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AN ACCOUNT OF CERTAIN TESTS OF THE TRANSVERSE STRENGTH AND STIFFNESS OF LARGE SPRUCE BEAMS.

[An address delivered before the American Society of Mechanical Engineers on November 3, 1882.]

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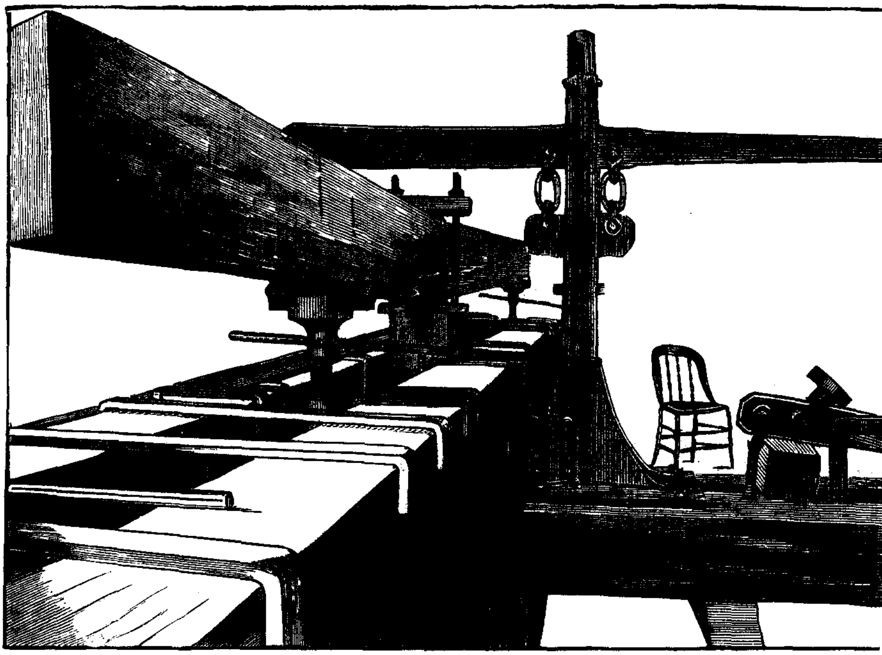
MR. PRESIDENT AND GENTLEMEN:—I beg leave to call your attention to the results of certain tests of the transverse strength and stiffness of full size spruce beams, carried on by members of my classes in my laboratory at the Massachusetts Institute of Technology. The machine with which they were made is a 50,000 pounds machine, and is capable of testing beams twenty-five feet long and under, as well as many of the framing joints used in practice.

It consists, as shown in the cut, of a compound lever, hung in a cast iron frame, to which is connected, by means of a steel rod and turn buckle, one end of a lever, of equal arms, placed below, this lever having a 12-inch leverage, and being connected at its other end by means of a chain, with the yoke shown in the cut. Two hard pine beams, each 20 inches deep, 10 inches wide and 26 feet long, are laid across the timbers of the machine in such a way that the chain already referred to is midway between them. Two common jack screws, each in a pair of wrought iron stirrups, are placed at a distance apart depending upon the span of the beam to be tested, the latter being placed, as shown in the cut,* upon the jack screws, and under the yoke. The jack screws are then screwed up, and the beam to be tested is thus raised at its two ends, and hence loaded at the point where the yoke is attached.



It was in operation about two months, last session, and has been in operation about one month, this present session. During that time we have tested about thirty specimens for breaking strength, and about fifteen for deflection. The breaking has been effected as rapidly as could be done, consistently with the determination of the deflections, and the deflections under various loads were measured within a very short time after the application of the loads. In short, no experiments have thus far been carried on to determine the effect of time upon these quantities, though some will be made very soon. It was also deemed best to keep to one kind of timber, until we should have a sufficient number of tests to warrant us in drawing a conclusion as to

* [We are indebted to the *Boston Journal of Commerce* for the use of this cut.]

No. of test.	Width and depth in inches.	Distance between supports. Ft.	In.	Manner of fixing the ends and loading.	Breaking weight in pounds.	Modulus of rupture in lbs. per sq. in.	Modulus of elasticity in lbs. per square inch.	Remarks.
1	2 x 12	6	8	Framed at ends........................	6,504			
2	4 x 12	6	8	Header..	10,338			
3	2 x 12	15		Load at middle..............................	5,894	5,526	1,237,215	
4	2 x 9	6	7·5	" "	7,322	5,389	1,067,893	
5	2 x 12	15		" "	5,586	5,237		
5(*a*)	2 x 12	7		" "	8,982			
6	2·75 x 9	6	8	" "	7,586	4,082	938,453	
7	3 x 9	4		" "	11,086	3,285		
8	3 x 9	10		" "	6,086	4,508		
9	3 x 9	15		" "	5,086	5,651		
10	3⅞ x 12	20		" "	6,586	4,253		
11	2·5 x 13·5	10		" "	9,585	3,787		
12	3·75 x 12	16		Load 4·5 ft. from one support....	7,585	3,271		
13	3·75 x 12	16		Ditto, mortised........................	9,085			
14	7 x 2	7		Load at middle..............................	1,944	8,748	....	Selected stock.
15	1·75 x 6·75	7		" "	4,785	7,562	....	
16	3 x 9	6	8	" "	9,985	4,931		
17	3 x 9	6	8	Load at 4 points, 16 ins. apart...	16,744	4,961		
18	3·9 x 12	16		Load 4·5 ft. from one support....	12,585	5,218		
19	2 x 12	14		Load at middle..............................	4,404	3,854	1,482,645	
20	2 x 12	14		" "	5,108	4,469	1,588,548	
21	3 15/16 x 12	14		" "	8,627	3,834	1,187,073	
22	3⅞ x 12	14		" "	12,545	5,666	1,332,715	
23	3⅞ x 12¼	14		" "	6,917	2,995	897,961	
24	3 x 11⅞	14		" "	8,927	5,442	1,572,470	
25	2 x 9¾	14		" "	3,198	4,239	1,460,620	
26	2¾ x 12	14		" "	6,819	4,339	1,396,667	
27	1 15/16 x 10	14		" "	4,306	5,601	1,355,860	
28	4⅛ x 12	18		" "	8,829	4,816	1,397,136	
29	4 x 12⅛	18		" "	8,324	4,586	1,259,224	
31	3⅛ x 12	18		" "	7,721	5,559	1,231,498	
						25)115,499	15)19,405,978	
					Av. mod. of rupture =	4,620	Av. mod. of elast. = 1,293,732	

the average value of the modulus of rupture, and of the modulus of elasticity of that kind of wood ; and spruce was selected, as a wood that is very much used in building. Experiments are now in progress in my laboratory to determine the same quantities for yellow pine.

The results that were obtained last session are shown above the double line in the accompanying table, and those obtained this present session, below.

At the beginning of this session these tests were continued, with the following objects in view:

1. Inasmuch as the lumber had, last session, been selected either by a carpenter, without reference to testing, or had been simply ordered at the yard, directions being given to the dealer to send merchantable stock, it seemed best that I should go to the yards myself and select from the piles some of the best and some of the average of what was on sale as merchantable stock, and thus that we should be able to speak with certainty about the values of the modulus of rupture and modulus of elasticity of such lumber.

2. Inasmuch as last year we had had only three determinations of the modulus of elasticity, it was desirable to obtain more values, and thus to be able to determine an average value.

3. It was desirable to see how far, in the light of what had already been done, we should be able to judge of the modulus of rupture by simply inspecting a piece of timber, and to endeavor also to train the students, to some extent, to have this ability.

That the values of the modulus of rupture which we have obtained should differ very considerably from those given in our text-books and engineers' handbooks, and deduced from tests of small pieces, I need not tell a company of engineers; but, as you may not carry in your minds the precise figures given by different authorities for the modulus of rupture of spruce, I will place them here:

Hatfield gives as mean value,		. .	9,900	lbs. per. sq. in.
Rankine,	"	" .	11,100	"
Laslett,	"	" . .	9,045	"
Trautwine,	"	" .	8,100	"
Rodman,	"	" . .	6,168	"

Trautwine advises for use to deduct one-third in the case of knotty and poor timber.

As a result of the tests thus far made in my laboratory, it seems to me safe to say, that if our Boston lumber yards are to be taken as a fair sample of the lumber yards in the case of spruce, that if such lumber is ordered from a dealer of good repute, no selection being made except to discard such pieces as might be classed as culled timber, *i. e.*, that which is rotten or has holes in it, that 3000 pounds per square inch is all that could with any safety be used for modulus of rupture, and even this might err in some cases, in being too large. 2. That if the lumber is carefully selected at any one lumber yard, so as to take only the best of their stock, it would not be safe to use for modulus of rupture a number greater than 4000, and if we required a lot of spruce lumber which should have a modulus of rupture of 5000 it would be necessary to select a very few pieces from each lumber yard in the city.

Next, as to the modulus of elasticity: until the beginning of this session we had made only three experiments on this subject, and these gave as an average 1,081,187; those made this autumn have contributed to raise this value somewhat, as will be seen from the table, where we obtain an average of 1,293,732.

Of course it is naturally to be expected that time tests will give much smaller values for both modulus of rupture and modulus of elasticity.

As to the variations of the values shown in the table, they are considerable, and depend upon the quality of the lumber, *i. e.*, upon the number and location of the knots, the shakes and cracks that are so commonly found at the heart of timber, also upon the degree of seasoning, although it is my opinion that the increase of strength due to this latter item has often been over-estimated. Knots near the middle of the span act very prejudicially, whether they are at the top or at the bottom, and by saying near the middle of the span I mean to include a very considerable range. It is impossible, however, to describe the mode of judging correctly, from inspecting a stick, what will be its modulus of rupture, and this ability can only be acquired by practice, and this very practice is one of the benefits that it is hoped to enable the students to gain to a greater or less degree.

As to the relation between the modulus of rupture and the modulus of elasticity, whilst it is generally true that those pieces that have a high value of the one have a high value of the other, and *vice versa*, nevertheless, I have not been able thus far to form any definite idea of the connection between them, at least such as to enable one to attempt to predict the modulus of elasticity from the appearance of the piece. Perhaps further experiments may satisfy this want, and as to the desirability of satisfying it no one can have any question, for the stiffness of beams is, or ought to be, as prominent a question to builders as their breaking strength.

We have already made three, and shall make quite a number of experiments on the strength of framing joints, such as headers, trimmers, etc., in regard to which we have thus far been entirely devoid of any experimental knowledge.

As to the method of fracture: while the most usual fractures in spruce beams have occurred either by tension or compression, or a combination of the two; nevertheless in some cases the beams have been split from the middle to one end, along or near the neutral axis; and while the experiments where this kind of fracture has occurred are not sufficient in number to warrant definite conclusions as yet, nevertheless it is an element that is forcing itself very strongly upon our attention as one that must be taken into account in practice.

A noticeable instance of this kind is to be found in the case of beam No. 22, another in beam No. 24, and a third in beam No. 31, which gave way in that manner.

At the meeting a number of photographs of the fractures obtained were exhibited and commented upon.

Table of Tests.

The following are the records of the tests made during the first month of the present session by students in the Department of Applied Mechanics of the Massachusetts Institute of Technology. In these tables, as far as the deflections are concerned, the first load is assumed as the start point, the deflection under that load being counted zero.

The deflections are recorded to the 10,000th of an inch, as the measurements were made with a micrometer screw that could be read to that degree of accuracy, and hence it was thought best to give the results as they were obtained, although it is not claimed that change of temperature or other disturbing causes, which would be inappreciable as far as any practical result is concerned, may not cause so great a variation as to render it unnecessary to read to such a degree of accuracy.

The spruce, with the exception of Nos. 22 and 23, was cut in the spring of 1882, and brought from Bangor, Me. Nos. 22 and 23 were cut in 1881. The students making the tests, hand in the reports of the same, and make the necessary computations of modulus of rupture, modulus of elasticity, etc. The values given in the tables have been re-computed by my assistant, Mr. Edward F. Ely.

The number given as the "Max. intensity of shear at neutral axis" is that which would be obtained by computing it from the breaking load in accordance with the ordinary theory of beams.

No. 19.—Spruce Joist, 2 in. by 12 in. Span 14 feet. Loaded at centre. Ordinary stock.

Tested by Messrs. Tompkins and Gustin.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
686	·0473	·0473	Rested over night.
510	....	....	Load on next morning.
485	·0000	....	Began new set of readings.
686	·0343	·0343	
887	·0825	·0482	
1,088	·1284	·0459	
1,088	·1309	....	After 1 hour.
1,289	·1764	·0455	
3,600	....	....	Cracks opened near centre above neutral axis.
4,103	....	....	Bulging on east side at top. At centre top slewed to west.
4,404	....	....	Breaking load.

Fracture occurred within an hour after application of breaking load.

Line of fracture followed the knots.

Modulus of rupture = 3,854 lbs. per square inch.

Mean deflection for 201 lbs. = ·0465.

Modulus of elasticity = 1,482,645 lbs. per square inch.

Maximum intensity of shear at neutral axis = 138 lbs. per square inch.

No. 20.—Spruce Joist, 2 in. by 12 in. Span 14 feet. Loaded at centre. Not many knots.

Tested by Messrs. Tompkins and Gustin.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
686	·0431	·0431	
887	·0885	·0454	
1,088	·1303	·0418	
5,813	....	....	Twisted badly in spite of bracing, and load fell off rapidly, it being impossible to keep this load on.
5,108	....	....	Breaking load.

Modulus of rupture = 4,469 lbs. per square inch.

Mean deflection for 201 lbs. = ·0434.

Modulus of elasticity = 1,588,548 lbs. per square inch.

Maximum intensity of shear at neutral axis = 160 lbs. per square inch.

No. 21.—Spruce Joist, $3\frac{15}{16}$ in. by 12 in. Span 14 feet. Loaded at centre. Ordinary stock.

Tested by Messrs. Tompkins and Gustin.

Load in lbs.	Deflection in inches.	Differences.	
686	·0000		
1,088	·0546	·0546	
1,490	·1033	·0487	
1,892	·1654	·0621	
2,294	·2192	·0538	
2,696	·2858	·0666	
3,098	·3397	·0539	
3,500	·4030	·0633	
3,902	·4644	·0614	
4,304	·5256	·0612	
4,706	·5898	·0642	Left over night.
4,203	.5845	....	Next morning.
4,706	·6529	....	Load increased to 4,706 again.
4,404	....	....	Next day.
5,610	....	....	Braced the stick.
8,627	....	....	Breaking load after carrying 15 minutes.

Modulus of rupture = 3,834 lbs. per square inch.

Mean deflection for 402 lbs. = ·0590.

Modulus of elasticity = 1,187,073 lbs. per square inch.

Maximum intensity of shear at neutral axis = 137 lbs. per square inch.

No. 22.—Spruce Joist, $3\frac{7}{8}$ in. by 12 in. Span 14 feet. Loaded at centre. Lower part of tree. Very free from knots. Had been seasoning on the wharf about one year.

Tested by Messrs. Tompkins and Gustin.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
887	·0534	·0534	
1,289	·1052	·0518	
1,691	·1583	·0531	
2,495	·2665	·1082	
3,299	·3748	·1083	
4,103	·4810	·1062	
4,907	....	....	Left over night.
4,203	....	....	Next morning.
12,545	....	....	Breaking load. Beam broke by tension and afterwards by shearing along the neutral axis. Shear extended from centre to one end, and pieces slid by one another about $\frac{7}{16}$ inches.

Modulus of rupture = 5,666 lbs. per square inch.

Mean deflection for 402 lbs. =·0534.

Modulus of elasticity = 1,332,715 lbs. per square inch.

Maximum intensity of shear at neutral axis = 202 lbs. per square inch.

No. 23. —SPRUCE JOIST, $3\frac{7}{8}$ in. by $12\frac{1}{4}$ in. Span 14 feet. Loaded at centre. Upper part of same tree as No. 22. Very knotty. Had been seasoning on the wharf about one year.

Tested by Messrs. Tenney and Mansfield.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
887	·0819	·0819	
1,289	·1457	·0638	
1,691	·2204	·0747	Left over night.
1,425	....	....	Next morning.
1,691	·2569	....	Raised load again.
2,093	·3269	·0700	
2,495	·4017	·0748	
2,897	·4828	·0811	
3,299	·5536	·0708	
4,103	·7073	·1537	
4,907	....	....	Left on for half an hour, during which time load fell off to 4,203; beam splitting and cracking at a large knot on lower edge near centre of span.
6,917	....	....	Breaking load (knot causing break about 15 inches from centre).

Modulus of rupture = 2,995 lbs. per square inch.

Mean deflection for 402 lbs. = ·0745.

Modulus of elasticity = 897,961 lbs. per square inch.

Maximum intensity of shear at neutral axis = 108 lbs. per square inch.

No. 24.—Spruce Joist, width $3\frac{1}{16}$ in. at bottom, $2\frac{7}{8}$ in. at top, depth $11\frac{7}{8}$ in. Span 14 feet. Loaded at centre. Not many knots.

Tested by Messrs. Scott and Foran.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
887	·0603	·0603	
1,289	·1247	·0644	
1,691	·1835	·0588	
2,093	·2485	·0650	Left 15 hours, when load had fallen to 1,766 lbs.
2,093	·2742		
2,495	·3285	·0543	
2,897	·3870	·0585	
3,299	·4521	·0651	
3,701	·5189	·0668	
4,103	·5746	·0557	
8,927	....	....	Breaking load. Broke by shearing along neutral axis. Split opening about 1½ inches.

Modulus of rupture = 5,442 lbs. per square inch.
Mean deflection for 402 lbs. = ·0610.
Modulus of elasticity = 1,572,470 lbs. per square inch.
Maximum intensity of shear at neutral axis = 190 lbs. per square inch.

No. 25.—Spruce Joist, 2 in. by $9\frac{3}{4}$ in. Span 14 feet. Loaded at centre. Ordinary stock.

Tested by Messrs. Scott and Foran.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
887	·1625	·1625	
1,289	·3342	·1717	
1,691	·5280	·1938	
3,198	....	....	Breaking load, by compression at top and tension at bottom.

Modulus of rupture = 4,239 lbs. per square inch.

Mean deflection for 402 lbs. = ·1760.

Modulus of elasticity = 1,460,620 lbs. per square inch.

Maximum intensity of shear at neutral axis = 123 lbs. per square inch.

No. 26.—Spruce Joist, $2\frac{3}{4}$ in. by 12 in. Span 14 feet. Loaded at centre. Ordinary stock.

Tested by Messrs. Tenney and Mansfield.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
887	·0534	·0534	
1,691	·2050	·1516	
2,495	·3610	·1560	
3,299	·5025	·1415	
5,610	....	....	Cracked somewhat.
5,713	....	....	Cross-grained fibre at bottom tore apart.
5,914	....	....	A sharp crack was heard and a long split appeared.
6,819	....	....	Breaking load.

Modulus of rupture = 4,339.

Mean deflection for 402 lbs. = ·0718.

Modulus of elasticity = 1,396,667 lbs. per square inch.

Maximum intensity of shear at neutral axis = 155 lbs. per square inch.

No. 27.—Spruce Joist, $1\frac{15}{16}$ in. by 10 in. Span 14 feet. Loaded at centre. Not many knots.

Tested by Messrs. Tenney and Mansfield.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
887	·1724	·1724	
1,289	·3272	·1548	Beam tipped and braces were put in at ends beyond the straight edges.
1,691	·5441	·2169	Wedge was used on west side to keep straight edge close to the beam.
4,306	....	....	Breaking load.

Modulus of rupture = 5,601 lbs. per square inch.
Mean deflection for 402 lbs. = ·1814.
Modulus of elasticity = 1,355,860 lbs. per square inch.
Maximum intensity of shear at neutral axis = 167 lbs. per square inch.

No. 28.—SPRUCE JOIST, width $4\frac{1}{4}$ in. at bottom, 4 in. at top, depth 12 in. Span 18 feet. Loaded at centre.

Tested by Messrs. Tenney and Mansfield.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
887	·1049	·1049	
1,691	·2999	·1950	
2,495	·5030	·2031	
3,299	·7033	·2003	
3,701	·8136	·1103	
4,103			
8,829	....	....	Breaking load.

Modulus of rupture = 4,816 lbs. per square inch.
Mean deflection for 402 lbs. = ·1017.
Modulus of elasticity = 1,397,136 lbs. per square inch.
Maximum intensity of shear at neutral axis = 134 lbs. per square inch.

No. 29.—SPRUCE JOIST, 4 in. by $12\frac{1}{8}$ in. Span 18 feet. Loaded at centre.

Tested by Messrs. Scott and Foran.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
887	·1048	·1048	
1,289	·2169	·1121	
1,691	·3267	·1098	
2,093	·4424	·1157	
2,495	·5488	·1064	
2,696	·6227	·0739	
2,897	·6768	·0541	
6,917	....	....	Slight cracks heard.
8,324	....	....	Breaking load.

Modulus of rupture = 4,586 lbs. per square inch.
Mean deflection for 402 lbs. = ·1128.
Modulus of elasticity = 1,259,224 lbs. per square inch.
Maximum intensity of shear at neutral axis = 129 lbs. per square inch.

No. 31.—Spruce Joist, $3\frac{1}{8}$ in. by 12 in. Span 18 feet. Loaded at centre.

Tested by Messrs. Davis and Morse.

Load in lbs.	Deflection in inches.	Differences.	
485	·0000		
887	·1486	·1486	
1,289	·3030	·1544	
1,691	·4514	·1484	
2,093	·6129	·1615	
2,495	·7615	·1486	
3,701	....	....	Cracking commenced.
7,721	....	....	Breaking load. Broke suddenly by compression of top fibres and shearing along the neutral axis. Split showed several small pin knots, running vertically in the beam, and apparently pinning the sides of the fracture together.

Modulus of rupture = 5,559 lbs. per square inch.
Mean deflection for 402 lbs. = ·1523.
Modulus of elasticity = 1,231,498 lbs. per square inch.
Maximum intensity of shear at neutral axis = 154 lbs. per square inch.

Fracture of Steel.—Ruptures often occur in steel, which are very difficult to explain. They are generally attributed to inequality in cooling or to imperfect annealing, but some experiments, which have been reported to the institution of naval architects, seem to show that the fractures are always attributable to a defect in the quality of the steel before rolling, and not to the inequality of the strains to which it is finally subject. When a piece of sound steel plate was heated to redness, and then cooled unequally by scattering water on various parts of the heated surface, it was hammered in various ways and submitted to a series of experiments of the most trying character, without giving any indication of fracture.—*Chron. Industr.*, No. 39. C.