1933

Fifth progress report on column tests at Lehigh University, Proc. AC1, Vol. 29 (1933), p. 433, Reprint No. 20(33-4)

I. Lyse

FIFTH PROGRESS REPORT ON COLUMN TESTS AT LEHIGH UNIVERSITY

by Inge Lyse*

SERIES 4 - TESTS ON THE AMOUNT OF LOAD A REINFORCED CONCRETE COLUMN WILL SUSTAIN INDEFINITELY

1. INTRODUCTION

The maximum load which a reinforced concrete column can sustain indefinitely has long been of interest to designers. Series 4 of the column investigation was therefore designed for the purpose of ascertaining how large a load could be carried for a reasonably long period of time. The program of tests is given in Table 1.

Table 1

Design Strength of Concrete, 3500 lb. per sq.in.

L = longitudinal reinforcement, per cent

S = spiral reinforcement, per cent

Test Load percent	Number of Columns Having Reinforcement of 4L+0S Group A	4L+1.2S Group B	4L+2.0S Group C	6L+2.0S Group D	Total No. of Columns
100	3	3	3	3	12
95	1	1	1	1	4
90	1	1	1	1	4
80	1	1	1	1	4
70	1	1	1	1	4
Total	7	7	7	7	28

* Research Assistant Professor of Engineering Materials
Lehigh University, Bethlehem, Pennsylvania

The columns included in this series of tests had an outside diameter of 8-1/4 in. and an overall length of 60 in. The concrete was designed for a strength of 3500 lb. per sq. in. at the age of 56 days, and both the longitudinal and the spiral reinforcement were of intermediate grade steel. The cement and aggregates used were from the same supply as those used in the previously reported series. The method of making, storing and testing to failure of the columns was also the same as that used in other series.

Particular acknowledgment is made to C. L. Kreidler, formerly Research Fellow in Civil Engineering, for the carrying out of these tests and for the reduction of the data.

2. CONTROL SPECIMENS

The consistency of the concrete as measured by the slump cone, varied from 2-1/2 to 4-1/4 in. for the four groups of columns. Due to a break-down of the 800,000-lb. testing machine Group B could not be tested at the scheduled age of 56 days and was tested at an age of 112 days instead. The average compressive strengths of the concrete were 3780, 4140, 3430 and 3360 lb. per sq.in. for Groups A, B, C and D respectively. The average results of the coupon tests of the reinforcement gave a tensile yield-point stress of 44,000 lb. per sq.in. and an ultimate of 64,400 lb. per sq.in. for the longitudinal steel used in the columns having 4 per cent reinforcement, and 44,700 and 70,000 lb. per sq.in. for yield-point and ultimate stress for the columns having 6 per cent reinforcement. No yield-point stress could be obtained on the spirals. The ultimate strength of the spiral reinforcement was 85,500 and 74,700 lb.per sq.in. for 1.2 and 2.0 per cent respectively.

In order to study whether the stressing of the longitudinal reinforcement beyond the yield-point stress in compression affected the load-carrying capacity of the reinforcement, compression tests were made on 3-in. long coupons which were cut from the 1/2-in. square bars used as reinforcement. The load-deformation curve for one of these coupons is shown in Fig. 1. It is noted that the load was released and reapplied at a strain below the yield-point, also at a strain slightly above the yield point, and again at a strain about fifteen times the initial yield-point strain of the steel. The bar continued to carry its full yield-point load at strains far above the yield-point strain. The yield-point stress was only slightly affected by excessive strains and the elastic properties of the steel remained the same. Although the strains were more than fifteen times the yield-point strain of the steel, the total load carried at these strains was only slightly greater than the original yield-point strength. The extreme amount of shortening shown in Fig. 1 is about 2.6 per cent.

3. COLUMNS

Three columns of each group were tested "fast" directly to failure in the same manner as that described in the First Progress Report from Lehigh University. A spherical bearing block was used at the top of the column and no attempt was made to restrict the motion of this block. The columns which were scheduled to sustain loads for a long period, were placed in a loading rig as shown in Fig. 2. This loading rig consisted of a number of heavy helical springs, three steel plates and four tension rods. A total of five rigs were made for these tests. The rods and plates for these rigs were donated by the Bethlehem Steel Company of Bethlehem, Pennsylvania, and fifty of the helical springs were loaned to the laboratory for three years through the courtesy of the Lehigh Valley Railroad Company.

The method of loading a column in the rig consisted of assembling the column and the loading rig on the floor of the laboratory and then placing the assembly on the table of the 800,000-lb. testing machine. The free space between the column and the rods was 1/2 in. Load was applied by bringing the head of the machine down on the loading rig, thus compressing the column and the springs until the correct load was reached. At this stage there was no load in the tension rods. Two 10-in. gage-lengths had been placed on each rod. The gage lengths were located on the opposite ends of the same diameter of the rod. Strain gage readings were taken on these gage lengths in order to establish a zero reading, the nuts were tightened on the rods, and the load exerted by the testing machine was released. The load on the columns was controlled by adjusting the nuts until the proper average strain was observed in the tension rods. Since the load was measured by the strains in the rods it was necessary to determine their modulus of elasticity. The resulting deformation diagram is shown in Fig.3. The modulus of elasticity as taken ffom this diagram was 29,450,000 lb. per sq.in.

The procedure for checking the load on the column was the same as for the loading. A new zero reading was taken on the rods each time the load was adjusted.

The summarized data of the column tests are given in Table 2. It is noted that 15-1/2 months elapsed between the making of the first and the last columns of this series. The time of making the columns was governed by the time at which loading rigs were available. The deterioration of the cement as measured by the compressive strength, was quite small during this time.

4. FAST LOADING

The results of the columns loaded "fast" to failure are presented in Table 2. In Fig. 4 the strengths of the columns having 4 per cent longitudinal reinforcement have been plotted against the percentage of spiral reinforcement.

The effect of the amount of spiral reinforcement on the load-deformation curve is shown in Fig. 5. The three curves in Fig. 5 lie so close together that the modulus of elasticity of the concrete in the columns seems to determine the position of the curves. Since the modulus of elasticity varies with the strength of the concrete, the columns having the highest cylinder strength should show the least strain at a given load. The curves in Fig. 5 arrange themselves in order of their cylinder strength so that it is reasonable to conclude that the spiral reinforcement had no effect on the stress-strain relation within the range of loads for which strain measurements were taken.

The effect of the amount of longitudinal reinforcement on the deformation of the columns is well illustrated in Fig. 6. It is noted that when the load carried by the longitudinal reinforcement is subtracted from the total load on the column, the stress-strain curves for the columns having 6 per cent and 4 per cent longitudinal reinforcement very nearly coincide. This means that the longitudinal reinforcement added its full stress value at any strain in the column.

5. TIME EFFECT

In Group A the three columns loaded "fast" to failure gave an average ultimate load of 217,000 lb., which was taken as the 100 per cent strength of all the columns in this group.

The columns in this group had 4 per cent longitudinal and 0 per cent spiral reinforcement. Column 4 was to be subjected to 95 per cent of the ultimate strength, but failed at a load of 93 per cent. Column 5 sustained 90 per cent of the load but held the load for only a few minutes. Column 6 was subjected to a load of 80 per cent, and Column 7 to 70 per cent. Because Column 6 showed no sign of distress it was deemed profitable to remove Column 7 from the rig and load it to failure, thus making the rig available for another column. Column 7 had been under 70 per cent of its ultimate load for 115 days when it was removed from the rig and loaded "fast" to failure. The deformation curves for Columns 6 and 7 are shown in Fig. 7. Column 7 developed lateral cracks during the release of the load. These cracks closed during the loading to failure and the column carried an ultimate load of 253,000 lb. or 17 per cent greater than the average ultimate load for the three columns which were loaded to failure at the age of 56 days. The fact that the longitudinal reinforcement had been stressed far beyond its yield point during the time under load evidently did not have any detrimental effect upon the ultimate load of the column. Column 6, which is sustaining a load of 80 per cent of its ultimate, has been under this load for 700 days. The deformation curve for this period is shown in Fig. 8. It is noted that for the first year under load the deformation increased quite fast. From then on the deformation increased very slowly, but has not stopped entirely as yet. At present the deformation of the column is approximately four times the yield-point strain of the longitudinal reinforcement. Except for a few vertical cracks near the ends of the column, which developed shortly after the column had been placed under load, no sign of distress is present. It may be concluded, therefore, that this column will carry 80 per cent of its ultimate strength indefinitely.

As previously stated, the columns in Group B were tested at the age of 112 days. The columns in this group had 4 per cent longitudinal and 1.2 per cent spiral reinforcement. The average ultimate strength of the three columns loaded "fast" to failure was 282,000 lb. Column 11 was placed under 95 per cent of this ultimate load and held this load for 45 minutes before failing. Column 12 sustained 90 per cent of the ultimate for 65 hours but deflected laterally so much that it rested against the tension rods of the rig. It was therefore removed from the rig and loaded to failure. The ultimate load was 287,000 lb. Column 13 was also subjected to 90 per cent of the ultimate and has sustained this load for 500 days. The deformation curve for this column is shown in Fig. 8, and it is noted that the strain is now approximately ten times the yield-point strain of the longitudinal reinforcement. Column 13 does not appear to be in immediate danger of failure, although the concrete outside the spiral has spalled off at several places as shown in Fig. 9. Column 14 was not placed under load but was stored with Column 13 as a control column for temperature and shrinkage strain. The maximum temperature and shrinkage strains to date correspond to a stress of approximately 7500 lb. per sq.in. in the longitudinal reinforcement.

The columns in Group C had 4 per cent longitudinal and 2.0 per cent spiral reinforcement. The average ultimate load for the three columns loaded "fast" to failure was 304,000 lb. Column 18 held 95 per cent of its ultimate for one day, but had then buckled so badly that the test was discontinued. Column 19 held 90 per cent of its ultimate for one day. It had then buckled so much that it touched the tension rods and the test was discontinued. Column 20 was placed under 85 per cent of its ultimate and has been under this load for more than 300 days. The average strain in the longitudinal reinforcement is at present about seven times the yield-point strain of the steel. The column has gradually buckled under this load so that at present it is touching one of the tension rods of the rig. This column should therefore be considered as failing under 85 per cent of its ultimate load. Column 21 was placed under 80 per cent of its ultimate load and has sustained this load for more than 300 days. At present the average strain in the steel in this column is 5-1/2 times its yield-point strain. The column shows no sign of immediate danger of failure, but it has buckled so much that it nearly touches the tension rods, and the concrete outside the spiral has begun to spall off.

The columns in Group D had 6 per cent longitudinal and 2 per cent spiral reinforcement. The average ultimate strength of the three columns loaded "fast" to failure was 335,000 lb. Column 25 was placed under a load of 90 percent of the ultimate and has sustained this load for nearly 300 days. The column deformed very much under this load and at present the average strain in the steel is about 7-1/2 times its yield-point strain. The large deformation caused the concrete outside the spiral to spall off at different places on the column and the column deflected so much that it is now touching one of the tension rods. Column 25 may therefore be considered as failing under a load of 90 per cent of its ultimate. Columns 26, 27 and 28 are being stored in the moist room for later tests, no loading rig being available as yet.

The time-strain curves for all the columns sustaining loads are shown in Fig. 8, and a photograph of these columns is presented in Fig. 9.

6. EFFECT OF RELEASE OF LOAD

In order to subject the five loaded columns to a more severe condition than the mere sustaining of load, it was decided to entirely release and then reapply the load. An extra load of 10,000 lb. was placed on the column, the nuts on the tension rods loosened, and the load released. After a few minutes the load was reapplied and the column subjected to further testing. Column 6 was tested first. When the load was released the vertical cracks in the column extended further, but no other change was apparent. During the reapplication of the load the column showed no further sign of distress until the correct load of 174,000 lb. was reached. At this load the column failed with a loud report. The vertical reinforcing bars all buckled perpendicularly to the surface of the column as shown in Fig. 10. Evidently the release of the load caused the reinforcement to slip with respect to the concrete near the ends of the column. This slip caused extension of the vertical cracks, and when the load was reapplied the reinforcing bars were free to take on initial buckling. The bars were covered with only a 1/2-in. layer of concrete and therefore had little lateral restraint. Consequently the bars buckled.

Column 13 scaled off to a larger extent during the reapplication of the load and also showed sign of initial bending. Otherwise no sign of distress appeared. The column is therefore sustaining a load of 254,000 lb. for an additional length of time.

Column 20 had buckled sufficiently to lean against the tension rods before the load was released. The column was moved away from the tension rods before the reapplication of the load. During the reapplication of the load the buckling increased to such an extent that the column touched the rods. Since it was deemed of little value to continue the loading of a column which was restrained against further buckling, the column was removed from the loading rig and loaded to failure. The maximum load was 385,000 lb., or 27 per cent more than the original strength of the companion columns.

Column 21 was subjected to the same cycle of test. Except for a slight extension of the flaking off, the column showed no sign of increased distress. The column is therefore sustaining load for further tests.

Column 25 leaned heavily against the tension rods prior to the release of the load. As it had already been moved away from the rods the total buckling was about one inch, and the column was removed from the loading rig and loaded directly to failure. The ~~ultimate~~ maximum load was 417,400 lb., or 25 per cent more than the original strength of the companion columns.

The release of the load on these columns which had strains in the longitudinal reinforcement far above the yield-point strain of the steel, evidently produced additional distress in the columns. For the tied column which had only a 1/2-in. layer of concrete for protection of the reinforcement, the release of the load caused sufficient reduction in the lateral restraint to permit buckling of the bars.

7. SUMMARY

While the number of tests included in this series was entirely inadequate for drawing ~~definite~~ final conclusions, the tests indicated that:

1. The stress-strain curve for columns loaded "fast" were substantially equal to the summation of the stress-strain curves for the longitudinal reinforcement and the concrete.

2. The amount of spiral reinforcement did not affect the stress-strain relation for the column at strains less than the yield-point strain of the longitudinal reinforcement.

3. The longitudinal reinforcement will carry its full yield-point stress at strains far beyond the yield-point strains.

4. The strength of the column was not decreased by being strained far beyond the yield point of its steel before the loading to failure.

5. A reinforced concrete column (tied or spiral column) will probably carry nearly 80 per cent of its ultimate load for an indefinite length of time.

6. A column of no spiral or a small amount of spiral reinforcement will carry 80 per cent of its ultimate load at less deformation and less sign of distress than will a column having a larger amount of spiral reinforcement.

7. The release of the sustained load caused additional distress in the columns and the tied column failed due to buckling of the reinforcing bars.

Fritz Engineering Laboratory
Lehigh University

January 24, 1933

TABLE 2 - SUMMARIZED DATA ON COLUMNS

Col. No.	Date Made	Slump in.	Load %	Load lb.	Remarks
Group A - 4% Longitudinal Reinforcement, 0% Spiral Reinforcement					
1	11-18-30	2-1/2	100	220,000	Loaded "fast" to failure
2	11-18-30	3	100	202,500	Loaded "fast" to failure
3	11-18-30	2-3/4	100	229,000	Loaded "fast" to failure
4	11-19-30	2	95	206,000	Reached only 202,300 lb.
5	11-19-30	2-1/2	90	195,000	Held load for only a few minutes
6	11-24-30	2-1/2	80	174,000	Under test
7	11-24-30	2-1/2	70	152,000	Held load for 115 days, loaded to failure, ult.load 253,000 lb.
Group B - 4% Longitudinal Reinforcement, 1.2% Spiral Reinforcement					
8	1-21-31	3	100	282,000	Loaded "fast" to failure
9	1-21-31	5	100	290,500	Loaded "fast" to failure
10	1-21-31	6	100	275,000	Loaded "fast" to failure
11	1-22-31	5	95	268,000	Held load for 45 minutes
12	1-22-31	5	90	254,000	Held load for 65 hours, ult.load 286,800 lb.
13	1-27-31	3	90	254,000	Under test
14	1-27-31	3	-	---	Stored in laboratory under no load
Group C - 4% Longitudinal Reinforcement, 2.0% Spiral Reinforcement					
15	12-10-31	3-1/2	100	290,000	Loaded "fast" to failure
16	12-10-31	3	100	301,000	Loaded "fast" to failure
17	12-10-31	3	100	322,000	Loaded "fast" to failure
18	12-10-31	3	95	289,000	Held load for one day
19	12-22-31	2-1/2	90	274,000	Held load for one day
20	12-22-31	4	85	258,000	Under test
21	12-22-31	3	80	243,000	Under test
Group D - 6% Longitudinal Reinforcement, 2.0% Spiral Reinforcement					
22	1-28-32	3-1/2	100	337,000	Loaded "fast" to failure
23	1-28-32	3-1/2	100	355,000	Loaded "fast" to failure
24	1-28-32	3-1/2	100	311,000	Loaded "fast" to failure
25	1-28-32	3-1/2	90	302,000	Under test
26	3- 1-32	2-1/2	-	---	Stored in
27	3- 1-32	3	-	---	moist room
28	3- 1-32	3	-	---	for later test

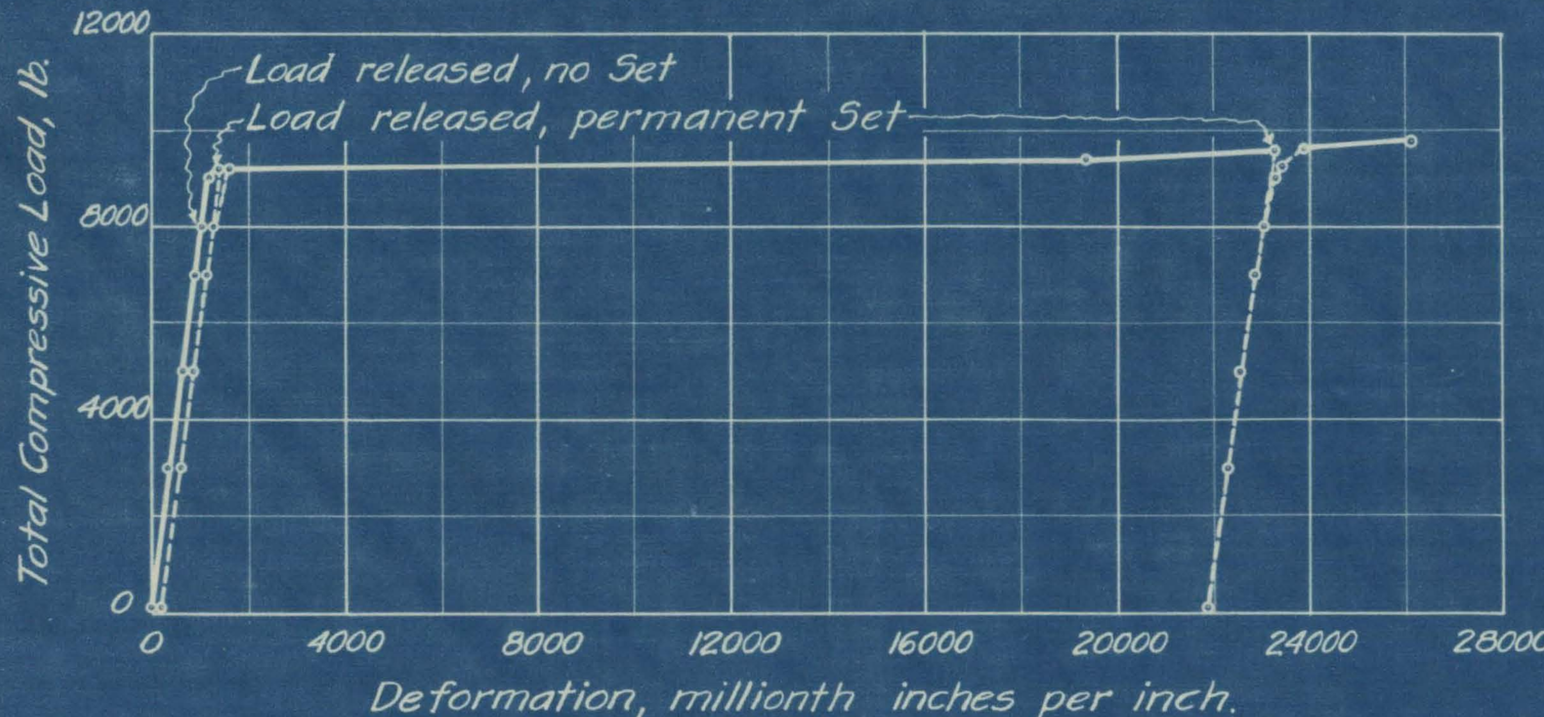

Fig. 1 – Load-Deformation Diagram for ½" sq. Bar, 3" in Length, cut from Longitudinal Reinforcement on Stock Pile.

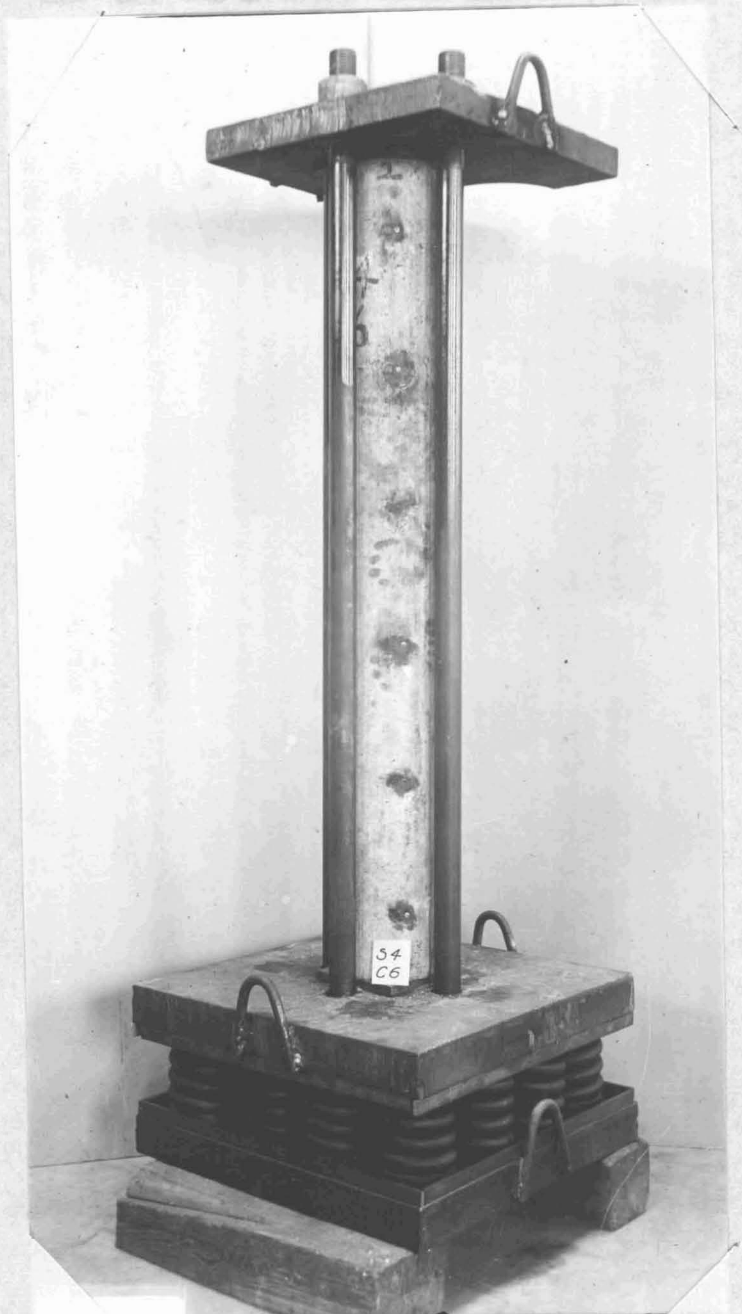

Fig. 2 - Loading Rig for Columns

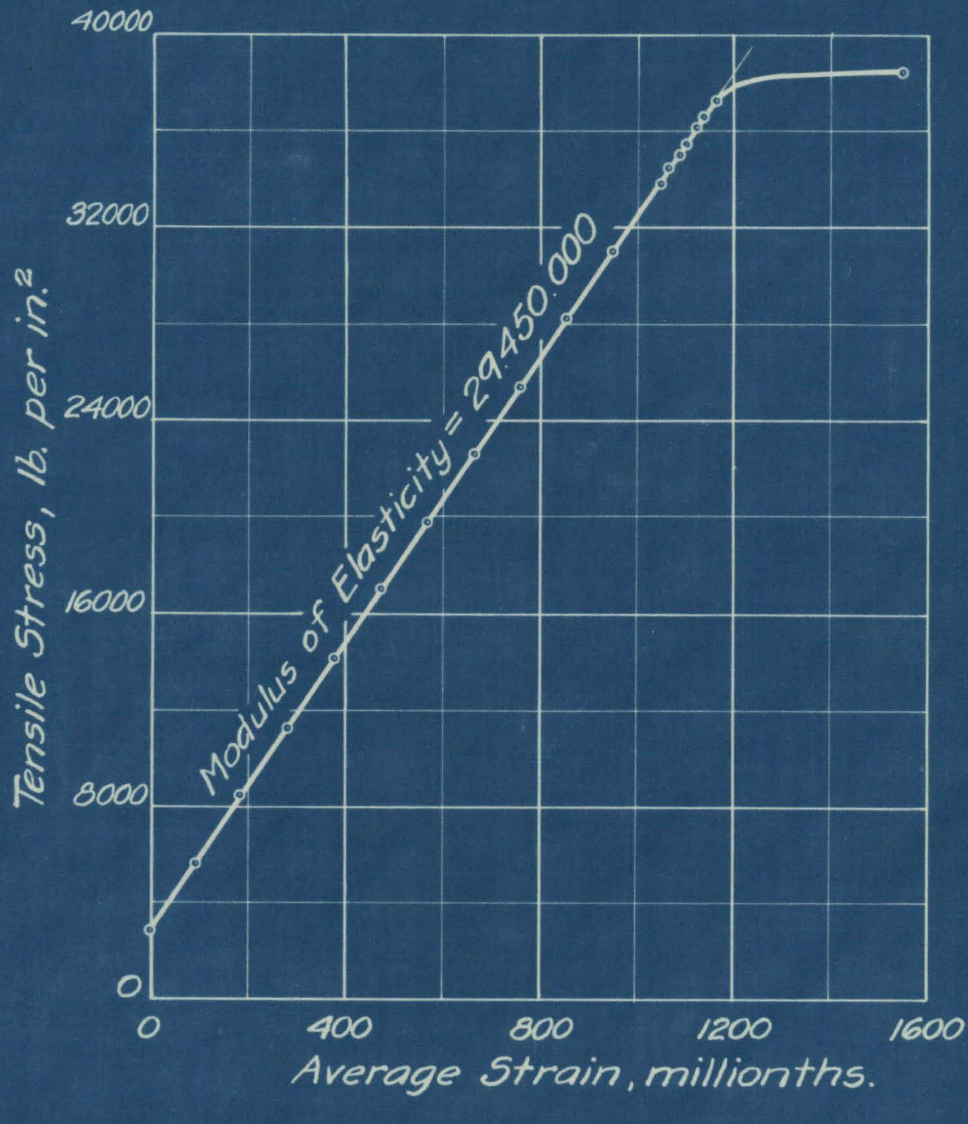

Fig. 3 - Stress-Strain Curve for Tension Rods used in Loading Rigs.

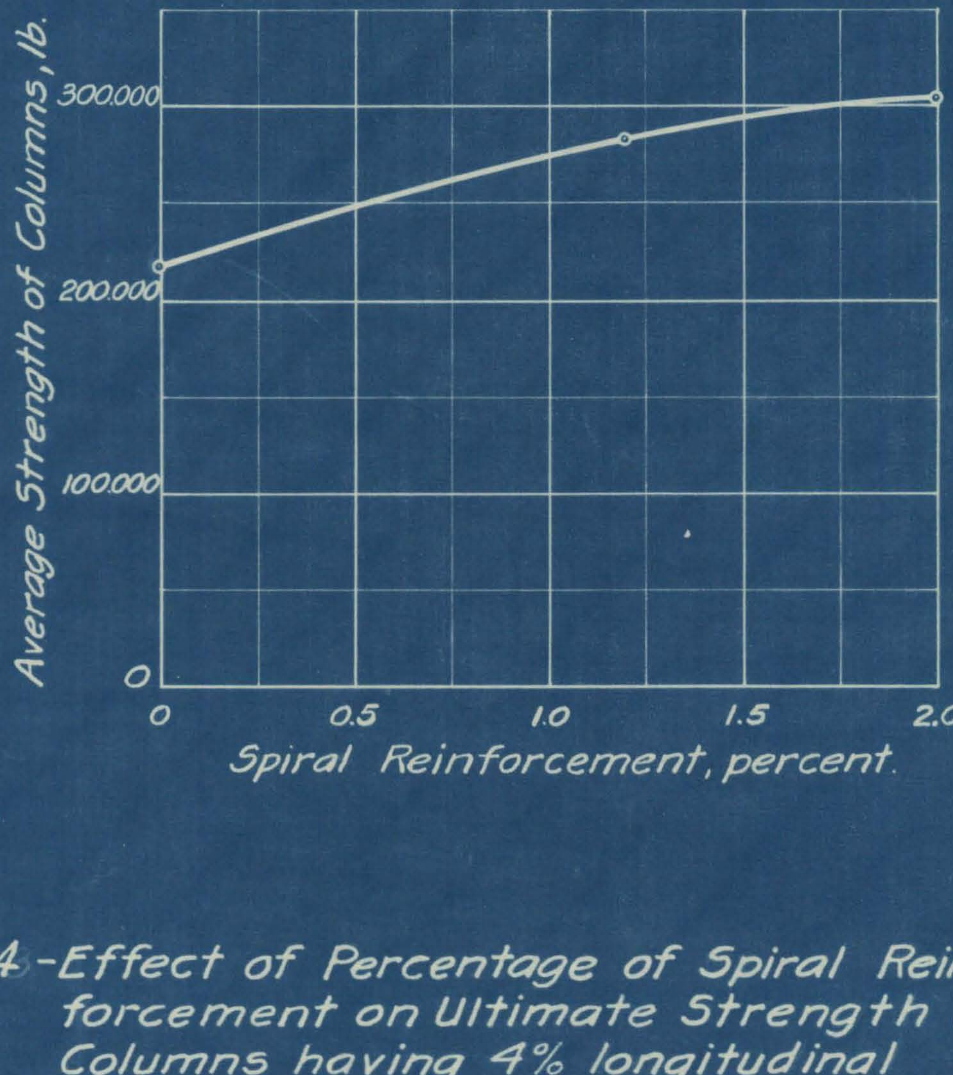

Fig. 4 -Effect of Percentage of Spiral Reinforcement on Ultimate Strength of Columns having 4% longitudinal Reinforcement.

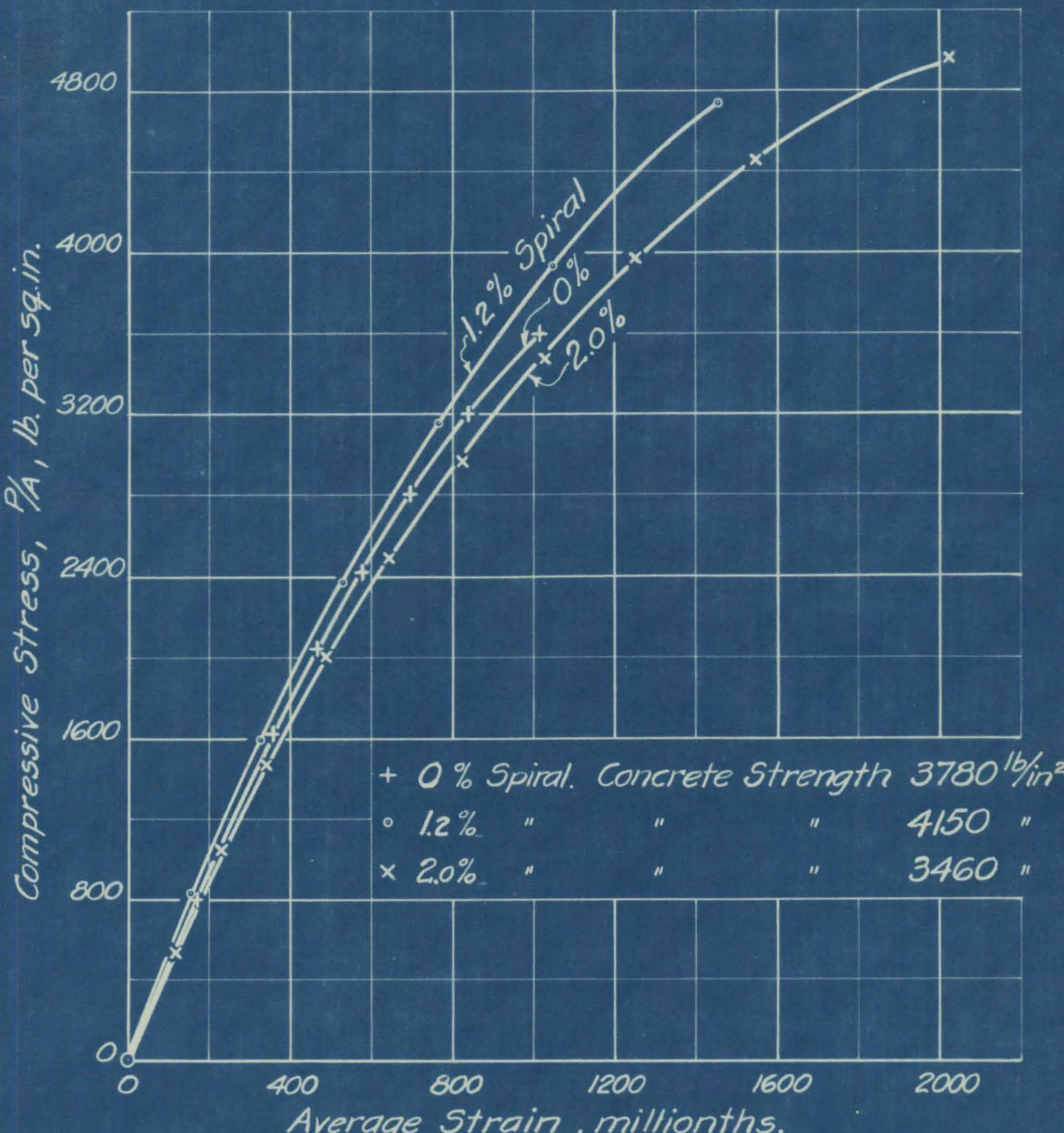

Fig. 5 - Stress-Strain Diagrams for Columns, loaded "Fast" to Failure, showing Effect of Spiral Reinforcement on the Strains. Longitudinal Reinforcement 4%.

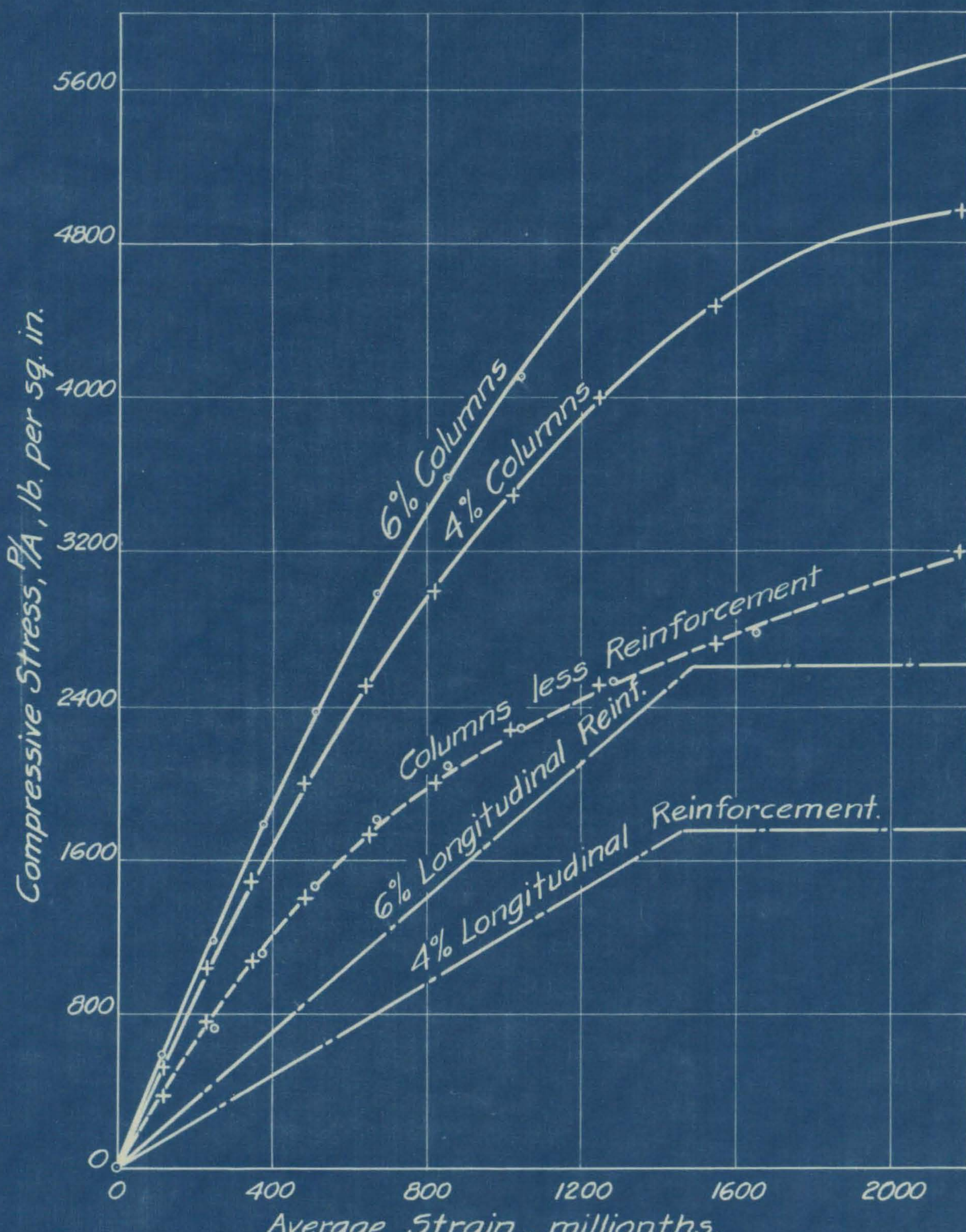

Fig. 6 - Stress-Strain Diagrams for Columns loaded "Fast" to Failure, Longitudinal Reinforcement 4 and 6%, Spiral Reinforcement 2%.

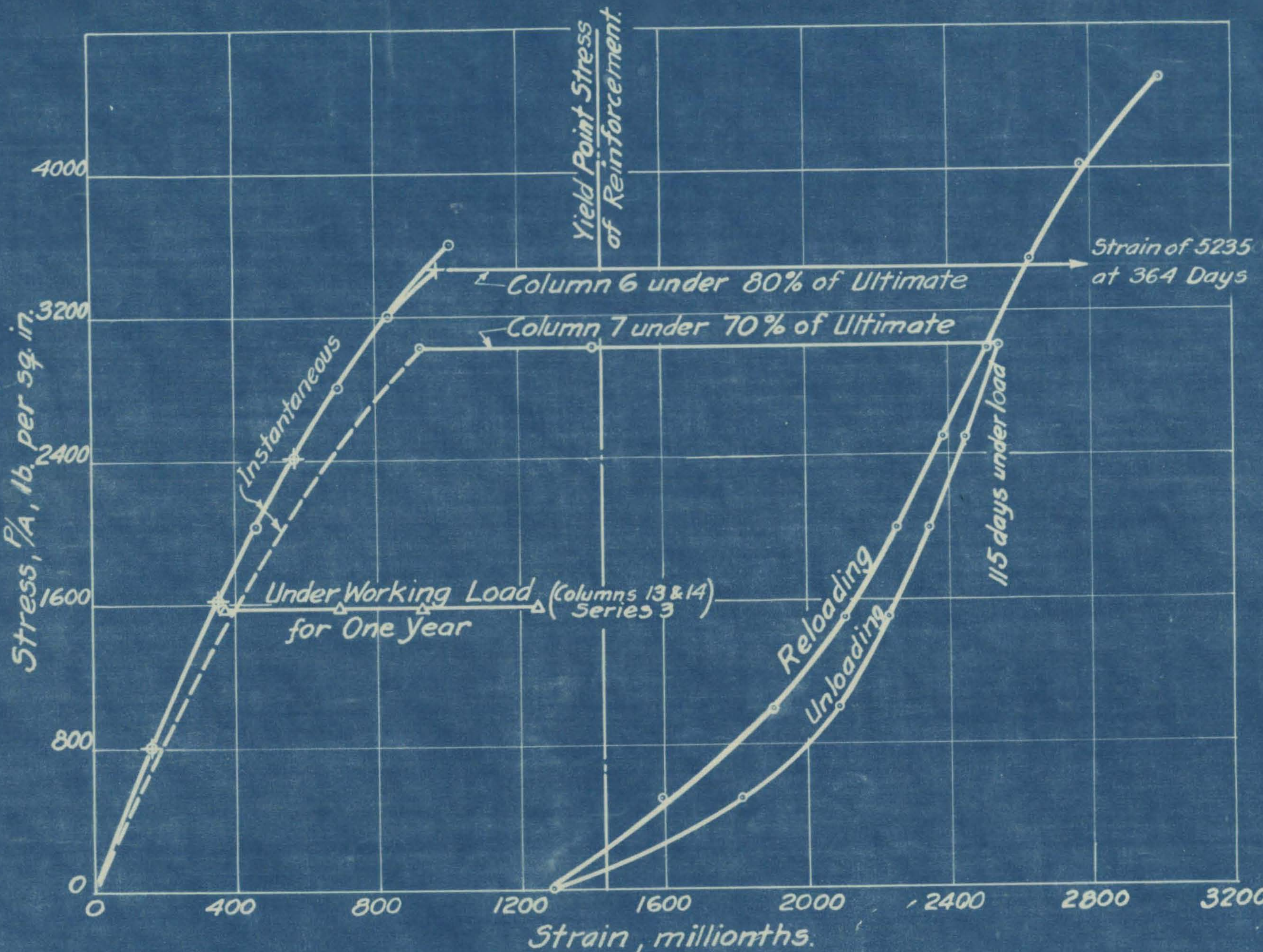

Fig. 7 - Stress-Strain Diagram of Columns Loaded Directly to Failure under 80% and 70% of Ultimate Load. Strength of Concrete 3780 lb/in², 4% Longitudinal and 0% Lateral Reinforcement.

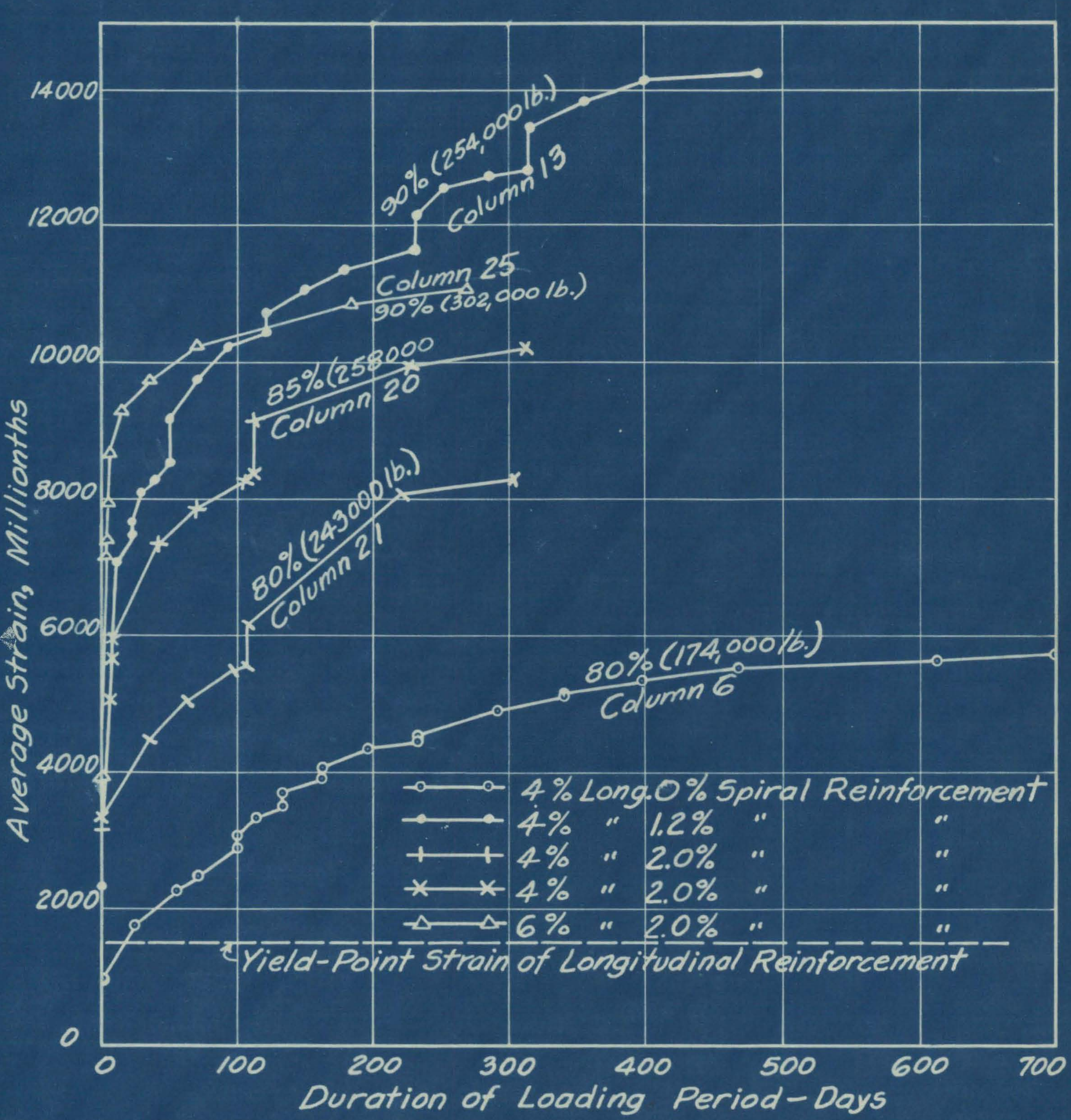

Fig. 8
Deformation of Column under Sustained Load

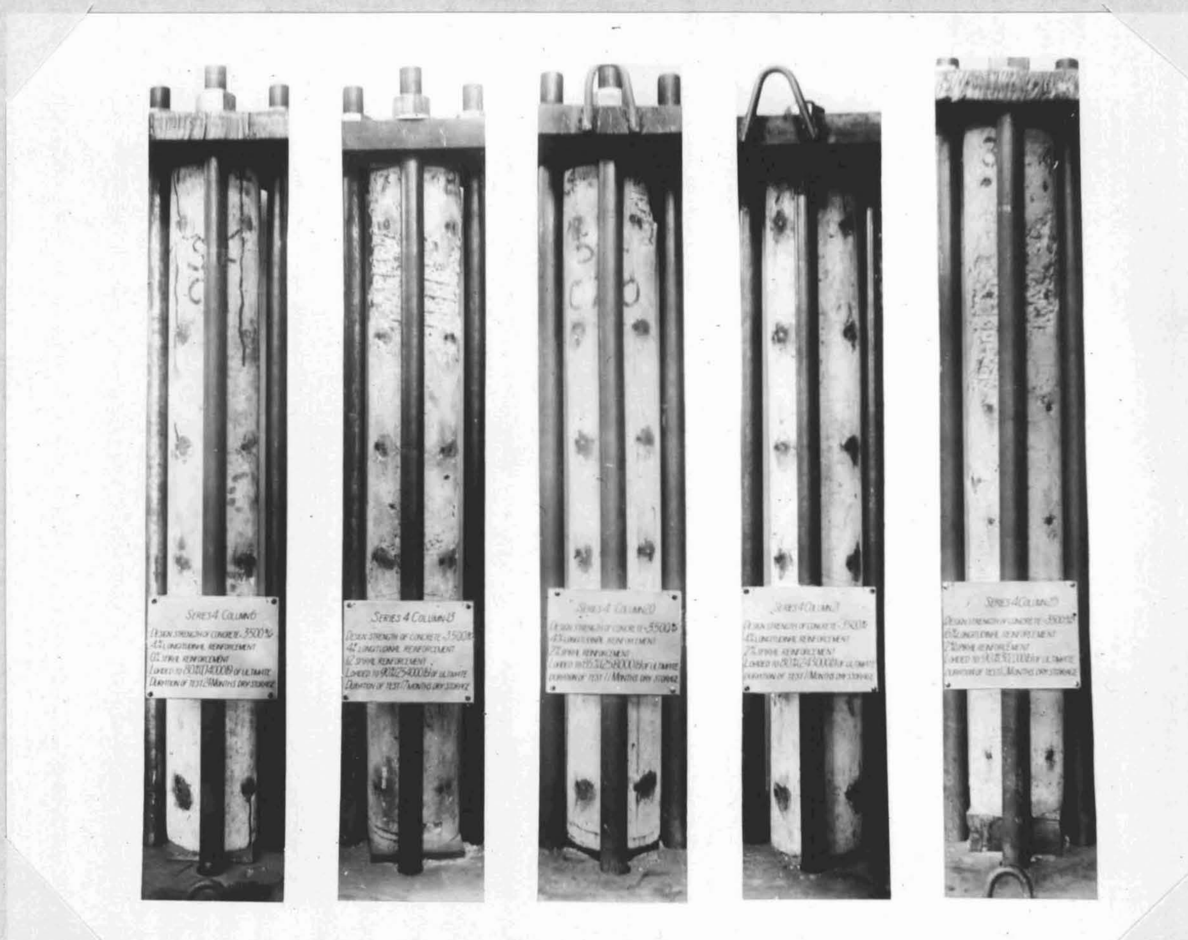

Fig. 9 - Appearance of Columns in January, 1933

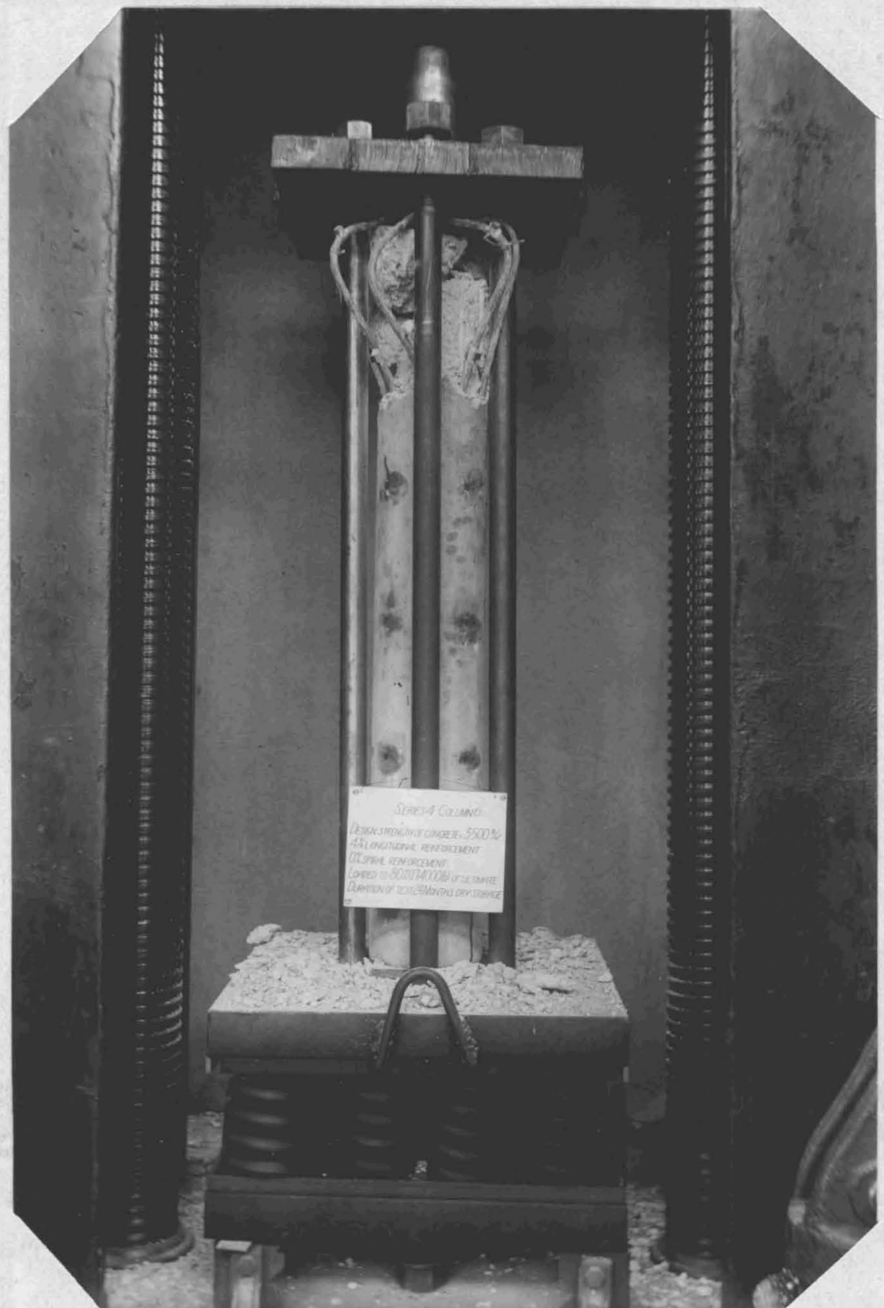

Fig. 10 - Failure of Column 6