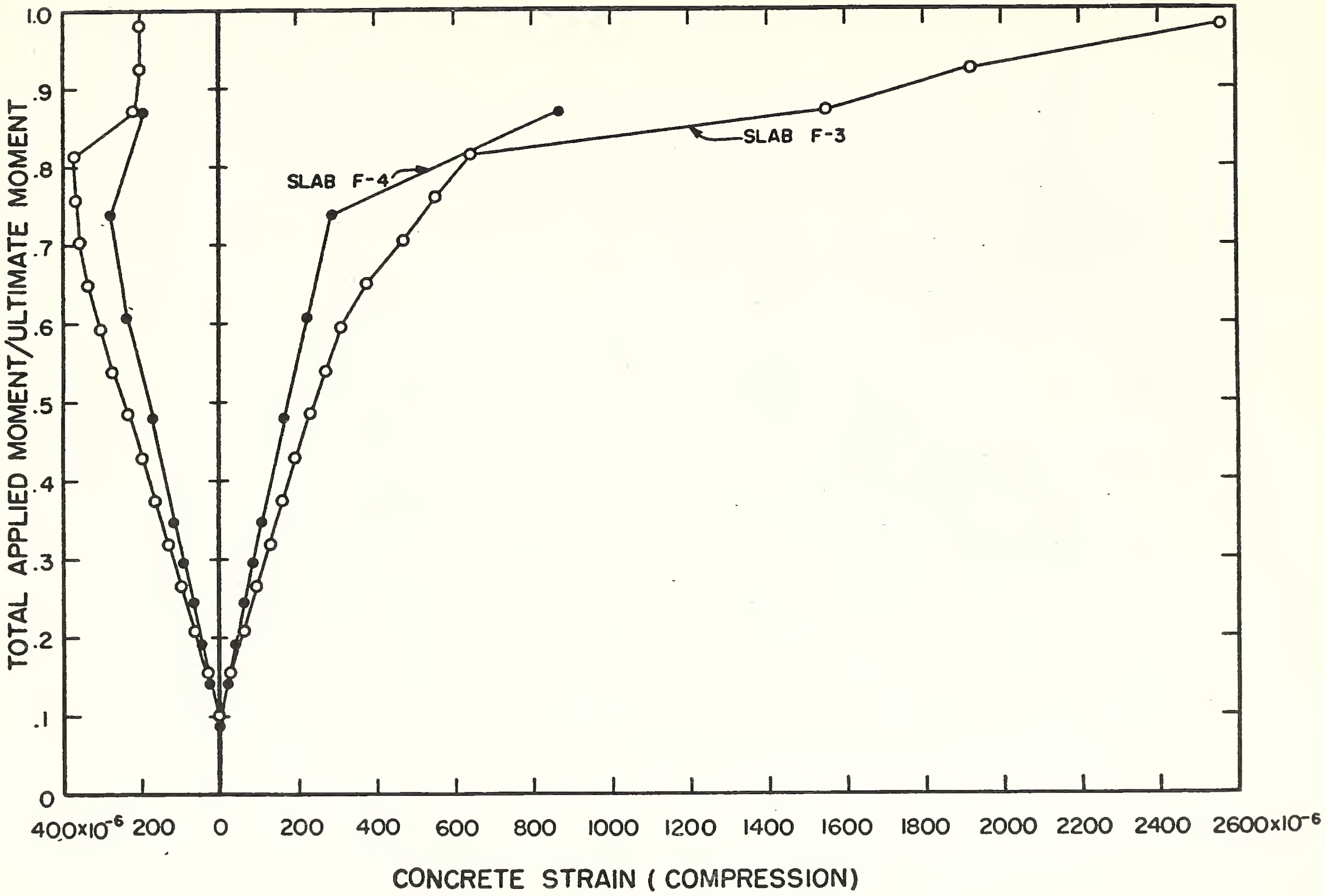


FIGURE 10 STRAIN IN CONCRETE AT MIDSPAN OF SLABS F-3 AND F-4

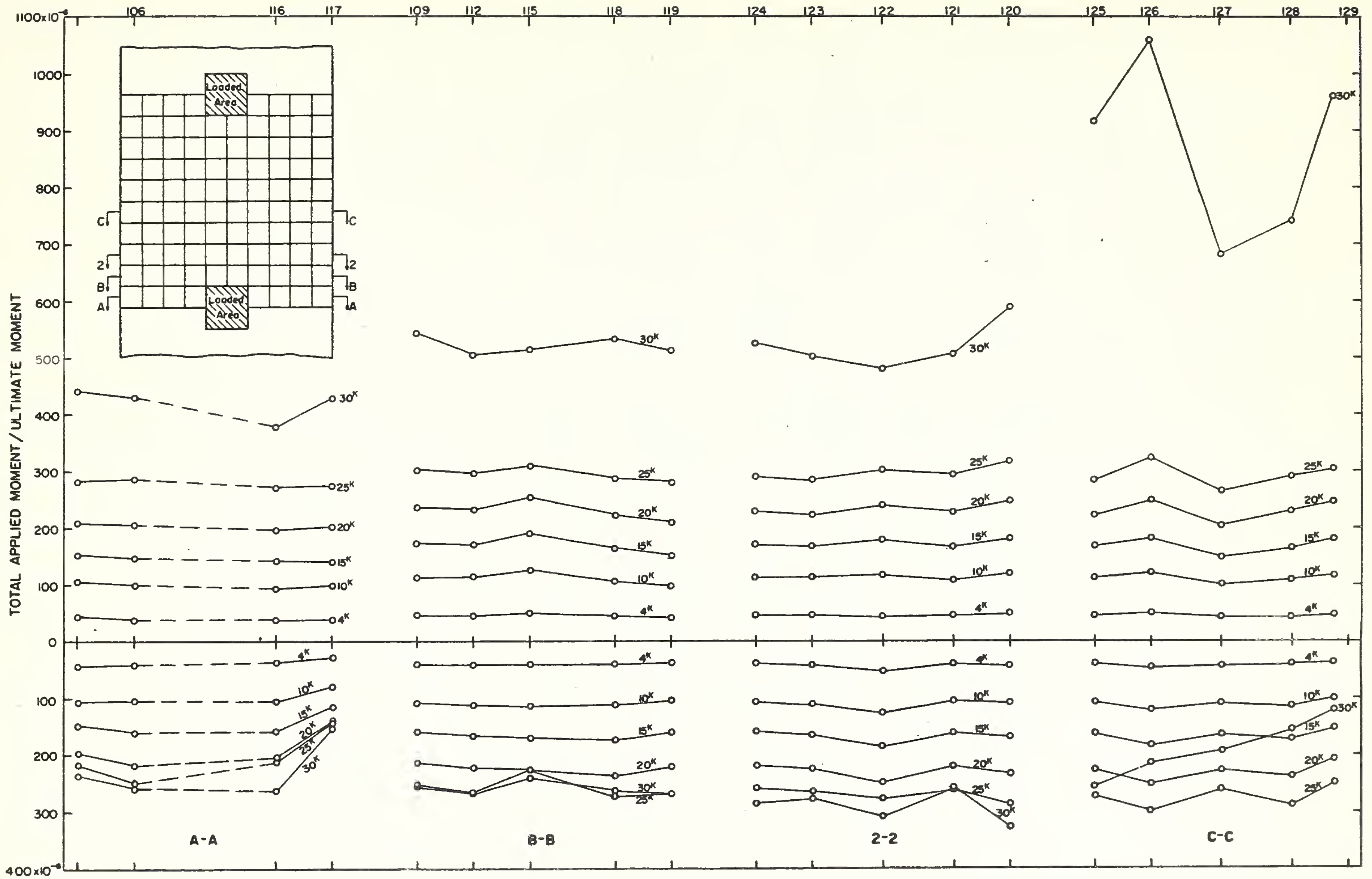


FIGURE 11. LONGITUDINAL STRAINS IN CONCRETE ALONG TRANSVERSE SECTIONS ON SLAB F-4

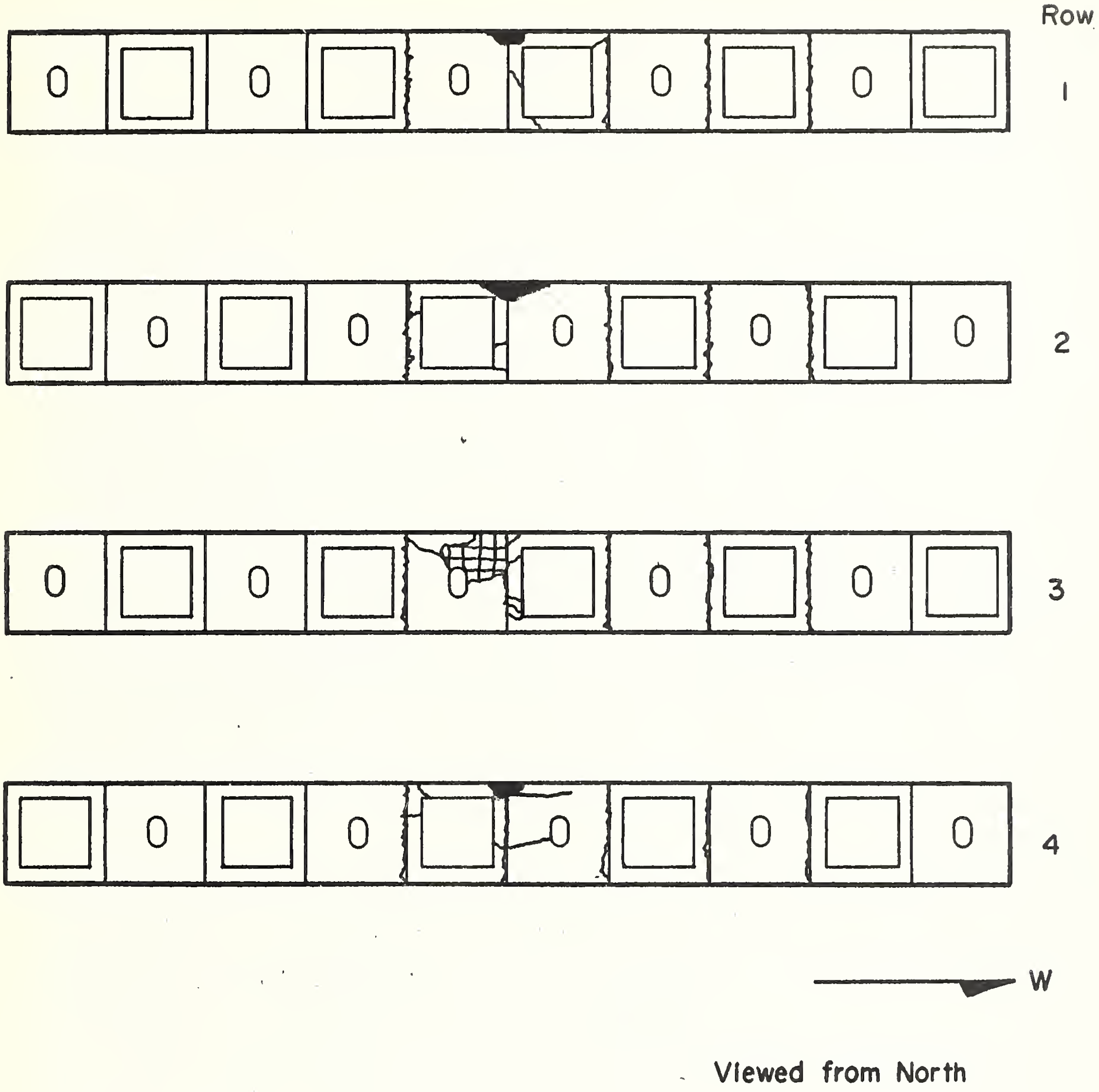


FIGURE 12 CRACK PATTERNS SLAB F-3

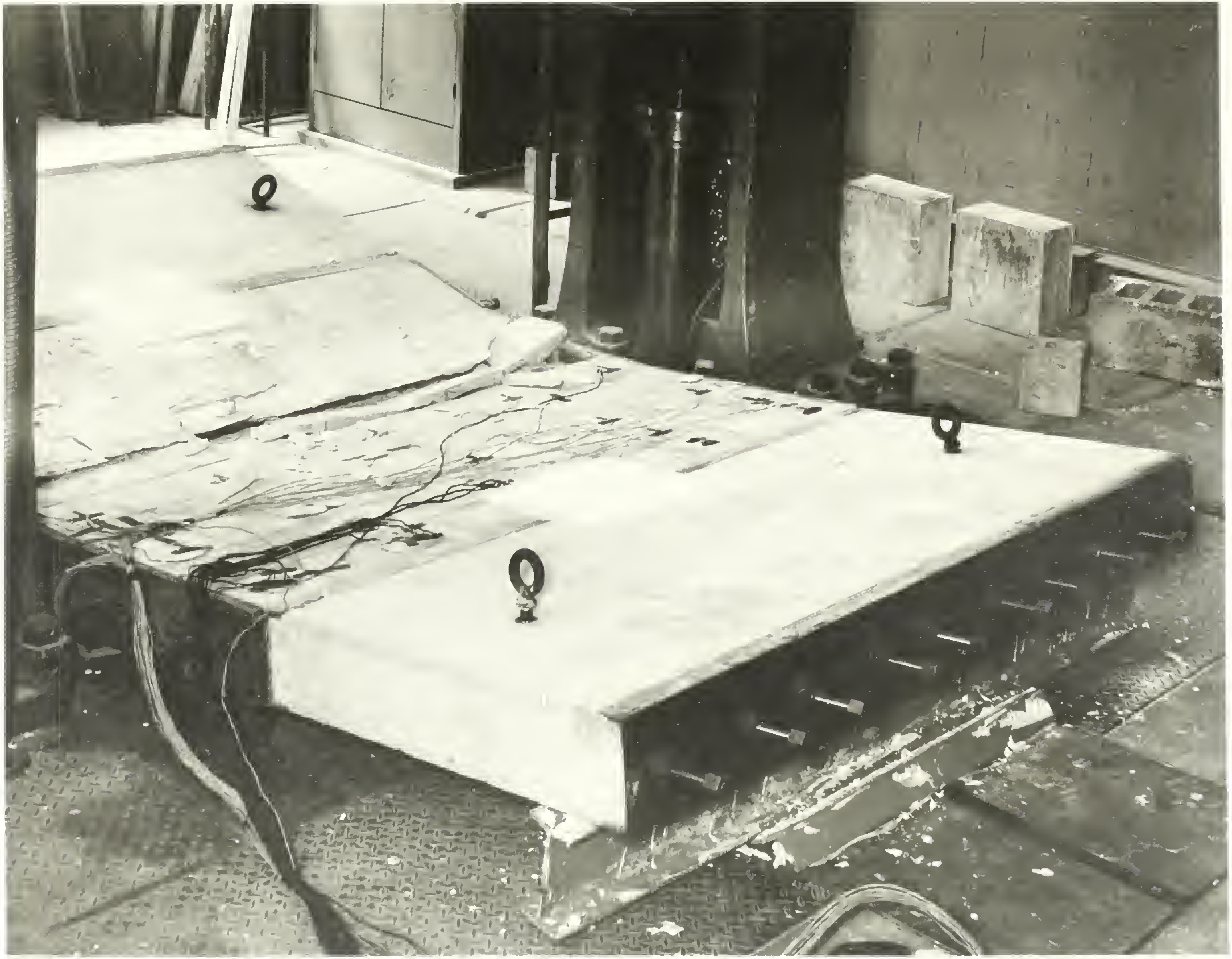


FIGURE 13. COMPRESSIVE FAILURE OF SLAB F-4.

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Frederick H. Mueller, Secretary
NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

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