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TESTS OF REINFORCED CONCRETE COLUMNS

by Inge Lyse*

INTRODUCTION

The reinforced concrete column investigation sponsored by the American Concrete Institute and toward which the American Society of Civil Engineers contributed financially, has established certain relationships between the properties of the materials and the strength of the column. The ultimate strength of the columns has been found to be made up of the strength of the concrete (column strength equal to about 85 per cent of the cylinder strength) and the yield-point strength of the longitudinal steel. For columns having spiral reinforcement which produced strength in excess of the strength of the fireproofing shell, the strength of the column was increased by the spiral. Since all columns included in the investigation had longitudinal reinforcement of only 6 per cent and less, it seemed important that tests be made on columns having greater percentages of reinforcement. Consequently the Fritz Engineering Laboratory of Lehigh University carried out an investigation on columns having as much as 17-1/2 per cent longitudinal reinforcement.

Furthermore, tests were made on columns which had a very high grade steel for reinforcement and on columns which had welded reinforcement.

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PROGRAM AND PROCEDURE

This series of tests included a total of 42 columns 8-1/4 in. in diameter and 60 in. long. The program for the tests is given in Table 1.

Two concretes, of 2000 and 4000 lb. per sq.in. designed strength, were used. Plain columns were made with each grade of concrete. For 2.0 per cent spiral reinforcement, the percentages of longitudinal reinforcement were 1-1/2, 6, 10-1/2, 14 and 17-1/2. With longitudinal reinforcement of 14 per cent the spiral reinforcement was either 0, 1.2 or 2.0 per cent. The bars in the columns having 1-1/2 and 6 per cent reinforcement were of the same stock as those used for reinforcement in the A.C.I. column investigation. The yield-point stress was 47,800 lb. per sq.in. for the 1-1/2 per cent reinforcement and 44,900 lb. per sq.in. for the 6 per cent reinforcement. The bars in the columns having 10-1/2, 14 and 17-1/2 per cent reinforcement were 1-1/2 in. in diameter and had an average yield-point stress of 36,900 lb. per sq.in. The spirals came from the same stock as those used in the A.C.I. investigation. No yield point could be determined from the tests of the spiral coupons. The ultimate strength was 82,200 lb. per sq.in. for the 1.2 per cent spiral and 74,560 lb. per sq.in. for the 2.0 per cent spiral. Additional tests were made on columns in which the 6 per cent longitudinal reinforcement consisted of bars having yield-point stress of 94,500 lb. per sq.in. and ultimate strength of 132,500 lb. per sq.in. Tests were also made on columns which had 17-1/2 per cent reinforcement where each bar was cut in half and welded together electrically before being placed in the column. The columns were made during October and November, 1932, and tested at the age of 28 days. The cement and other materials for the concrete came from the same supply, and the method of making, curing, and testing was the same as that used in the A.C.I. investigation. (See Lehigh University Research Circulars No. 64 and 81). A photograph of the reinforcing units used for 14 per cent longitudinal and no spiral reinforcement, is shown in Fig. 1.

DISCUSSION OF RESULTS

Both concrete mixes had the same water content per cubic yard of concrete. The average slumps for the concrete were 6.3 and 7.6 for the 2000 lb. and 4000 lb. per sq.in. mixes respectively. A summary of the results of the tests is given in Table 2.

It is noted that the strengths of both concrete mixes remained fairly constant for all the columns. The uniformity in strength results of companion columns was very good throughout the tests.

The load-deformation-curves are shown in Fig. 2 and 3 for columns having design strengths of concrete of 2000 and 4000 lb. per sq.in. respectively. In Fig. 4 the relation between the deformation of the longitudinal reinforcement and the load carried by the reinforcement is shown for the various percentages used. On comparing the diagrams of Fig. 4 with those of Fig. 2 and 3 a striking similarity is noticed. The distances between the curves for the various percentages of reinforcement are very nearly the same in the three figures, indicating that the steel is giving its full stress value to the column at any strain regardless of the amount or grade of steel. Except for the columns having only 1-1/2 per cent and 6 per cent longitudinal reinforcement, a sharp break in the deformation curves at strains corresponding approximately to the yield-point strain of the reinforcement indicates a yield point of the columns. The greater the percentages of longitudinal reinforcement, the sharper is the break in the deformation curves. It is noted that the deformation curves for the columns having the High Yield Point steel showed a greater increase in load with increase in the strain beyond the yield point than did the curves for columns having mild steel. This is evidently due to the fact that the High Yield Point steel did not have a sharp yield point. The testing machine showed no drop of the lever at the yield point of this steel, which yield point had to be determined from the stress-strain diagram. The strength results indicate that at the maximum load of the columns the High Yield Point steel carried load corresponding to 120 per cent of its yield-point strength. Attention is called to the fact that the total deformation at the yield point of the column was more than twice as large for the High Yield Point steel as for the ordinary reinforcing steel. Thus the amount of flow in a column may be doubled before the yield-point stress of the steel has been reached. Sponsors of design for effect of flow on stress in reinforcement should therefore welcome the introduction of the High Yield Point steel. The advantage of this steel on the strength of the column is, furthermore, so outstanding that special attention should be given to this type of steel.

The effect of the amount of spiral reinforcement on the deformation of the columns is illustrated in Fig. 5. The deformation curves for columns having no spiral, and those having 1.2 per cent spiral reinforcement are seen to very nearly coincide, both for 2000 and 4000 lb. per sq.in. concrete. The deformation curves for the columns having 2.0 per cent spiral, however, are somewhat steeper than for the other columns. This is partly due to the difference in the strength of the concrete in the columns. Table 2 shows that the strength of the concrete used in the columns having 2.0 per cent spiral reinforcement was about ten per cent higher than the concrete used in the columns having no spiral or 1.2 per cent spiral reinforcement. When corrections are made for this difference in the strength, the deformation curves, as well as the yield point of the columns, would very nearly coincide for the columns having various amounts of spiral reinforcement.

STRENGTH RESULTS

The strengths of all the columns are given in Table 2. The strengths of columns having 2.0 per cent spiral reinforcement have been plotted against the yield-point strength of the longitudinal reinforcement in Fig. 6. This figure proves conclusively that the longitudinal reinforcement adds its full yield-point strength to the column, regardless of amount, up to 17-1/2 per cent reinforcement. The high yield point steel is found to contribute an amount of load corresponding to 120 per cent of its yield-point strength to the strength of the column. Furthermore, the parallelism of the curves in Fig. 6 shows that the grade of concrete has no effect upon the strength added by the longitudinal reinforcement. These results are in harmony with those obtained in the A.C.I. column investigation, in which a maximum of 6 per cent longitudinal reinforcement was used. It may therefore be concluded that for reinforced concrete columns having less than 17-1/2 per cent longitudinal reinforcement, the strength of the column is equal to the strength of the concrete in the column, plus the yield-point strength of the longitudinal reinforcement plus whatever amount is added by the spiral reinforcement.

The tests indicate that the strength added by the spiral reinforcement is approximately equal to two times the yield-point strength of the spiral less the amount of load carried by the protective shell outside the spiral.

SUMMARY

1. The deformation curve of reinforced concrete columns having ten per cent or more longitudinal reinforcement showed a definite yield point. This yield-point strain corresponded approximately to the yield-point strain of the longitudinal reinforcement.

2. The columns having high grade steel gave yield-point deformation more than twice as large as did columns having ordinary reinforcing steel.

3. The longitudinal reinforcement added its full yield-point strength to the column for as much as 17-1/2 per cent reinforcement, the largest amount used in this investigation.

4. The high yield point steel added about 20 per cent in excess of its yield-point strength to the strength of the column.

5. The strength of tied columns and of spiral columns in which the spiral reinforcement had a strength equal to or less than the strength of the protective shell, is equal to 85 per cent of the cylinder strength of the concrete times the total area of concrete, plus the yield-point stress of the longitudinal reinforcement times its area.

6. For design purposes the effectiveness ratio of the spiral reinforcement may be considered equal to 2.0.

TABLE 3 - SUMMARY OF RESULTS OF COLUMN TESTS

Reinforcement		Strength of Columns			Average Strength of Columns	Average Cylinder Strength	Effectiveness of	
Long.	Spiral						Concrete	Spiral*
percent		lb.			lb.	lb/sq.in.		
0	0.	115,300	119,500	116,800	117,200	2350	0.93	--
0	0	207,500	207,400	230,000	215,000	4020	1.00	--
14.0	0	347,000	363,500		355,200	2390	.91	--
14.0	0	401,600	416,800		409,200	3780	.91	--
14.0	1.2	398,500	401,500		400,000	2360	.85+	1.87
14.0	1.2	449,000	457,000		453,000	3780	.85	1.91
14.0	2.0	440,500	437,000		438,750	2550	.85	1.85
14.0	2.0	524,500	501,000		512,750	4160	.85	2.18
1-1/2	2.0	231,000	234,000		232,500	2740	.85	1.78
1-1/2	2.0	295,000	301,000		298,000	4010	.85	2.05
6.0	2.0	331,000	327,000		329,000	2680	.85	2.01
6.0	2.0	384,200	380,300		382,250	4340	.85	1.71
6.0 H.Y.	2.0	532,000	508,000		520,000	2830	.85	1.74°
6.0 H.Y.	2.0	580,000	561,000		570,500	4460	.85	1.40°
10-1/2	2.0	379,000	375,000		377,000	2820	.85	1.62
10-1/2	2.0	445,000	444,000		444,500	4530	.85	1.68
17-1/2	2.0	512,000	519,000		515,500	2630	.85	2.11
17-1/2	2.0	578,000	554,500		566,250	4580	.85	1.70
17-1/2 W≠	2.0	495,000	508,500		501,750	2640	.85	1.80
17-1/2 W≠	2.0	568,000	569,000		568,500	4280	.85	2.00

* Based on 44,000 lb. per sq.in. yield-point stress.
\+ Assumed.
° Based on Effectiveness of Longitudinal Steel = 120% yield-point strength.
≠ Welded bars.

TABLE 1 - PROGRAM OF TESTS

Reinforcement Long. (per cent)		Reinforcement Spiral (per cent)	Design Strength of Concrete (lb. per sq. in.)		Number of Each Kind	Total No. of Columns
0		0	2000	4000	3	6
1-1/2		2.0	2000	4000	2	4
6		2.0	2000	4000	2	4
6	H.Y.*	2.0	2000	4000	2	4
10-1/2		2.0	2000	4000	2	4
14		0	2000	4000	2	4
14		1.2	2000	4000	2	4
14		2.0	2000	4000	2	4
17-1/2		2.0	2000	4000	2	4
17-1/2	W**	2.0	2000	4000	2	4
					Total -	42

* High Yield-Point Steel

** Welded Reinforcing Bars

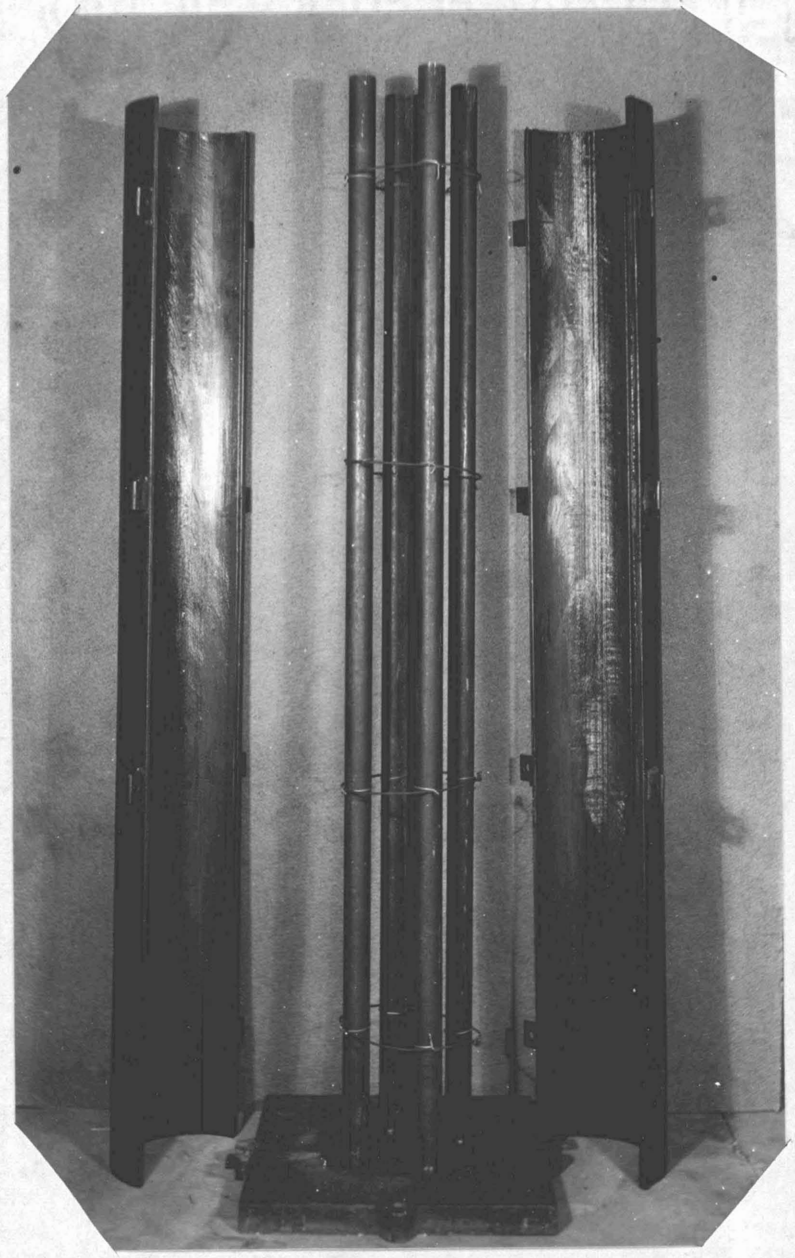


Fig. 1 - Fourteen Per Cent Longitudinal Reinforcement

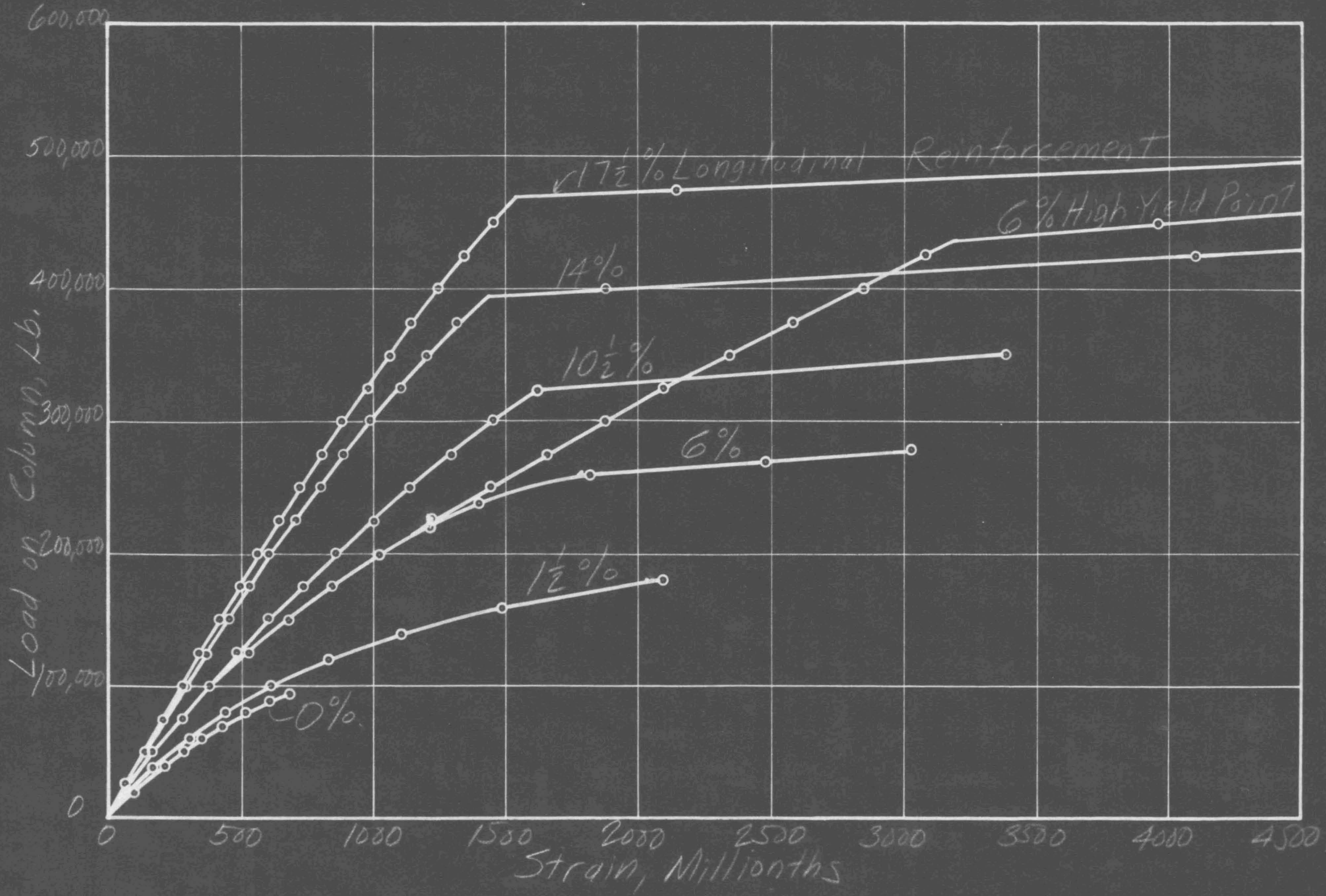


Fig 2 - Deformation Diagram for Columns having 2000 #/in² Concrete.

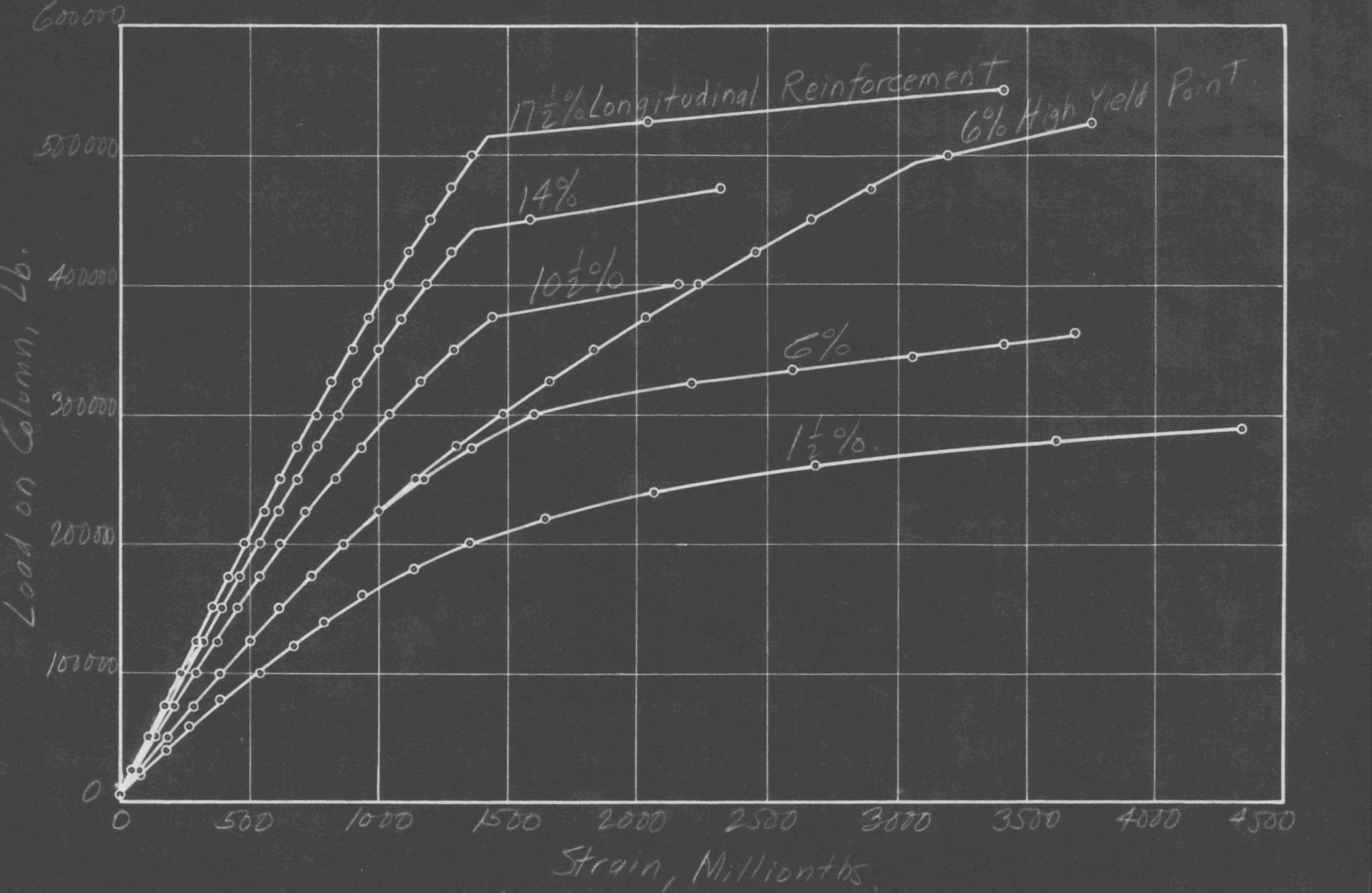


Fig. 3 - Deformation Diagram for Columns having 4000 #/□" Concrete.

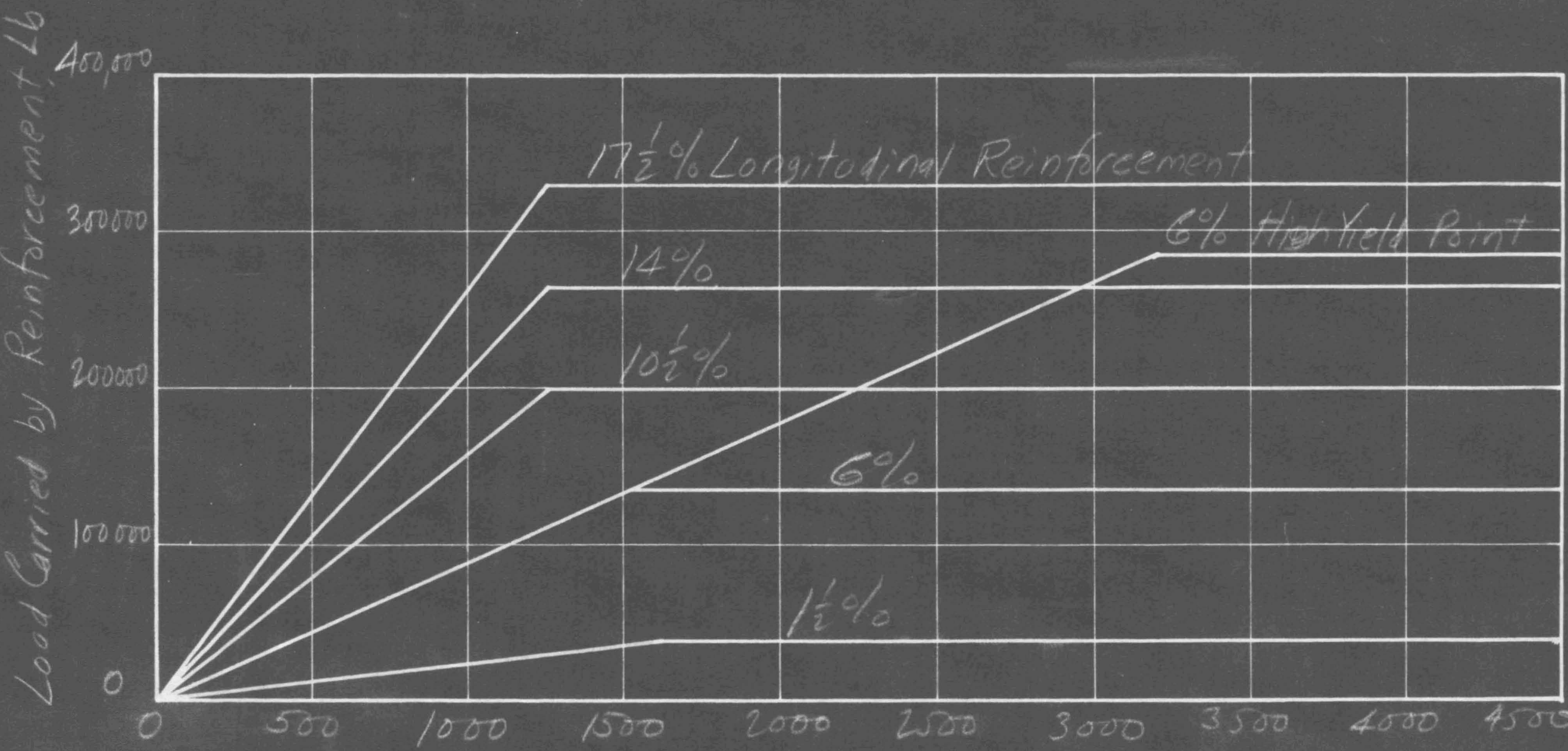


Fig. 4 Deformation Diagram for Longitudinal Reinforcement.

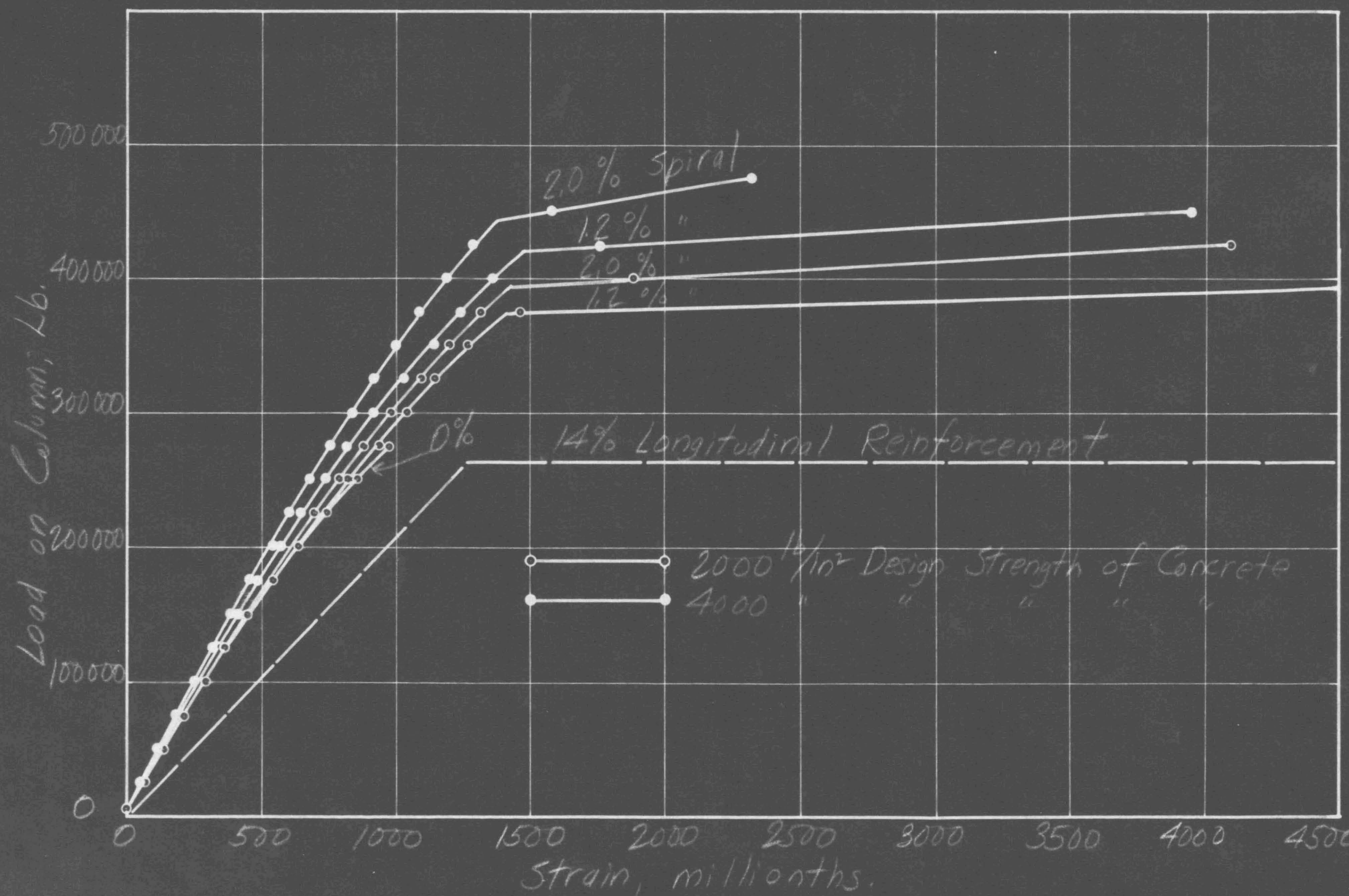


Fig. 5 - Effect of Spiral Reinforcement on Deformation and Yield Point of Columns.

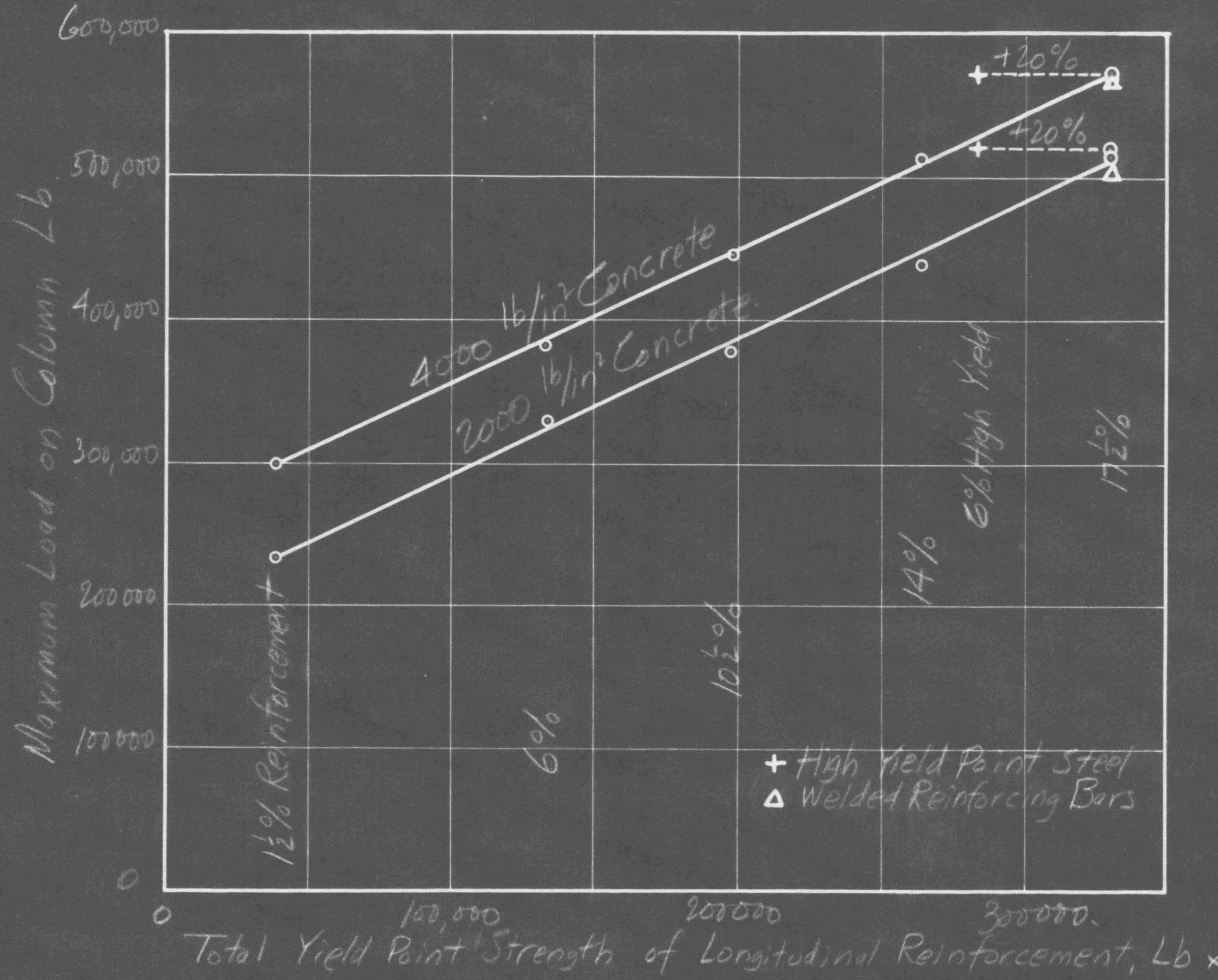
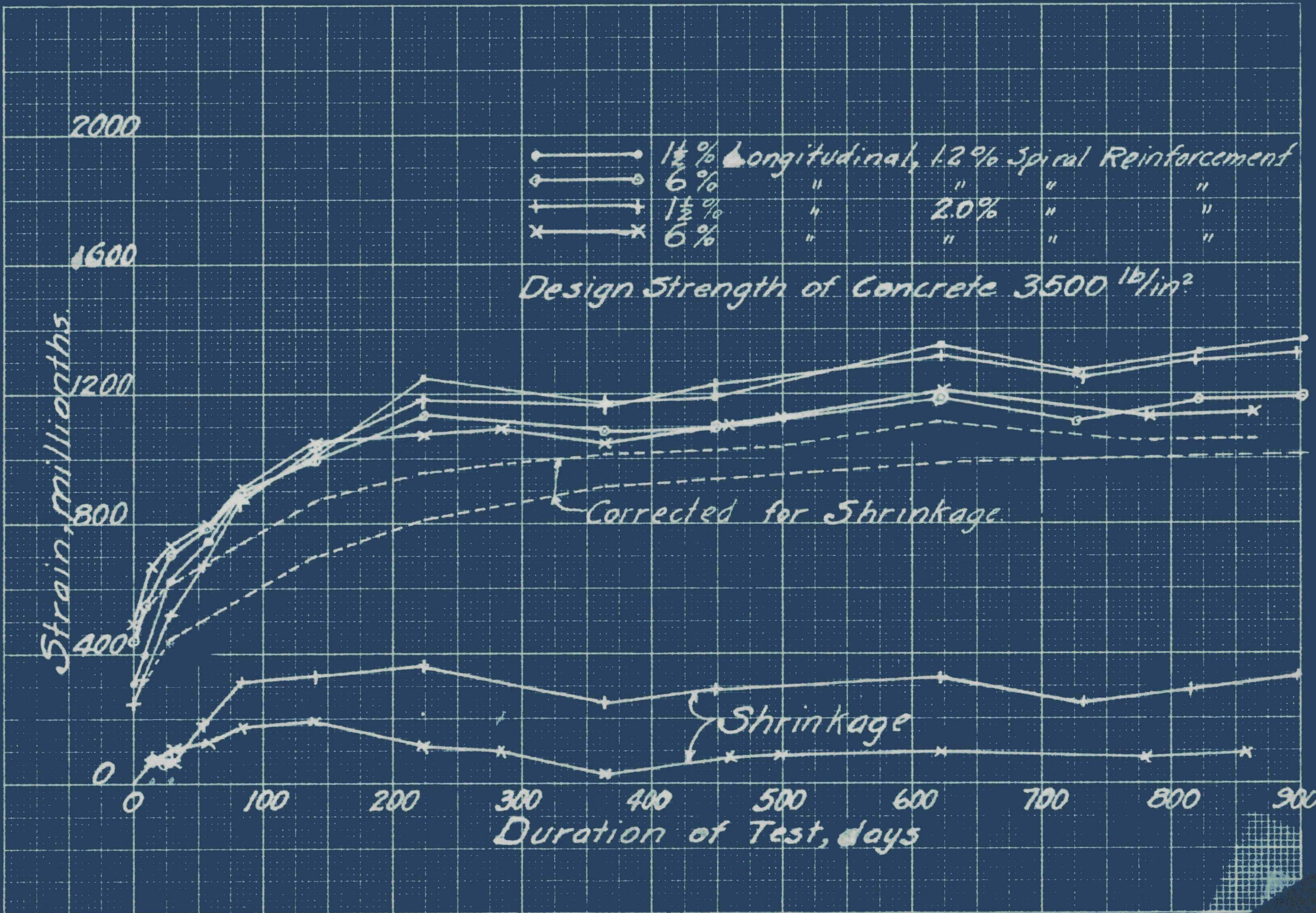
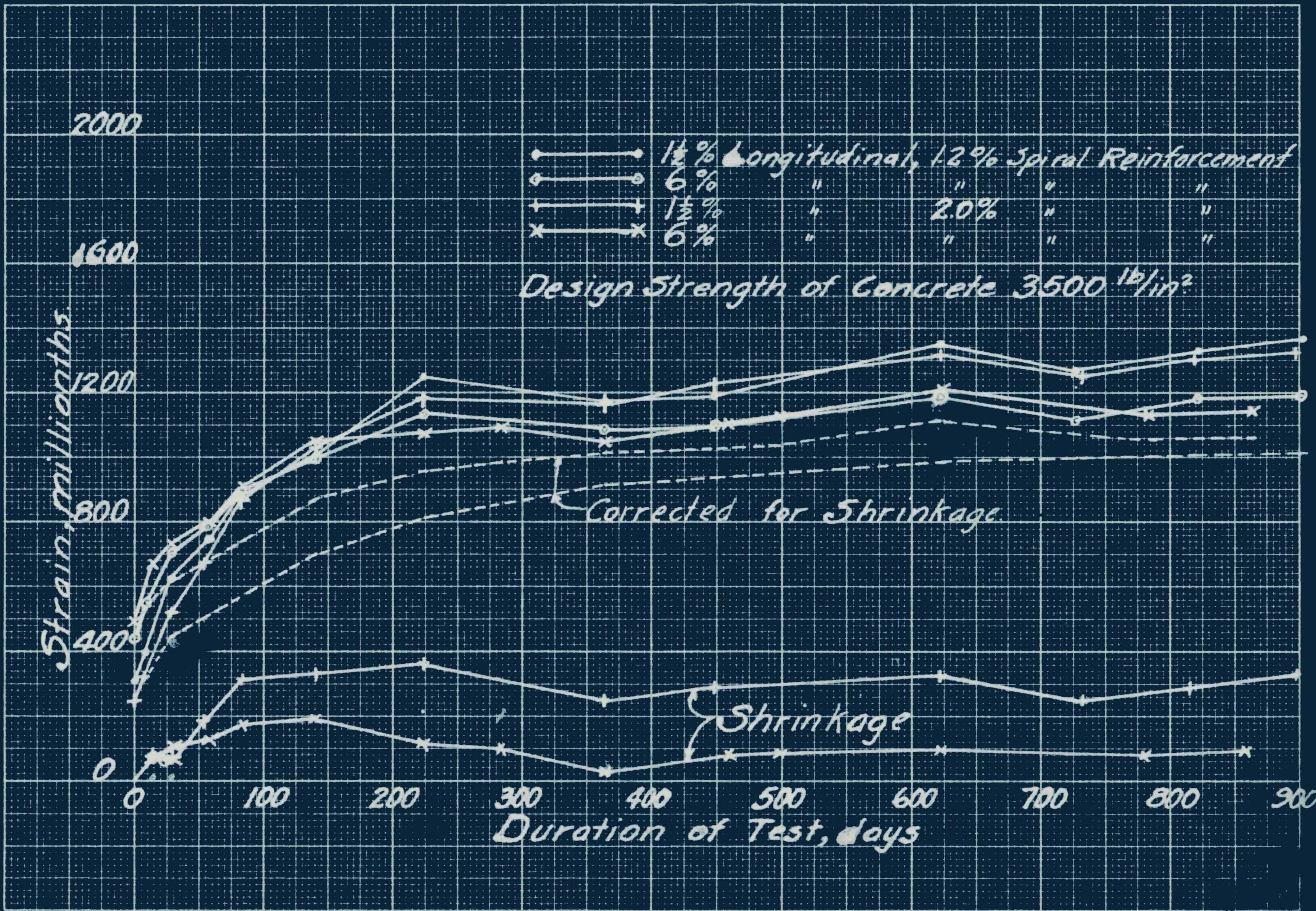


Fig.6 - Effect of Yield-Point Strength of Longitudinal Reinforcement on Strength of Column



2000
1600
1200
800
400
0
Strain, millionths.
1½ % Longitudinal, 1.2 % Spiral Reinforcement
6 % " " " "
1½ % " 2.0 % " "
6 % " " " "
Design Strength of Concrete 3500 lb/in²
Corrected for Shrinkage
Shrinkage
0
100
200
300
400
500
600
700
800
900
Duration of Test, days


1½% Longitudinal, 1.2% Spiral Reinforcement
6% " " " "
1½% " 2.0% " "
6% " " " "
Design Strength of Concrete 3500 lb/in²
Corrected for Shrinkage
Shrinkage
Strain, millionths
2000
1600
1200
800
400
0
0
100
200
300
400
500
600
700
800
900
Duration of Test, days