COMPRESSIVE TESTS OF JOINTED H-SECTION STEEL COLUMNS

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ABSTRACT

Jointed steel columns consisting of various combinations of 10-inch, 12-inch, and 14-inch rolled steel H-sections, were tested in compression. Some of the tests were made with the axes of the columns in line and the others with the outer faces of both upper and lower columns in the same plane. Each combination of H-sections and column arrangement was tested with five bearing plates ranging in thickness from 1 inch to 4¼ inches using "low loads" giving an average stress not exceeding 8,500 lbs./in.^{2} in the smaller (upper) column. Tests to failure and repeated-load tests were made on a few specimens. Strain-gage readings were taken on 2-inch gage lines on the columns and on 8-inch gage lines on the plates. The deflection of the bearing plates was measured.

The stress in the web of the column was found to be greater than the average stress for the entire H-section. The highest ratio of web stress to average stress was at the level of gage lines in the lower column 3 inches below the bearing plate. A ratio of web stress to average stress of 3.10 was found for the 10-inch columns over 14-inch columns. The use of heavy 10-inch H-sections directly over 14-inch H-sections is not recommended.

The stresses in the bearing plates were lower than those usually used in structural design. The stress in the specimens having bearing plates more than 2 inches thick was only slightly lower than for those having 2-inch plates, except for the specimens having heavy 10-inch H-sections over 14-inch H-sections.

The ultimate compressive strength of the specimens tested to failure was approximately the same as that of a single H-section having the cross-sectional dimensions of the smaller H-section of the specimen and a length equal to that of the specimen, except for the specimen having a 10-inch H-section over a 14-inch H-section.

No appreciable change in the stresses in the columns nor in the deflections of the bearing plate was observed after nine repetitions of an average stress of 16,000 lbs./in.^{2} in the smaller (upper) column.

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I. INTRODUCTION

1. GENERAL

The vertical members of steel-frame buildings consist of columns the length of which is usually equal to the height of two stories of the building. The ends of these columns are finished in a milling machine. When in place in the structure, the end of the upper column bears directly upon the end of the lower column. The ends of the columns are usually held in alignment by splice plates which extend across the joint and are riveted to both the upper and the lower columns. These splice plates, however, are not designed to carry any portion of the compressive load. At each floor level loads are transferred from the floor to the columns so that the lower columns carry greater loads than the upper and usually, therefore, have a greater cross-sectional area. Where columns having an H-shaped cross section are used, it is desirable to have the same depth of section for the upper and lower columns. The greater cross-sectional area of the lower column is therefore obtained by selecting a section of the same depth as the upper column, but having a thicker web and wider flanges. The web and flanges of the upper column are then supported by the corresponding parts of the lower column and the distribution of stress at the joint is simple.

In tall buildings the loads on the lower part of the building may be so great that to obtain the required cross-sectional area, the columns in the lower part of the building must be of a greater depth than those in the upper part. At joints between columns of different depths, the flanges of the upper column are not supported by the flanges of the lower column. The axes of the interior columns are usually placed in line. The flanges of the upper column are then not in line with those of the lower column. For exterior columns the outside faces of one flange of the upper and of the lower column are usually in the same plane. The inside flange of the upper column is then not supported by the inside flange of the lower column. If the web of the upper column is thicker than the web of the lower column it is not fully supported. These two arrangements of upper and lower columns are shown in Figure 1.

When the depth of the upper column is less than that of the lower column, it is usually supported on a flat steel plate placed on top of the lower column. The plate transfers loads to the lower column from those parts of the upper column which without the plate would be

unsupported. In so doing, it is subjected to unknown bending stresses. The distribution of stress in the ends of the columns and in the plate is complex, and some of the stresses may be high.

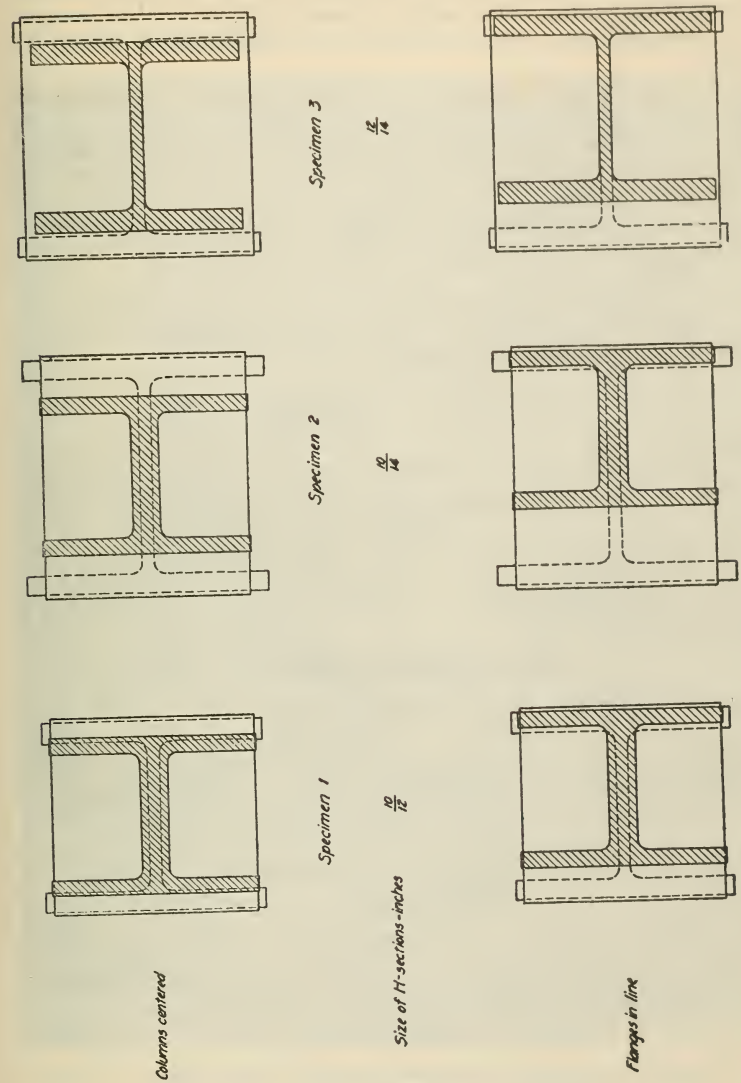


FIGURE 1.—*Arrangement of the columns for each specimen tested under "low loads"*

Upper column indicated by cross hatching, lower column indicated by dashed lines.

2. SCOPE OF INVESTIGATION

This investigation was undertaken to determine experimentally the distribution of stress near the ends of the columns and in the bearing plates. The specimens consisted of two 3-foot lengths of H-section steel columns of unequal depth placed end to end with a flat steel plate between them. Compressive loads were applied in the direction of the axes of the columns. The effect of differences in the depth of the

columns and their arrangement and of differences in the thickness of the bearing plates were also studied.

As splice plates riveted or welded to the ends of the columns at the joint do not appreciably affect the distribution of stress in the columns and in the bearing plates, the results obtained may be used in designing column connections in which the ends of the columns are joined by splice plates.

The investigation included tests under three types of loading, as follows:

1. *Tests under "low loads."*—Six specimens were tested with each of five thicknesses of bearing plates under "low loads" to determine the distribution of stress.

2. *Tests to failure.*—Four specimens were tested to failure to determine the distribution of stress under high loads and the ultimate strength.

3. *Tests under repeated load.*—One specimen was tested under nine applications of load to determine the effect of repetitions of load on the magnitude and distribution of the stress.

3. METHOD OF LOADING

The specimens were tested in the vertical hydraulic compression machine having a capacity of 10,000,000 pounds. A steel base plate was centered on the lower platen of the testing machine, and on this the specimen was assembled. A spherical bearing block was placed between the top of the specimen and the upper platen of the machine in the tests under "low loads" and was adjusted as the initial load was applied. In the other tests a steel cap plate was used instead of a spherical bearing block.

4. ACKNOWLEDGMENTS

The American Bridge Co. furnished the specimens which were designed by James H. Edwards, chief engineer. O. E. Hovey, assistant chief engineer, and other members of the company's engineering staff assisted in making the tests. Prof. Elmer O. Bergman, research associate, contributed considerably to the analysis of the test data.

II. TESTS UNDER "LOW LOADS"

1. SPECIMENS

(a) COLUMNS

The columns were H-section steel columns rolled by the Carnegie Steel Co. Data for the columns are given in Table 1.

TABLE 1.—H-*section columns*

[These data were taken from "Carnegie Beam Sections" (1st ed., 1927)]

Number of pieces	Section index	Depth		Weight, nominal	Area		
		Nominal	Actual		Nominal	Measured	Length, nominal
		Inches	*Inches*	*Lbs./ft.*	*Square inches*	*Square inches*	*Feet*
1	CB 105	10	10.0	140	41.17	41.42	3
1	CB 126	12	12.0	150	44.12	44.03	3
1	CB 146	14	14.9	165	48.52	47.94	3

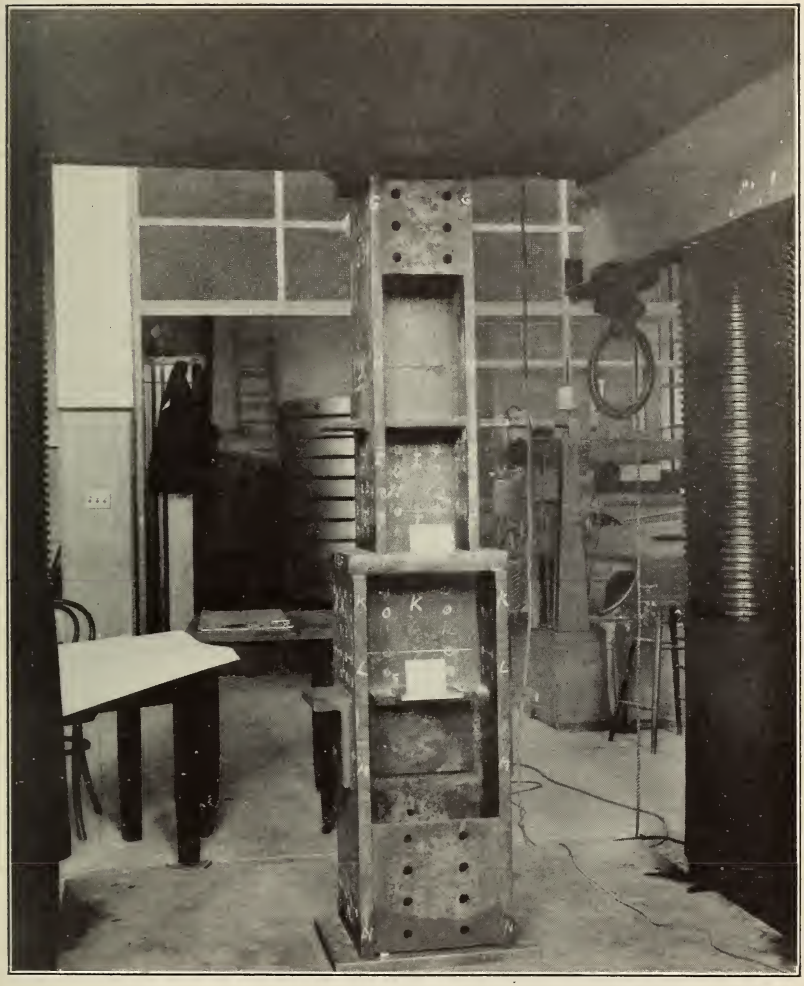


FIGURE 2.—*Specimen 2 in the testing machine; 10-inch* H-*section over 14-inch* H-*section, centered; bearing plate 1.871 inches thick*

The plates and angles welded to the columns were used for another investigation.

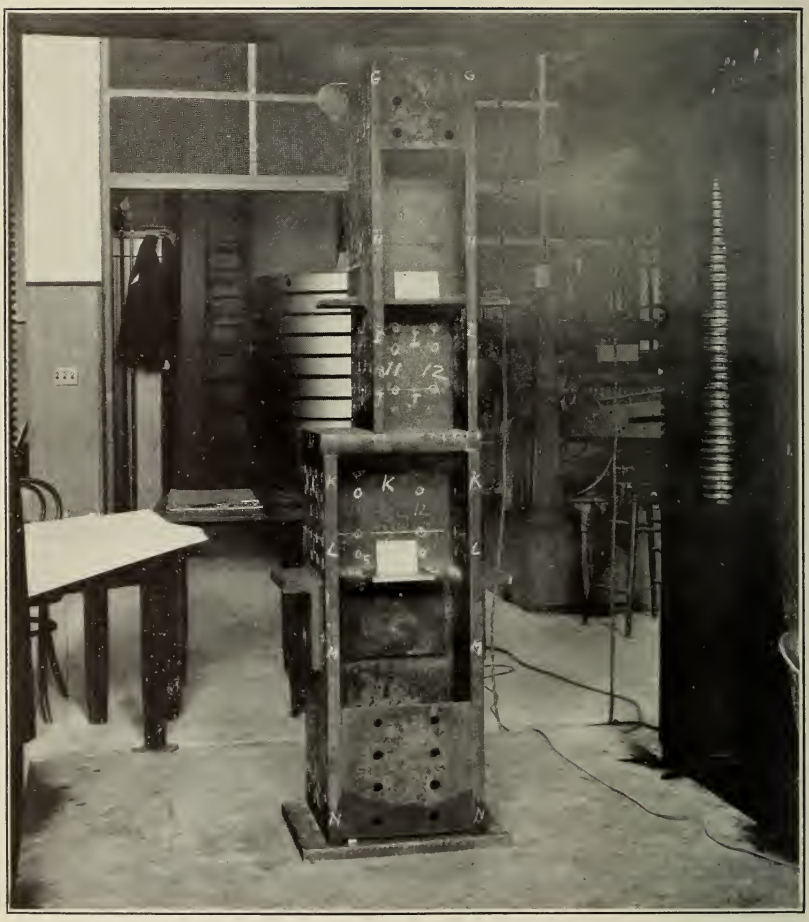


FIGURE 3.—*Specimen 5 in the testing machine; 10-inch* H-*section over 14-inch* H-*section, flanges in line; bearing plate 1.871 inches thick*

The plates and angles welded to the columns were used in another investigation.

The measured areas were computed from measurements taken at several places on the web and flanges of each column. The nominal size of the fillets was used in computing these areas.

The columns had the customary milled ends when they reached the laboratory. Preliminary tests, made by using hot pressed bearing plates having unmachined surfaces, gave erratic stress distributions in the columns. Therefore both ends of each column were faced in an engine lathe. The ends of the columns appeared plane when tested with a steel straightedge.

(b) PLATES

The bearing plates had been heated and pressed between parallel surfaces at the fabricating plant. Both faces were finished in a planer at the laboratory to obtain a more consistent distribution of stress. Sufficient material was removed to "clean up" the surface which appeared plane when tested with a steel straightedge. The dimensions of the plates are given in Table 2.

TABLE 2.—*Bearing plates*

Plate No.	Dimensions				Remarks (used with specimens)
	Length, nominal	Width, nominal	Thickness, nominal	Thickness measured after planing	
	Inches	*Inches*	*Inches*	*Inches*	
a	12½	13	1	0.887	1 and 4
b	15½	13	1	.918	2 and 5
c	15½	14½	1	.910	3 and 6
d	12½	13	1½	1.408	1 and 4
e	15½	13	1½	1.435	2 and 5
f	15½	14½	1½	1.455	3 and 6
g	12½	13	2	1.899	1 and 4
h	15½	13	2	1.871	2 and 5
i	15½	14½	2	1.962	3 and 6
j	12½	14½	2¾	2.730	1 to 6
k	12½	14½	4¼	4.246	1 to 6

(c) MAKE-UP OF SPECIMENS

The make-up of the six specimens used in the tests under "low loads" is given in Table 3. The specimens are shown in cross section in Figure 1. The specimens designated "centered" were tested with the axis of the upper column in line with that of the lower column, as shown in Figure 2. The specimens designated "flanges in line" were tested with the outer faces of one flange of both columns in the same plane, as shown in Figure 3.

TABLE 3.—*Make-up of specimens*

Specimen No.	Column depth		Column arrangement
	Upper	Lower	
	Inches	*Inches*	
1	10	12	Centered.
2	10	14	Do.
3	12	14	Do.
4	10	12	Flanges in line.
5	10	14	Do.
6	12	14	Do.

Each specimen was tested with five different thicknesses of bearing plates; this made a total of 30 tests. The dimensions of the plates used for each specimen are given in Table 2.

2. TEST PROCEDURE

(a) PROGRAM

H sections having depths of 10, 12, and 14 inches were selected to represent the depths most frequently used in steel-frame building construction. Tests were made with both of the arrangements shown in Figure 1, namely, with "columns centered" and with "flanges in line." It was decided that five bearing plates, ranging in thickness from 1 to 4¼ inches, would give sufficient information on the effect of the thickness of the bearing plate on the distribution of stress.

Because it was desired to study the elastic behavior of the specimens and because each column was to be used for several specimens, the maximum compressive load applied, in these tests under "low loads," did not exceed 8,500 lbs./in.^{2} in the smaller (upper) column. The strain-gage readings did not indicate any permanent set under loads of 250,000 pounds on specimens 2 and 5 for plates having a nominal thickness of 1, 1½, and 2 inches, nor under loads of 350,000 pounds for these specimens with thicker plates. The other specimens did not show any permanent set after loading to 350,000 pounds. The average stress, computed by dividing the total load by the cross-sectional area of the smaller H section ranged from 5,200 to 8,400 lbs./in.^{2}.

Strain-gage readings were taken at zero load and at maximum load. Readings of the deflection of the bearing plates were taken at a load of 50,000 pounds and at maximum load. Deflection readings were not taken at zero load because some of the specimens rocked slightly under zero load so that consistent readings could not be obtained.

(b) STRAIN-GAGE MEASUREMENTS

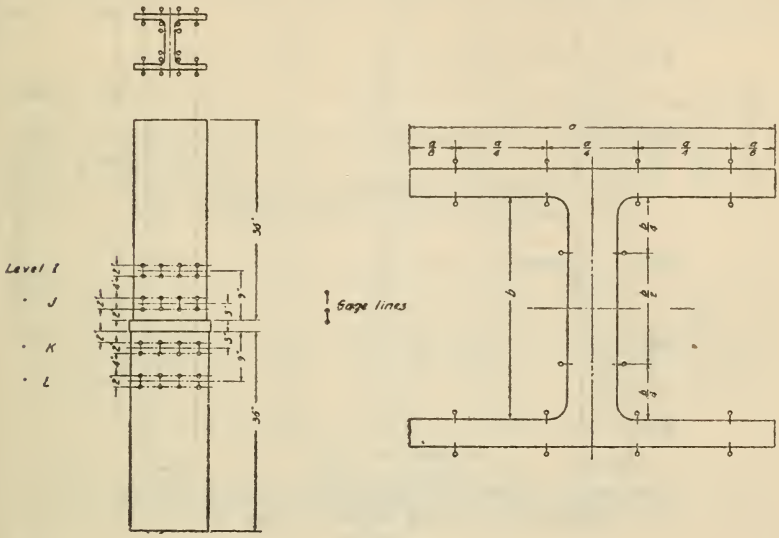
The strain in the columns was measured by using a 2-inch Berry strain gage. The gage lines were parallel to the axes of the columns. There were 20 lines at each of two levels in each column. As measured from the mid-points of the gage lines, these levels were 3 inches and 9 inches from the bearing plate. They were designated *I*, *J*, *K*, and *L*, beginning with the top level as shown in Figure 4.

The strain gages were calibrated at the beginning of the tests and comparison readings were taken on a standard bar before and after each set of from 8 to 16 observations. Measurements on each gage line were repeated until two consecutive readings were obtained having a difference not greater than 0.0001 inch for the 2-inch gage length. Assuming a value of 29,000,000 lbs./in.^{2} for the modulus of elasticity of steel this difference in reading represented a difference in stress of 1,450 lbs./in.^{2}.

The strain in the plates was measured with a West strain gage on 8-inch gage lines. These lines were on the vertical sides of the plates which were parallel to the webs of the columns. The lines were one-eighth inch from the upper and the lower edge of the plates as shown in Figure 5. These strain-gage readings were repeated until the difference in consecutive readings did not exceed 0.0001 inch for the 8-inch gage length. This difference represented a difference in stress of 363 lbs./in.^{2}.

(c) DEFLECTION MEASUREMENTS

Small holes were drilled in the lower surface of the bearing plates as gage points for measuring the deflection of the plate. The posi-



FIGRUE 4.—*Location of gage lines on specimens tested under "low loads" and on specimens tested to failure*

tion of these gage points on the plates 13 inches wide is shown in Figure 6 and on the plates 14½ inches wide in Figure 7. Reference plates were fastened to the shelf angles welded to the web of the lower column, as shown in Figures 2 and 3. These plates had holes in their upper surface vertically below the holes in the bearing plate. The deflection was measured by using a dial micrometer graduated to 0.001 inch attached to a bar of suitable length. To make a reading, the conical end of the bar carrying the dial was placed in one of the holes in the reference plate and the conical end of the spindle of the dial in the corresponding hole in the bearing plate. It is evident that changes in distance between the bearing plate and the reference plate were caused not only by the deflection of the plate, but also by the elastic compression of the portion of the lower column above the shelf angle.

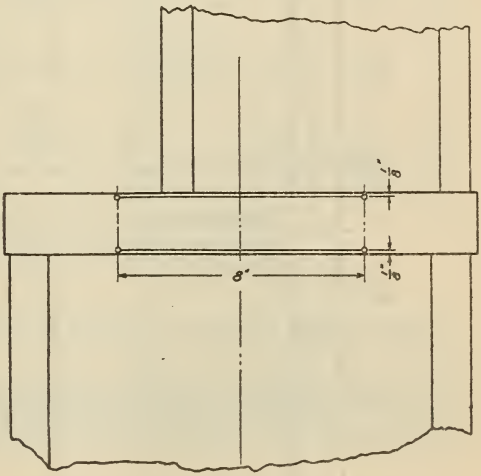


FIGURE 5.—*Location of strain-gage lines on bearing plates*

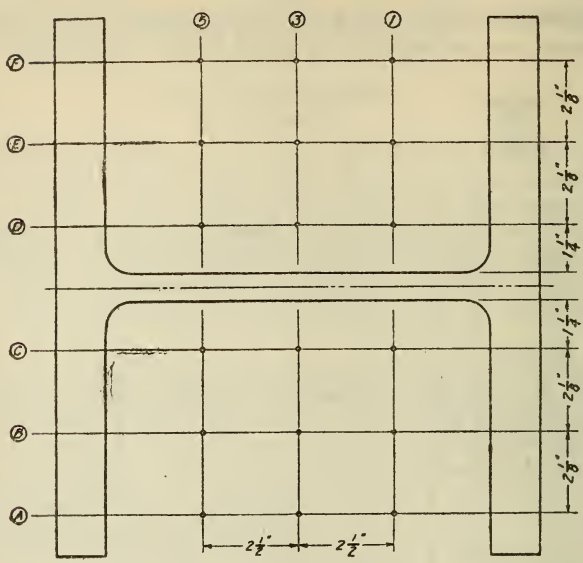


FIGURE 6.—*Location of gage points for measuring the deflection of bearing plates 13 inches wide*

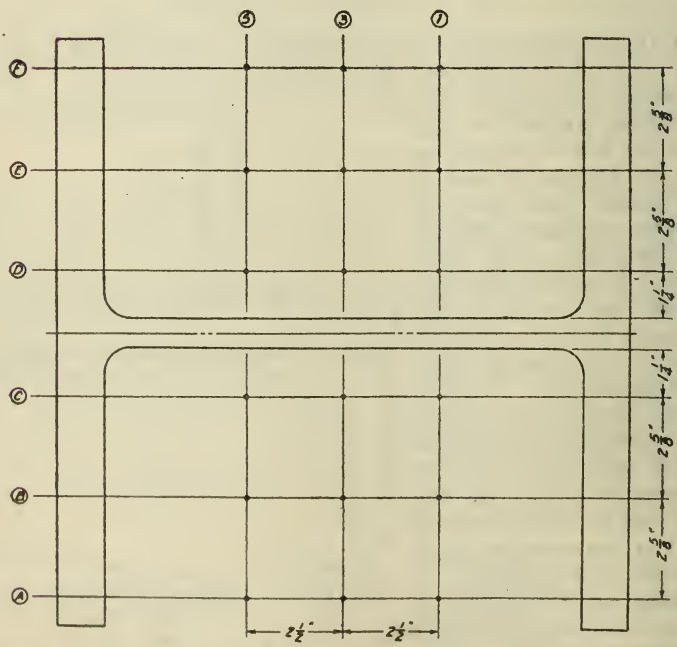


FIGURE 7.—*Location of gage points for measuring the deflection of bearing plates 14½ inches wide*

3. RESULTS AND DISCUSSION

(a) STRESSES IN COLUMNS

(1) *Typical stress data.*—The stresses computed from the strains found in specimen 5 when tested with 1, 2, and 4¼-inch bearing plates

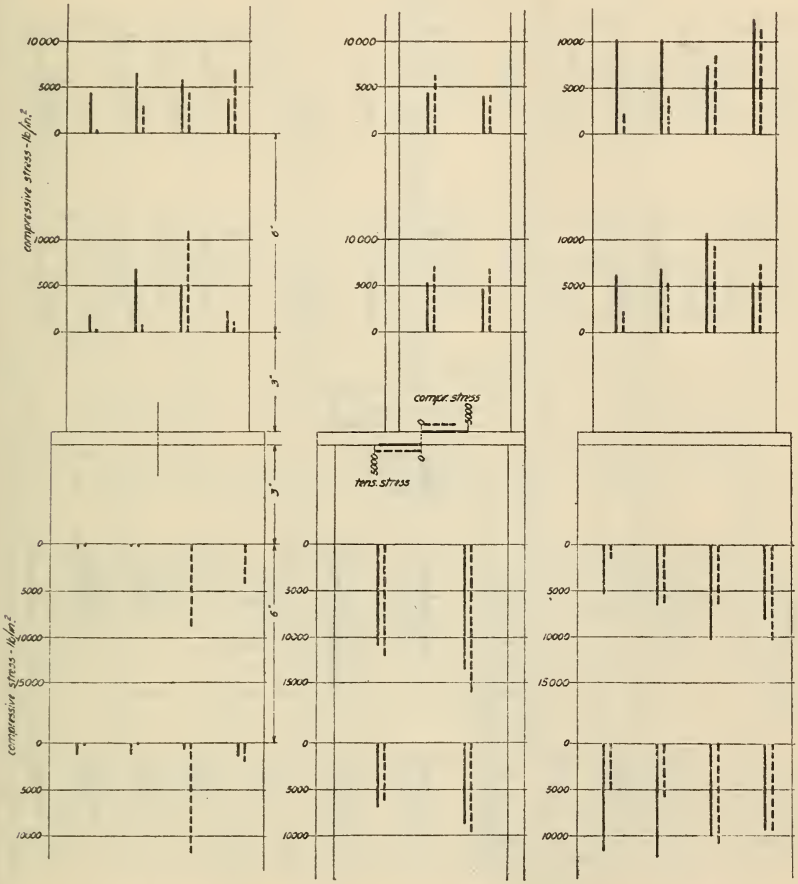


FIGURE 8.—*Stresses in specimen 5 with 1-inch bearing plate*

Column arrangement, flanges in line.
Total load, 250,000 pounds.
Upper column: Ten-inch H section, CB-105, 140 pounds/ft. Average stress, 6,000 pounds/inch.²
Lower column: Fourteen-inch H section, CB-146, 165 pounds/ft. Average stress, 5,200 pounds/inch.²
0.918 inch bearing plate.

In the flange views the full lines represent stresses in the outer face of the flange and the dashed lines represent stresses in the inner face. In the web views the full lines represent stresses in the near side of the web and the dashed lines represent stresses in the far side. The stresses in the columns were all compressive; for convenience those in the upper column were plotted upward and those in the lower column downward. In the bearing plates, stresses plotted to the right are compressive, those to the left are tensile.

are shown graphically in Figures 8, 9, and 10. The variation in stress which these figures show is typical of that found in all the tests.

(2) *Ratio of web stress to average stress.*—The strain-gage readings indicate that, in general, the stresses in the webs were higher than the average stresses for the entire H section. In order to show the

relative magnitude of flange and web stresses, the stresses for the different gage lines for all the specimens have been averaged, and are shown graphically in Figures 11 to 16.

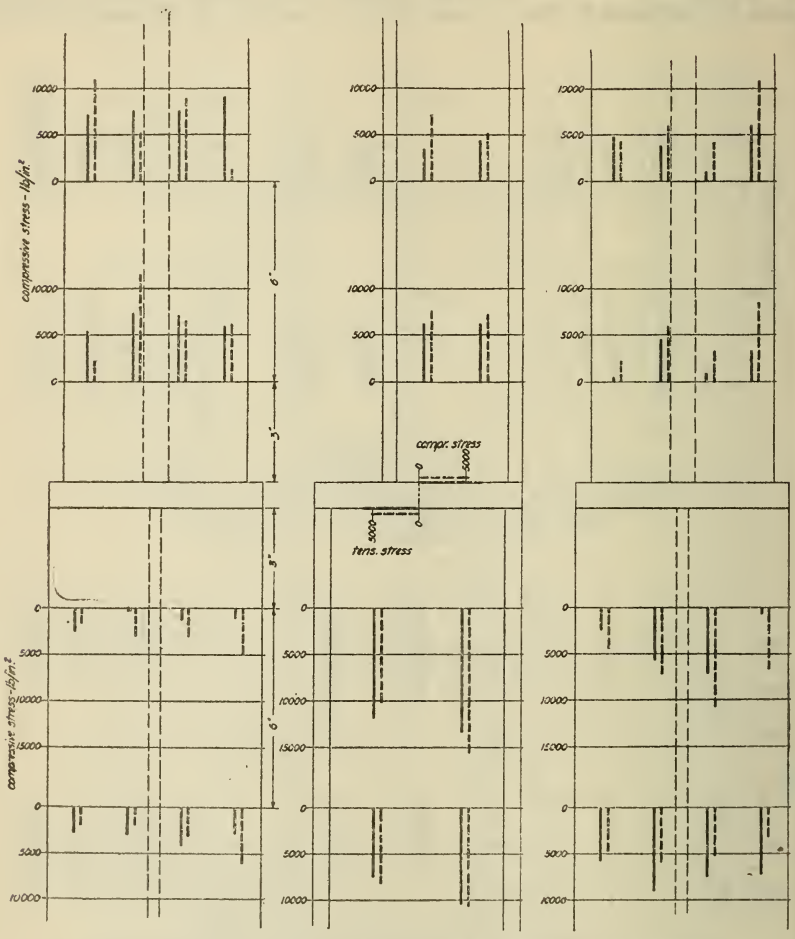


FIGURE 9.—*Stresses in specimen 5 with 2-inch bearing plate*

Column arrangement, flanges in line.
Total load, 250,000 pounds.
Upper column: Ten-inch H section, CB-105, 140 pounds/ft. Average stress, 6,000 pounds/inch.²
Lower column: Fourteen-inch H section, CB-146, 165 pounds/ft. Average stress, 5,200 pounds/inch.²
1.871 inches bearing plate.
In the flange views the full lines represent stresses in the outer face of the flange and the dashed lines represent stresses in the inner face. In the web views the full lines represent stresses in the near side of the web and the dashed lines represent stresses in the far side. The stresses in the columns were all compressive; for convenience those in the upper column were plotted upward and those in the lower column downward. In the bearing plates, stresses plotted to the right are compressive, those to the left are tensile.

A maximum load of 250,000 pounds was used in the tests of specimens 2 and 5 with bearing plates 1, 1½, and 2 inches thick. The corresponding stresses were multiplied by the ratio $\frac{350,000}{250,000}$ before they were plotted in Figures 12 and 15 so that they would be directly

comparable with those produced by loads of 350,000 pounds. The data from the test to failure of specimen 9 (fig. 22) which was similar to specimen 5 show an approximately straight-line variation in stress

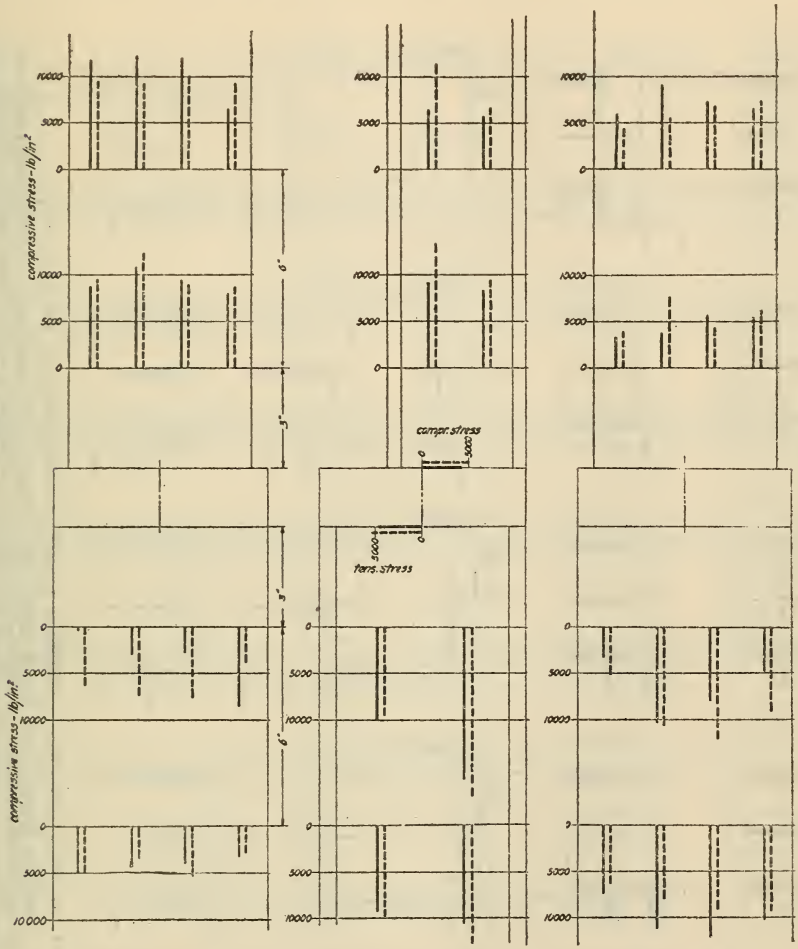


FIGURE 10.—*Stresses in specimen 5 with 4¼-inch bearing plate*

Column arrangement, flanges in line.
Total load, 350,000 pounds.
Upper column: Ten-inch H section, CB-105, 140 pounds/ft. Average stress, 8,400 pounds/inch.²
Lower column: Fourteen-inch H section, CB-146, 165 pounds/ft. Average stress, 7,300 pounds/inch.²
4.246 inch bearing plate.

In the flange views the full lines represent stresses in the outer face of the flange and the dashed lines represent stresses in the inner face. In the web views the full lines represent stresses in the near side of the web and the dashed lines represent stresses in the far side. The stresses in the columns were all compressive; for convenience those in the upper column were plotted upward and those in the lower column downward. In the bearing plates, stresses plotted to the right are compressive, those to the left are tensile.

up to loads of 350,000 pounds (8,400 lbs./in.² in upper column, 7,900 lbs./in.² in lower). These stresses are, therefore, a close approximation to the stresses which would have been produced by a load of 350,000 pounds.

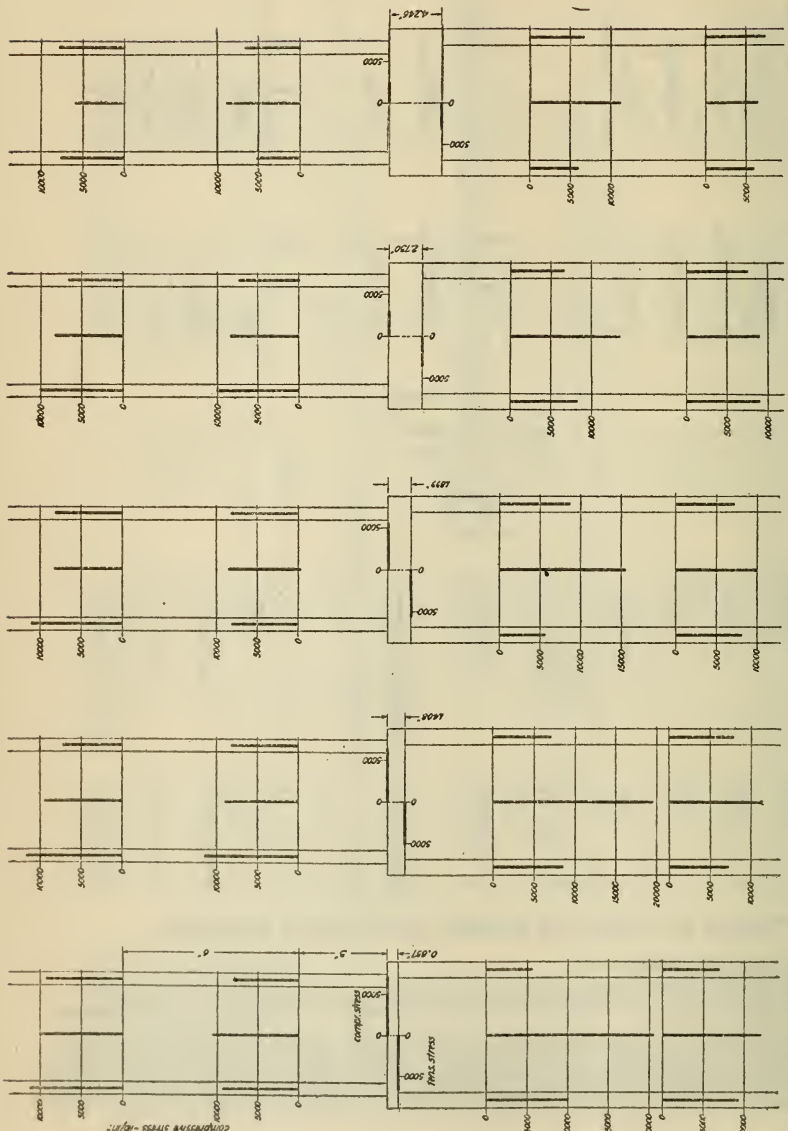


FIGURE 11.—*Average stresses in specimen 1 with five thicknesses of bearing plate*

Column arrangement, centered. Total load, 350,000 pounds. Upper column: 10-inch H section, CB-105, 140 lbs./ft. Average stress, 8,400 lbs./in.^{2} Lower column: 12-inch H section, CB-126, 150 lbs./ft. Average stress, 7,900 lbs./in.^{2} The stresses in the columns were all compressive; for convenience those in the upper column were plotted upward and those in the lower column downward. In the bearing plates, stresses plotted to the right are compressive, those to the left are tensile. In this figure the stress shown for each flange is the average for the eight gage lines on that flange. The web stresses are the averages for the four gage lines on the web. The stresses in the plates are the average of the two readings, one on each side.

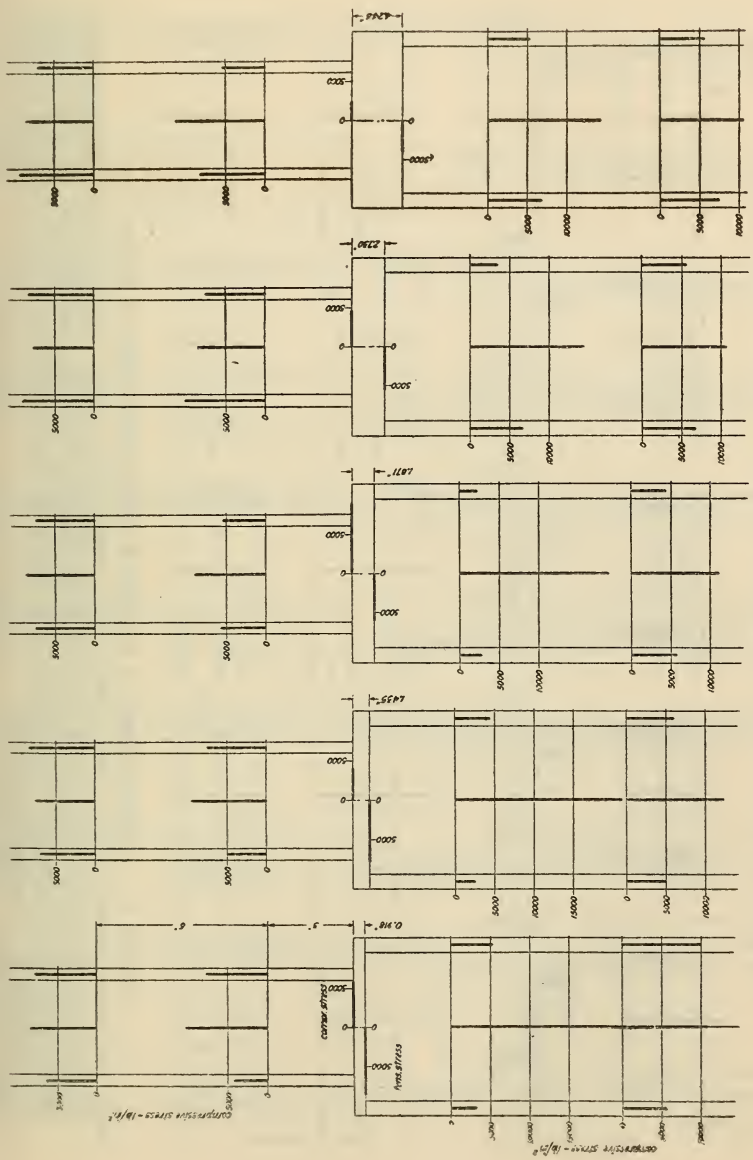


FIGURE 12.—*Average stresses in specimen 2 with five thicknesses of bearing plate*

Column arrangement, centered. Total load, 350,000 pounds. Upper column: 10-inch H section, CB-105, 140 lbs./ft. Average stress, 8,400 lbs./in.² Lower column: 14-inch H section, CB-146, 165 lb./ft. Average stress, 7,300 lbs./in.² The stresses in the columns were all compressive; for convenience those in the upper column were plotted upward and those in the lower column downward. In the bearing plates, stresses plotted to the right are compressive, those to the left are tensile. In this figure the stress shown for each flange is the average for the eight gage lines on that flange. The web stresses are the averages for the four gage lines on the web. The stresses in the plates are the average of the two readings, one on each side.

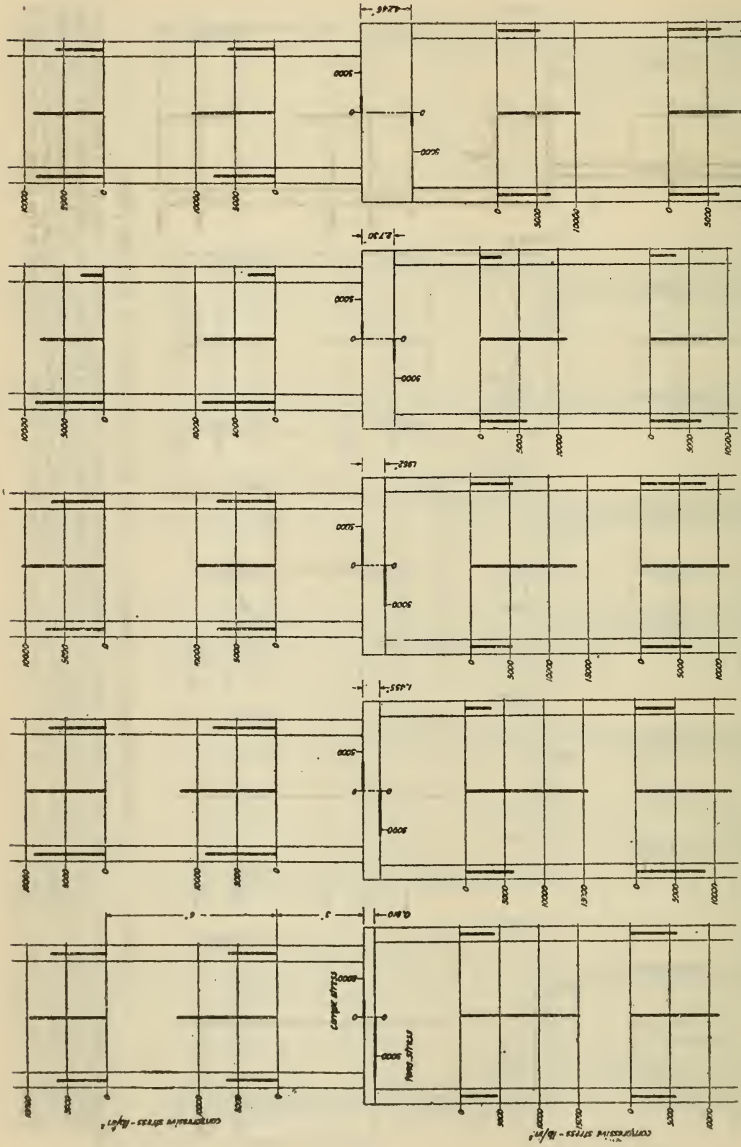


FIGURE 13.—*Average stresses in specimen 3 with five thicknesses of bearing plate*

Column arrangement, centered. Total load, 350,000 pounds. Upper column: 12-inch H section, CB-126, 150 lbs./ft. Average stress, 7,900 lbs./in.² Lower column: 14-inch H section, CB-146, 165 lbs./ft. Average stress, 7,300 lbs./in.² The stresses in the columns were all compressive; for convenience those in the upper column were plotted upward and those in the lower column downward. In the bearing plates, stresses plotted to the right are compressive, those to the left are tensile. In this figure the stress shown for each flange is the average for the eight gage lines on that flange. The web stresses are the averages for the four gage lines on the web. The stresses in the plates are the average of the two readings, one on each side.

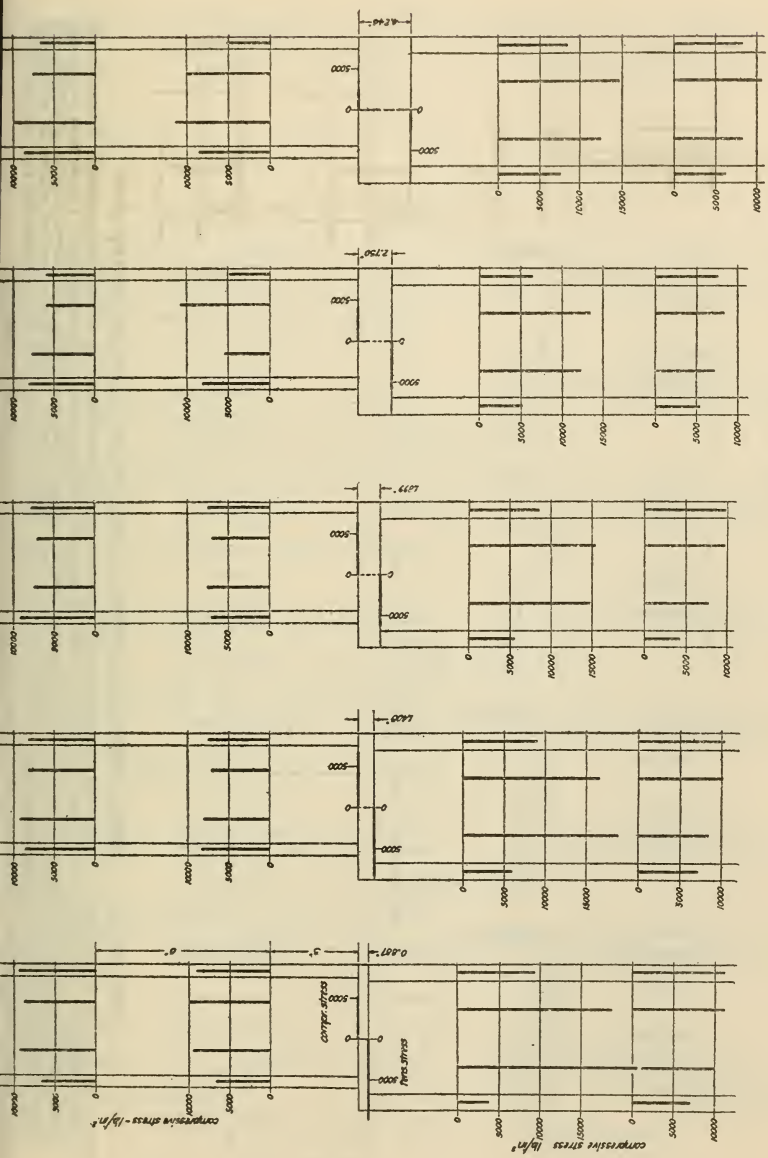


FIGURE 14.—*Average stresses in specimen 4 with five thicknesses of bearing plate*

Column arrangement, flanges in line. Total load, 350,000 pounds. Upper column: 10 inches H section, CB-106, 140 pounds/ft. Average stress, 8,400 pounds/in.^{2} Lower column: 12 inches H section, CB-126, 150 pounds/ft. Average stress, 7,900 pounds/in.^{2} The stresses in the columns were all compressive; for convenience those in the upper column were plotted upward and those in the lower column downward. In the bearing plates, stresses plotted to the right are compressive, those to the left are tensile. In this figure the stress shown for each flange is the average for the eight gage lines on that flange. Each of the two values of the stress in the web is the average for the two gage lines, one on each side of the web. The stresses in the plates are the average of the two readings, one on each side.

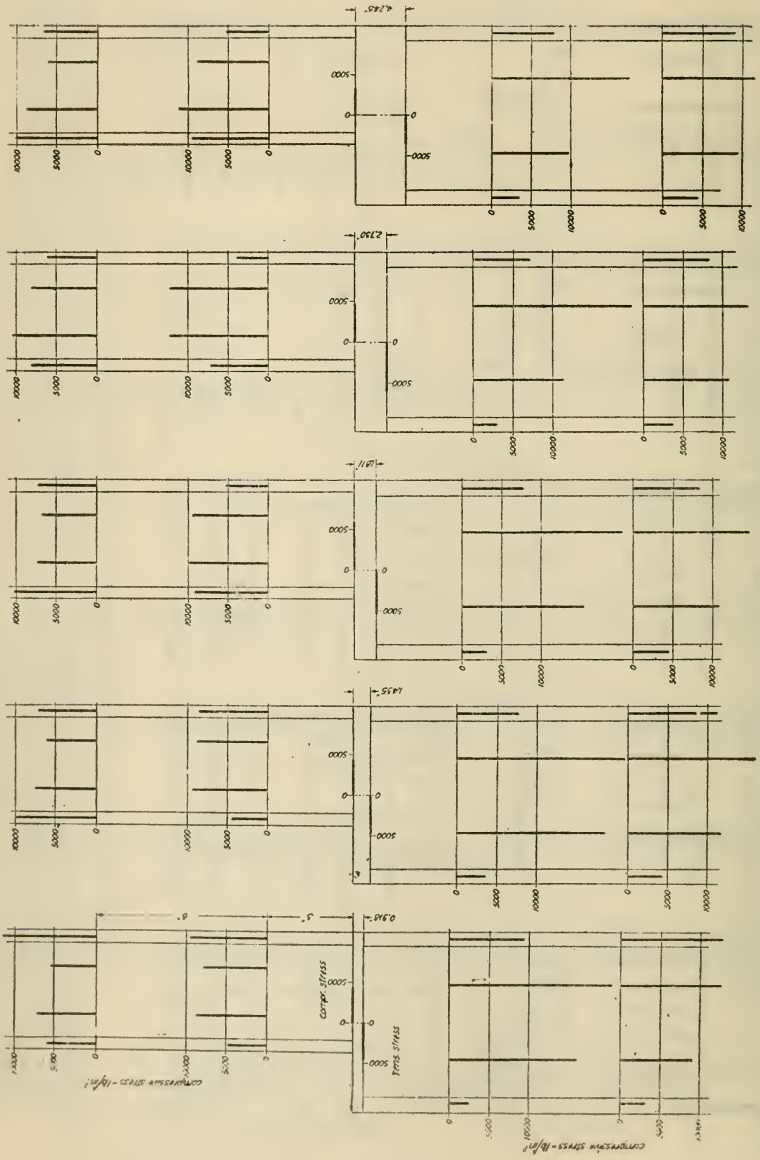


FIGURE 15.—*Average stresses in specimen 5 with five thicknesses of bearing plate*

Column arrangement, flanges in line. Total load, 350,000 pounds. Upper column: 10 inches H section, CB-105, 140 pounds/ft. Average stress, 8,400 pounds/in.² Lower column: 14 inches H section, CB-146, 165 pounds/ft. Average stress, 7,300 pounds/in.² The stresses in the columns were all compressive; for convenience those in the upper column were plotted upward and those in the lower column downward. In the bearing plates, stresses plotted to the right are compressive, those to the left are tensile. In this figure the stress shown for each flange is the average for the eight gage lines on that flange. Each of the two values of the stress in the web is the average for the two gage lines, one on each side of the web. The stresses in the plates are the average of the two readings, one on each side.

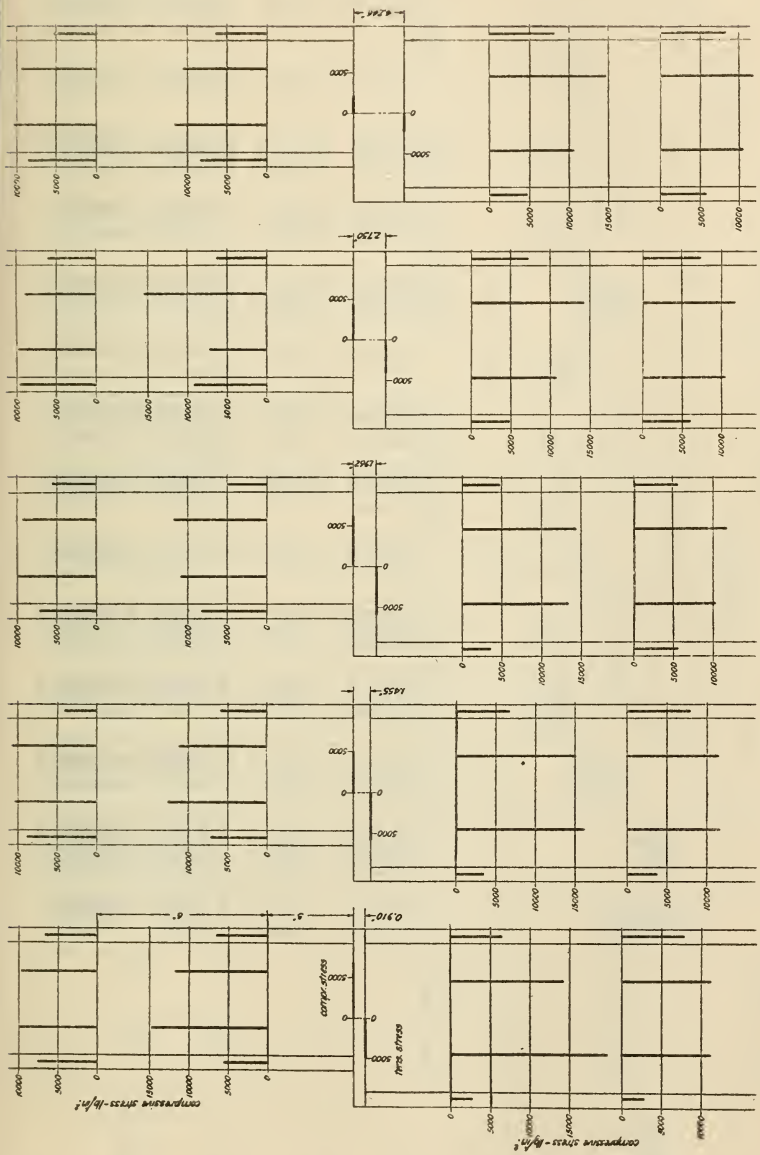


FIGURE 16.—*Average stresses in specimen 6 with five thicknesses of bearing plate*

Column arrangement, flanges in line. Total load, 350,000 pounds. Upper column: 12 inches H section, CB-126, 150 pounds/ft. Average stress, 7,900 pounds/in.^{2} Lower column: 14 inches H section, CB-146, 165 pounds/ft. Average stress 7,300 pounds/in.^{2} The stresses in the columns were all compressive; for convenience those in the upper column were plotted upward and those in the lower column downward. In the bearing plates, stresses plotted to the right are compressive, those to the left are tensile. In this figure the stress shown for each flange is the average for the eight gage lines on that flange. Each of the two values of the stress in the web is the average for the two gage lines, one on each side of the web. The stresses in the plates are the average of the two readings, one on each side.

TABLE 4.—*Stresses in* H *sections*

Specimen No.	Column arrangement	Column depth		Bearing plate thickness, actual	Maximum load	Stress														
						Upper column							Lower column							
						Stress from load, average	Stress from strain gage						Stress from load, average	Stress from strain gage					
							3 inches from plate			9 inches from plate				3 inches from plate			9 inches from plate		
		Upper	Lower				Flanges and web C	Web only W	Ratio $\frac{W}{C}$	Flanges and web C	Web only W	Ratio $\frac{W}{C}$		Flanges and web C	Web only W	Ratio $\frac{W}{C}$	Flanges and web C	Web only W	Ratio $\frac{W}{C}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Inches	*Inches*	*Inches*	*Pounds*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*		*Lbs./in.²*	*Lbs./in.²*		*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*		*Lbs./in.²*	*Lbs./in.²*	
1	Centered	10	12	0.887	350,000	8,400	10,300	10,100	0.98	9,300	10,600	1.14	7,900	10,000	20,400	2.04	8,800	12,100	1.37
				1.408	350,000	8,400	9,600	9,500	.99	9,600	9,600	.94	7,900	9,900	19,500	1.97	8,300	11,300	1.36
				1.899	350,000	8,400	9,100	8,200	.90	8,300	8,600	1.03	7,900	8,500	15,400	1.81	8,000	9,900	1,24
				2.730	350,000	8,400	8,400	8,300	.99	8,700	8,500	.98	7,900	8,400	13,500	1.61	8,300	8,900	1.07
				4.246	350,000	8,400	7,200	6,000	.83	7,100	9,000	1.27	7,900	7,200	11,200	1.56	6,500	6,400	.98
2	do	10	14	.918	250,000	6,000	5,400	6,100	1.13	5,400	7,400	1.37	5,200	6,400	18,100	2.83	6,700	10,600	1.58
				1.435	250,000	6,000	5,400	5,400	1.00	5,200	6,700	1.29	5,200	5,200	15,000	2.88	4,900	8,800	1.80
				1.871	250,000	6,000	5,600	6,200	1.11	4,800	6,500	1.36	5,200	4,300	13,300	3.10	4,800	7,800	1.62
				2.730	350,000	8,400	8,200	7,600	.93	8,700	8,600	.99	7,300	6,900	14,200	2.06	7,100	10,600	1.49
				4.246	350,000	8,400	8,300	8,600	1.03	8,200	11,200	1.37	7,300	7,700	14,000	1.82	7,300	10,500	1.44
3	do	12	14	.910	350,000	7,900	7,100	9,600	1.35	7,500	12,800	1.71	7,300	6,700	15,000	2.24	6,900	11,200	1.62
				1.455	350,000	7,900	8,300	9,800	1.18	9,100	12,200	1.34	7,300	7,000	15,500	2.22	8,100	12,200	1.50
				1.962	350,000	7,900	7,700	10,400	1.35	7,800	10,000	1.28	7,300	7,000	13,400	1.92	8,200	11,200	1.37
				2.730	350,000	7,900	6,100	8,000	1.31	6,800	9,000	1.32	7,300	5,800	11,000	1.90	5,900	9,700	1.64
				4.246	350,000	7,900	7,600	8,800	1.16	7,500	10,500	1.40	7,300	7,000	10,600	1.52	7,500	10,900	1.45
4	Flanges in line	10	12	.887	350,000	8,400	8,500	9,200	1.08	8,500	9,800	1.15	7,900	9,100	20,600	2.26	9,500	10,700	1.13
				1.408	350,000	8,400	8,600	8,900	1.04	8,200	7,700	.94	7,900	9,400	17,900	1.90	9,000	9,500	1.06
				1.899	350,000	8,400	8,400	7,700	.92	7,500	7,500	1.00	7,900	8,700	15,200	1.75	7,400	8,800	1.19
				2.730	350,000	8,400	7,000	6,800	.97	7,200	8,300	1.15	7,900	7,100	13,000	1.83	6,700	7,800	1.16
				4.246	350,000	8,400	8,200	8,800	1.07	8,500	11,000	1.29	7,900	9,000	13,700	1.52	7,700	9,600	1.25

5	do	10	14	.918	250,000	6,000	5,800	4,800	.83	5,500	6,100	1.11	5,200	6,200	13,200	2.13	6,300	7,900	1.25
				1.435	250,000	6,000	5,700	5,000	.88	5,400	6,600	1.22	5,200	6,300	14,200	2.26	6,600	10,000	1.52
				1.871	250,000	6,000	5,800	5,000	.86	5,800	6,900	1.19	5,200	5,800	12,700	2.19	5,600	9,200	1.64
				2.730	350,000	8,400	7,900	9,400	1.19	7,900	12,400	1.57	7,300	7,400	15,700	2.12	7,300	12,000	1.64
				4.246	350,000	8,400	8,100	7,600	.94	8,400	10,200	1.22	7,300	7,600	13,600	1.79	7,700	10,700	1.39
6	do	12	14	.910	350,000	7,900	8,300	9,700	1.17	7,200	13,200	1.83	7,300	7,300	17,000	2.33	6,700	11,300	1.69
				1.455	350,000	7,900	7,200	10,600	1.47	7,500	11,800	1.57	7,300	7,400	15,600	2.11	7,100	11,600	1.63
				1.962	350,000	7,900	7,000	9,600	1.37	7,500	11,400	1.52	7,300	6,200	13,800	2.22	6,800	11,000	1.62
				2.730	350,000	7,900	8,200	9,400	1.15	8,300	11,400	1.37	7,300	7,400	12,500	1.69	7,600	11,000	1.45
				4.246	350,000	7,900	7,700	10,000	1.30	8,100	11,400	1.41	7,300	7,800	12,800	1.64	7,900	11,000	1.39

Numerical values of the stresses in the columns are given in Table 4. The "stress from load, average" was found by dividing the maximum load on the specimen by the cross sectional area of the H section and is given in column 7 of the table for the upper column and in column 14 for the lower column. The average stress from strain-gage measurements was obtained by weighting the stress computed from each gage reading in proportion to the area of the portion of the cross section nearest the gage line. The stress, "C," for the entire cross-sectional area of the column (flanges and web) for the gage lines at each of the four levels is given in columns 8, 11, 15, and 18. The stress, "W," in the web only is given in columns 9, 12, 16, and 19. The ratio of the stress in the web to the stress in the entire cross section is given in columns 10, 13, 17, and 20.

The average stress in the web of the upper columns 9 inches above the bearing plate was for most of the specimens greater than the average stress on the upper column both for specimens with columns centered and those with flanges in line. Three inches above the bearing plate the proportion of the load carried by the web had decreased due to the deflection of the plate, downward, which caused the flanges to carry a greater proportion of the load. In the lower columns the ratio of web stress to average stress was, except for one specimen, greater than unity, and was greater 3 inches below the plate than at 9 inches below. It is reasonable to assume that the web stresses in the lower column at the bearing plate were considerably higher than those 3 inches from the plate.

Besides showing the relation between web and flange stresses, Figures 11 to 16 show the effect on the distribution of stress caused by differences in the thickness of the bearing plates. The stresses in the lower column 3 inches below the bearing plate were the highest stresses observed, and they are the only stresses which will be discussed here. The best thickness of plate is that for which the maximum value of stress at this level is the lowest. Figures 14 and 16 show the stresses in specimens 4 and 6, that is, 10-inch over 12-inch columns and 12-inch over 14-inch columns with flanges in line. For the 1-inch and 1½-inch plates the larger of the two web stresses was the one farther from the flanges in line, while for the 2¾-inch and 4¼-inch plates the larger stress was the one nearer the flanges in line. For the 2-inch plate the two web stresses were approximately equal. Moreover, their value was approximately equal to the larger value for the 2¾-inch and 4¼-inch plates, so that no material reduction in the maximum web stress was obtained by using the 2¾-inch or the 4¼-inch plates. For specimens having 10-inch over 12-inch columns (specimen 1, fig. 11) and 12-inch over 14-inch columns (specimen 3, fig. 13) columns centered, there seems to be little advantage in using plates thicker than 2 inches. The 10-inch over 14-inch columns had high web stresses except for specimen 2, columns centered, with the two thickest plates. These tests indicate that it is not advisable to change directly from a 10-inch H section to a 14-inch H section.

TABLE 5.—*Maximum stresses in the bearing plate*

Specimen No.	Column size		Column arrangement	Load on specimen	Plate thickness, actual	Average stress in extreme fiber from strain readings			Stress from deflection measurements [1]
	Upper	Lower				Top	Bottom	Average	
	Inches	*Inches*		*Pounds*	*Inches*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*
1	10	12	Centered	350,000	0.887	7,400	6,600	7,000	10,200
				350,000	1.408	6,400	5,100	5,800	3,000
				350,000	1.899	5,900	5,700	5,800	8,700
				350,000	2.730	3,000	3,600	3,300	----------
				350,000	4.246	2,500	3,100	2,800	----------
2	10	14	do	250,000	.918	5,800	8,500	7,200	1,400
				250,000	1.435	4,000	7,700	5,800	3,700
				250,000	1.871	8,800	5,900	7,400	8,200
				350,000	2.730	6,400	7,600	7,000	7,500
				350,000	4.246	3,300	5,400	4,400	8,000
3	12	14	do	350,000	.910	2,300	7,600	5,000	3,700
				350,000	1.455	3,700	5,700	4,700	4,000
				350,000	1.962	4,600	5,000	4,800	7,000
				350,000	2.730	2,200	3,000	2,600	2,900
				350,000	4.246	2,100	1,600	1,800	2,300
4	10	12	Flanges in line	350,000	.887	5,300	9,900	7,600	7,700
				350,000	1.408	6,900	8,400	7,700	9,200
				350,000	1.899	6,500	6,300	6,400	10,300
				350,000	2.730	4,200	5,800	5,000	9,000
				350,000	4.246	2,500	2,500	2,500	9,000
5	10	14	do	250,000	.918	4,200	4,800	4,500	5,400
				250,000	1.435	4,400	4,900	4,600	8,400
				250,000	1.871	6,100	5,500	5,800	8,700
				350,000	2.730	6,800	8,600	7,700	12,600
				350,000	4.246	4,600	5,000	4,800	9,200
6	12	14	do	350,000	.910	7,000	5,000	6,000	3,300
				350,000	1.455	5,500	5,900	5,700	5,100
				350,000	1.962	6,500	6,100	6,300	7,500
				350,000	2.730	4,600	4,200	4,400	----------
				350,000	4.246	2,300	2,300	2,300	15,000

[1] These stresses were found by averaging the values for *A* and *F* of Figures 6 and 7.

(b) STRESSES IN PLATES

(1) *From strain-gage measurements.*—The strain in the bearing plates was measured on gage lines which were one-eighth inch from the faces of the plate as shown in Figure 5. Since the strain in the bearing plate due to bending is approximately proportional to the distance from the neutral axis, the strains in the upper and lower faces of the plate were computed by multiplying the readings on the gage lines by the factor

$$K=\frac{\frac{t}{2}}{\frac{t}{2}-\frac{1}{8}}$$

where t is the thickness of the bearing plate in inches. The maximum stresses in the plates were computed from the strains in their upper and lower faces.

These stress values are given in Table 5 and are shown graphically in Figures 11 to 16. The values are rather erratic. In general, there was a decrease in the stress in the plates as their thickness was increased. The stress values were in all cases much lower than the stresses used in designing steel structures. It is evident, therefore,

that the bending stresses in the plates may be disregarded in designing structures having columns similar to those tested in this investigation.

(2) *From deflection measurements.*—It is seen from Figure 17 that the deflection of the point A–3 with respect to a line through the points A–1 and A–5 is the difference between the deflection of the point A–3 and the average deflection of the points A–1 and A–5. The location of these gage points on the plates is shown in Figures 6 and 7. Data for computing this deflection in a typical case are given in Table 6.

TABLE 6.—*Deflection data for specimen 3*

[12-inch over 14-inch columns, centered; bearing plate 0.910 inch thick]

Point on bearing plate	A–1	A–3	A–5
	Inch	*Inch*	*Inch*
Reading for 350,000-pound load	0.2875	0.2770	0.2740
Reading for 50,000-pound load	.2770	.2657	.2640
Increment due to 300,000-pound load	.0105	.0113	.0100

The deflection of A–3 relative to a line through A–1 and A–5 is

$$d=0.0113-\frac{0.0105+0.0100}{2}=0.0011 \text{ inch}$$

The stress for a given deflection of A–3 may be found from the theory of bending, according to which

$$R=\frac{Ec}{S}$$

Referring to Figure 17, $R=\frac{a^2}{2d}$ (very closely). Equating these two values of R, substituting the value $c=\frac{t}{2}$, and solving for S:

$$S=\frac{Etd}{a^2}$$

where

S = stress in extreme fiber, pounds per square inch.
c = distance of extreme fiber from neutral axis, inch.
E = modulus of elasticity, pounds per square inch.
t = thickness of bearing plate, inch.
R = radius of curvature of the elastic curve of the plate, inch.

According to this formula the stress in the outer fibers of a 1-inch steel plate having a deflection of 0.001 inch is 4,800 lbs./in.^{2}

The lowest load for which deflection readings were taken was 50,000 pounds, whereas the lowest load for which strain-gage readings were taken was zero load. To facilitate comparison with the stresses obtained from the strain-gage measurements, the stresses computed from the deflection measurements were increased proportionally for a loading range from zero to the maximum load on the

specimen. These increased values are given in Table 5. These stresses are comparatively small, but they are much more erratic than those computed from the strain-gage readings. This is because they are based not on the measured deflections themselves, but on small differences between the measured deflections.

(3) *Theoretical computation of stresses.*—An attempt was made to compute the stresses in the bearing plates from formulas which were derived analytically, on the basis of simplifying assumptions. The stresses in the plates were first computed by assuming that the plate was divided into strips parallel to the webs of the columns, supported on the flanges of the lower column and loaded as beams by the flanges of the upper column. The stresses in these strips were computed by using the usual formulas for simple beams. The stresses were, also, computed by considering the portion of the plate on one side of the axial plane through the middle of the web of the lower column. This portion of the plate was assumed to be uniformly supported along three edges by the two flanges and the web of the lower column and loaded uniformly by the flange or flanges of the upper column. The values of the stresses obtained by these methods agreed with those determined from the strain-gage measurements only in order of magnitude.

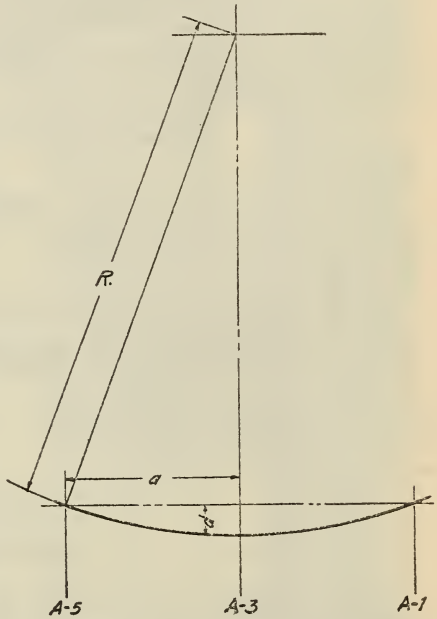


FIGURE 17.—*Deflection of gage point A–3 relative to a line through A–1 and A–5*

The conditions in the specimens which were tested were very different from those which were assumed and were for practical purposes indeterminate. In particular, the load on the plates was far from uniform. Comparatively small changes in the location of the action lines of the resultant loads caused large changes in the magnitude of the computed stress.

The shearing stresses in the plates were very high and a theoretical analysis which adequately considers their effect presents unusual difficulties. It is believed that a rational analysis of this problem is very difficult, and that a solution would be of little use to engineers designing structures of this kind.

III. TESTS TO FAILURE

1. SPECIMENS

The dimensions of the columns used in the specimens tested to failure are given in Table 7.

TABLE 7.—*Columns for specimens tested to failure*

[These data were taken from "Carnegie Beam Sections" (1st ed., 1927).]

Number of columns	Section index	Depth, nominal	Weight, nominal	Area, nominal	Length, nominal
		Inches	*Lbs./ft.*	*Square inches*	*Feet*
3	CB 105	10	140	41.17	3
3	CB 126	12	150	44.12	3
2	CB 146	14	165	48.52	3

The make-up of the four spcimens tested to failure is given in Table 8. The three columns designated "faced" had been used in the tests under low loads. Their ends had been finished in an engine lathe at the laboratory. The ends of the other five columns had been milled at the fabricating plant. The bearing plates had been used in the tests under "low loads." They had been finished in a planer at the laboratory.

TABLE 8.—*Specimens tested to failure*

Specimen No.	Columns				Plate			Column arrangement
	Upper		Lower					
	Depth nominal	Finish	Depth nominal	Finish	Length nominal	Width nominal	Thickness actual	
	Inches		*Inches*		*Inches*	*Inches*	*Inches*	
7	10	Faced	12	Faced	12½	13	1.408	Centered.
8	10	Milled	12	Milled	15½	13	1.435	Flanges in line.
9	10	do	14	Faced	15½	13	1.871	Do.
10	12	do	14	Milled	15½	14½	1.962	Do.

2. TEST PROCEDURE

(a) PROGRAM

Three specimens having the flanges in line and one having the columns centered were tested. The tests under "low loads" had shown that higher stresses occurred in the specimens with flanges in line. Specimens with flanges in line were, therefore, made for each of the possible combinations of column depths. One specimen was tested with columns centered to allow a comparison to be made of the strength of the two arrangements.

Strain-gage readings were taken on the columns for ten different loads. The deflection of the bearing plates was not measured. The tests were continued until the load decreased considerably below the maximum.

(b) STRAIN-GAGE MEASUREMENTS

The strain in the columns was measured by using a Berry strain gage on 2-inch gage lines parallel to the axes of the columns as shown in Figure 4. The location of the gage lines and the method of taking the measurements were the same as for the tests under "low loads." No strain-gage measurements were made on the bearing plate.

FIGURE 18.—*Specimen 7 after failure; 10-inch over 12-inch columns, centered; 1.408-inch bearing plate*

The plates and angles welded to the columns were used for another investigation.

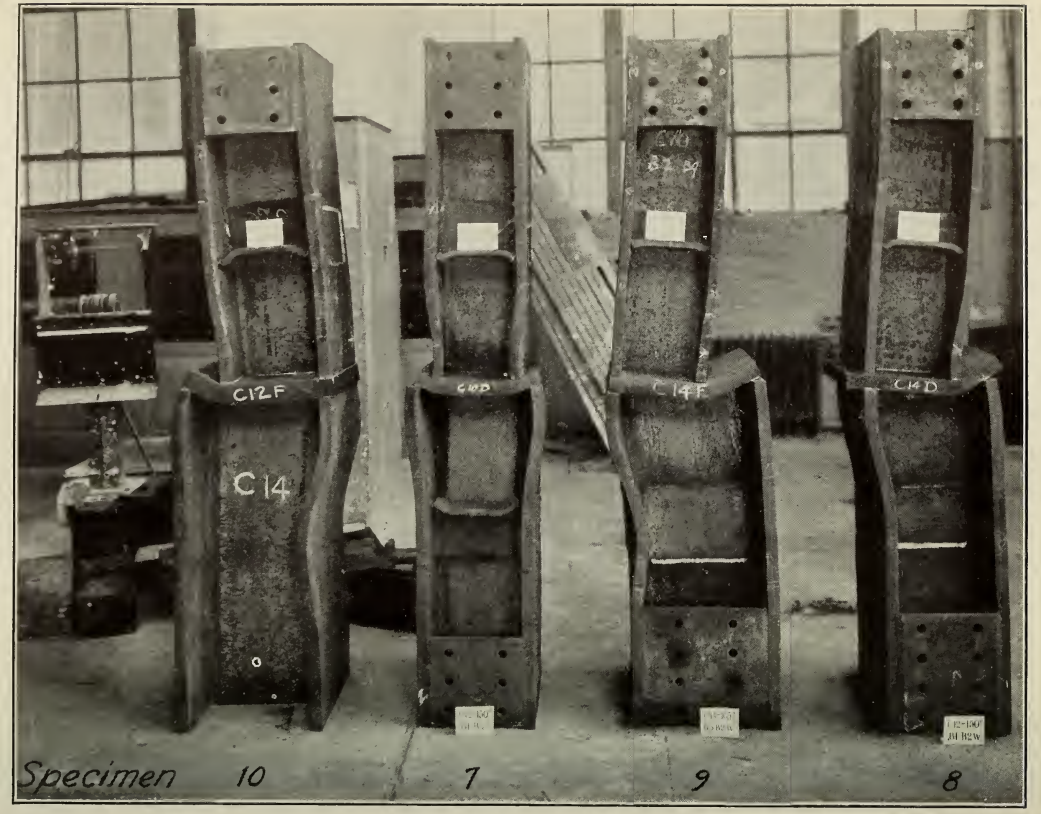


FIGURE 19.—*Specimens 7, 8, 9, and 10 after failure*

The plates and angles welded to the column were used for another investigation.

3. RESULTS AND DISCUSSION

The specimens failed at the ends of the columns near the bearing plates. Figure 18 shows specimen 7 having 10-inch over 12-inch columns, centered, after failure. Figure 19 shows all four specimens after failure. The maximum loads sustained by the specimens and the maximum average stresses in each column are given in Table 9.

TABLE 9.—*Results of tests to failure*

Specimen No.	Depth of column nominal		Plate thickness actual	Column arrangement	Maximum load	Maximum stress upper column	Average lower column
	Upper	Lower					
	Inches	*Inches*	*Inches*		*Pounds*	*Lbs./in.²*	*Lbs./in.²*
7	10	12	1.408	Centered	1,667,000	40,200	37,900
8	10	12	1.435	Flanges in line	1,516,000	36,600	34,400
9	10	14	1.871	do	1,389,700	33,500	39,000
10	12	14	1.962	do	1,639,000	37,200	34,200

Average stress-strain curves for these specimens are shown in Figures 20, 21, 22, and 23. The ordinates represent average stress computed from the total load on the specimen by assuming a uniform stress distribution over the H section. The abscissas show the average value of the strains measured on the gage lines. The origin of each curve is at the midpoint of the corresponding gage line. The short, heavy transverse lines on the curves have been drawn at a strain of 0.00069 inch per inch. This corresponds to a stress of 20,000 lbs./in.² in the material. If the stress were uniform over the H section, each of these transverse lines would pass through the point of intersection of its curve with the horizontal line corresponding to a compressive stress of 20,000 lbs./in.².

The curves show fairly uniform distribution of stress in the upper column for loads up to about 20,000 lbs./in.². At level *I*, 9 inches above the bearing plate, the curves are, in general, similar and show a tendency for the compressive strain to increase more rapidly as the load increases. At level *J*, 3 inches above the bearing plate, the strain in the web did not increase as rapidly as that in the flanges, though at low values of load the difference was small. It is evident that as the plate deflected under load the web of the upper column took less stress than the flanges.

In the lower columns these conditions were reversed. At level *K*, 3 inches below the plate, the deformation of the web was greater than that of the flanges. The same high ratio of web to flange stress was found as in the tests under "low loads." The flanges of the specimen with columns centered bent locally, as shown in Figure 18. This caused the compressive strain to decrease as the bending increased. In the specimens with flanges in line, tensile strains occurred on the outer faces of the lower-column flanges which were not in line. The compressive strains in the lower column flanges which were in line were almost as large as those in the webs. At level *L*, 9 inches below the plate, the curves were not as near alike as those for the section 9 inches from the plate in the upper column. Tensile strains occurred in the flanges not in line and high compressive strains in the flanges in line.

The 10-inch over 12-inch specimen (7) with columns centered was about 10 per cent stronger than the corresponding specimen (8) with flanges in line. It was 20 per cent stronger than the specimen (9) with 10-inch over 14-inch columns, which showed the lowest ultimate strength. With flanges in line, the latter specimen was subjected to a greater eccentricity of loading. In addition, the deflection of the bearing plate was greater because the load from the unsupported flange of the upper column was applied closer

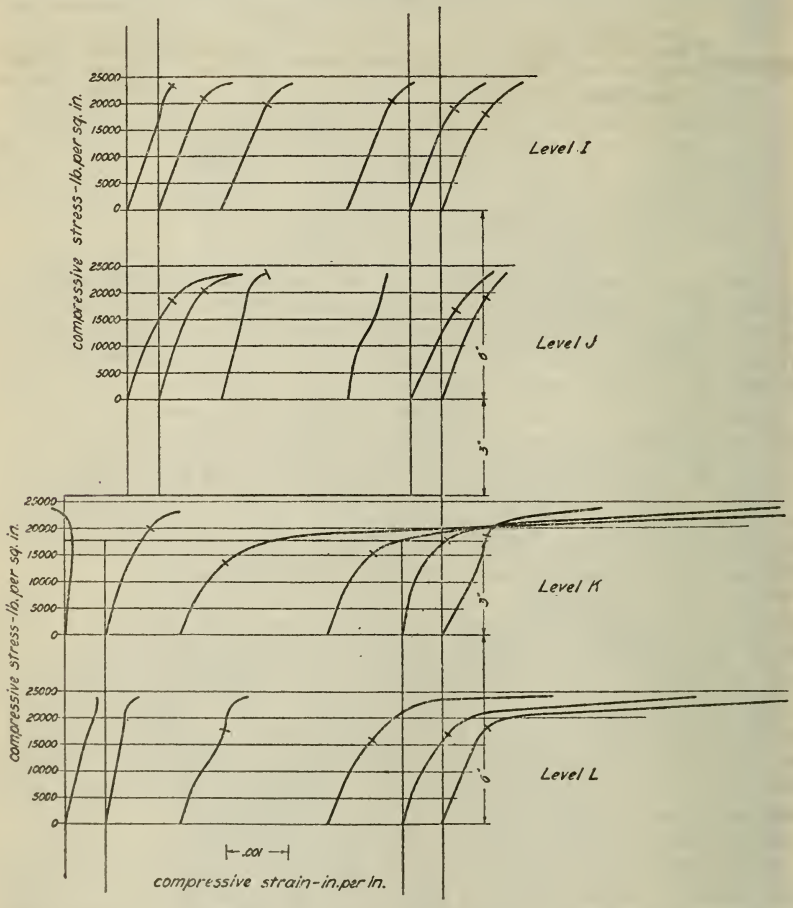


FIGURE 20.—*Stress-strain diagrams for specimen 7; 10-inch over 12-inch columns, centered; 1.408-inch bearing plate; maximum load, 1,667,000 pounds*

to midspan. This greater deflection caused higher stress in the web of the lower column, with failure at a lower load.

The mill tests on coupons taken from the material from which these columns were cut showed a yield point of 36,900 lbs./in.^{2} for the 10-inch columns, 37,000 lbs./in.^{2} for the 12-inch columns, and 37,500 lbs./in.^{2} for the 14-inch columns. With the exception of specimen 9 having 10-inch over 14-inch columns, the other three specimens had approximately the ultimate strength that would be

expected of a single H section having the cross-sectional dimensions of the upper column of the specimen and a length equal to that of the specimen.

IV. TESTS UNDER REPEATED LOAD

1. SPECIMEN

The specimen used in the repeated-load test consisted of a 10-inch H section over a 12-inch H section with the columns centered.

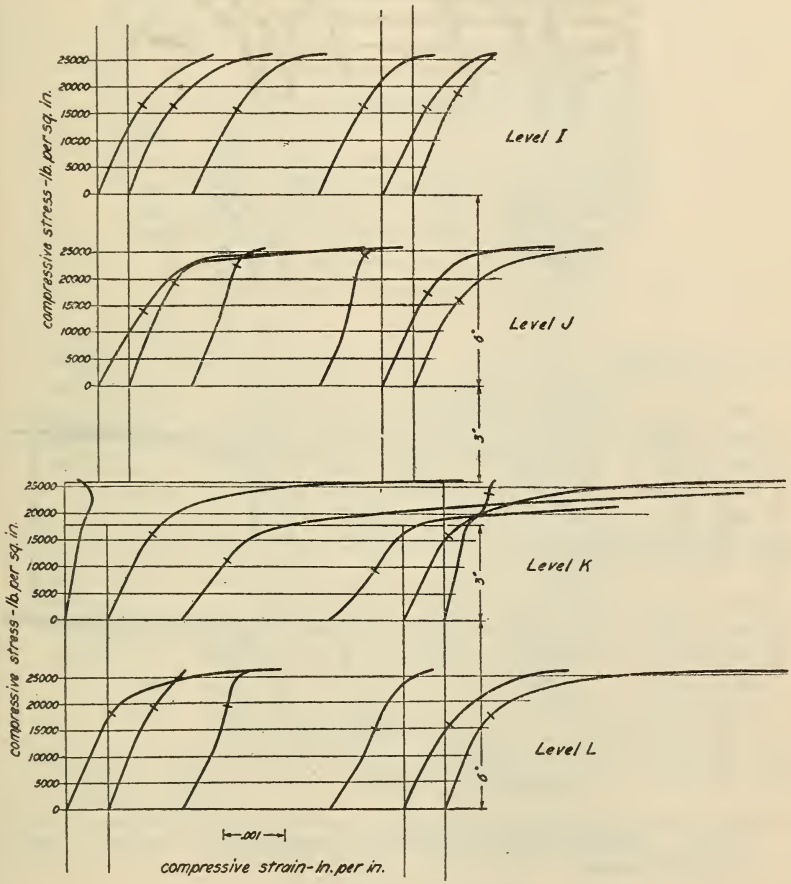


FIGURE 21.—*Stress-strain diagrams for specimen 8; 10-inch over 12-inch columns, flanges in line; 1.435-inch bearing plate; maximum load, 1,516,000 pounds*

The bearing plate was 13 by 12½ by 1.899 inches. The dimensions of the columns are given in Table 10. The ends of the columns had been milled at the fabricating plant, and the plate had been faced in a planer at the laboratory. The plate had been used in the tests under the "low loads"; the columns had not been used in any other tests.

TABLE 10.—*Column tested under repeated load*

Number of pieces	Section index	Depth, nominal	Weight, nominal	Area, nominal	Length, nominal
		Inches	*Lbs./ft.*	*Square inches*	*Feet*
1	CB 105	10	140	41.17	3
1	CB 126	12	150	44.12	3

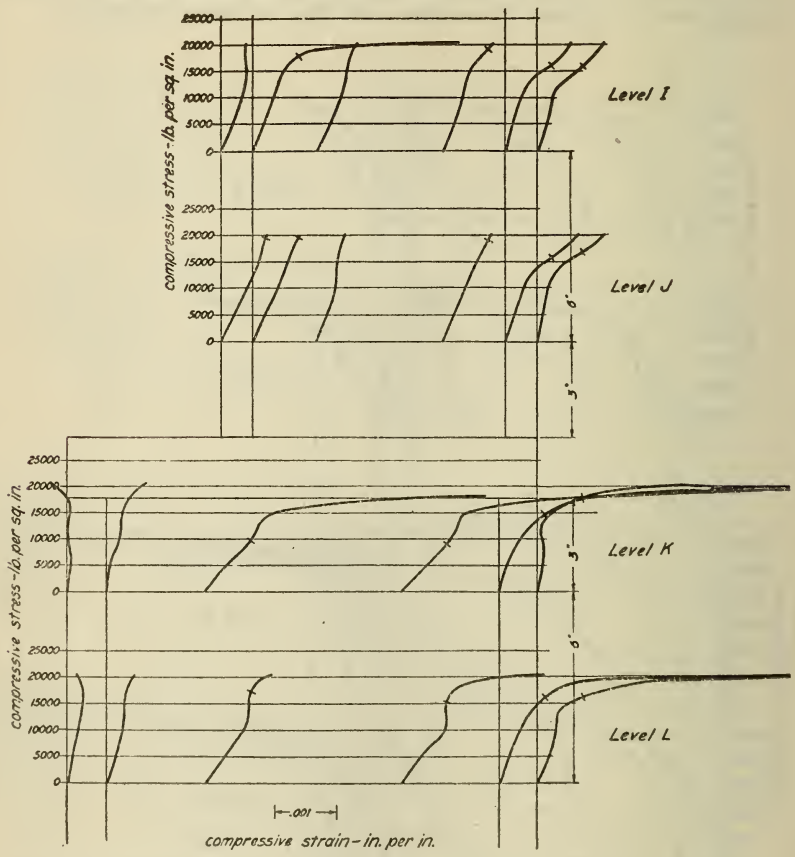


FIGURE 22.—*Stress-strain diagrams for specimen 9; 10-inch over 12-inch columns, flanges in line; 1.871-inch bearing plate; maximum load, 1,389,000 pounds*

2. TEST PROCEDURE

(a) PROGRAM

One specimen was loaded nine times, each time a loading range from 50,000 to 660,000 pounds being used, to determine the effect of repetitions of load on the magnitude and distribution of the stress and to give further assurance that the proportional limit was not passed in the specimens tested under "low loads." The maximum load applied gave a stress of 16,000 lbs./in.^{2} in the upper column.

Strain-gage readings were taken on the first three and the ninth loadings and deflection readings on the other loadings. With the apparatus used to measure the deflection of the bearing plate, measurements of strain and deflection could not both be made for the same loading. The test program is given in Table 11.

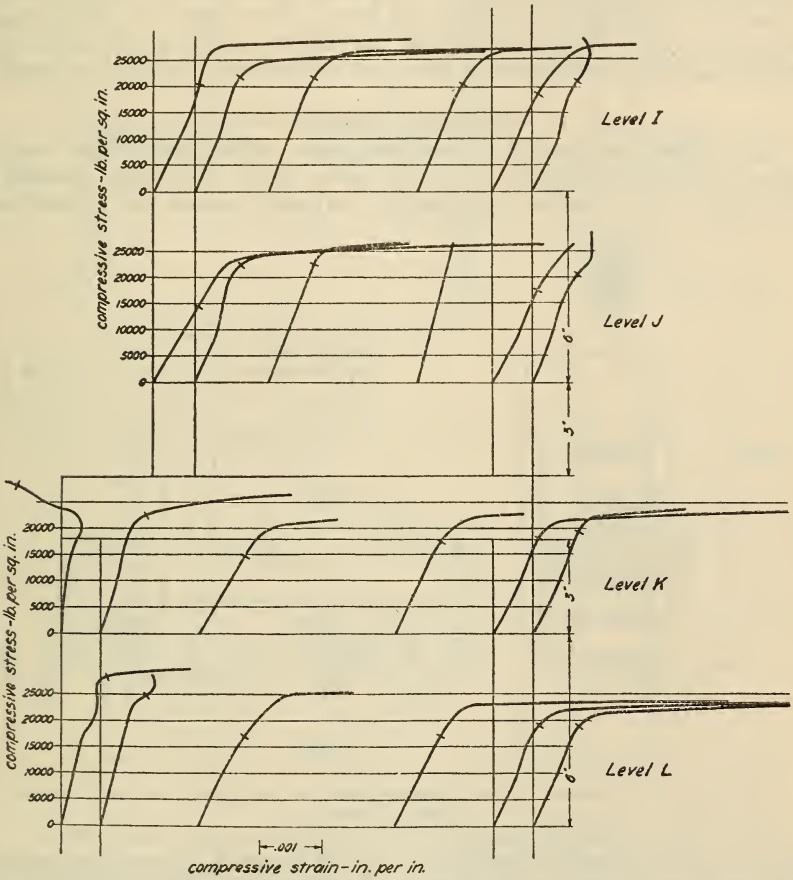


FIGURE 23.—*Stress-strain diagrams for specimen 10; 12-inch over 14-inch columns, flanges in line; 1.962-inch bearing plate; maximum load, 1,639,000 pounds*

TABLE 11.—*Repeated-load test program*

Loading No.	Kind of reading
1	Strain gage.
2	Do.
3	Do.
4	Deflection.
5	Do.
6	Do.
7	Do.
8	Do.
9	Strain gage.

(b) STRAIN-GAGE MEASUREMENTS

The strain in the columns was measured on 2-inch gage lines laid off parallel to the axes of the columns as shown in Figure 24. There were 24 lines at each of three levels on each column. As measured from the midpoints of the gage lines, these levels were 3, 9, and 18 inches from the bearing plate. They have been designated *H*, *I*, *J*, *K*, *L*, and *M*, beginning with the top level. Two types of strain gages were used, the Whittemore and the Berry. The gages were calibrated and the readings were taken as in the tests under "low loads."

(c) DEFLECTION MEASUREMENTS

The apparatus used for measuring the deflection of the bearing plate is shown in Figure 25. Four pins, *A–A*, *B–B* were secured in the sides of the plate at mid height, vertically above the center lines

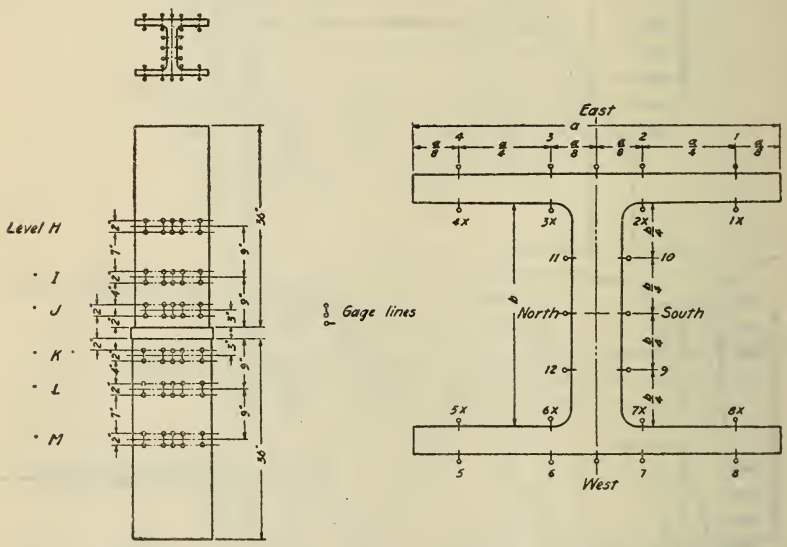


FIGURE 24.—*Location of strain-gage lines on the specimen tested under repeated loads*

of the flanges of the lower column. A stiff frame, *C*, was placed around the plate and rested on the pins. Notches in the frame located the frame on the pins *A–A* and horizontal surfaces of the frame rested on the pins *B–B*. The horizontal bars *D–D* below the bearing plate were secured to the frame *C* and each carried three dial micrometers *E–E*. The spindles of these dials were in contact with the lower surface of the bearing plate. The deflection of the plate under load was indicated on these dials. The deflection was measured only for the six gage points on line 3 shown in Figure 6.

3. RESULTS AND DISCUSSION

The stresses at each of the six levels of gage lines on the columns were computed from the strain-gage readings. The stress values for the first and ninth loadings are given in Figure 26.

The measured deflections of the bearing plate are given in Table 12. After the first five loadings there was no appreciable change due to subsequent loads, although there was a slight indication of increasing

deformation in the first few loadings for which deflection readings were taken. This was presumably caused by yielding under local bearing stresses and is of little importance from an engineering standpoint.

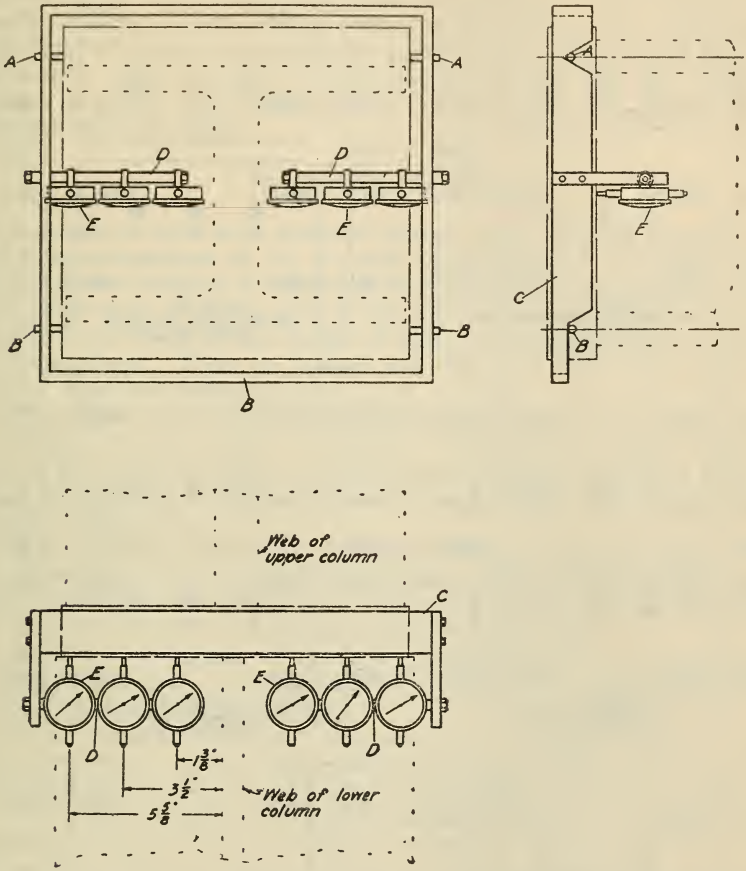


FIGURE 25.—*Apparatus used for measuring the deflection of the bearing plate*

The stiff frame *C* rested on four pins *A–A*, *B–B* secured in the plate. The dial micrometers *E* were carried by horizontal bars *D–D* secured to the frame. The deflection was measured only for the six gage points on line 3 shown in Figure 6.

TABLE 12.—*Deflection of bearing plate*

Loading No.	Deflection at distance from face of web of lower column (inches)					
	North			South		
	5⅝	3½	1⅜	1⅜	3½	5⅝
	Inch	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*
4	0.0060	0.0052	0.0040	0.0040	0.0050	0.0062
5	.0055	.0046	.0035	.0033	.0048	.0060
6	.0054	.0048	.0038	.0036	.0049	.0061
7	.0054	.0046	.0034	.0033	.0049	.0061
8	.0054	.0050	.0040	.0037	.0048	.0061

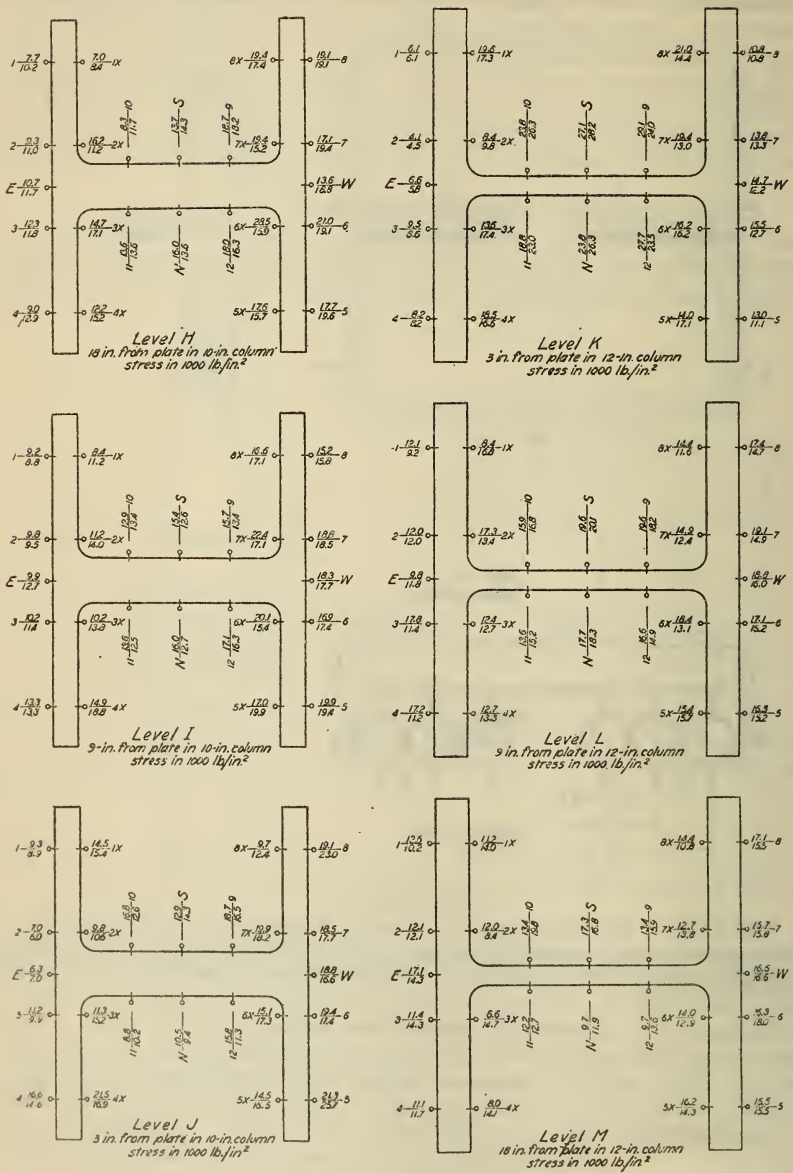


FIGURE 26.—*Stresses in specimen tested under repeated load. Stresses are in kips. One kip equals 1,000 lbs./in.²*

Stresses for the first loading are given above the line and for the ninth loading below the line. The symbol at the end of each line designates the gage line.

Loading the specimen nine times to 660,000 pounds caused no appreciable permanent set in the material in the portions of the specimen on which strain measurements were made. The changes found in the readings were not greater than those which could be caused by observational and instrumental errors and by high local stresses due to the irregularities of the bearing surfaces of the plate and H sections. There is no reason to believe that repeating this load an indefinite number of times would appreciably change the readings observed after the ninth loading.

V. CONCLUSIONS

Compressive tests were made of jointed steel columns consisting of various combinations of 10, 12, and 14 inch rolled H sections with bearing plates ranging in thickness from 1 inch to 4¼ inches. Some of the tests were with the axes of the columns in line, the others were with the outer faces of one flange of both upper and lower columns in the same plane. Tests to failure and repeated load tests were included. The conclusions are:

1. The stress in the web of the columns was greater than the average stress over the entire H section. The ratio of web stress to average stress was greatest in the lower column near the bearing plate. The average value of this ratio at 3 inches below the bearing plate was 2.04.
2. The stress in the web of the lower column was very high for 10-inch H sections over 14-inch H sections. The highest ratio of web stress to average stress was 3.10. The use of heavy 10-inch H sections directly over 14-inch H sections is not recommended.
3. With the exception of the 10-inch over 14-inch specimens, the stress in the columns with plates over 2 inches thick was only slightly less than that with 2-inch plates.
4. The maximum bending stresses in the bearing plates for all thicknesses from 1 inch to 4¼ inches were considerably lower than the value of 16,000 lbs./in.^{2} usually used in the design of steel structures.
5. With the exception of the 10-inch over 14-inch specimen, the ultimate strength of the specimens tested to failure was about the same as that of a single H section having the cross-sectional dimensions of the smaller column of the specimen and a length equal to that of the specimen.
6. No appreciable change in the stresses in the columns nor in the deflections of the bearing plate was observed after nine repetitions of the load giving an average stress of 16,000 lbs./in.^{2} in the smaller (upper) column.