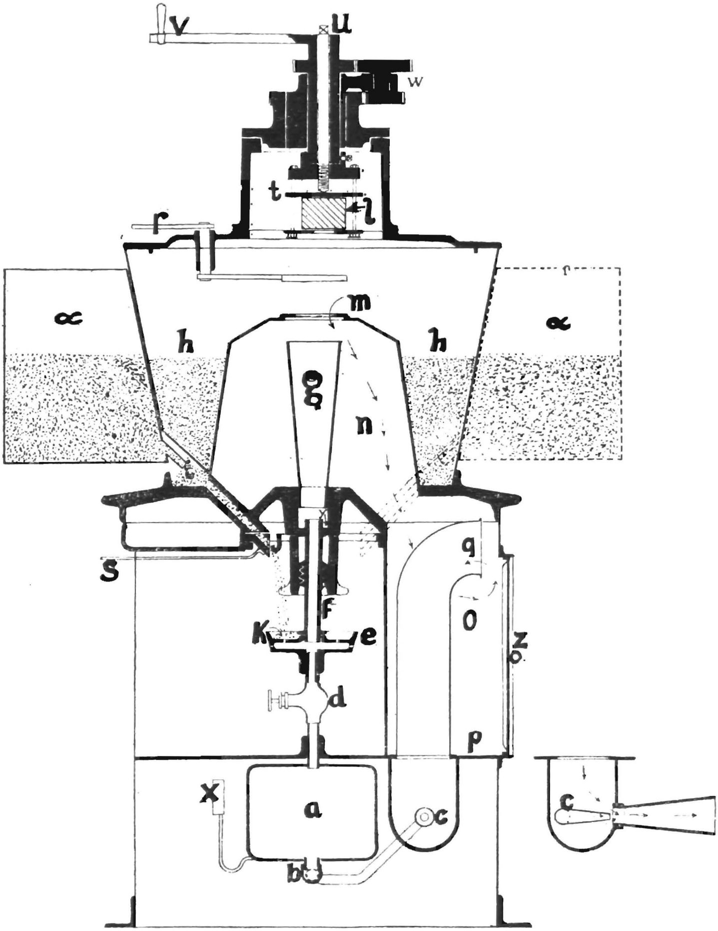

FIG. 29.

The flow of sand through the pipe *i* is regulated by a perforated ring *j*, partially rotated by means of a lever *s*, so that the orifices at *j* may be opened or closed as desired.

The specimen *l* is held in place by a screw *u*, which presses the plate *t* against it. The specimen is rotated about its own axis, and, by means of an epicyclic wheel train *w*, the axis itself rotates along the circumference of a circle.

We thus see that every part of the exposed surface of the specimen is subjected to the action of the jet, thus assuring a uniform rate of abrasion over the exposed part of the specimen.

x is a pressure gauge marked in kilogrammes per square millimetre.

At the back of the apparatus we have a door *z*, which is opened for cleaning the machine. *y* is a rubber ring to make a tight joint.

A constant pressure of 3 kilogrammes per square millimetre, which is equivalent to 42.6 lb. per square inch, was used throughout the tests.

In order that each particle of sand may strike the specimen once only, and not be used again, two feeding devices ∝ ∝ have been arranged, to allow the fresh sand to flow through *i* and *j* on to the tray *e*.

The used sand accumulated in the receiver *h* is removed about every three hours.

As in all hardness tests there is no absolute standard; we have no unit for expressing the resistance to abrasion, except by comparing the relative behaviour of materials tested under similar condition.

If we decide upon some material as a standard, then it is possible to give the hardness of other materials as a ratio of the hardness of the standard in the same way as the specific gravity of a material is expressed in regard to that of water as a standard.

We therefore have to decide on some material to be used as a standard for hardness. For this purpose North Coast blackbutt has been decided upon, and the hardness of all the other timbers are given in terms of this standard.

As in the Brinell-Ball test, there are three different directions in which the timber can be tested, namely, those marked A, B, C, in Fig. 30.

We have picked on C (i.e., tangential to the annual rings) as that direction in which we test the timber for the standard determination of the resistance to abrasion.

The sand used in these tests was supplied by the Emu Plains Road-metal and Gravel Company, and has all been passed through a sieve of 900 meshes to the square inch.

The specimens are all cut to a size, 3 in. x 3 in. x 1 in., and are weighed to the nearest grain before being subjected to the test.

When the tests are over, the specimens are immediately weighed again, and the loss of weight noted. It is necessary that the weighing should be done not long before, and as soon as possible after, the test, as, owing to the hygroscopic properties of the timber, we are likely to get a change in weight on account of the timber absorbing or giving off moisture.

Having noted the weight thus abraded, we must divide by the weight per cubic inch of the timber, which will give us the volume in cubic inches abraded.

We multiply this by a constant ($10^3 = 1,000$) so as to bring the result to a convenient size, and we can follow the same procedure for each timber, thus obtaining a series of numbers.

We could write these numbers down as the hardness numbers of the various timbers, provided that the conditions of testing were always the same.

The greatest discrepancy in the constancy of the conditions is likely to occur in the case of the sand, as we cannot always be certain of getting sand of the same quality.

It might, for example, contain more quartz particles or be less finely divided than the last lot, which would tend to greatly alter the results of the two series, though each timber in either series would be perfectly comparable with any other timber in that series of tests.

And so we can, by using a piece of the standard timber in each series of tests, reduce both series to a common basis, and compare them one with the other, irrespective of what the conditions were in each series, provided, of course, that those conditions were kept constant throughout the series.

The test for the standard timber is 2 minutes under a steam pressure of 42.6 lb. per square inch.

In the case of tests on the end of the grain, in order to decrease the likelihood of error in weighing the very small amount which would be abraded in 2 minutes, we increase the time to, say, 3 or 5 minutes. This we can easily reduce to 2 minutes by multiplying the result by $\frac{2}{3}$ or $\frac{2}{5}$, as the case may be.

In the tests carried out, 6 specimens of each timber were tested; 2 as in A (Fig. 30), 2 as in B, and 2 as in C, i.e.:—

A.—Parallel to direction of fibre.

B.—Perpendicular to direction of fibre, and also perpendicular to annual rings.

C.—Perpendicular to direction of fibre, and also tangential to annual rings.

Plates VIII. to X. show the specimens after testing.

Since the harder the timber is the less the amount abraded, we see we get a large number for a soft timber and a small number for a hard timber.

The results of the test are shown in Plate VII.

In this table the columns marked "Number" simply give the number of the timber and the number of the specimen of that timber, 1 and 2 being for direction of blast C; 3 and 4 being for direction of blast B; 5 and 6 being for direction of blast A.

The third, eighth, and twelfth columns give the weights abraded in the three directions of test.

The fourth column is the weight per cubic foot.

The fifth column gives the volume abraded,

$$\frac{\text{weight abraded.}}{\text{weight per cubic inch.}}$$

and multiplied by 10^3 to make the number a convenient size.

In testing the standard we get 118 under the fifth column, and so we must multiply all results by $\frac{100}{118}$ to reduce them to a common basis, so that they can be compared with any other series of tests.

The rest of the table needs no remark, except, perhaps, the last column, where the hardnesses in the three directions are given relatively to each other.

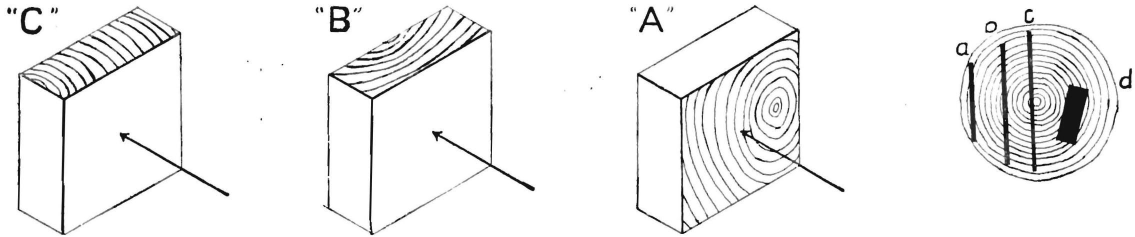

FIG. 30.

"C."—Tested in a direction tangential to the annual rings, and perpendicular to the fibre.

"B."—Tested in a direction perpendicular to the annual rings, and also to the fibre as used in flooring boards.

"A."—Tested in a direction parallel to the fibre as used in street paving.

This figure shows a cross-section of a tree from which boards *a*, *b*, and *c* (shown in cross-section) are cut.
a in use is subjected to wear as in "B."
b in use is subjected to wear as in both "B" and "C."
c in use is subjected to wear as in "C."
shows a wood block.

In Table 9 we have the timbers given with their various hardnesses in the three different directions

Table 9.

Name.	No.	Mean. C.	Hardness B.	Numbers. A.
North Coast.				
Blackbutt	1	100	76	25
Tallow-wood	2	153	103	25
Grey Gum	3	119	66.5	24
Grey Ironbark	4	77.5	55.5	15.5
Blue Gum	6	154	55.5	23.5
Brush Box	7	93	42	21.5
Turpentine	8	61	37	27.5
Red Mahogany	9	143.5	86.5	27.5
White ,, ...	10	95.5	62.5	26
Colonial Teak	11	95	116	44
South Coast.				
Grey Box	12	76	43.5	21
Woollybutt	13	57.5	36	21
Spotted Gum	14	51	44	21.5
Turpentine	15	74.5	38	21
Blackbutt	16	74.5	53	21.5
Stringybark	18	82	33.5	29.5

From this table, Table 10 is made up, which just gives the timbers arranged in order of hardness in the three directions, C, B, and A.

Table 10.

Order.	C.	B.	A.
1	Spotted Gum, S.C.	Stringybark, S.C.	Grey Ironbark, N.C.
2	Woollybutt, S.C.	Woollybutt, S.C.	Woollybutt, S.C.
3	Turpentine, N.C.	Turpentine, S.C.	Grey Box, S.C.
4	Turpentine, S.C.	Turpentine, N.C.	Turpentine, S.C.
5	Blackbutt, S.C.	Brush Box, N.C.	Brush Box, N.C.
6	Grey Box, S.C.	Grey Box, S.C.	Blackbutt, S.C.
7	Grey Ironbark, N.C.	Spotted Gum, S.C.	Spotted Gum, S.C.
8	Stringybark, S.C.	Blackbutt, S.C.	Blue Gum, N.C.
9	Brush Box, N.C.	G. Ironbark, N.C.	Grey Gum, N.C.
10	Colonial Teak, N.C.	Blue Gum, N.C.	Blackbutt, N.C.
11	W. Mahogany, N.C.	W. Mahogany, N.C.	Tallow-wood, N.C.
12	Blackbutt, N.C.	Grey Gum, N.C.	W. Mahogany, N.C.
13	Grey Gum, N.C.	Blackbutt, N.C.	Turpentine, N.C.
14	R. Mahogany, N.C.	R. Mahogany, N.C.	R. Mahogany, N.C.
15	Tallow-wood, N.C.	Tallow-wood, N.C.	Stringybark, S.C.
16	Blue Gum, N.C.	Colonial Teak, N.C.	Colonial Teak, N.C.

If we add the three numbers which represent their positions in descending order in each table, we can find their order of combined hardness in the three directions. As an example, take Blackbutt, N.C., in Table 10, it comes twelfth in column C, thirteenth in column B, and tenth in column A. Now, adding these, we get the number 35. If we treat each timber similarly, we get numbers as shown in Table 11.

Table 11.

Name.	No.	Order			
		C.	B.	A.	C and B and A.
North Coast.					
Blackbutt	1	12	13	10	35
Tallow-wood	2	15	15	10	40
Grey Gum	3	13	12	9	34
Grey Ironbark	4	7	9	1	17
Blue Gum	6	16	9	8	33
Brush Box	7	9	5	5	19
Turpentine	8	3	3	13	19
Red Mahogany	9	14	14	14	42
White Mahogany	10	11	11	12	34
Colonial Teak	11	10	16	16	42
South Coast.					
Grey Box	12	6	6	2	14
Woollybutt	13	2	2	2	6
Spotted Gum	14	1	7	5	13
Turpentine	15	4	4	2	10
Blackbutt	16	5	8	5	18
Stringybark	18	8	1	15	24

Now, arranging these in descending order of hardness, we get Table 12.

Table 12.—Order of Combined Hardness in the three planes, A, B, and C.

1 Woollybutt, S.C.
2 Turpentine, S.C.
3 Spotted Gum, S.C.
4 Grey Box, S.C.
5 Grey Ironbark, N.C.
6 Blackbutt, S.C.
7 Turpentine, N.C.
8 Brush Box, N.C.
9 Stringy-bark, S.C.
10 Blue Gum, N.C.
11 Grey Gum, N.C.
12 White Mahogany, N.C.
13 Blackbutt, N.C.
14 Tallow-wood, N.C.
15 Red Mahogany, N.C.
16 Colonial Teak, N.C.

A test was made on well-seasoned N.S.W. hardwood timbers, comparing them with Western Australian Jarrah.

The specimens were obtained from samples kept in the Macleay Museum, cut from pieces which were tested in 1889, and were therefore very dry.

Table 13 shows the results of testing these specimens in direction A as used in timber pavements.

Table 13.

Timber.	Weight abraded	Mean.	Time of Test, Minutes.	Weight reduced to 2 mins.	Weight per cub. ft.	Volume abraded X 10³.	Volume reduced to standard hardness, Blackbutt, direction C=100
Spotted Gum	20		5				
	17	19	5	7.6	71.1	26.4	22.4
	20		5				
Blackbutt ..	22		5				
	19	20.6	5	8.24	59.6	34.1	28.9
	21		5				
Tallow-wood	25		5				
	25	26.3	5	10.52	71.4	36.1	30.6
	29		5				
Jarrah	21		5				
	24	22.3	5	8.92	56.2	39.1	33.2
	22		5				

REMARKS—

These figures are strictly comparable with each other and also with column 16 of Plate VII., and show the relative resistance to abrasion when used in a street pavement.

We see from this that Spotted Gum is the hardest of these four timbers, with Blackbutt, Tallow-wood and Jarrah following in that order, but very close together.

IMPACT TESTS

The machine used for these tests is of the falling weight type, and consists of a hammer which may be allowed to fall from any height up to 4 metres (= 13.1 ft.). The apparatus is provided with hammers of various weights in order to obtain a wide range of tests.

In order to ascertain the energy taken to break the test piece with a single blow, a recording apparatus is provided (Fig. 31).

The tup is raised between two parallel guides by means

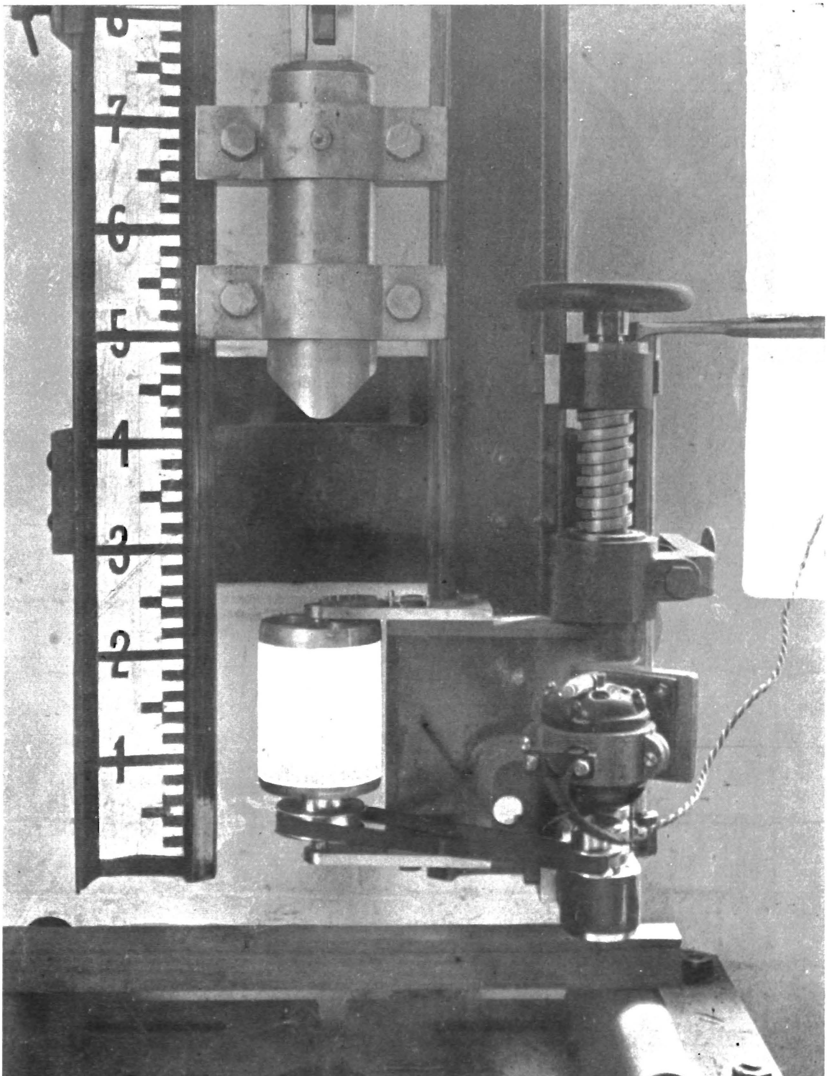

FIG 31

of a chain wound on a drum. The specimen (in this case a beam 2′ × 2″ × 2″) is placed on two horizontal supports at the required distance apart, with its centre vertically below the centre of the tup.

There is a scale graduated in cms. parallel to and beside the guides, so that the height of the tup can be easily read off before each test.

A pencil is fixed in the tup to draw a line on the drum of the recording gear.

The recording gear works as follows:—A small $\frac{1}{16}$ h.p. motor (series wound) drives, by means of a belt, the drum on which a piece of paper has been fixed. The drum, as can be seen from the figure, revolves about a vertical axis. The drum is in gear by means of a pinion on its axis with a spur wheel with two pins on it, which, by engaging with a piece of metal kept in place by a string, causes a click every revolution of the wheel.

The diameters of the pinion and spur wheel are as 1 : 11.6.

The diameter of the drum is 4.3 inches when the paper is in position, and so it is easy to calculate the peripheral velocity if we count the clicks.

When the paper is in place on the drum, and the specimen has been put in position and the weight raised, the motor is set going and allowed to run for a minute or so till the speed becomes constant.

When the speed is constant the number of revolutions of the clicker is taken over one minute, the weight being allowed to fall after the first half minute.

When the tup comes into a position level with the drum the pencil draws a line on the drum which is approximately straight, as the tup is falling with almost constant velocity over any small distances.

As the tup passes the centre of the drum it comes into contact with the test piece, and as this is strained the line is gradually bent, and when the piece is fractured the line takes a tangential position and is once more approximately straight.

Figs. 32—35 give examples of curves from actual tests.

There are two methods which can be employed to work out the energy absorbed in breaking a test piece.

The first method takes into account the speed of the drum, while the second does not, and so we get the better results from the second method, as it is always very difficult to obtain the exact speed of the drum at any particular instant.

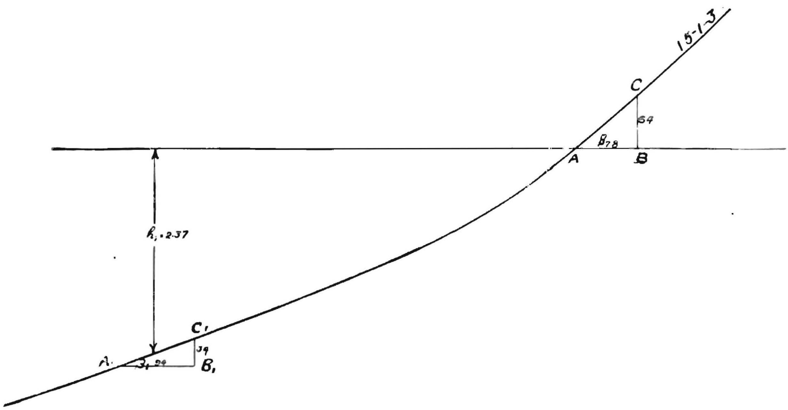

FIG. 32.

First Method.—Fig. 32 shows the curve obtained by testing a small beam of South Coast Turpentine, 15-1-3.

The speed of the drum is:—

$S_p = 11.6\, n\, \pi\, d$ inches per minute.

Where n = number of revolutions per minute.
d = the diameter of the drum ; = 4.3 inches.
s_p = peripheral speed in inches per minute.

The time taken for the pencil to describe the distance $A_1\, C_1$, Fig. 32, is :—

$$\frac{A_1\, B_1}{S_p}$$

The velocity of the pencil is :—

$$v = \frac{S_p \times B_1\, C_1}{A_1\, B_1} = S_p \tan \beta_1 \text{ inches per minute}$$

$$= 11.6\, n\, \pi\, d \tan \beta_1 \text{ inches per minute}$$

$$= 11.6 \times 4.3\, n\, \pi\, d \tan \beta_1 \times \frac{1}{12 \times 60} \text{ feet per second}$$

$$= n \tan \beta_1 \times k_1$$

$$\text{where } k_1 = \frac{11.6 \times 4.3 \times \pi}{12 \times 60}$$

We can express the velocity in terms of the height from which a weight must fall freely under the action of gravity to acquire that velocity.

Let h_d denote the height necessary to produce the velocity v_1, then :—

$$v_1^2 = 2gh_d$$

$$h_d, = \frac{n^2 k_1^2 \tan^2 \beta_1}{2g} = n^2 k^2 \tan^2 \beta_1$$

$$\text{where } k^2 = \frac{k_1^2}{2g} = 0.000736,$$

so that in order to find h_d we require to know only n and $\tan \beta_1$; the former is counted, and the latter obtained by scaling off the diagram, Fig. 32, in the manner indicated.

The total work done in breaking the specimen is—

$$W (h + h_1 - h_d),$$

where W = the weight of the falling weight or tup;
h = the height to the zero line of the diagram, Fig. 32;
h_1 = the height between zero line and the point on the diagram where $\tan \beta_1$ is determined;
h_d = the height corresponding with the velocity v_1 found as already described.

The work necessary to produce rupture expressed in foot pounds per cubic inch of the specimen is :—

$$\frac{W (h + h_1 - h_d)}{l\,b\,d}$$

where $l\,b\,d$ = the volume of the specimen in cubic inches.

Second Method.—The velocity of the falling weight at the point A in Fig. 32 is :—

$$v = s_p \tan \beta$$

Also at the point where $\tan \beta_1$ is determined, the velocity is :— $v_1 = s_p \tan \beta_1$

$$\text{But } v^2 = 2gh, \text{ and } v_1^2 = 2gh_d \therefore h - h_d = \frac{v^2 - v_1^2}{2g}$$

$$= \frac{v^2}{2g}\left(1 - \frac{v_1^2}{v^2}\right) = h\left(1 - \frac{v_1^2}{v^2}\right)$$

But $\frac{v_1^2}{v^2} = \frac{\tan^2\beta_1}{\tan^2\beta}$ $\therefore h - h_d = h\left(1 - \frac{\tan^2\beta_1}{\tan^2\beta}\right)$

The work done in breaking the specimen is:—

W $(h + h_1 - h_d)$, as before, or $Wh\left(1 - \frac{\tan^2\beta_1}{\tan^2\beta}\right) + Wh_1$

The work necessary to produce rupture per cubic inch of the specimen is:—

$$\frac{Wh\left(1 - \frac{\tan^2\beta_1}{\tan^2\beta}\right) + Wh_1}{l\,b\,d}$$

We may determine the energy necessary to fracture the test piece in a single blow by either method, but the second method is slightly more simple.

Example.—Data obtained from the experiment:—

Revolutions of the drum = 100 per min.

Height of fall to zero line = 150 cms. = 4.92 feet.

Size of specimen, 2′ 0″ × 2″ × 2.08″,

Diagram obtained, Fig. 32. Weight of tup = 79.5 pounds.

First Method.—

$$h_d = n^2\tan^2\beta_1 \times .000736$$

$$= 100^2\left(\frac{34}{94}\right)^2 \times .000736$$

$$= 0.964 \text{ feet.}$$

The work done in breaking the beam is:—

79.5 (4.92 + .19 − .964) = 330 ft. pounds.

$$\left(h_1 = \frac{2.37}{12} = \cdot 19\right)$$

Second Method.—

The work done $= 79.5 \times 4.92\left(1 - \frac{\tan^2\beta_1}{\tan^2\beta}\right) + 79.5\,h_1$

$$79.5 \times 4.92\left\{1 - \frac{\left(\frac{34}{94}\right)^2}{\left(\frac{64}{78}\right)^2}\right\} \times 79.5 \times .19$$

= 329 ft. pounds.

The work done on the beam expressed in foot pounds per cubic inch (since $l\,b\,d = 24 \times 2 \times 2{\cdot}08 = 99.84$ cubic inches) by the first method is:—

$$\frac{330}{99.84} = 3.30:$$

by the second method we have :—

$$\frac{329}{99.84} = 3.29.$$

The agreement between the two methods is very satisfactory.

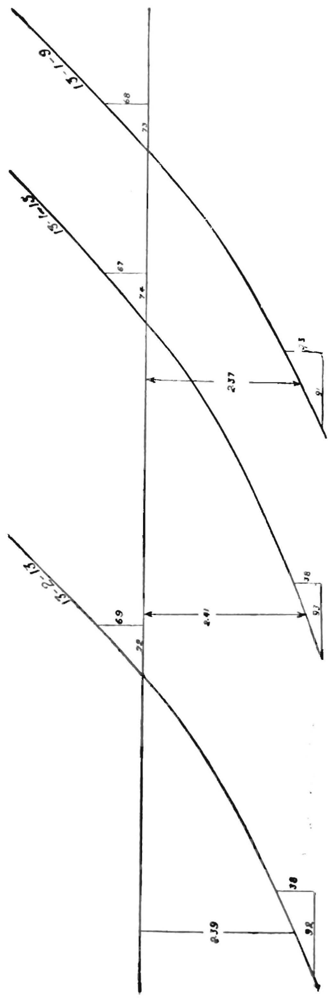

FIG 33

We may take another example to further illustrate the methods :—

Data.—

Revolutions of the drum = 99 per minute.
Height of fall to zero line = 200 cms. = 6.56 feet.
Size of specimen 2′ 0″ × 2″ × 2.04″.
Diagram obtained Fig. 33, h_1 = .20 foot.
Weight of tup = 79.5 pounds.

First Method.—

$$h_d = n^2 \tan^2\beta_1 \times .000736$$

$$= 99^2 \left(\frac{38}{92}\right)^2 \times .000736$$

$$= 1.23 \text{ feet.}$$

Work done on the test piece = 79.5 (6.56 + .20 − 1.23)
= 440 foot pounds.

Second Method.—

Work done on the test piece

$$= 79.5 \times 6.56 \left(1 - \frac{\tan^2\beta_1}{\tan^2\beta}\right) + 79.5 \times .30$$

$$= 79.5 \times 6.56 \left\{ 1 - \frac{\left(\frac{38}{92}\right)^2}{\left(\frac{69}{72}\right)^2} \right\} + 79.5 \times .20$$

= 441 foot pounds.

The volume of the test piece = 97.92 cubic inches. So that the work done per cubic inch is :—

$$\text{First method} = \frac{440}{97.92} = 4.50 \text{ foot pounds,}$$

$$\text{Second method} = \frac{441}{97.92} = 4.51 \text{ foot pounds,}$$

The three curves shown on Fig. 33 were all obtained from specimens of South Coast Woollybutt.

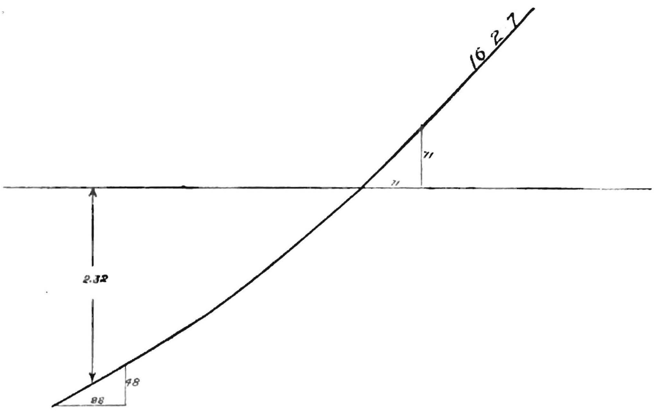

FIG. 34.

is an example of a curve taken from a piece of South Coast Blackbutt.

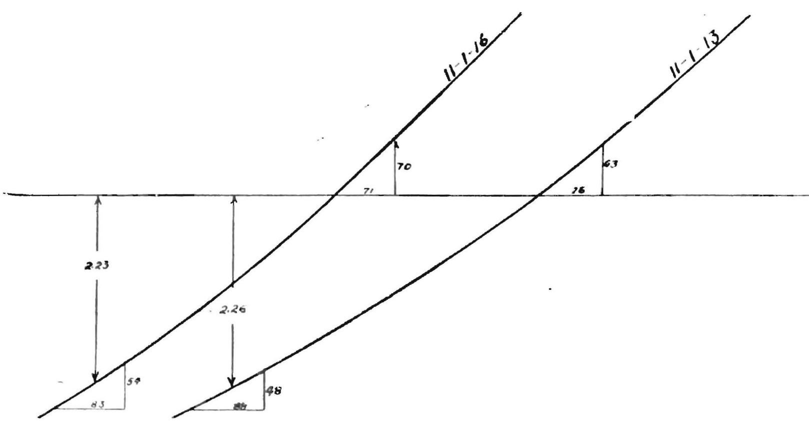

FIG. 35

The two curves in this figure are from North Coast Colonial Teak.

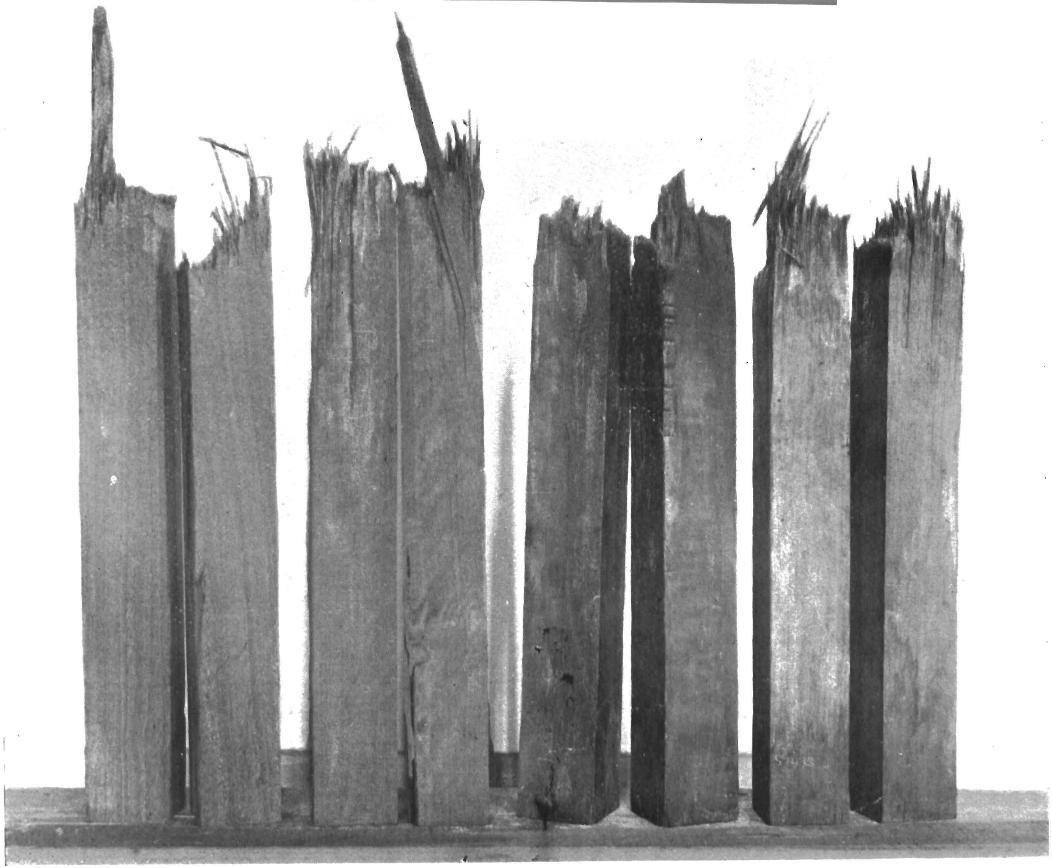

FIG. 36

This shows four specimens after fracture. From the left they are Colonial Teak, Mountain Ash, Turpentine, and Spotted Gum. It can be noticed that Colonial Teak and Turpentine give a very brittle break.

Table 14.—New South Wales Timbers. Impact Tests of 2 in. x 2 in. x 2 ft. Beams.

Local Name.	No	No. of Tests made.	Moisture per cent			Total work done in Breaking Beam.			Work done per Cubic Inch.		
			Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
Blackbutt	1	5	17.5	14.3	15.7	413.7	297.9	365.6	4.37	3.16	3.87
Tallow-wood	2	8	22.1	11.8	17.3	345.1	219.8	295.6	3.70	2.43	3.13
Grey Gum	3	5	16.9	14.3	15.4	338.8	215.9	256.6	3.70	2.44	2.78
Grey Ironbark	4	8	17.7	14.9	16.9	503.0	339.0	406.0	5.22	3.61	4.25
Blue Gum	6	8	18.8	13.0	16.9	481.0	328.0	410.5	5.01	3.42	4.04
Brush Box	7	7	19.2	14.2	17.6	413.8	158.4	337.3	4.43	1.65	3.61
Turpentine	8	7	27.0	12.9	16.8	401.5	308.8	338.5	4.21	3.37	3.65
Red Mahogany	9	8	16.6	11.6	15.2	395.0	278.7	335.5	4.08	3.03	3.54
White Mahogany	10	8	16.2	11.1	13.5	348.9	129.9	207.1	3.18	1.37	2.13
Colonial Teak	11	8	15.8	12.1	14.2	309.1	190.3	252.5	3.18	2.07	2.64
Grey Box	12	15	20.2	12.3	15.7	650.0	455.0	575.9	7.08	4.87	6.18
Woollybutt	13	10	21.4	13.4	17.2	597.0	250.0	414.7	6.90	2.60	4.41
Spotted Gum	14	14	24.1	12.4	16.2	371.1	224.7	250.5	4.01	2.32	2.72
Turpentine	15	10	18.6	12.1	16.0	396.0	111.5	215.3	4.45	1.23	2.36
Blackbutt	16	8	17.0	13.7	15.3	522.8	309.1	427.1	5.45	3.25	4.52
Mountain Ash	17	8	15.3	10.9	13.4	643.3	346.9	520.6	6.80	3.67	5.55
White Stringybark ..	18	8	14.0	11.6	12.8	345.9	264.7	312.0	3.70	2.94	3.39

Table 14 gives the results of nearly 150 tests collected together.

It will be noticed that the brittle timbers, such as Turpentine and Colonial Teak, give very low averages, while the stringy timbers, such as Mountain Ash, give high results.

The order of merit in which the timbers stand for impact is accordingly:—

1. Grey Box, S.C.
2. Mountain Ash, S.C.
3. Blackbutt, S.C.
4. Woollybutt, S.C.
5. Grey Ironbark, N.C.
6. Blue Gum, N.C.
7. Blackbutt, N.C.
8. Turpentine, N.C.
9. Brush Box, N.C.
10. White Stringybark S.C.
11. Red Mahogany, N.C.
12. Tallow-wood, N.C.
13. Grey Gum, N.C.
14. Spotted Gum, S.C.
15. Colonial Teak, N.C.
16. Turpentine, S.C.
17. White Mahogany, N.C.