a-21

1578

COMPARATIVE TESTS OF BAMBOO WITH OTHER WOODS FOR STRUCTURAL PURPOSES.

By

Vicente G. Manalo

and

George A. Moffatt.

SPRING TERM

1908.

------- O U T L I N E -------

1. SUBJECT:

Comparative Tests of Bamboo with other Woods for Structural Purposes.

2. APPARATUS:

a. Riehle Testing Machine (Including Drawing)

b. Description of the Machine

3. MATERIALS USED:

a. Bamboo.

b. Spruce.

4. DATA:

1. Compression.

a. Discussion.

2. Transverse(Including Curves)

b. Discussion.

3. Tension

c. Discussion.

4. Triangular Beams.

d. Discussion.

5. CONCLUSION.

The apparatus used during the test was a "Riehle" Testing Machine of 100,000 lbs. capacity and located at the Engineering Laboratory, Kansas State Agricultural College. In general the machine is classified into the following parts.

1. The Straining Mechanism.
2. The Weighing Apparatus.
3. The Screw and Vernier Beams.
4. The Driving Mechanism.

The Straining Mechanism is of the screw power type and is composed of the following parts.

1. Tension top head.
2. Weighing table.
3. Iron Supports.
4. Movable head.

The weighing table rests upon eight hardened steel knife edges in the main levers. These levers rest on shells which are fitted in cast iron bearings in the cover plate. Beneath this cover plate and bolted to it is the cast iron box containing the main gears, and to which the bracket supporting the beam and lever-stands is attached. In the compression test the specimen is crushed between the two crushing tools, one being attached to the underside of the pulling head, and the other resting centrally on the table. In transverse test, one knife edge is attached to the lower side of the pulling head, the other two knife edges resting on the table equidistant from the first and as far from it as desirable. The specimen rests on the two knife edges placed on the table and is broken by the third knife edge pressing down on it. For tensile tests the ends of the specimens are held by hardened steel wedges, or "grips" which fit into the opening in the heads. Owing to their wedge shape, the grips hold the specimen the more firmly as the stress on it increases. There are liners of various thickness by which the distance between the grips can be adjusted to suit the size of the specimen. The flat grips are for oblong or flat specimens, the centre of the grips being slightly raised to give a better hold.

The table rests wholly upon the main levers, the recoil bolts passing through it loosely, and any pressure on it is transmitted directly through the levers to the beam. There are two main levers; the one resting inside the other, and arranged so as to be nearly of equal length. The knife edges on which the table rests are in the vertical planes of the pulling screws, thus insuring the pressure being equally distributed, and making the power applied by the screws to be transmitted to the weighing apparatus in exactly the same line.

Each of the levers branches into a Y under the table to spread the points of support, and also to allow the screws to pass down into the box. At the far end of the main lever a clevis transmits the strain to the intermediate lever, and link connects this with the beam. A heavy weight hanging from the short end of the beam serves to counterbalance the weight of the other end, and a smaller weight above this, which can be shifted by a screw and hand wheel, allows for the zero adjustment.

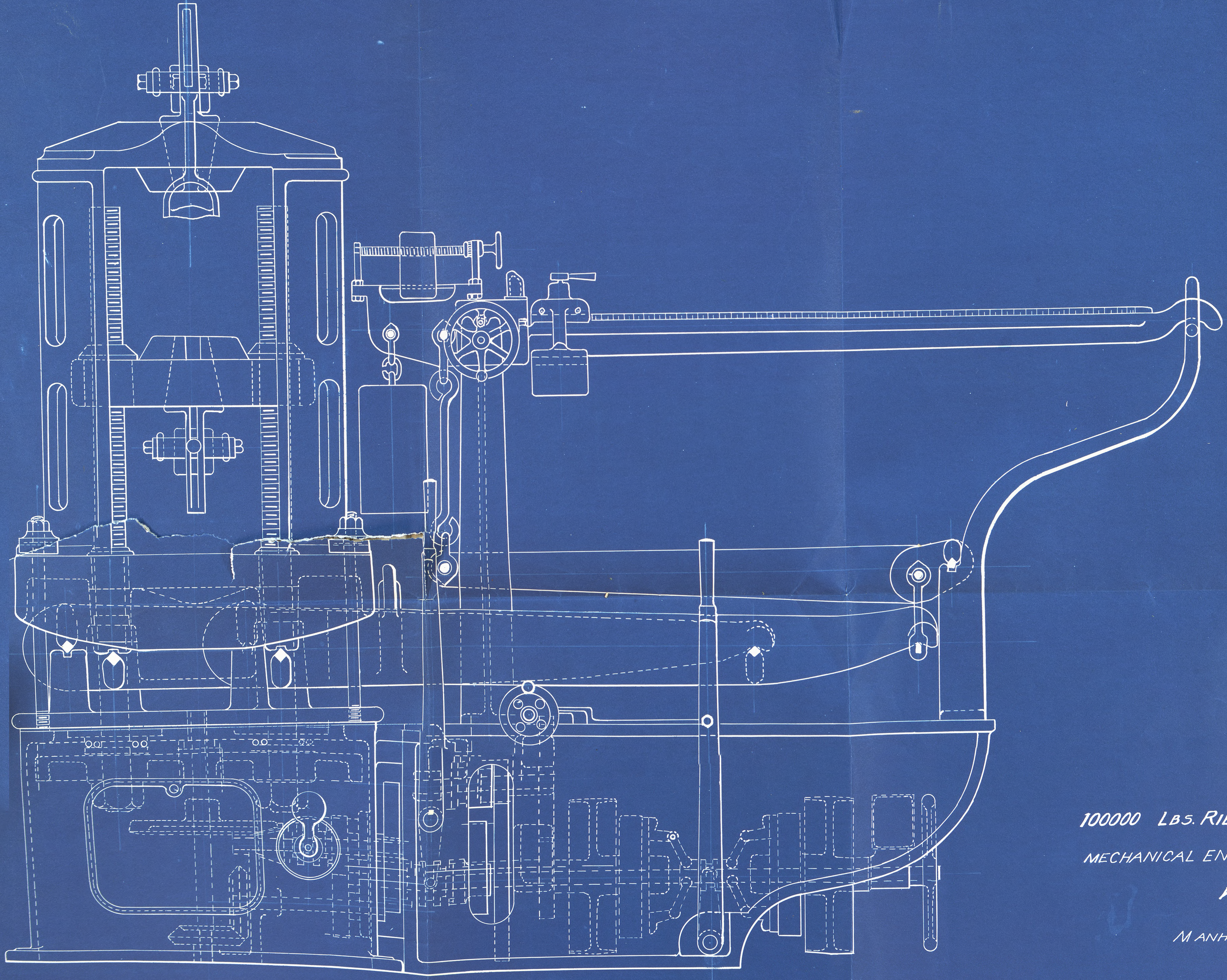
Before making any test the adjustment of the beam should examined to see that it is in equipose. Place the poise at zero and adjust the counterpoise till the beam vibrates freely between the upper and lower bar at the smaller and farther end of the beam. In making a test it is desirable to have the weight registered on the beam simultaneously with the increase of the load applied to the specimen, the equipose of the beam being mantained as nearly as possible. Bear in mind that the load on the specimen is only weighed accurately when the beam is in equipose. When the beam is against the upper bar the load on the specimen is greater than the poise on the beam is indicating, and it is difficult to tell how much greater it is except when the beam is again balanced by the outward movement of the poise. The excess of the load may be smaller or greater, and in such cases it is advisable to stop the pull on the specimen and balance the beam. In the case of beam being down the poise is moved backward until the beam is again balanced.

The screw beam used is of the Riehle Dial Type. It is graduated to 1000 lbs. on the beam and from the dial at the operating end of the beam the 100 lbs. and 10 lbs. are read.

The two pulling screws pass down through long bearings in the cover plate and to their lower ends are keyed the main gears. Between these gears and the cover plate are thrust plates and ball bearings consisting of double rows of hardened steel balls and bearing plates, which take the thrust and reduce friction.

A small pinion engages with the main gears and on this pinion shaft is a large bevel gear which is driven by a smaller gear.

On this same shaft is a mitre gear and the arrangement is such that the machine may be driven through either the bevel or mitre gears, according to the position of the clutch. On the main bracket is the controlling lever which starts, stops or reverses the machine by throwing in or out one or the other of the friction clutches of the driving pulleys. To secure reversal of motion these pulleys are driven the one by an open the other by a crossed belt.



100000 LBS. RIEHLE TESTING MACHINE.

MECHANICAL ENGINEERING LABORATORY.

K. S. A. C.

MANHATTAN – KANSAS.

With the development of aerial navigation comes the demand for a light and strong structure for holding the engines and other machanisms. The materials used for this purpose are:

1. Steel tubing.
2. Spruce.
3. Bamboo.
4. Aluminum tubing.

The chief objection to steel tubing is its weight; also much skill is required in making the joints. For long and bulky structure its weight is so great that spruce, fir, bamboo and other woods are used in its place. The same can be said of aluminum tubing. Our object is to find which of the woods (bamboo and spruce) is the most desirable for this purpose. Let us first acquaint ourselves with the nativity and characteristic of the two woods under discussion.

The term bamboo is applied to hundred of species varying in size from mere grasses to the Gigantochloa. Aspera of Java which some times grows as high as 175 ft. and upwards of 18 in. in diameter. The only bamboo which is seen in this country and on which our test were made is known as Japanese Cane. Bamboo in the tropics is used for nearly every thing. One writer on the subject says in substance; Bamboo is to the people of the tropics what the oak, the pine and the chestnut in woods and iron steel a and brass in metals are to us. Even more than this for textile fabrics and food are also produced by this mighty grass and in some climes it seems as though it can be made to serve every actual necessity of man and beast. It supplies the fence around the garden patch, the dwelling from corner-post to clap-board, water pots, water pipes, flower pots, cups and other utensiles, chairs, tables, beds, hammocks, food for both man and beast, hedges and decoration shrubbery for the lawn.

To this might be added a long list of other things such as bridges, masts for sail-boats, shafts for spears, rugs, carpet etc.

To make a roof the bamboo is split and laid over lapping forming an excellent water shed.

Bamboo is used for bottles and fruit jars. They can be made in any size desired. Freshly cut bamboo is so full of moisture that flowers can be sent long distances in it. Some species of bamboo bear a juicy berry which is used as food. It is preserved and kept in jars or bottles made of bamboo.

The growth of the bamboo is remarkable as it does most of its growing in the night. The growth is also very rapid.

Robusta has grown 18 ft. in a month. Vulgarus 40 ft. in one season. Fulda 20 to 30 ft in a month, and the common chinese species have been reported to have grown at the rate of 3 in. an hour.

Spruce is an evergreen which grows in the northern part of the United States and in some of the mountainous parts of the southern states. Some species will grow in almost any part of the temperate zone. The wood resembles soft pine in that it is very soft and tough.

COMPRESSION TEST ON SPRUCE.

No.	Dimensions.	Area.	Breaking Load per Square Inch.	Remarks.
1.	1" X 1" X 4"	1 Sq. In.	8845 lbs.	
2.	"	"	8200 "	
3.	"	"	8580 "	
4.	"	"	8730 "	Specimens failed
5.	"	"	8720 "	by crushing and
6.	"	"	8345 "	splitting.
7.	"	"	8450 "	
8.	"	"	8040 "	
9.	"	"	7900 "	
10.	"	"	7840 "	
Total.............................			83650 "	
Average...........................			8365 "	

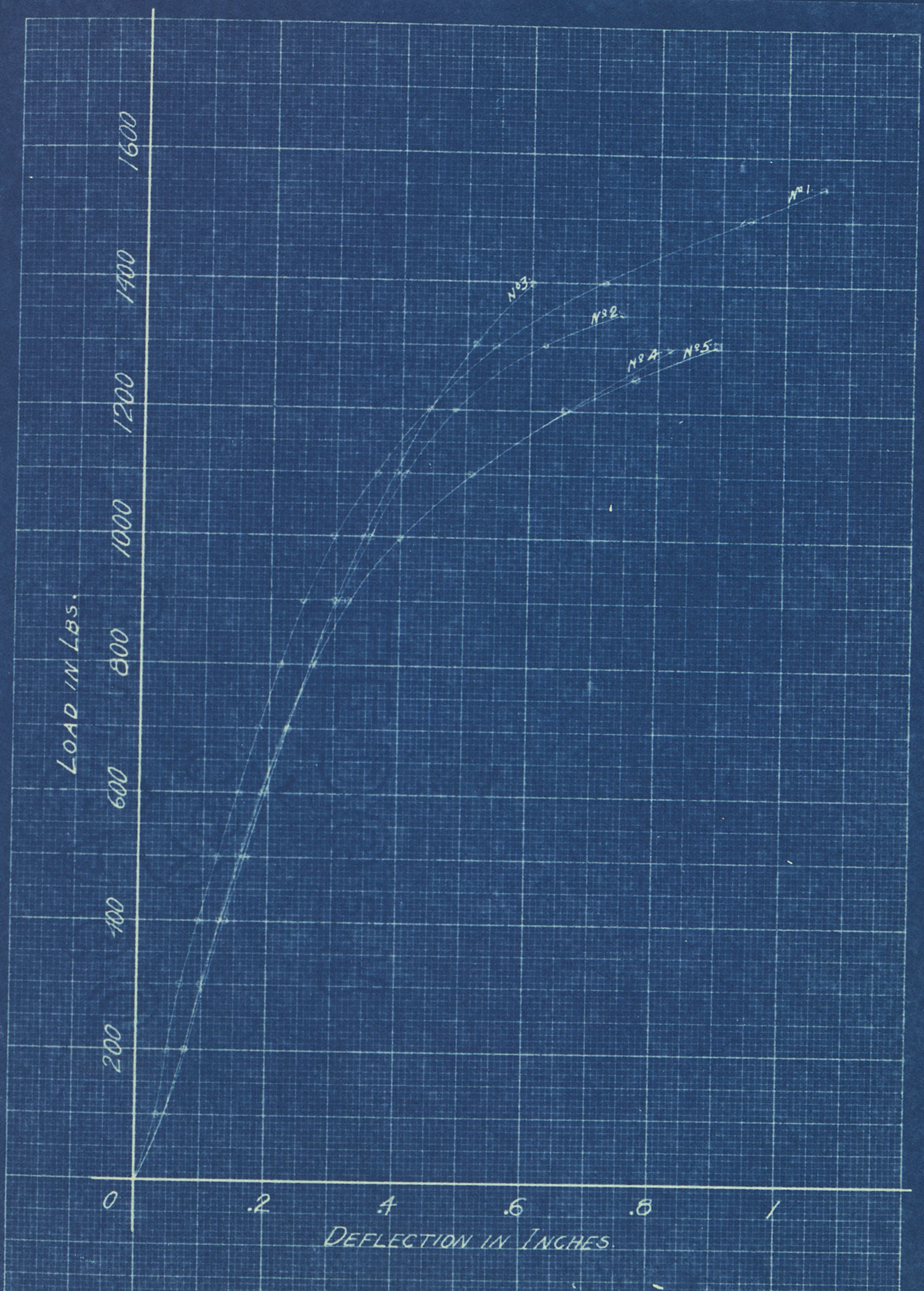
COMPRESSION TEST ON BAMBOO.

No.	Inside Diameter	Outside Diameter	Thickness	Area.	Total Breaking Load	Breaking Load Per. sq. in.
1.	.906	1.187	.140	.449	6150 lbs.	13700 lbs.
2.	.906	1.187	.140	.449	5910 "	13150 "
3.	.906	1.187	.140	.449	6070 "	13500 "
4.	.937	1.187	.125	.404	4790 "	11850 "
5.	.968	1.187	.109	.357	5110 "	14300 "
6.	.828	1.203	.187	.592	7600 "	12840 "
7.	.875	1.156	.140	.455	7280 "	13110 "
8.	.843	1.187	.172	.554	7100 "	12816 "
9.	.875	1.234	.179	.586	6060 "	10343 "
10.	.890	1.172	.141	.453	5230 "	11545 "
Total.	8.934	11.887	1.473	4.898	61300 "	127104 "
Mean.	.893	1.188	.147	.489	6130 "	12710 "

In comparing bamboo with spruce for compression it was necessary to use small sized specimens as no longer sized bamboo could be had. In order to make the specimens of nearly the same size, also for convenience, the spruce was made 1 in. in section and sufficiently short to insure that the specimen would not fail by bending. It was impossible to obtain bamboo with an area equal to 1 sq. in. so the specimens were selected at random and the load per sq. in. calculated. The bamboo failed by crushing and splitting while the spurce failed mainly by shearing. The bamboo is much the stronger of the two as can be seen by the data. The average breaking load per sq. in. of the bamboo is 12710# while that of the bamboo is 8360#. The spruce is there fore about two thirds as strong as the bamboo.

TRANSVERSE TEST ON SPRUCE.

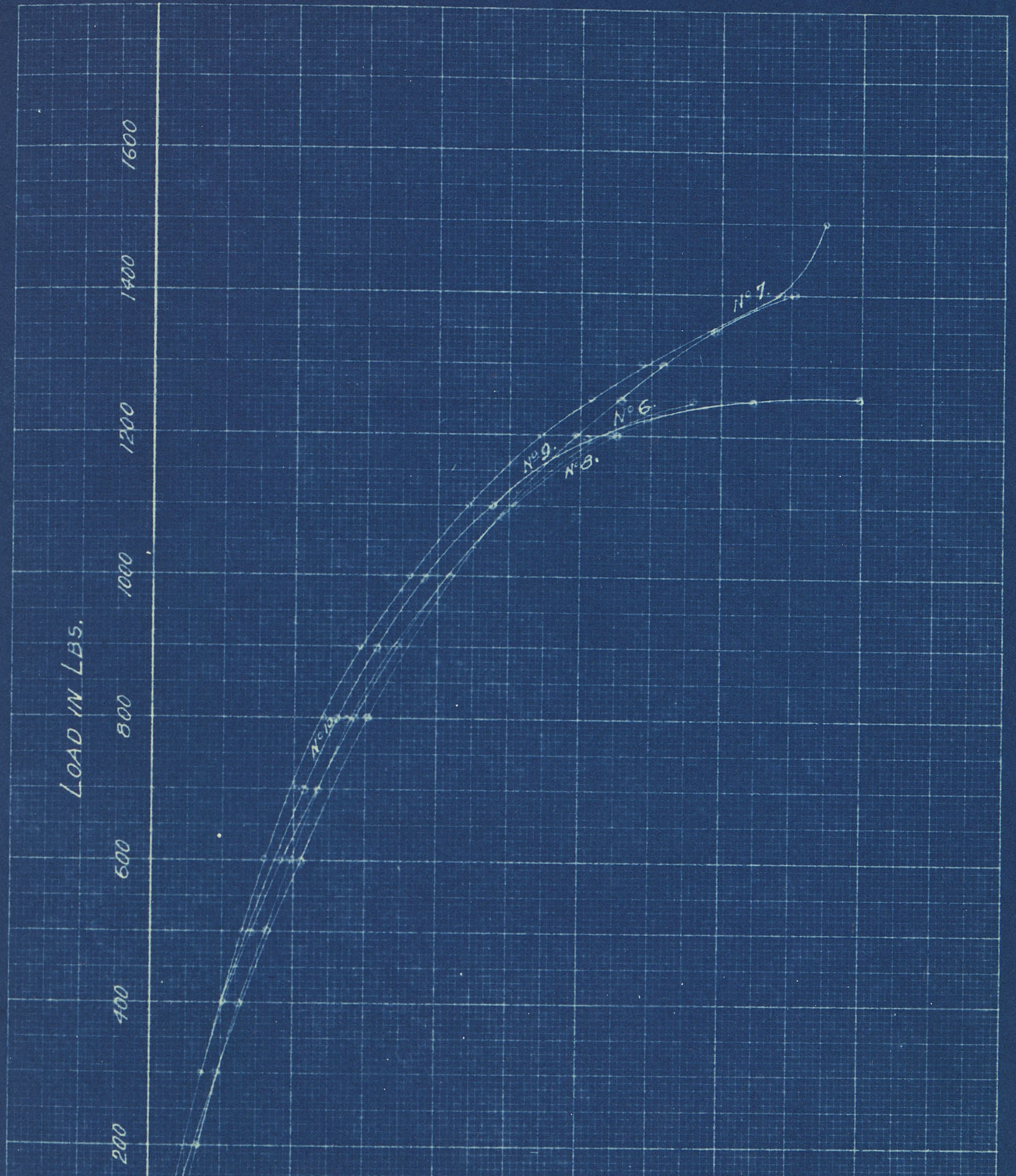
No. 1		No. 2		No. 3		No. 4		No. 5	
Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load.	Defl.
100	.032	100	.044	100	.049	100	.045	100	.032
200	.048	200	.071	200	.079	200	.077	200	.066
300	.069	300	.099	300	.108	300	.090	300	.094
400	.096	400	.124	400	.135	400	.131	400	.126
500	.121	500	.151	500	.172	500	.174	500	.168
600	.156	600	.189	600	.199	600	.204	600	.198
700	.186	700	.221	700	.230	700	.238	700	.230
800	.216	800	.266	800	.268	800	.272	800	.270
900	.250	900	.312	900	.305	900	.325	900	.332
1000	.299	1000	.353	1000	.348	1000	.402	1000	.416
1100	.368	1100	.392	1100	.399	1100	.519	1100	.518
1200	.445	1200	.485	1200	.454	1200	.650	1200	.661
1300	.546	1250	.562	1300	.514	1300	.826	1250	.661
1400	.722	1300	.622	1400	.604	1340	B.L.	1300	.897
1500	.942	1350	.741	1460	.742			1340	B.L.
1550	1.560								



LOAD IN LBS.
1600
1400
1200
1000
800
600
400
200
0
.2
.4
.6
.8
1
DEFLECTION IN INCHES.
No1
No3
No2
No4
No5

TRANSVERSE TEST ON SPRUCE.

No. 6.		No. 7.		No. 8.		No. 9.		No. 10.	
Load.	Defl.	Load	Defl.	Load.	Defl.	Load	Defl.	Load	Defl.
100	.029	100	.033	100	.052	100	.033	100	.031
200	.052	200	.045	200	.071	200	.068	200	.055
300	.077	300	.080	300	.089	300	.098	300	.077
400	.104	400	.106	400	.121	400	.131	400	.105
500	.142	500	.142	500	.161	500	.168	500	.142
600	.181	600	.169	600	.194	600	.213	600	.185
700	.230	700	.205	700	.233	700	.279	700	.218
800	.264	800	.247	800	.272	800	.303	800	.265
900	.348	900	.299	900	.331	900	.352	900	.325
1000	.423	1000	.362	1000	.422	1000	.428	1000	.385
1100	.512	1100	.448	1100	.492	1100	.486	1100	.472
1200	.647	1200	.549	1200	.645	1200	.597	1200	.616
1250	.760	1250	.614	1250	.847	1250	.662	1250	1.021
1300	B.L.	1300	.684			1300	.714		
		1350	.772			1350	.791		
		1400	.885			1400	.906		
		1450	.945			1450	B.L.		


Load in Lbs.
1600
1400
1200
1000
800
600
400
200
0
.2
.4
.6
.8
1
Actual Deflection in In.
No. 7.
No. 6.
No. 9.
No. 8.
V.G.M.

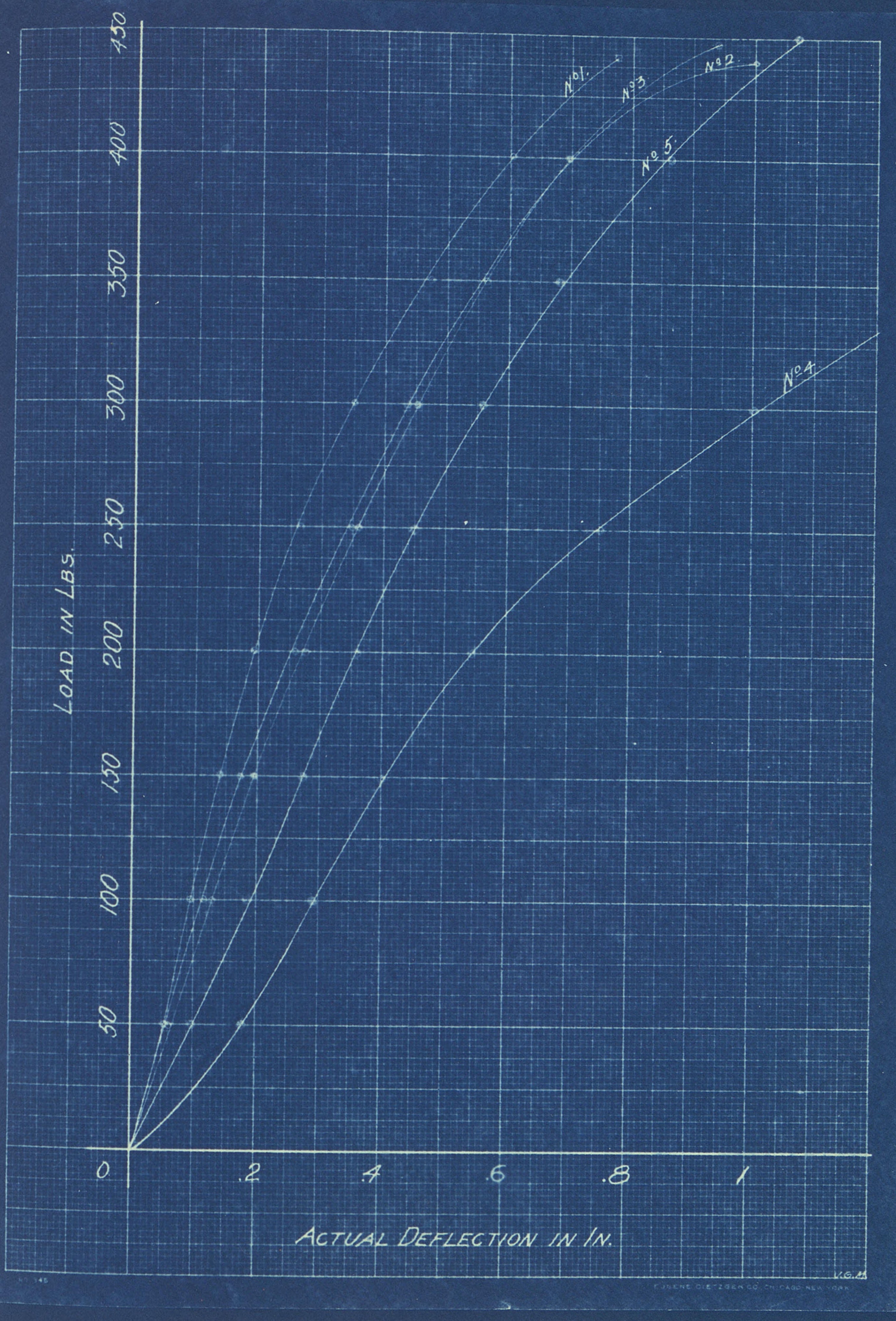
TRANSVERSE TEST ON SPRUCE.

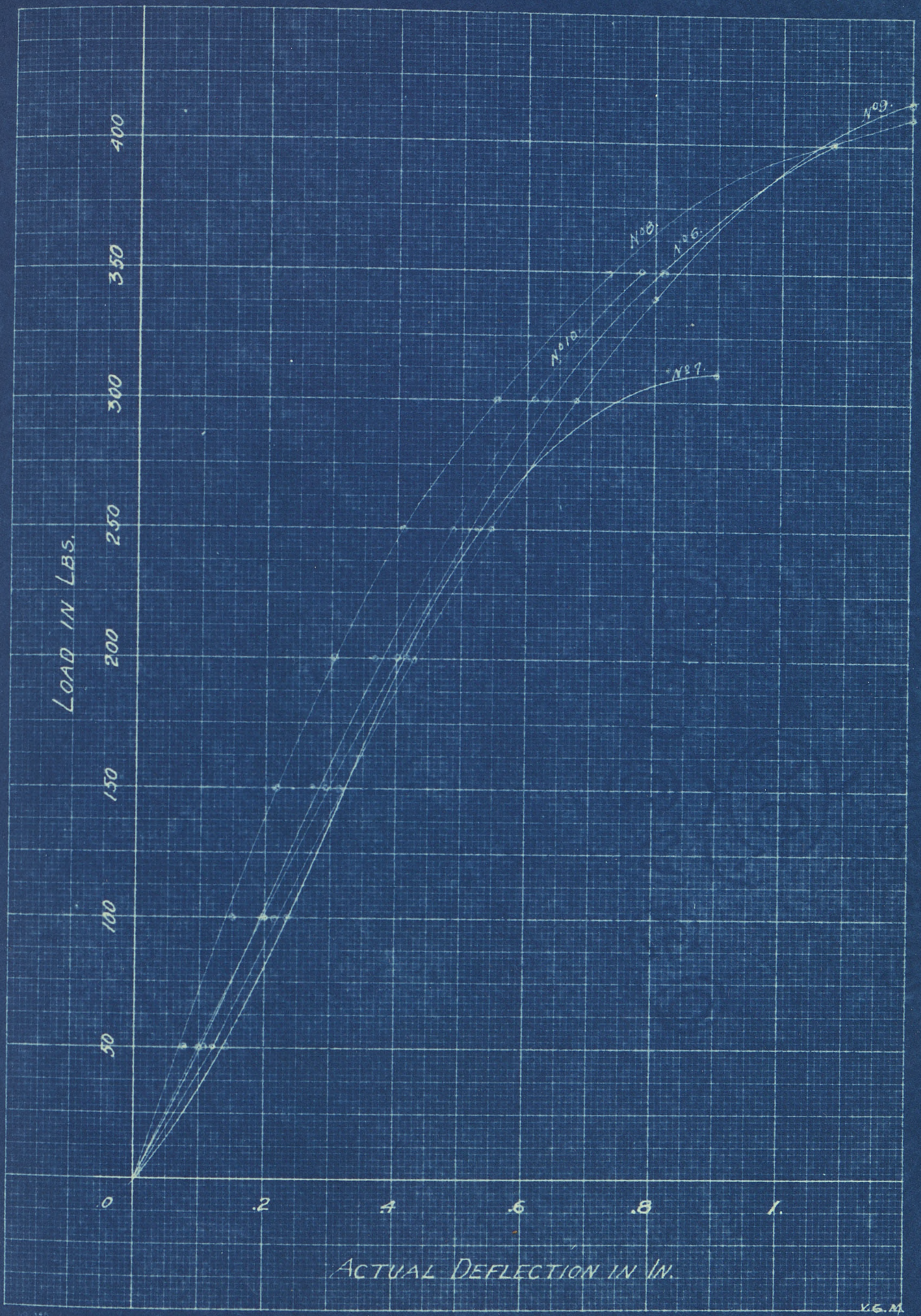
No.	Dimensions.	Area Sq. in.	Total Breaking Load.	Breaking Load per Sq. in.	Modulus of Rupture	Modulus of Elasticity
1.	1 1/8" X 2" X 2'	2.25	1550	689	12,400	1,422,222
2.	"	2.25	1350	600	10,800	1,154,885
3.	1 3/32" X 2" X 2'	2.18	1460	669	12,044	1,180,932
4.	1 1/16" X 2" X 2'	2.13	1340	629	11,356	1,190,699
5.	1 3/32" X 2" X 2'	2.18	1340	614	11,044	1,199,000
6.	1 1/8" X 2" X 2'	2.25	1300	578	10,400	1,195,000
7.	1 3/32" X 2" X 2'	2.18	1450	665	11,950	1,317,000
8.	1 1/8" X 2" x 2'	2.25	1250	557	10,000	1,134,000
9.	"	2.25	1450	644	11,600	1,023,000
10.	1 1/16" X 2" X 2'	2.13	1250	587	10,000	1,195,000
Total...............		22.05	13740	6232	111,594	12,011,738
Mean................		2.20	1374	623	11,159	1,201,173

TRANSVERSE TEST ON BAMBOO.

No. 1		No. 2.		No. 3.		No. 4.		No. 5.	
Load	Defl.	Load	Defl.	Load	Defl.	Load.	Defl.	Load.	Defl.
50	.059	50	.068	50	.072	50	.191	50	.103
100	.098	100	.118	100	.130	100	.286	100	.186
150	.142	150	.171	150	.192	150	.401	150	.275
200	.195	200	.262	200	.282	200	.545	200	.360
250	.262	250	.350	250	.355	250	.766	250	.444
300	.349	300	.434	300	.456	300	1.002	300	.552
350	.471	350	.564	350	.513	350	1.822	350	.680
400	.601	400	.691	400	.693			400	.877
440	.771	440	1.065	450	.841			450	1.600
				460	.988				

No. 6.		No. 7		No. 8.		No. 9.		No. 10.	
Load	Defl.	Load	Defl.	Load	Defl.	Load.	Defl.	Load.	Defl.
50	.097	50	.146	50	.088	50	.121	50	.117
100	.199	100	.236	100	.154	100	.215	100	.198
150	.291	150	.308	150	.215	150	.321	150	.263
200	.402	200	.410	200	.301	200	.407	200	.363
250	.502	250	.510	250	.409	250	.505	250	.409
300	.620	310	.905	300	.551	300	.614	300	.547
350	.814			350	.724	340	.808	350	.788
375	1.179			400	1.084	400	1.090	400	B.L.
				430	1.384	420	1.230		


Load in Lbs.
0
50
100
150
200
250
300
350
400
450
.2
.4
.6
.8
1
Actual Deflection in In.
No 1.
No 3
No 2
No 5.
No 4.



LOAD IN LBS.
400
350
300
250
200
150
100
50
0
.2
.4
.6
.8
1.
ACTUAL DEFLECTION IN IN.
No9.
No8.
No6.
No10.
No7.
V.G.M.
EUGENE DIETZGEN CO. CHICAGO-NEW YORK

TRANSVERSE TEST ON BAMBOO.

No.	Outside Diameter	Insid Diameter	Thickness	Area Sq in.	Total Breaking Load.	Breaking Load per sq. in	Modulus of Rupture	Modulus of Elasticity
1.	1.218	.882	.169	.558	440	788	20,500	3,160,000
2.	1.226	.905	.160	.525	440	838	19,450	2,475,000
3.	1.218	.890	.164	.546	460	842	22,200	2,680,000
4.	1.156	.757	.199	.606	350	577	17,340	1,306,000
5.	1.187	.859	.164	.542	460	849	23,375	2,320,000
6.	1.156	.878	.141	.451	375	831	20,808	2,294,000
7.	1.078	.780	.149	.438	310	708	22,134	2,912,000
8.	1.171	.797	.187	.576	430	747	20,980	3,230,000
9.	1.093	.734	.179	.510	420	824	25,039	1,983,000
10.	1.023	.711	.156	.420	400	952	29,941	2,510,000
Total-	11.526	8.189	1.668	5.172	4085	8056	221,767	24,810,000
Mean..	1.152	.818	.166	.517	408	805	22,176	2,487,000

The transverse test on spruce and bamboo were by far the most important of all, because this is the manner in which they are most liable to fail. Here again the size of the bamboo and spruce could not be made the same, but it was necessary to compare them by suitable formulae.

The load was applied at the center with a span of 2 ft. in both cases.

In order to make the comparison more plainly seen the theorical deflections for beams of similar sections were obtained for both from the formulae

$$\delta = \frac{WL^3}{48EI}$$

I was assumed to be unity in both cases and E as calculated for each set of tests.

The results can be seen from the following table and curves.

TENSION TEST ON SPRUCE.

No.	Area in Square Inches.	Breaking Load per Square Inch.	Remarks.
1.	1	9150 lbs.	
2.	1	8580 "	
3.	1	8270 "	
4.	1	8450 "	No. 7 did not fail from one end to the other but pulled in two in the middle.
5.	1	8110 "	
6.	1	8580 "	
7.	1	10060 "	
8.	1	9280 "	
9.	1	9310 "	
10.	1	8470 "	
Total...........................		88260 "	
Mean............................		8826 "	

TENSION TEST ON BAMBOO.

No.	Inside Diameter	Outside Diameter	Area.	Total Breaking Load.	Breaking Load Per sq. in.
1.	.75	1.00	.343	16030 lbs.	46700 lbs.
2.	.875	1.125	.393	10940 "	27820 "
3.	.919	1.125	.491	9630 "	19560 "
4.	.875	1.187	.506	12000 "	23700 "
5.	.703	.984	.343	9110 "	26200 "
6.	.719	.937	.284	9600 "	32750 "
7.	.812	1.062	.368	9050 "	23580 "
8.	.859	1.046	.281	9670 "	34350 "
9.	.812	1.031	.318	9600 "	30100 "
10.	.657	1.125	.656	14830 "	21320 "
Total..	7.982	10.749	3.988	110460 "	286080 "
Mean..	.798	1.074	.398	11046 "	28608 "

As was mentioned before there was a difficulty in secureing bamboo of the same cross-section as that of spruce, the latter was therefore made 1 in. sq. The mean breaking load in tension for this was 8826# per sq. in., while that of the bamboo was 28,-608# per sq. in.

Fig 2. (a) shows the arrangement for the tension test of spruce. The specimen consisted of 1 1/8" X 3" X 24" material, its size reduced down to 1 in. sq. at the middle and extending about 8" in length from its biggest cross-section. Fig. 1 (2) shows the special device used in bamboo in order to avoid end crushing between clamps. The joints were bored to the same size as the inside diameter and a round piece of wood of the same size and about 8" long was glued inside the specimen making it a solid specimen. Pieces of hard woods were also glued outside the bamboo in order to prevent the clamps from injuring the specimen.

A careful examination of spruce specimens showed that most of them began to crack from one end to the other or in other words they failed by longitudunal shear. "End slip"; that is; ends slipping from square blocks of woods glued in bamboo was often experienced during t e test. This is due to the fact that the breaking stress of bamboo is greater than the adhesion of the glue. These troubles were overcome, however, by nailing the pieces of wood and bamboo together.

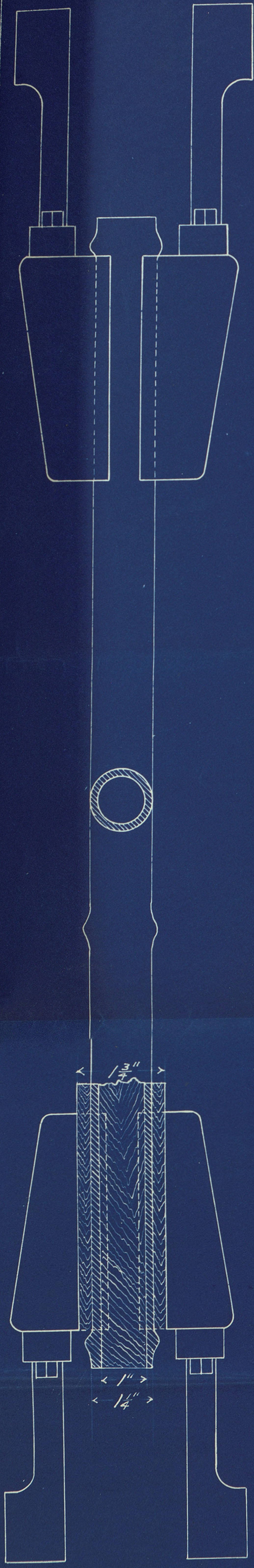


Fig. I.

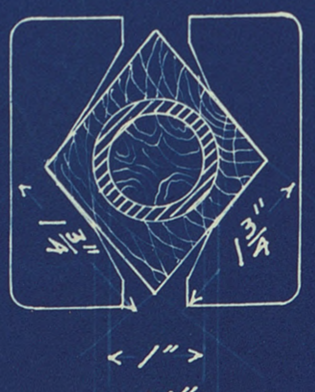


Fig. I A.

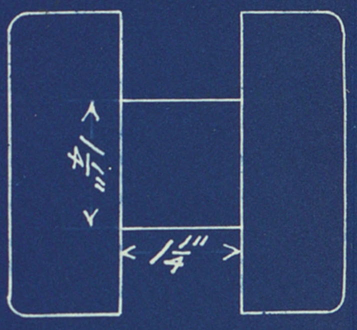


Fig. 2 A.

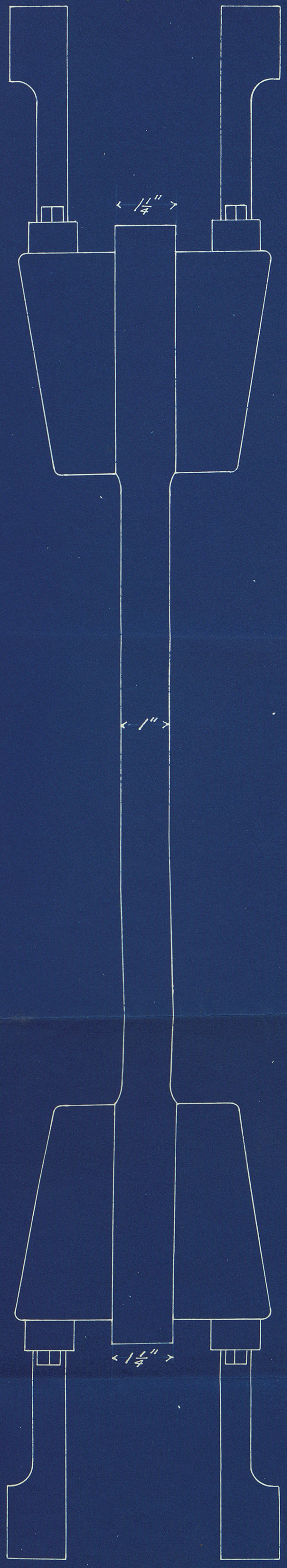


Fig. 2.

CONNECTIONS
FOR
TENSILE TEST
ON
BAMBOO AND WOOD

SCALE = HALF SIZE.

V.G.M.

TRANSVERSE TEST ON

TRIANGULAR BEAMS.

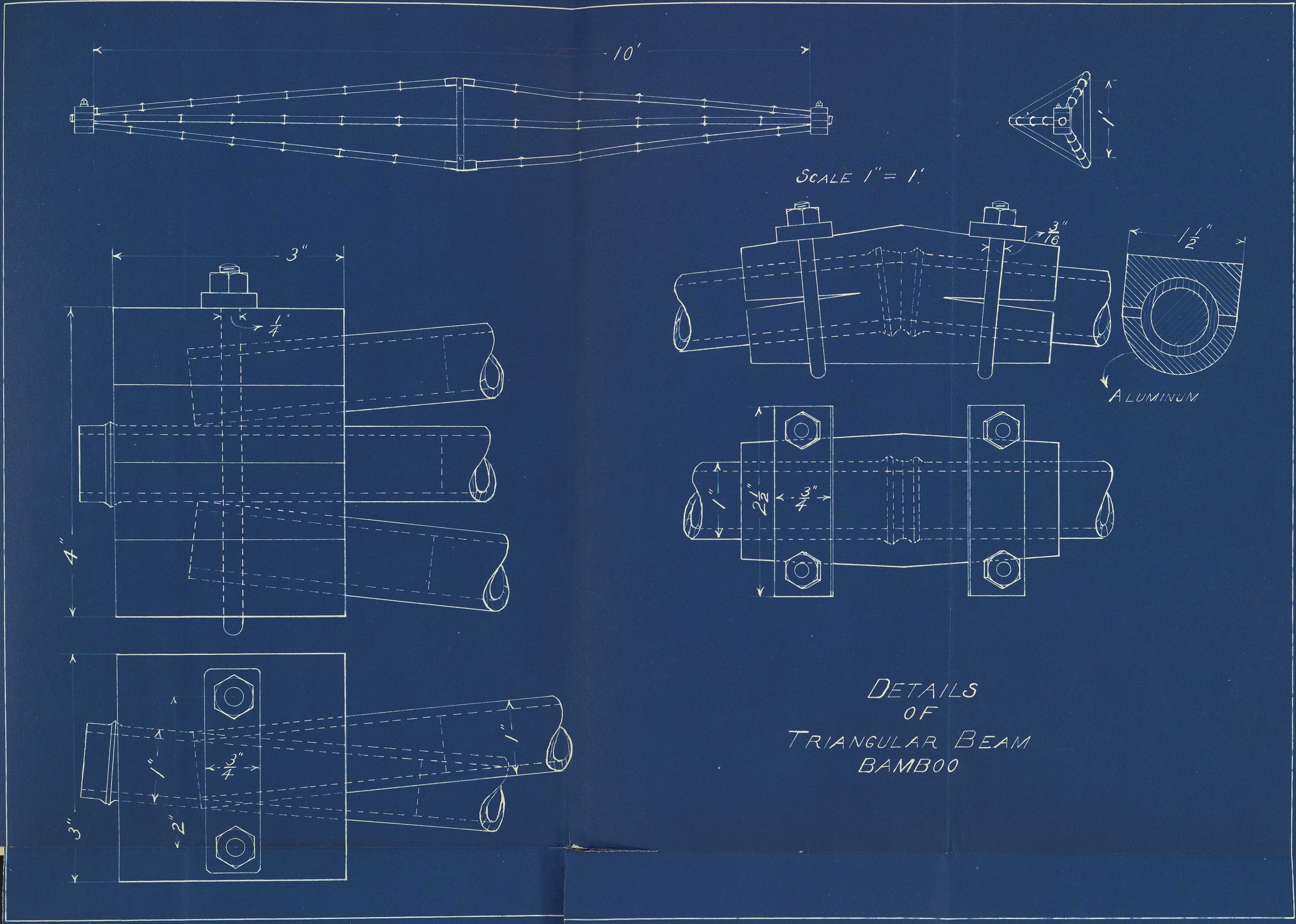
Weight of triangular beam of spruce including clamps and braces = 8 lbs and 3 1/2 oz.

Weight of triangular beam of bamboo and blocks for holding joints, also braces = 9 lbs. 2 1/2 oz.

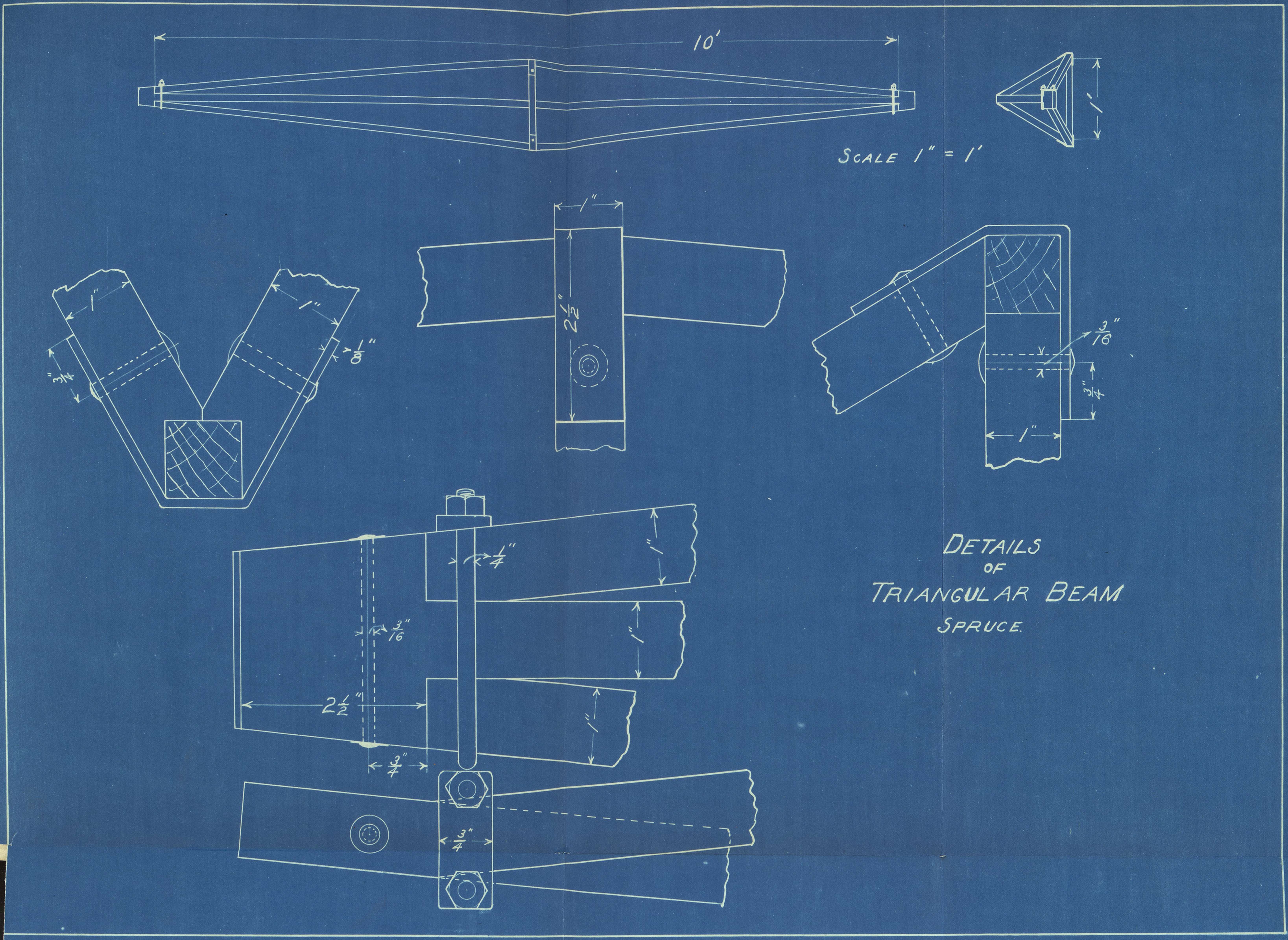
The load was applied at the center placing one member in tension and the other two in compression. The spruce failed by bending while the bamboo failed by the middle joint slipping.

Data:

	Maximum Breaking Load.
Bamboo Beam	700 lbs.
Spruce Beam	600 "


10'
1'
SCALE 1" = 1'
3"
1/4"
4"
3/16"
1 1/2"
ALUMINUM
1"
2 1/2"
3/4"
3"
1"
3/4"
2"
1"
DETAILS
OF
TRIANGULAR BEAM
BAMBOO

G.A.M.

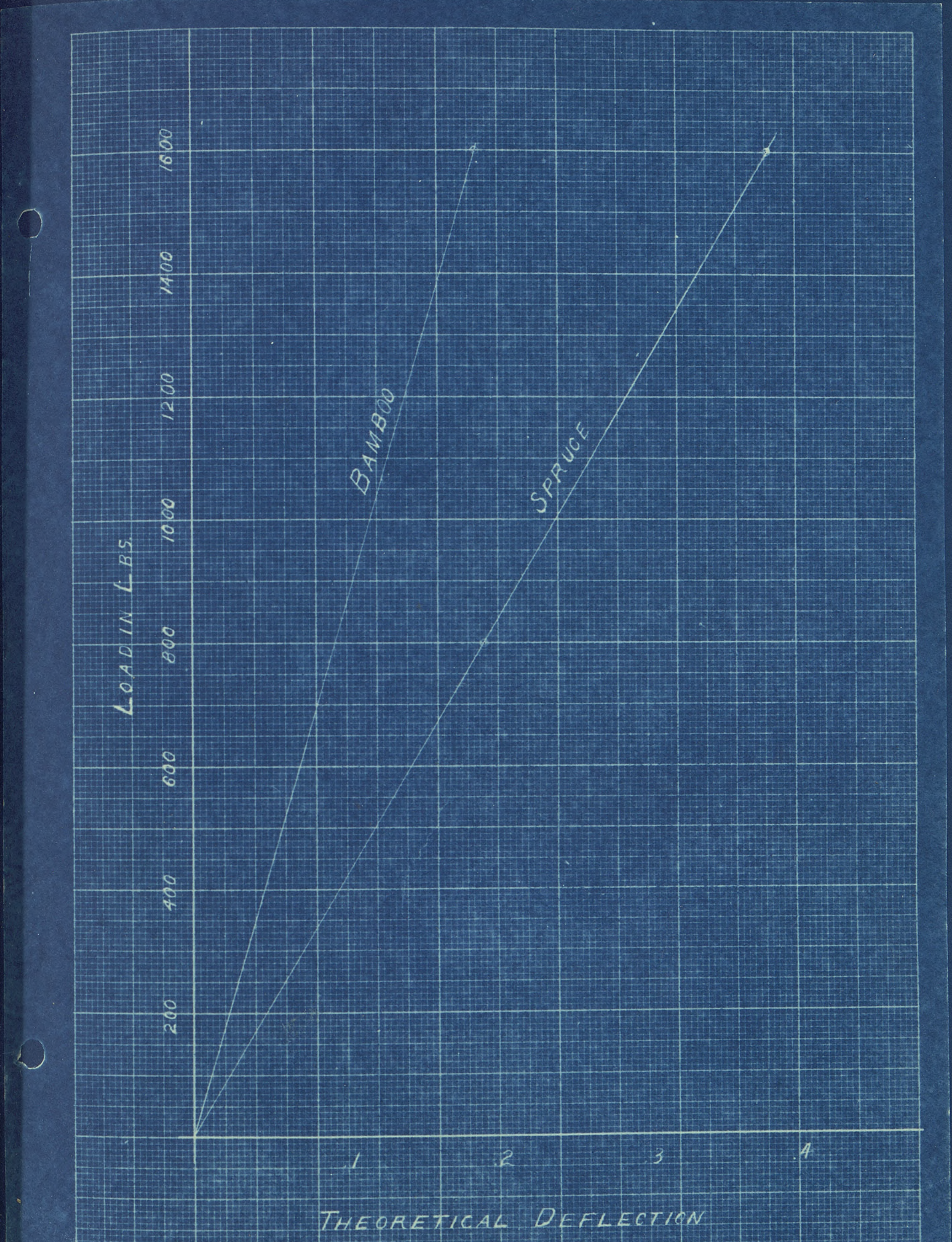


10'
1'
SCALE 1" = 1'
1"
$2\frac{1}{2}$"
$\frac{3}{4}$"
$\frac{1}{8}$"
$\frac{3}{16}$"
$\frac{1}{4}$"
DETAILS
OF
TRIANGULAR BEAM
SPRUCE.

G.A.M.

SUMMARY COMPARISON CURVE.

Load .	Theorical Deflection. Bamboo.	Spruce.
100	.0115	.0239
200	.0231	.0479
300	.0347	.0719
400	.0463	.0958
500	.0579	.1198
600	.0694	.1438
700	.0810	.1665
800	.0926	.1903
900	.1042	.2141
1000	.1316	.2397
1100	.1316	.2636
1200	.1389	.2636
1300	.1505	.3116
1400	.1621	.3355
1500	.1737	.3595
1600	.1852	.3835



LOAD IN LBS.
200
400
600
800
1000
1200
1400
1600
BAMBOO
SPRUCE
.1
.2
.3
.4
THEORETICAL DEFLECTION

In order to compare the strength of the two woods it was found desirable to build a structure of both and compare them . The chief difficulty was in designing a joint that would hold the bamboo and yet be slight. Of the two materials, aluminum and wooden blocks,-that were used to clamp the ends of the bamboo; the latter held the better but was heavy and bulky.

The test showed that the bamboo was the stronger of the two. However, the bamboo structure was heavier than the spruce due to the heavy joints which weighed as much as the bamboo itself. If the section of the bamboo had been equal to that of the spruce the difference would have been more marked.

The tests as a whole show that the bamboo is stronger in every way than the spruce. One draw-back to the test is that the bamboo of sufficient size could not be had to make the area of both the same so that the comparison is not direct. Also a hollow specimen is compared with a solid one, but could not be avoided not it is necessary as this is the manner in which they are both used in practice.

From the results of tests carried on in the laboratory on the strength of wood, there is no doubt but that bamboo is stronger in every way than any of the common woods.