five of these quantities being known it is an easy matter to calculate the sixth. For example, in the case of our red spruce beam, 6,000 pounds pressure produced a deflection of 1.9 inches, whence we have

$$E = \frac{6,000 \times 168 \times 168 \times 168}{4 \times 1.9 \times 6 \times 8 \times 8 \times 8}, = 1,244,842.$$

Conversely, if we know the value of E and wish to calculate what weight will produce a sag of 2 inches in a red spruce beam similar to the one tested, but six inches square and having a span of ten feet, then we have the equation

$$1,244,842 = \frac{w \times 120 \times 120 \times 120}{4 \times 2 \times 6 \times 6 \times 6 \times 6}, \text{ whence } w = 7,469 \text{ lbs.}$$

Cross-breaking Strength.—When forced beyond the elastic limit the piece being tested acquires a permanent set and finally breaks at what is known as the "point of failure," or "maximum load." When this occurs the "modulus of rupture" is calculated by means of the formula $R = \frac{3\,W\,l}{2\,b\,h^2}$, which in the case of our red spruce beam gives us $R = \frac{3 \times 7,580,168}{2 \times 6 \times 8 \times 8} = 4,974.$

For bending tests of this kind the early experimenters used small pieces because of the difficulty in holding and bringing strains to bear upon larger ones. Bauschinger used beams 20 inches square and nine feet long with 98.4 inches between their supports. At the Massachussetts Institute of Technology, Lanza used beams varying from four to twenty feet long, from 2 to 6 inches in width and from 2 to 12 inches in depth. In Johnson's work on large beams, smaller pieces (measuring 4 inches square) were cut from the large ones as soon as they failed and were then tested to see whether the same *moduli* would apply, and this was found to be the case *whenever similar conditions existed.*

Many Tests Required.—On account of the great variations that occur in the weight of any kind of wood, the proportion of heartwood to sapwood, differences in minute structure due to different conditions of growth or of wood taken from different parts of the same tree, and the enormous variations that may occur in the moisture content of the test pieces, it is evident that reliable figures on the strength of wood must be based upon the average of a large number of tests. The following figures (Table II), for the cross-breaking strength of woods containing 12 per cent. moisture, show a wide range.

TABLE II.

Species.	No. of tests.	Highest single test.	Lowest single test.	Average of all tests.
Pignut hickory ...	30	25,000	11,000	18,700
Shagbark hickory .	187	23,300	5,700	16,000
White oak	218	20,300	5,700	13,100
Red oak	57	16,500	5,700	11,400
Red pine	95	12,900	3,100	9,100
White pine	120	11,800	4,600	7,900
White cedar	87	9,100	3,500	6,300

Effect of Permanent Loads.—Thurston experimented on small wooden beams one inch square and four feet long for the purpose of determining the effect of permanent loads on their strength as compared with the results obtained with testing machines, and found that 60 per cent. of the breaking load in the machine would break the beams if the load was left on them for nine months time. Later on Johnson experimented with well-seasoned wooden columns and came to the conclusion that "The ultimate strength of wooden columns is only about one-half the utilimate strength of those same columns as determined by a testing machine."

Endwise Compression.—The failure of a piece of wood under pressure along the grain is a very complex phenomenon. At first the fibres act like a number of hollow columns firmly bound together, but as the load becomes too great they tear apart and act as a number of independent pieces and finally bend over when the piece fails. In all test pieces it is advisable to have the length less than 15 times the least diameter, else they are liable to fail by bending sideways before the full load they are capable of sustaining is reached. A number of tests of West Australian timber showed that 60 per cent. of the columns having a ratio of 18 to 1 failed in this way, and every builder is familiar with the common practice of bracing the studding in a wall to prevent the failure of the upright pieces by sidewise flexure. The endwise compression strength of wood is given in pounds per square inch, and is read directly from the testing machine. Johnson says that the result of over 40,000 tests shows that 55 per cent. of the results fall within 10 per cent. of the general average and that 90 per cent. of them fall within 25 per cent. of the general average. This is a greater range of variation in strength than is usually found in other kinds of building material, and is partly due to variations in the structure of the wood itself. The following figures (Table III), illustrates some of the variations that occur.

TABLE III.

Endwise Compression, in Pounds Per Square Inch.

(For 12% moisture).

Kind of wood.	No. of tests.	Highest single test.	Lowest single test.	Average of all tests.
Pignut hickory ..	30	13,000	8,700	10,900
Shagbark hickory .	137	13,700	5,800	9,500
White oak	218	12,500	5,100	8,500
Red oak	57	9,700	5,400	7,200
Red pine	100	8,200	4,300	6,700
White pine	130	8,500	3,200	5,400

In spite of the complex nature of woody structures it is rather a surprise to learn that properly designed wooden columns will support a greater load than an equal weight of cast-iron or steel of similar proportions.

Crushing Strength Across the Grain.—A timber column is frequently designed for its maximum load and is then set on a sill of the same wood without knowing that the crushing strength across the grain is very much less than it is in the endwise direction. Many failures of timber structures are due to this cause alone. For very heavy loads, it is therefore, advisable to use caps and sill pieces to distribute the load and thus prevent crushing across the grain as much as possible. The crushing takes place layer by layer and woods with thin-walled fibres, like pine and spruce, give way sooner than those with thicker walls, such as oak and hickory. Furthermore, in woods containing large pith rays, like oak and sycamore, the crushing strength in the radial or "edge-grain" direction is greater than in the tangential or "slash-grain" direction. Naturally the greater the percentage of moisture present the more easily the wood crushes, as is well illustrated in Table IV.