Fig. 1 shows the test piece in the machine with Extensometers attached.

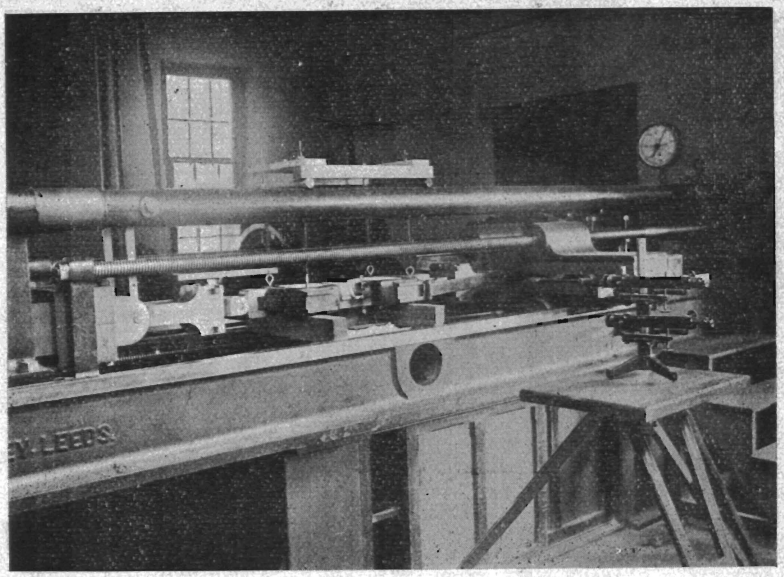


FIG. 1.

Comparing the deformations and breaking loads of a test piece reinforced with steel rods and a plain test piece not reinforced, it will be seen that the increase in strength is very decided, also the decrease in extensibility for a given stress, and therefore increase in the co-efficient of elasticity. In every case the co-efficient of elasticity decreases as the stress increases, the curves plotted from the results of tests were convex to the axis of stresses, but the curves for the reinforced pieces were slightly flatter.

The following tension tests were made on specimens hardened in air consisting of both mortar and concrete:—

TABLE V—TENSILE TESTS, MORTAR BRIQUETTES.

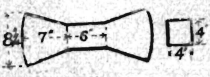
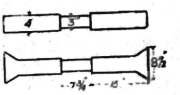
Description.	Age in Days.	Total Load in thousand pounds.	Tensile Stress in pounds per square inch.	Extension in .0004 inch on 4 inch.	Coefficient of Elasticity in millions of pounds per square inch.	Total unit stress E—Tal Unit Strain 500 lbs. initial load always subtracted.	Breaking Load in pounds per square inch.	Reference to Curves	Adhesion pounds per square inch if surface of rods approximate.
1	2	3	4	5	6	7 $\times 10^6$	8	9	10
1 cement to 3 sand;	764	1	63	·06	4·528	5·330	356	I.a. 1	88
1 ½ in. bar.		2	125	·25	2·388	3·760			
Section 4 x 4 in.		3	188	·60	1·862	2·618			
		4	250	·90	1·758	2·433			
		5	313	1·31	1·620	2·153			
	765	1	63	·04	5·390	8·000	491	I.a. 2	94
1 cement to 3 sand;		3	188	·40	2·921	3·925			
4 ½ in. bars.		5	313	·85	2·845	3·320			
Section 4 x 4 in.		6	375	1·07	2·845	3·215			
	760	2	125	·08	4·740	11·750	516	I.a. 3	82
1 cement to 3 sand;		4	250	·46	2·791	4·783			
5 ½ in. bars.		6	375	·92	2·720	3·740			
Section 4 x 4 in.		8	500	1·36	2·720	3.450			
	943	1	63	·10	3·360	3·200	266	I.a. 4	
1 cement to 4 sand;		2	125	·14	1·596	6·714			
no bars.		3	188	·90	·979	1·744			
Section 4 x 4 in.		4	250	1·58	·750	1·390			
	30	2	167	·40	·907	3·125	833	I.b. 1	190
1 cement to 3 sand;		4	334	4·33	·450	·675			
5 ⅜ in bars.		6	501	7·35	·690	·627			
Section 4 x 3 in.		8	668	9·80	·684	·638			
									
1 cement to 3 sand;	32	2	205	·55	1·220	2·800	922	I.b. 2	176
5 ⅜ in. bars.		5	513	2·68	1·727	1·725			
Section 3¼ x 3 in.		8	820	5·88	·720	1·308			
1 cement to 3 sand;	24	2	208	·86	1·710	1·814	381	I.b. 3	163
5 ⅜ in. bars.		4	417	1·66	2·030	1·211			
Reinforced with 4		6	625	2·87	2·170	2·000			
⅜ in. bars at end.		8	834	3·71	2·820	2·108			
Section 3.2 x 3 in.									
1 cement to 3 sand;	36	2	208	·95	·465	1·642	993	I.b. 4	190
5 ⅜ in. bars.		5	520	7·05	·673	·665			
Section 3-2 x 3 in.		8	834	10·84	3·260	·720			
1 cement to 3 sand;	42	2	222	·61	1·060	2·721	1611	I.b. 5	..
5 ⅜ in. bars, stiffened at ends.		6	667	5·62	·905	1·222			
		10	1111	10·60	·905	1·000			
Section 3 x 3 in.		14	1555	15·63	·905	·958			
1 cement to 3 sand;	40	2	222	·57	1·060	3·350	1583	I.b. 6	..
5 2-3 in. bars.		6	667	5·75	·850	1·105			
Section 3 x 3 in.		10	1111	10·59	·800	1·018			
		14	1555	15·33	·836	·992			

TABLE VI.—TENSILE TESTS CONCRETE BRIQUETTES.

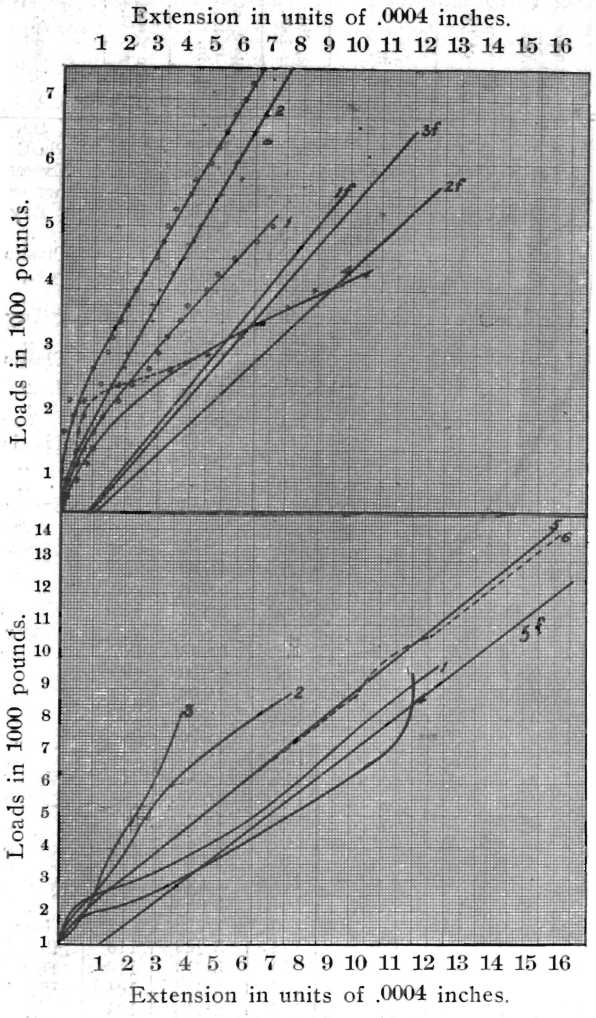
Section 4 inch by 4 inch, unless stated otherwise.

Composition.	Age in days.	Total Load in thousand pounds.	Tensile Stress, pounds per sq. in.	Extension in .0004	Coefficient of Elasticity in millions of pounds per square inch.	E = Tal Unit Stress / Tal Unit Strain	Breaking Load in pounds per square inch.	Adhesion, pounds per square inch.
						$\times 10^6$		
1	2	3	4	5	6	7	8	10
1 cement, 2 sand, 2 ¾ in. shivers	59	1	63	·02	2·500	16·000	203	
		2	125	·42	1·740	2·215		
		3	188	·78	1·550	2·000		
Ditto	59	1	63	·12	2·840	2·667	250	
		2	125	·32	2·500	2·939		
		3	188	·62	2·236	2·533		
Ditto	242	1	63	·10	2·950	3·200	219	
		2	122	·39	2·290	2·410		
		3	188	·67	3·300	2·344		
Ditto	244	1	63	·08	3·750	4·000	203	
		2	125	·32	1·670	2·937		
		3	188	·87	1·140	1·805		
1 cement, 2 sand, 3 ¾ in. shivers ..	239	1	63	·05	5·680	6·400	259	
		2	125	·15	4·115	6·265		
		3	188	·32	3·170	4·909		
		4	250	·57	2·695	3·841		
Ditto	240	1	63	·13	3·065	2·830	266	
		2	125	·35	3·270	2·686		
		3	188	·62	2·765	2·532		
		4	250	·82	2·855	2·606		
1 cement, 2 sand, 3 ¾ in. shivers, 4 ½	61	1	63	·10	2·720	3·200	297	
		5	125	·40	2·670	2·350		
		3	188	·60	2·640	2·818		
		4	250	·84	2·110	2·606		
Ditto	60	1	63	·08	4·220	4·000	278	
		1	94	·10	·279	6·300		
		2	125	1·34	1·410	·702		
		3	188	1·62	2·400	·969		
		4	250	1·86	2·125	1·178		
Ditto	59	1	63	·10	2·600	3·200	278	
		2	125	·36	2·680	2·611		
		3	188	·70	2·540	2·244		
		4	250	·90	2·220	2·433		
1 cement, 3 grit with dust	57	2	125	·48	1·590	1·957	278	
		3	219	1·58	·771	1·197		
	58	2	125	·88	1·250	1·070	273	
Ditto		3	219	1·34	·736	1·403		
	238	1	63	·10	2·315	3·200	209	
Ditto		2	125	·38	2·895	1·670		
		3	188	·58	2·660	2·706		
Ditto	239	1	63	·28	1·157	1·143	145	
		2	125	1·06	·800	·887		
1 cement, 2 sand, 2 ¾ in. shivers ..	48	2	125	·22	3·720	4·273	500	100
		4	250	·56	2·600	3·990		
4½ in. bars. ..		5	313	1·50	·468	1·860		
		7	438	3·92	·500	1·036		

TABLE VI—Continued.

Composition.	Age in Days	Total Load in thousand pounds	Tensile Stress, lbs. per square inch	Extension in .0004 inch on 4 inches.	Coefficient of Elasticity in millions of pounds per square inch.	$E = \frac{\text{Tal. Unit Stress}}{\text{Tal. Unit Strain}}$	Breaking Load in pounds per square inch	Adhesion, pounds per square inch.
						× 10 6		
1	2	3	4	5	6	7	8	9
1 cement, 2 sand, 3 ¾ in. shivers, 4 ½ in. bars	48	2	125	·26	3·060	3·615	422	44
		4	250	·90	1·190	2·433		
		5	313	1·56	·770	1·807		
		6	375	2·30	1·260	1·500		
Ditto	46	2	125	1·28	2·890	·734	656	165
		4	250	1·82	1·408	1·200		
		5	375	3·48	·676	·903		
		7	438	4·30	·845	·946		
		10	626	6·20	·884	·960		
1 cement, 2 sand, 2 ¾ in. shivers, 4 ½ in. bars.	82	2	125	·27	2·980	3·481	694	162
		6	375	1·07	2·160	3·214		
		8	500	1·86	·728	2·521		
		10	625	4·12	·356	1·444		
1 cement, 2 sand, 2 ¾ in. shivers, 4 ½ in. bars.	121	2	125	·19	2·400	4·949	688	159
		6	375	1.12	·800	3·070		
		8	500	4·12	·346	1·137		
		10	626	7·67	·410	·776		
1 cement, 2 sand, 2 ¾ in. shivers, 4 ½ in. bars	237	2	125	·17	2·315	5·530	419	18
		4	250	·57	2·800	3·840		
		6	375	1·33	2·720	2·585		
1 cement, 2 sand, 3 ¾ in. shivers, 4 ½ in. bars	230	2	125	·22	2·315	4·275	531	109
		4	250	·95	·962	2·305		
		6	375	2·78	·736	1·238		
		8	500	3·72	·388	1·261		
1 cement, 2 sand, 2 ¾ in. shivers, 4 ½ in. bars	123	2	125	·00	4·460	..	656	147
		5	315	·91	·781	3·090		
		7	438	3·80	·725	1·071		
		10	626	7·10	·625	·837		
1 cement, 2 sand, 2 ¾ in. shivers, 4 ½ in. bars.	124	2	125	·16	3·300	5·876	563	117
		5	313	·92	·350	3·065		
		7	438	4·54	·530	3·960		
1 cement, 2 sand, 3 ¾ in. shivers, 4 ½ in. bars	128	2	125	·06	4·460	15·660	720	177
		6	375	1·37	·880	2·510		
		11	688	7·89	·500	·754		
1 cement, 2 sand, 3 ¾ in. shivers, 4 ½ in. bars	127	2	125	·31	2·500	3·032	588	132
		6	375	2·00	·925	1·720		
		9	563	4·15	·771	1·282		
1 cement, 2 sand, 3 ¾ in. shivers, 4 ½ in. bars	128	2	125	·15	3·125	6·268	625	145
		5	313	1·03	2·083	2 736		
		7	438	1·76	·745	2·311		
		10	626	4·57	1·80	1 361		
1 cement, 2 sand, 3 ¾ in. shivers, 4 ½ in. bars	127	2	125	·21	2·238	4·178	651	143
		5	315	69	3·900	4·007		
		7	438	2·17	·500	1·865		
		10	626	4·32	·694	1 366		
1 cement, 2 sand, 2 ¾ in. shivers, 4 ½ in. bars.	236	2	125	·20	2·170	4·700	589	114
		5	315	2·17	·500	1·299		
		8	500	5·37	·539	·873		
1 cement, 2 sand, 5 ¾ in. shivers, 4 ½ in. bars	231	2	125	·18	2·170	5 221	594	
		5	313	1·52	·863	1 855		
		8	500	4·00	·718	1 172		

Some of the stress strain diagrams obtained in these tension tests are shown in Figs. Ia and Ib, and it should be noted that the extensions are plotted in units of 0.0004 inches.



A valuable series of tests have been made by Mr. W. H. Henby in a paper read before the Engineers Club of St. Louis in 1900. The cross-section of the test pieces was 2⅞ x 3½ inches for a length of 14 inches, and the elongations were measured over a length of 10 inches. The results are recorded in the following tables:—

TABLE VII.

HENBY'S TENSILE TESTS OF PORTLAND CEMENT CONCRETES.

No.	Age Days.	Composition. Cement.	Sand.	Stone.	Brand of Cement.	Kept in	Weight, lbs. per cubic foot.	Coefficient of Elasticity in million lbs. sq. in.	Tensile strength, lbs. per sq. in.	Consistency.
1	7	1	2	4	L	Air dry	..	2·000	130	Dry
2	8	1	2	4	A	A r	157	3·720	213	Plastic
3	18	1	2	4	M	Air dry	...	2·286	75	Excess of water
4	30	1	2	4	L	,, ,,	142	2·882	108	Dry
5	30	1	2	4	L	,, ,,	148	4·721	227	,,
6	30	1	2	4	L	,, ,,	142	2·209	191	Plastic
7	30	1	2	4	A	Air	148	3·306	192	,,
8	30	1	2	4	A	,,	150	3·600	241	,,
9	30	1	2	4	A	,,	149	8·360	183	Dry
10	30	1	2	4	A	,,	149	7·280	214	,,
11	30	1	2	4	A	,,	153	3·750	223	Plastic
12	30	1	2	4	A	Water	158	3·550	279	,,
13	35	1	2	4	L	Air dry	147	4·543	149	,
14	64	1	2	4	A	Air	151	7·744	252	Dry
15	65	1	2	4	A	,,	144	3·810	143	Plastic
16	65	1	2	4	A	,,	140	3·724	102	,,
17	65	1	2	4	A	Water	150	3·440	82	,,
18	90	1	2	4	M	Air dry	147	3·550	125	Excess Water
19	96	1	2	4	L	,, ,,	146	3·992	190	Plastic
20	96	1	2	4	L	,, ,,	147	4·760	226	,,
21	100	1	2	4	L	,, ,,	147	5·073	209	,,
22	120	1	2	4	M	,, ,	143	3·473	136	Excess Water
23	7	1	2	5	A	Air	152	3·068	147	Plastic
24	14	1	2	5	M	Air dry	139	2·000	85	,,
25	18	1	2	5	M	,, ,,	..	2·106	120	,,
26	30	1	2	5	A	Air	145	4·532	165	,,
27	30	1	2	5	A	,,	152	4·425	242	,,
28	30	1	2	5	A	Water	155	5·006	230	,,
29	60	1	2	5	A	Air dry	144	1·857	111	Very dry
30	60	1	2	5	A	,, ,,	146	3·253	128	Dry
31	60	1	2	5	A	,, ,,	146	3·023	180	,,
32	63	1	2	5	A	Air	146	4·980	154	,,
33	63	1	2	5	A	,,	146	3·744	192	,,
34	90	1	2	5	A	Air dry	144	3·696	129	Very dry
35	90	1	2	5	A	,, ,,	144	3·896	93	,, ,,
36	90	1	2	5	M	,, ,,	140	3·776	142	Dry
37	7	1	3	5	A	Water	154	3·828	115	Plastic
38	30	1	3	5	A	Air	150	3·810	110	Dry
39	30	1	3	5	A	,,	147	2·427	104	Plastic
40	30	1	3	5	A	,,	148	2·440	128	,,
41	30	1	3	5	A	,,	144	4·496	93	,,
42	30	1	4	8	A	Air	143	3·553	71	Plastic
43	30	1	4	8	A	Water	149	6·108	125	Dry
44	90	1	3	-	M	Air dry	136	3·988	199	,,
45	90	1	3	-	M	,, ,,	139	5·202	234	,,
46	120	1	3	-	M	,, ,,	136	5·144	144	Very dry
47	120	1	3	-	M	,, ,,	136	5·150	154	,, ,,
48	95	1	-	-	M	Water	137	6·423	645	Plastic

(x) M=Medusa. L=Lehigh A=Atlas.

Some of the values for the co-efficient for elasticity are very high, due probably to the specimens being more thoroughly consolidated. The stone consisted of limestone broken to a maximum size of 1½ to 2 inches, having a per centage of voids of from 43 to 46. The co-efficient of elasticity, as shown in the author's tests, as well as Henby's does not appear to be much affected by the age, or whether the specimens are kept in air or water.

Professor W. K. Hatt (*), 1902, gave the following results for concrete consisting of cement 1, sand 2, and broken stone 4, at the ages of 25, 26, 28, and 33 days, for use in reinforced concrete structures.

TABLE VIII.

	Co-efficient of Elasticity in millions of lbs. per square inch.	Tensile strength in lbs. per sq. inch.
Maximum	2.700	360
Mean	2.100	311
Minimum	1.400	280

In reinforced concrete structures it would appear from the foregoing experiments that the concrete should be moist enough to flow between the reinforcing members so as to fully develop the adhesive resistance, but should not be so wet that it will not stand ramming. The co-efficient of elasticity for use in designing tension members should be taken not higher than from 2.500 to 3.00 million pounds per square inch, depending on the quality of the concrete. Considere, in the construction of the shords and web members of the bow-string struss bridge tested to destruction at Ivry, Paris, in November, 1903, used metal bars the full length of the members

*Amer. Soc. of the International Assoc. for the Testing of Materials.

they reinforced, in order to avoid sections which possess smaller resistance, such as occur in riveted members.

COMPRESSION TESTS.

These tests consist of the compression of prisms of mortar and concrete, with and without reinforcement. The following table gives the results of testing prisms of Portland cement mortar without reinforcement 12 inches long by 6 in. x 6 in. in cross-section. The specimen in the machine, with the Marten's mirror apparatus attached, is shown in Fig. 2.

As in all the author's tests, the sand was clean washed river sand, sifted through 400 and caught on 900 meshes per sq. inch, unless otherwise stated. The co-efficient of elasticity, even allowing for the usual unavoidable variation in results, appears to be slightly greater in the older specimens. The co-efficient diminishes with the increase in stress, similar to the results obtained from tension tests.

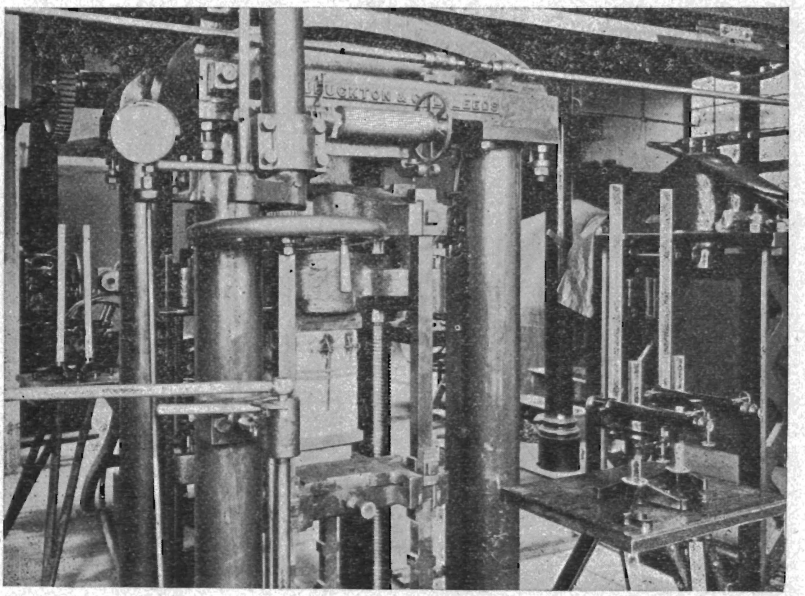


Fig. 2.

TABLE IX

COMPRESSION TESTS OF MORTAR PRISMS, LENGTHS 12 INCHES, CROSS SECTION 6 x 6 inches. KEPT IN WATER.

Composition.	Age in Days	Compressive Stress in lbs. per sq. in.	Compression .0008 inch on 8 inches	Coefficient of Elasticity in millions of lbs. per sq. in.	Breaking Load, lbs. per square inch.
1 Cement to 2 Sand	28	410	0·75	4·640	2985
		905	2·00	4·215	
		1650	4·00	3·970	
	28	285	0·75	2·973	2923
		620	2·00	2·790	
		1120	4·00	2·645	
		1560	6·50	2·496	
		1993	9·00	2·145	
	91	315	0·75	3·373	3557
		795	2·00	3·665	
		1450	4·00	3·470	
		2130	6·50	1·643	
	381	360	0·50	5·960	4640
		1140	2·00	5·390	
		2020	4·00	4·895	
		3020	7·50	4·344	
	28	280	0·75	2·906	2196
		560	2·00	2·490	
		970	4·00	2·270	
		1305	6·00	2·071	
		1730	9·75	1·710	
	29	220	0·75	2·106	2003
		440	2·00	1·890	
		720	4·00	1·645	
		980	6·00	1·530	
		1360	9·50	1·366	
1 cement to 3 sand	91	320	0·75	3·440	2923
		660	2·00	2·990	
		1135	4·00	2·682	
		1540	6·00	2·463	
		1925	8·25	2·258	
	91	130	0·75	·906	2643
		505	2·00	2·215	
		955	4·00	4·465	
		1345	6·00	3·207	
		1855	9·25	2·988	
	423	280	0·50	4·360	2115
		940	2·00	4·390	
		1710	4·00	4·120	
		2115	5·25	3·910	
	379	160	0·50	1·960	3129
		610	2·00	2·740	
		1140	4·00	2·695	
		1860	7·25	2·480	

COMPRESSION TESTS (Continued).

Composition.	Age in Days	Compressive Stress in lbs. per sq. in.	Compression of .0003 inch on 8 inches	Coefficient of Elasticity in millions of lbs. per sq. inch	Breaking Load, lbs. per square inch.
1 Cement to 4 Sand	29	280	0·75	2·906	1356
		500	2·00	2·190	
		750	4·00	1·720	
		920	6·00	1·430	
		1120	9·50	1·113	
	28	225	0·75	2·140	1468
		440	2·00	1·890	
		685	4·00	1·557	
		895	6·00	1·388	
		1095	8·50	1·215	
	91	230	0·75	2·240	1841
		480	2·00	2·090	
		800	4·00	1·845	
		1100	6·50	1·597	
	91	400	0·75	4·506	1692
		560	2·00	2·490	
		900	4·00	2·095	
		1150	6·00	1·813	
	416	260	0·50	3·960	2096
		720	2·00	3·290	
		1325	4·25	2·971	
	421	200	0·50	2·760	2333
		680	2·00	3·090	
		1160	4·00	2·745	
		1605	6·75	2·286	

The following tables give the results of testing prisms of plain and reinforced concrete by the author. Table X. gives the results of testing prisms of mortar and concrete 12 inches long, cross-section 6 in. x 6 in. without reinforcement. Table XI. gives the results of testing prisms of concrete 24 inches long, cross-section 6 in. x 6 in. without reinforcement, and also reinforced with longitudinal rods bound together at intervals with soft iron wire, and with iron grills. In some cases the prism was loaded up to a certain stress, then un-

loaded, and again loaded and unloaded. The compression strain (shortening of the prism) was measured on 8 inches for the prisms 12 in. long, and on 20 inches for the prisms 24 inches long. Some of the results have been plotted—Figs. IVa, IVd, IVb—and show smooth curves, convex to the load axis.

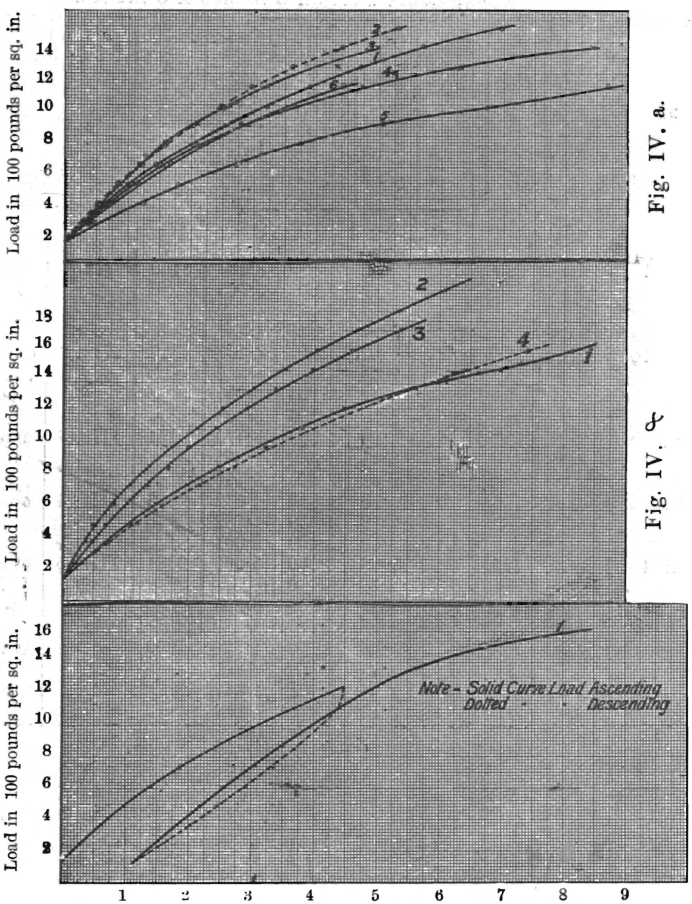


Fig. IV. a.

Fig. IV. &

Fig. IV. B.

TABLE X.— COMPRESSION TESTS OF MORTAR PRISMS.

Lengh 12 inches; Cross Section 6 inches x 6 inches.

Composition.	Age in Days	Compressive Stress, pounds per square inch	Compression in Units of .0008 inch on 8 inches	Coefficient of Elasticity in millions of pounds per square inch	Tal Unit Stress / Tal Unit Strain	Breaking Load in pounds per square inch	Number on Curve	Remarks
					$\times 10^6$			
1	2	3	4	5	6	7	8	9
1 cement to 2 sand	720	373	·31	5·300	8·481	5109	IIIa. 1	cracked at
		1120	1·99	4·110	5·125			170,000
		2240	4·86	3·830	4·382			pounds
		3360	7·58	4·220	4·287			
1 cement to 2 sand	721	373	·59	5·410	4·457	4617	IIIa. 2	cracked at
		1120	2·32	4·010	4·352			134,000
		2240	5·61	3·120	3·798			pounds
		3360	9·56	1·950	3·400			
1 Cement to 3 Sand	725	373	·48	4·980	5·479	3204	IIIa. 3	cracked at
		1120	2·08	4·360	4·855			108,000
		2240	5·62	2·410	3·790			pounds
1 cement to 3 sand	726	373	·58	4·840	4·532	2868	IIIa. 4	cracked at
		1120	2·18	4·050	4·632			89,600
		2240	5·60	2·490	3·801			pounds
1 cement to 4 sand	727	373	·85	3·260	3·093	2364	IIIa. 5	cracked at
		871	2·37	3·060				78,500
		1120	3·15	2·950	3·205			pounds
		1493	4·57	2·770	3·028			
1 cement to 4 sand	729	373	·55	4 150	4·780	2209		cracked at
		871	1·85	5·720				72,000
		1120	2 04	7·001	4·951			pounds
		1493	2·96	3·830	4·672			