TESTS OF STEEL CONCRETE BEAMS

Thesis for the Degree of B. S.

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-: THESIS :-

T E S T S O F S T E E L - C O N C R E T E B E A M S .

BY

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Class '03.

THESIS

TESTS OF STEEL-CONCRETE BEAMS.

The object of this set of tests was to determine how well the results obtained by means of the theory proposed by W. Kendrick Hatt, of Purdue University would agree with the results obtained by tests made on beams which were of varied proportions of matrix and aggregate and of the reinforcing material and which were also made under varied conditions.

The beams used in these tests were made in wooden moulds. Those marked dry and normal in Table I. being thoroughly tamped, while those marked very wet were tamped but little. The beams were of a uniform size, all being six (6) inches square and of sufficient length to give a span of seventy-two (72) inches between supports, except beams 5a and 5b which had a span of thirty-six (36) inches.

The reinforcing material used consisted of 3/8" and 1/2" round rods of mild steel and were all placed 1" from tension face of beam, two being used in each beam.

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Two different brands of cement were used (Atlas and Aetna). The Atlas being a well known standard brand, and the Aetna, a local cement which is made at Fenton, Michigan. Tests of standard briquettes were made on both cements, the results being shown in Table IV.

All beams were made indoors and were left there until taken from moulds, which time varied from one to four days according to the amount of water used in mixing, after which they were set out doors until tested. Beams were all of gravel concrete. As sand was in excess, the gravel was all sifted through a sieve of sixteen meshes to the square inch, all stones larger than $1\frac{1}{2}$" inch in diameter being rejected, then the sand passing through the sieve and the stones caught by it were mixed with the cement in the ratios (by volumes) as shown in Table I.

The beams were tested at ages varying from 7 to 64 days as shown in Table II. All of the beams were broken by means of the Tinurs Olsen testing machine in the Mechanical Laboratory. A 10" beam, which was calculated to have a deflection of less than .001 of an inch for any of the loads applied, was used to support the beams

and as the deflection of the concrete beam was only read to .01 of an inch, the error due to deflection of I beam was not taken into account. The knife edges upon which the beams were supported were of cast iron and one inch in width, as was also the one at the centre where the load was applied. The load was applied in increments of 200# each and the deflection at the center was measured by means of scale graduated to hundredths, the scale being fastened to the concrete beam, as the beam deflected the scale was caused to pass down over an index on the flange of the I beam, and the deflection caused by each increment of load applied, was read directly from the scale. With the results obtained from these tests load deflection diagrams were plotted, the loads being used as ordinates and the deflection as abscissa. These diagrams nearly all contain quite clearly defined and characteristic points, the first somewhat indefinite point where the curve first turns from a straight line, in the case of these beams it varies from 400# to 1,200# as may be seen by observing curve sheets. This point is called point A by Prof. Hatt. And, secondly, the point of first crack of the concrete where the curve again turns very abruptly and the deflection begins to increase much more rapidly than the load. Prof. Hatt includes also a 3rd point at which the elastic limit of the reinforcing metal is reached, he calls this point the point of failure. But, as all the beams in these tests failed by crushing of the concrete instead of by breaking of the rods, the theory proposed by him would hardly apply at the point of failure for these beams. No curves were plotted for beams 5a and 5b which were of plain concrete without reinforcement as the total deflection for either was less than .01 of an inch, and the only value of the tests of these two is to show to what a marked degree the flexibility of the beams is increased by the addition of the metal reinforcement.

The assumptions upon which the theory proposed by Mr. Hatt are based are as follows: 1. The cross sections of the beams remain plain surfaces; 2. The applied forces are perpendicular to the neutral surface of the beam; 3. The values of the moduli of elasticity obtained in simple tension and compression tests will apply to the material in the beams when under flexion; 4. There is no slipping between the concrete and the reinforcing metal; 5. There are no initial stresses in the beam due to contraction of the concrete while setting. The analysis also supposes the fracture to be due to bending and not horizontal shear. If the cross sections are assumed to remain plain surfaces during flexture the distortion of any fibre will be proportional to its distance from the neutral axis. It follows that the law of variation of stresses will be represented by the stress strain diagram shown on curve sheets. These stress strain diagrams are assumed to be parabolic arcs. This assumption has been justified in the case of compressional stress strain dia-diagram, by a large number of experiments but does not seem to be so clearly shown in this case.

The quantities used in the formulas for theoretical results were as follows:

hx = distance from compression face to neutral axis.

hu = distance from compression face to the center of gravity of the reinforcement.

p = ratio of area of steel to that of cross section of beam.

Es, Ec, Et = moduli of elacity of the steel, concrete in compression and concrete tension, respectively.

$$n = \frac{Ec}{Et}$$

$$m = \frac{Es}{Et}$$

f = stress in metal reinforcement.

$c =$ compression stress in outer fibre of concrete.

$t =$ tensional stree in outer fibre of concrete assumed to be 300#.

E_c and E_t are measured at the stresses c and t. The values x, u and p are ratios; p and u are at the control of the designer, while x depends on p, u, n and m; n and m are fixed by the quality of the materials, and they change during flexure with varying values of c, f and t; that is, the modulus of elasticity of the concrete varies with the stress at which it is measured. For practical purposes of computation, however, the constant values of n and m may be used appropriate to the point A and to the point of cracking. The values proposed by Prof. Hatt were $n = 2$ and $m = 12$ at point A, and $n = 12$ and $m = 90$ at point of first crack, and these values were used in computing the results shown in Table III. On the assumption of plane cross section during flexure we may determine the ratio of f to c and f to t in the following formulas

$$c = \frac{tnx}{1 - x}$$

$$f = \frac{tm(u - x)}{1 - x}$$

Next, to locate the neutral axis; i e, to determine the value of x, we may equate the forces of tension and compression on the cross section, assuming, as before, that the stress strain diagrams are arcs of parabolas,

$$\tfrac{2}{3}\,cx = \tfrac{2}{3}\,t(1 - x) + pf$$

into which the values of f and c above may be substituted and, solving for x, we get

$$\tfrac{2}{3}\,x^2 n = \tfrac{2}{3}(1 - x)^2 + pm(u - x)$$

and, after solving, this reduces to

$$x = \frac{-\left(\frac{4 \quad 3}{2}\right) + \sqrt{4n + \frac{9}{4}p\ m + p\left[6m(u[n - 1] + 1)\right]}}{2(n - 1)}$$

Having obtained x we may compute c and f and finally obtain the moment of resistance of the section. Taking moments about the neutral axis, we have

$$M = tfh^2\left[\frac{5}{12}(1 - x)^2 + \frac{5nx^2}{12(1 - x)} + p\,\frac{(n - x)^2}{1 - x}m\right]$$

These equations are to be applied to compute the load at point **A.** At the load corresponding to the cracking of the concrete in the tension face, these equations should be modified to correspond to the fact that the stress strain diagram for the concrete in tension is more nearly a rectangle than a parabola. The difference, however, between the results at the time of the appearance of the

crack due to the assumption of a rectangle or a parabola is very small. With proper values of n and m the equations may be allowed to stand. When, however, the crack having formed itself, extends throughout the lower region of the cross section the equations must be modified by the omission of the effect of tensional forces due to the resistance of concrete under tension. We then have:

$$\frac{2}{3}cx = pf \text{ or } p\,\frac{Es}{Ec}(u - x) = \frac{2}{3}x^2.$$

which serves to locate the neutral axis.

The loads combuted by the application of the foregoing equations are shown in Table III and are to be compared with those given in Table II, which are the loads carried by the beam tested.

From an inspection of Table II, it may be seen that both the point A, and point of first crack varied considerably for the different beams, but this would be expected, as the beams were purposely made with as many varying conditions as possible.

The ratio of the greatest to the least value of A was as 3:1, and for the point of first crack less than 2:1, and both cases the theoretical load was a mean between the two, therefore we may conclude that with a large fa ctor of safety, such as is

necessarily used in concrete construction due to the fact that two pieces of concrete made under similar conditions, do not show concordant tests, it would be practical to use these formulas with the constants here employed for the design of concrete steel beams.

TABLE NO. I.

		Kind.	Condition when made.	After Test.	Wt. lbs.
No. 1.	5:3:1	Aetna	Rather dry	First cracked on bottom then crumbl-ed on top.	250
No. 2.	"	"	" "	Same as No. 1., Also slivered along rods.	256
No. 3.	"	"	" "	Crushed on bottom crumbled on top.	263
No. 4.	3:2:1	Atlas	" "	Cracked on bottom crumbled on top.	250
5a and 5b	"	"	" "	Cracked clear through did not crush.	a - 118 b - 131
No. 6.	3:2:1	Aetna	Normal	Cracked on bottom then crushed on top.	254
No. 7.	"	"	"	Cracked on bottom then crushed on top.	261
No. 8.	3:2:1	Atlas	Very wet	Split along rods on half of beam..	259
No. 9.	"	"	" "	Split along rods on half of beam.	260
No. 10.	4:2:1	"	" "	Cracked on bottom then crushed on top.	259
No. 11.	3:2:1	"	" "	Split along rods on half of beam.	255
No. 12.	"	"	" "	Cracked on bottom then crushed on top.	2 46
No. 13.	3:2:1	"	" "	Cracked on bottom then crushed on top and sli-vered short dis. on side	267
No. 14.	"	"	" "	Cracked on bottom crumb-led on top then broke out chunck on bottom	267
No. 15.	3:2:1	Aetna	Normal	Cracked on bottom crush-ed on top then cracked diagonally across beam	255
No. 16.	"	"	"	Broke nearly straight across.	255

TABLE NO. II.

Beam No.	Kind.	Age in Days.	Point A. Load pounds	Point A. Defl. inches	Crack. Load pounds	Crack. Defl. inches	Failure. Load pounds	Failure. Defl. inches	
1.	.61%	7	1,000	0.12	2,000	0.40	2,100	0.75	
2.	.61%	64	600	0.05	2,800	0.38	3,000	0.75	
3.	.61%	64	600	0.05	2,800	0.38	3,000	0.75	
4.	.61%	28	1,000	0.08	-----	----	2,500	0.32	
5a.	Plain	28	-----	----	-----	----	1,300	0.008	"
5b.	"	28	-----	----	-----	----	1,300	0.01	"
6.	.61%	31	1,200	0.04	3,400	0.35	3,600	0.90	
7.	.61%	31	800	0.03	3,200	0.30	3,600	0.74	
8.	1.09%	34	-----	----	1,800	0.20	2,000	0.41	
9.	.61%	34	400	0.02	2,200	0.28	2,100	0.32	
10.	1.09%	29	600	0.01	1,800	0.19	2,000	0.27	
11.	1.09%	29	1,000	0.12	1,600	0.22	1,800	0.27	
12.	1.09%	29	400	0.04	1,800	0.24	2,000	0.28	
13.	1.09%	29	1,000	0.07	3,000	0.29	3,300	0.45	
14.	1.09%	29	1,000	0.08	2,800	0.28	3,400	0.48	
15.	1.09%	25	1,200	0.08	2,200	0.24	2,800	0.49	
16.	.61%	25	1,200	0.03	2,000	0.18	3,000	0.38	

" 5a abd 5b 3' between supports.

TABLE NO. III.

Reinforced per cent	Load at Point A.	Load at First Crack.	Stress per sq. in. steel. Point A.	Stress per sq. in. steel. First Crack.	Concrete in Comp. Point A.	Concrete in Comp. First Crack.	Value of x for Point A.	Value of x for First Crack.
.61	974	2,178	2,554	20,712	443	1,428	.425	.284
1.09	1,062	2,920	2,524	20,385	473	1,878	.441	.318

Moment due to weight of Beam to be deduced from theoretical dead loads.

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TABLE NO. IV.

Tensile Strength of Standard Briquettes of Atlas Portland Cement.

Neat.	7 days.	21 days.	
"	524	640	
"	514	622	
"	475	635	
	504.3	632	Average

3 : 1	7 days.	21 days.	
"	137	252	
"	160	200	
	148.5	226	Average.

Fineness of Atlas Cement

99.2% passed No. 50 seive
93.2% " " 100 "

Same Quartz Used as for Aetna.

25% Water for neat.
14% " " 3:1

TABLE NO. IV.

Tensile Strength of Standard Briquettes, Aetna Portland Cement made at Fenton Michigan.

Neat.	7 days old.	21 days.
"	425 lbs.	612 lbs.
"	450 "	635 "
"	415 "	630 "
	430 lbs. Ave.	625.6 lbs. Ave.

3 : 1	7 days old.	21 days.
"	125 lbs.	170 lbs.
"	147 "	225 "
"	120 "	200 "
	130.6 lbs. Ave.	198.3 lbs. Ave.

Fineness of Cement

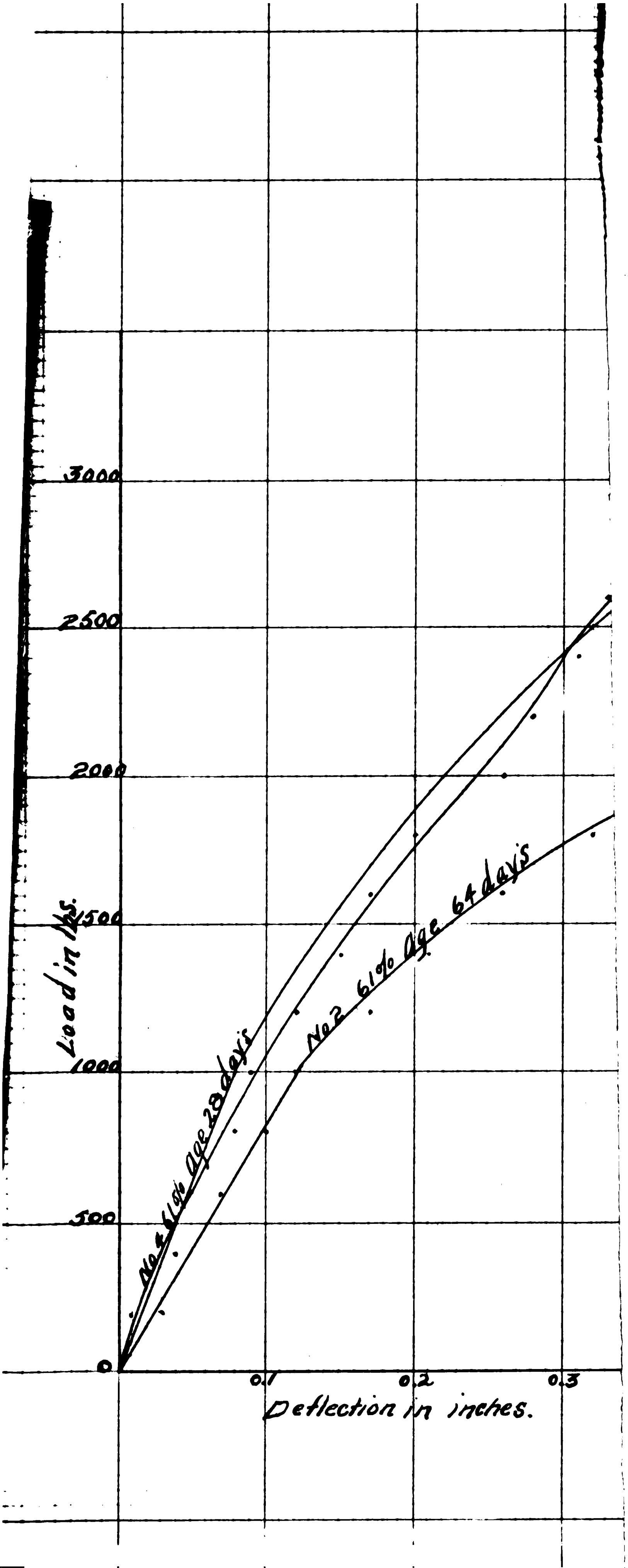
99.73% passed No. 50 seive
92.8 % " " 100 "

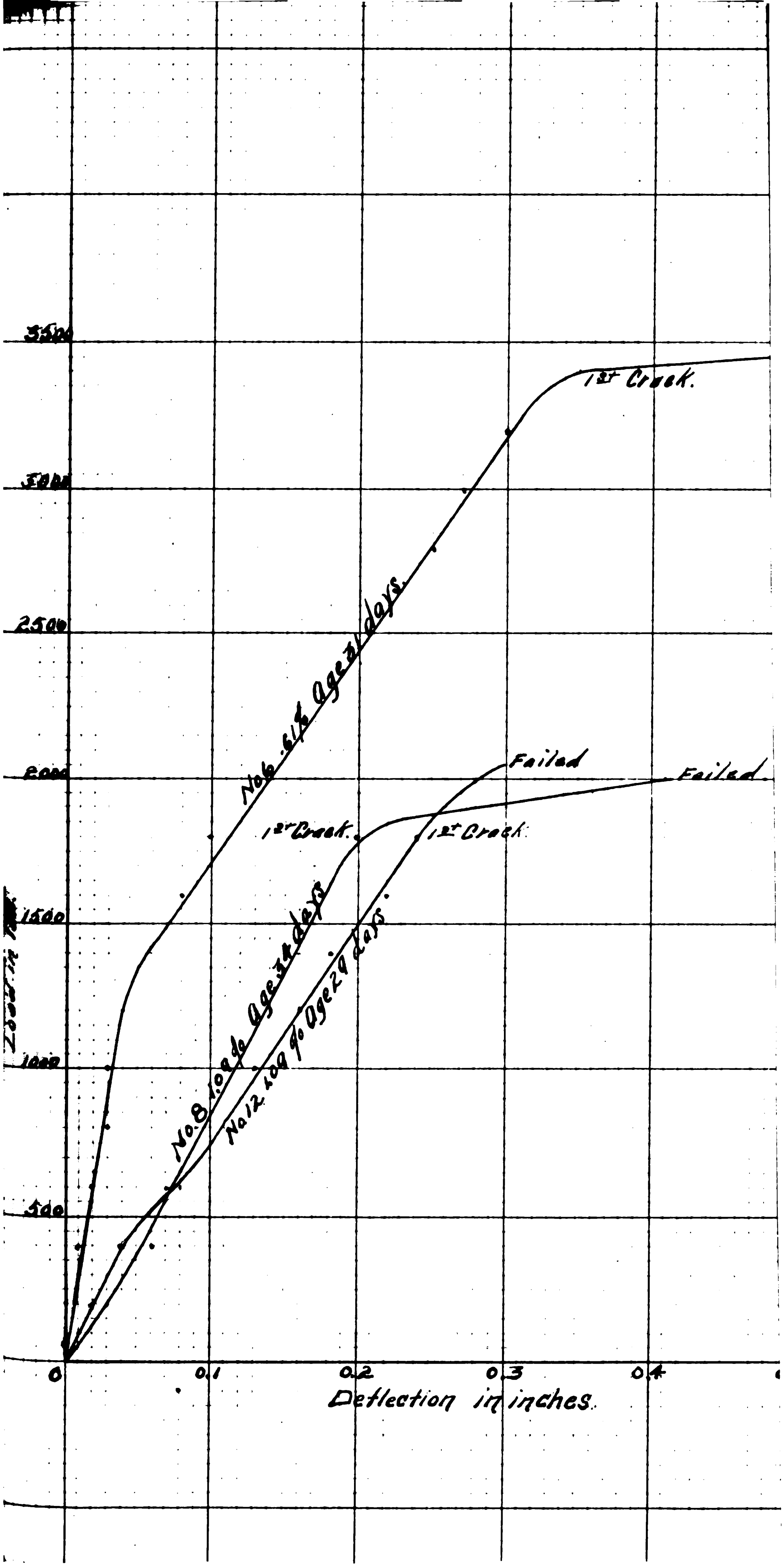
Fineness of Quartz used

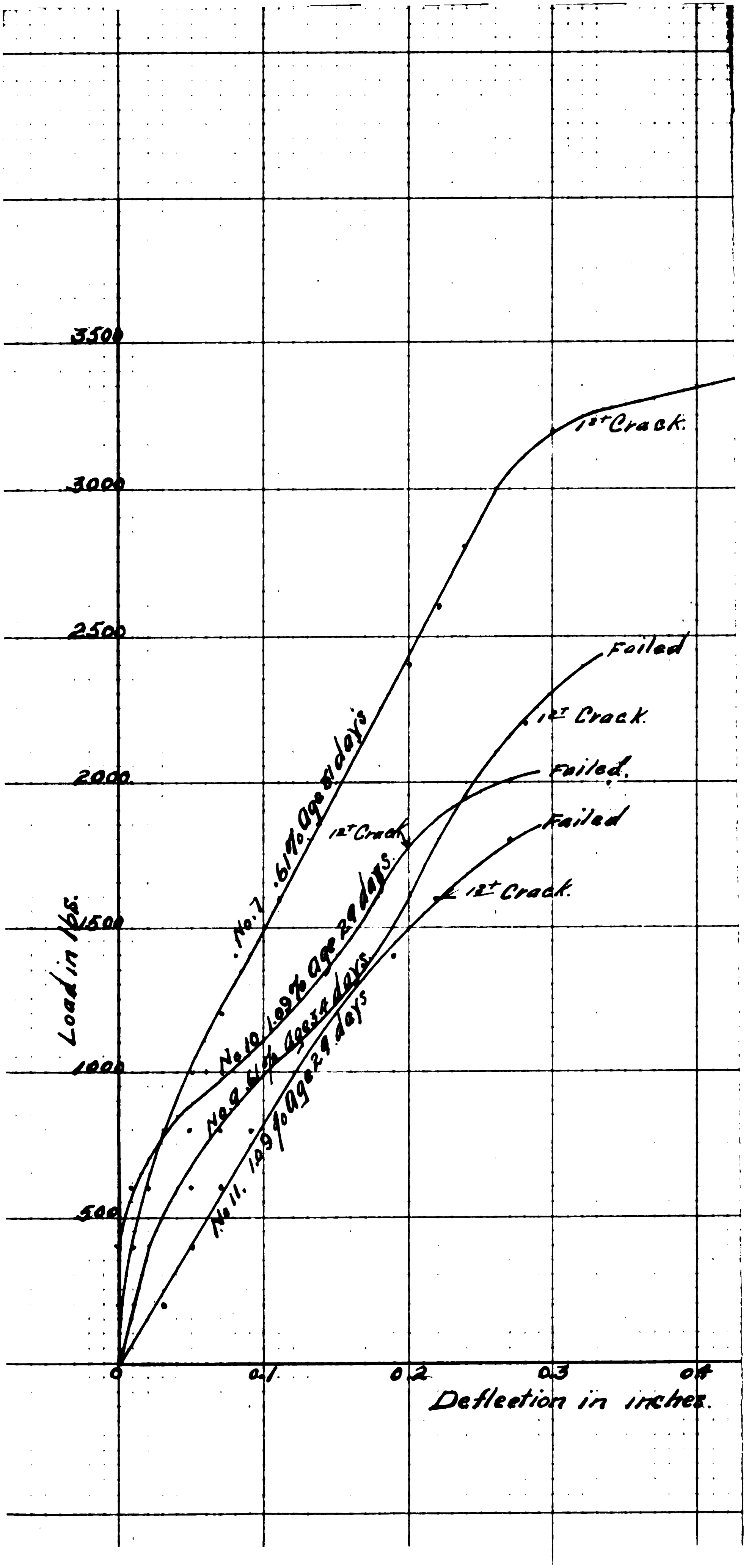
94.24% passed No. 20 seive
60.44% " " 30 "

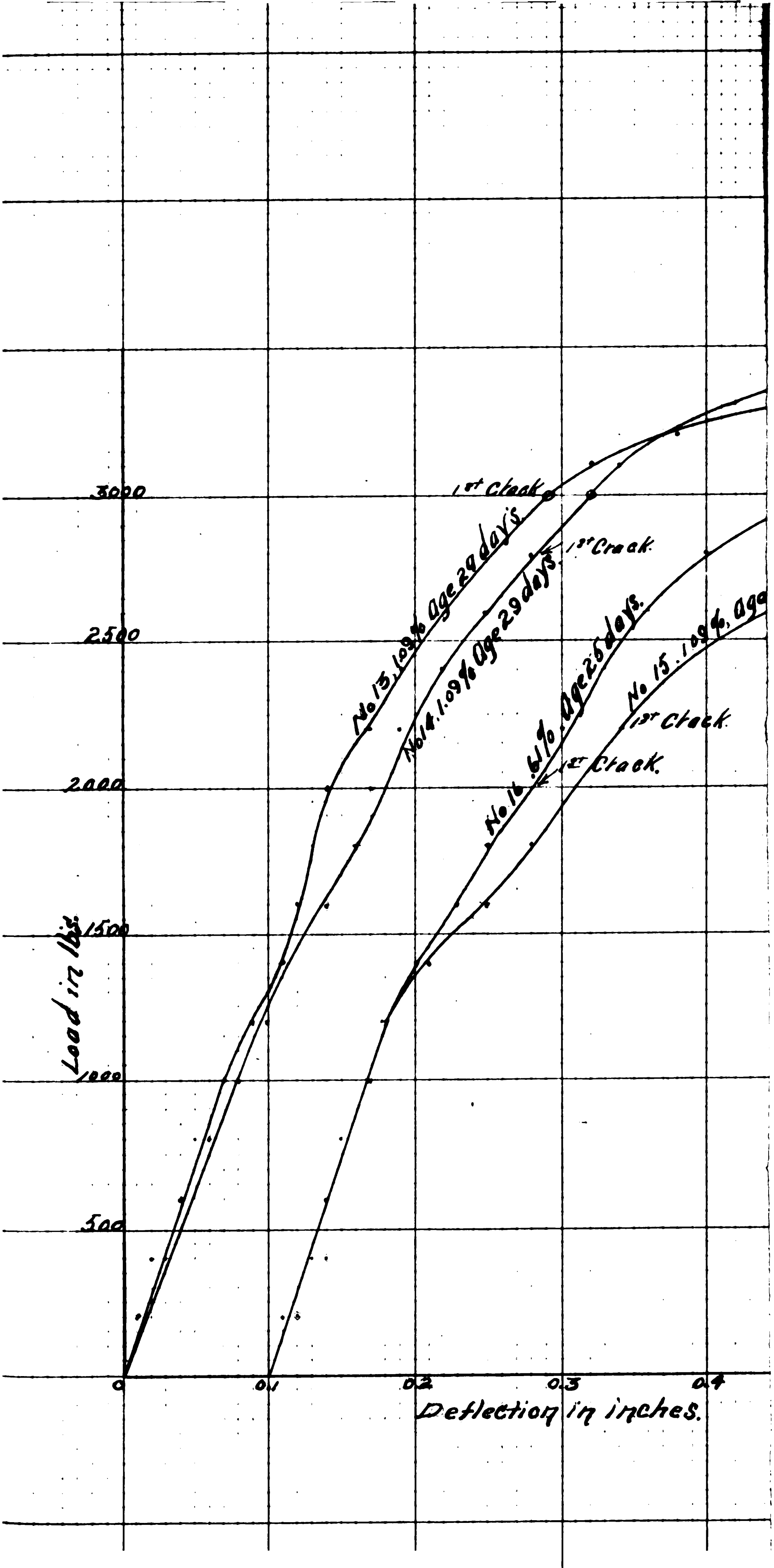
25.5% Water for Neat
8 % " " 3:1

Neat bore smaller needle in three hours.


3000
2500
2000
1500
1000
500
0
0.1
0.2
0.3
Load in lbs.
Deflection in inches.
No 4 61% Age 28 days
No 2 61% Age 64 days


3500
3000
2500
2000
1500
1000
500
Load in
0
0.1
0.2
0.3
0.4
Deflection in inches.
1st Crack.
No.6 .61% Age 31 days.
Failed
Failed.
1st Crack.
1st Crack.
No.8 1.09% Age 34 days
No.12 .09% Age 29 days.


3500
3000
2500
2000
1500
1000
500
0
0.1
0.2
0.3
0.4
Load in lbs.
Deflection in inches.
No. 7 .61% Age 31 days
No 10 1.09% age 29 days
No. 9 .61% Age 34 days
No 11. 1.09% Age 29 days
1st Crack.
Failed
1st Crack.
Failed.
1st Crack
Failed
1st Crack.



3000
2500
2000
1500
1000
500
0
0.1
0.2
0.3
0.4
Load in lbs.
Deflection in inches.
1st Crack
1st Crack.
1st Crack.
1st Crack.
No 13. 1.09% Age 29 days.
No 14. 1.09% Age 29 days.
No 16. .61% Age 25 days.
No 15. 1.09%. Age