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IMPACT TESTS OF MATERIALS.

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In railway materials, such as rails, tyres, axles, couplings, etc., the streses developed under normal working conditions are more or less suddenly applied. Again in machinery and engines the stresses are of a similar character. The ordinary tension tests, in which the load is gradually applied, do not always reveal the capacity of the material to withstand suddenly applied loads, but this property is best determined by subjecting specimens of the material to shock in a suitable impact machine. The subject of impact tests, and the most suitable impact machines and apparatus, has been much investigated during the last few years, chiefly owing to the efforts of the International Association for Testing Materials. A Society which is daily growing in importance and usefulness, and which has done more than any other, to establish the methods of testing the materials of construction upon a sound scientific and practical basis. The effect of the blow, on specimens of materials subjected to impact, depends not only on the weight, and height of drop of the hammer, but also upon the weight of the anvil, and its foundation supporting the specimens. Fig. 1 illustrates an impact testing machine, designed by Prof. Martens, of Berlin, and used in the author's laboratory. This machine can be used for a great variety of tests, and fig. 2 shows the method of using it for tension tests.

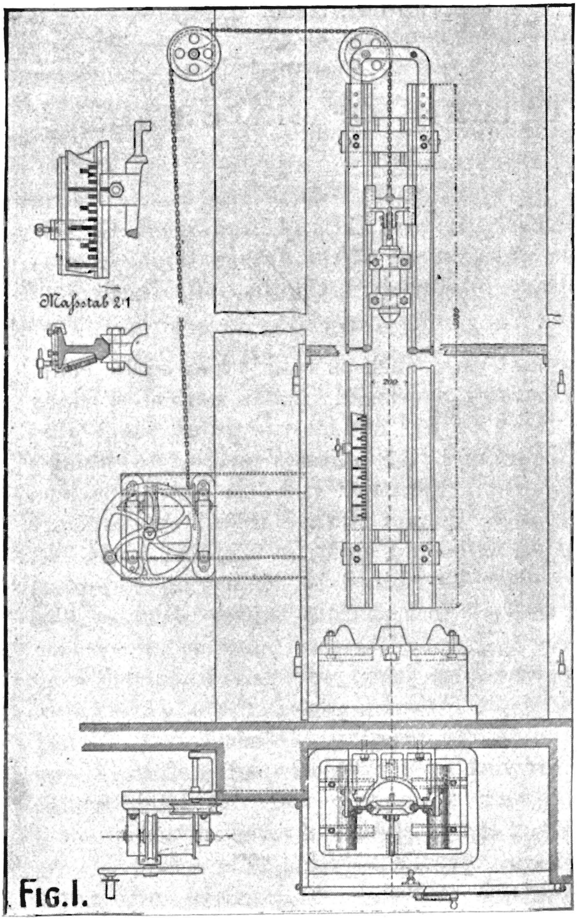


FIG. I.

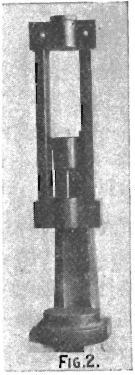
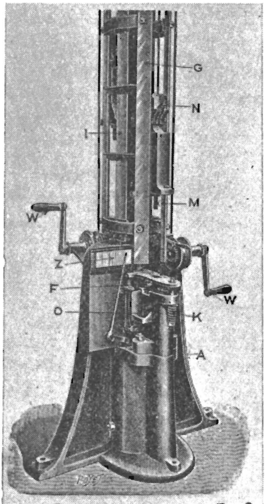


FIG. 2.

The machine is provided with a variety of hammers, and the anvil weighs 22.5 times as much as the heaviest ram employed. The anvil is set upon a concrete foundation, quite distinct from the foundation of the building.

The arrangements for making tension tests shown in fig. 2, may be objected to, as a portion of the energy of the blow is necesarily absorbed by the auxiliary appliances for holding the specimen, but with standard test bars there is no difficulty in the determination of the relative shock resistance of various materials under a blow from a hammer of given weight falling from a given height under similar conditions. Fig. 3 shows the lower portion of the Frémont's machine for impact tests. The design is made double so that two may operate on the same machine at the same time. The hammers weigh 20 and 30 pounds respectively, and the anvils are bolted on opposite side of the base the whole weighing not more than 1500lb.,This machine enables the operator to break the specimen with a single blow, and measure the residual energy still remaining in the hammer. The hammer is made to fall upon a cap which compresses two springs, the motion of which is multiplied by means of a lever. The specimens used are 3-8in. wide, 5-16in. thick, 1¼in. long, with a saw cut 1-16in. deep.



Fremont Impact Machine. FIG. 3.

It is, of course, impossible in the tension tests to avoid a portion of the energy of the blow being absorbed by the auxilliary appliances for holding the specimen, but with standard test pieces, hammer and heights of drop, reliable results can be obtained.

Fig. 4 shows a pendulum impact machine designed by M. G. Charpy*, which is an excellent machine of its kind. Like Frémont's machine, the actual work absorbed by the test piece can be accurately determined when the specimen is factured by a single blow; but in Charpy's machine it is merely necessary to note the difference in the heights of the departure and the arrival of the hammer. The weights of the ram used in Charpy's machine are 50 and 300 kilos., and the form of the ram is so arranged that the plane of the blade which produces the shock passes through the centre of gravity of the oscillating system.

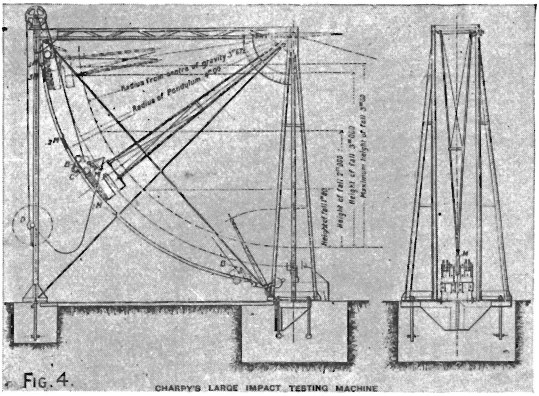


FIG. 4. CHARPY'S LARGE IMPACT TESTING MACHINE

Pendulum Impact Testing Machines have been designed and used by Prof. Rudeloff and others. The author has adopted the smaller Charpy machine, which is also provided with an arrangement for making tension

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* Civil Engineer at St. Jacques' Montlucon Factories.

tests, in which the energy absorbed is breaking the specimen by means of a single blow is determined.

THE GUILLERY IMPACT TESTING MACHINE.

The Guillery apparatus is illustrated in figs. 5, 6 and 7, and is distinguished by its small size, compared with other machines for impact tests. The test pieces used are 60 x 10 x 10 m.m.m. size, and a square notch is cut in the centre 2 m.m. wide, by 2 m.m. deep.

It consists essentially of a perfectly balanced steel fly wheel, B, carrying on its periphery the knife, A, which fractures the test bars. The spindle of the fly wheel is carried on ball bearings when running free, and on plain bearings of large size at the moment when the blow is delivered. The bearings are supported on a cast-iron frame work of sufficient mass not to be injured by the shock or the subsequent reactions, C. The fly wheel is set in motion by hand or mechanically until it attains so great a velocity that:—

a. The energy accumulated in the mass is greater than that which is required to break the test piece; and that—

b. The velocity of impact is the same as that usually employed in Fragility test, *i.e.*, is a velocity equal to that of a body falling freely from a height of four metres.

The fly-wheel is driven through the agency of a cylindrical disengaging gear, the moving clutch of which is carried by a lever F. The lever is fastened to the frame of the machine when the clutch is out of gear; but when it is released, a spring throws the clutch in again, and the fly-wheel can be revolved until it acquires the necessary speed, either by means of the hand crank E, or by means of a belt running over the grooved pulley.

The notched bar is carried between light jaws on a moveable anvil of cast-steel, H, faced with a flush plate of hardened steel, where the blow falls. A coil spring of considerable strength tends to push the anvil towards the

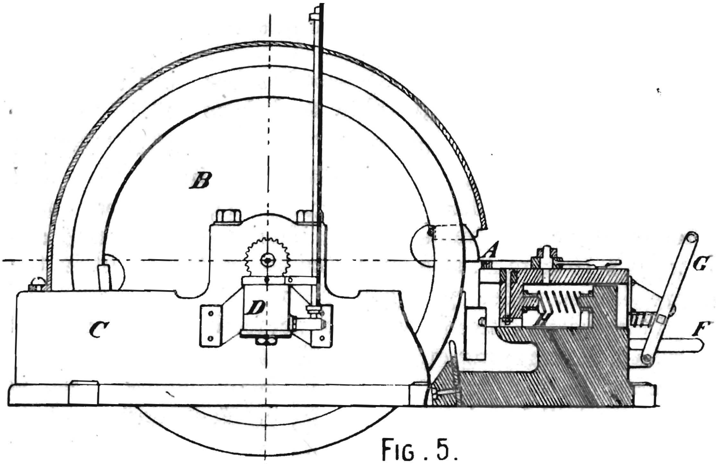


FIG. 5.

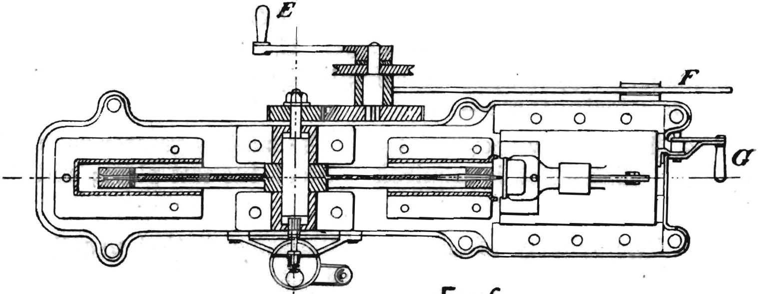


FIG. 6.

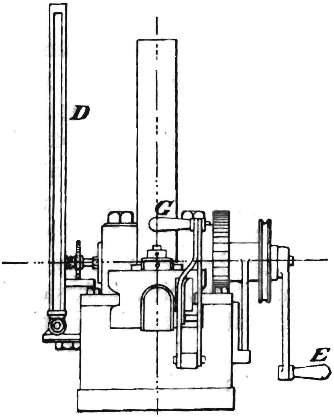


FIG. 7

fly-wheel, *i.e.*, to bring it into the necessary position for the notched bar to receive a blow from the revolving knife. Attached to the anvil is the mechanism that prevents the test piece from coming under the hammer before proper time arrives. The mechanism in question consists of a cam engaging the anvil, carried on a spindle which is free to move in a longitudinal direction, but which cannot rotate without rotating the cam. The spindle is provided with a spring tending to draw it back towards the operator, and to keep it in such a position that the cam engages with the anvil. When the operating lever G is pulled, it draws the anvil away from the fly-wheel, and a lateral projection at the end of the spindle near the fly-wheel assumes a horizontal position. When the lever is next pushed away from the operator, the spindle is also pushed towards the fly-wheel until the lateral projection at the far end receives a light blow from the knife edge the first time it comes round, immediately the projection is so struck, the spindle rotates, the cam disengages from the anvil, the anvil assumes its working position without loss of time; and at the next revolution of the fly-wheel, the knife edge descends upon the test-piece. The tachometer is a small centrifugal pump with vertical axis D, showing at a glance from the level of the water in a graduated tube the velocity at any moment, and the work absorbed. A safety device is fitted to the machine that renders it impossible to place a sample upon the anvil, or even to move the jaws when the anvil is freed from the withholding cam. The fly-wheel is surrounded with a case of cast-iron to protect the operator from flying pieces.

The work accumulated in the mass is 60 kg., the velocity of impact 8800 m., corresponding to 293 revolutions. The author has used this apparatus for a variety of tests, and has found it as satisfactory as it is ingenious.

The machine shown in fig. 1 may also be used to determine the energy absorbed in breaking the test piece by means of a single blow, and the author is arranging to apply it in this manner to beams of Australian timber. It can also be applied in a similar manner to impact tests of beams of steel and other materials. The method will be more fully described later, but it consists of a recording drum upon which the diagram is produced by means of a pencil attached to the falling weight; also of a tuning fork record from which the velocity of the falling weight at any instant is determined.

Impact tests consist of bulging or upsetting tests of materials, in metals such as cast-iron and steel, using small cylinders, and in timber using small prisms subjected to sudden compression. Impact tests of beams supported at the ends and struck in the centre, as practiced for railway axles, and on smaller specimens of material notched on the tension side.

Impact tension tests, where, however, the energy actually absorbed by the test piece is much more difficult to determine. All these tests may be made either with a number of blows, or by means of a single blow. The method of making such tests will now be described, and the law of similarity in the form of the test pieces, and the conditions under which the tests are made such as in regard to the time interval between the blows, must be clearly borne in mind, and rigidly observed if the results are required to be strictly comparable.

Upsetting (*or Bulging*) *tests*:—

A prismatic or cylindrical body is used of length l, and diameter d, such that:—

$$l = d, \text{ or } l = 0.886d,$$

$$\therefore \frac{\sqrt{a}}{l} = 1$$

The gross work done on the body eq. Wh., in connection with the shortening or upsetting — λ. The specific impact or work absorbed per unit of volume, compared with the unit of length is:—

$$- \frac{\lambda}{l}$$

If v eq. the volume of a body in cubic inches, and w its weight in pounds, the specific work of impact is:—

$$i = \frac{Wh;}{v} \text{ or } i = \frac{Wh}{w}$$

The upsetting will be :—

$$\frac{\lambda}{l} = \frac{l - l_1}{l} \text{ or in per cent.} = \left(1 - \frac{l_1}{l}\right)100.$$

If the body does not change its volume during deformation there will be a relation between the latered length and diameter denoted by l_1 and d_1 respectively, which neglecting bulging is:—

$$V = V_1\,;\ \cdot 7854 d^2 l = \cdot 7854 d_1^2 l_1$$

$$\text{or when } d = l = 1,\ l_1 = \frac{1}{d_1^2}$$

$$\text{when } l = 0.886d,\ l_1 = \frac{0.886.}{d_1^2}$$

Effect of Speed.—The work done by the falling weight Whn. where n is the number of drops was found by Kick to not affect the results noticeably with certain metals. In lead where d ep. l eq. 0.59 in., under an impact of 12.5 foot pounds, or for v eq. 0.16 cubic in.

$$i' = 70.1 \frac{\text{ft. lbs.}}{V}$$

he found the following results:—

Impact.	1	2	3
a. Height of drop, h = 10ft.; weight of ball, w = 1.25lbs.	19.3	35.0	47%
b. Height of drop, h = 0.85ft.; weight of ball, w = 14.75lbs.	19,8	34.4	46·3%

The velocities of impact are 25.4, and 7.2 feet per second respectively; or—

$$\frac{V_a}{V_b} = \frac{3.5}{1}$$

Under similar conditions for other lead cylinders—

$d = l = 0.7$ and $i = 46.5 \frac{\text{ft. lbs.}}{V}$ he found :—

Impact.	1	2	3	4
a. Drop h = 10ft.; v = 25.4 ft. per sec. ...	15.1	25.6	34.8	41.8%
b. Drop h = 0.85; v = 7.2ft. per sec. ...	15.1	26.5	35.9	44.4%

Therefore the effect of striking velocity does not appear to be great.

Under similar conditions rupture is produced in geometrically similar bodies of identical material by identical amounts of specific impact. Prof. Martens has proposed the term, "Crushing factor," for the specific impact in ft., lb., which, when applied to a body of fundamental shape (sphere, cube standard, plug) in a single blow will either just produce rupture, or crushing eq. 80 per cent.

Marten's has proposed the following methods of procedure in impact upsetting tests. Five plugs are necessary, the first is struck with a number of blows each equal to a specific impact of i, the second plug $2i$, the third of $4i$. The fourth and fifth are to be struck with one blow producing rupture of the plug, or shortening of 80 per cent., the specific impact of the final blow is estimated from the previous series. The following values of i are recommended:—

1. For soft metals (lead, etc.), i eq. 2.96 ft., lb. per cubic inch.
2. For cast-iron, i eq. 29.6 ft., lb. per cubic inch.

3. For copper, bronze, and soft alloys, i eq. 59.2 ft., lb. per cubic inch.

4. For iron and stronger metals, i eq. 118.4 ft., lb. per cubic inch.

Although it has been shown by Kick that the velocity of impact exerts a small influence on the deformation of lead, generally it has been found that, heavy blows produce greater deformation than light blows of equal specific impact. Under equal impact Wh., heavier weights of hammer produce greater deformation.

Impact Transverse Tests.—The impact transverse test generally known as the drop-test, is made by placing a bar across two supports, and dropping a hammer or ram so as to strike it suddenly in the centre, the number of blows necessary to produce rupture, or a definite deflection is noted, and the total work done is, nWh. ft. lb.

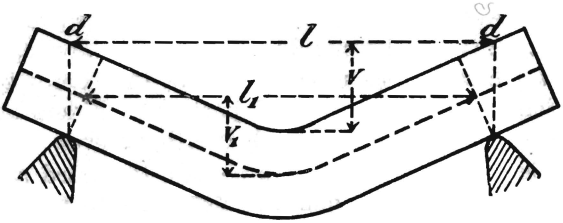


FIG. 8.

The deflection V_1, fig. 8, is measured by means of a three-legged compass, or a straight edge of length l, is placed upon the upper surface of the test piece, its ends touching the points *dd*, fig. 8, and the deflection V measured by means of a slide at the centre of the straight edge.

The drop-test is largely used for testing axles, tyres, and other railway material, and rules are given in the British Standard Specifications, in regard to weight of hammer usually a ton, height of drop, and span in the case of axles. The rules adopted by the German railway managements provided that:—

For rails l eq. 1 metre, total length eq. 1.3 metres.

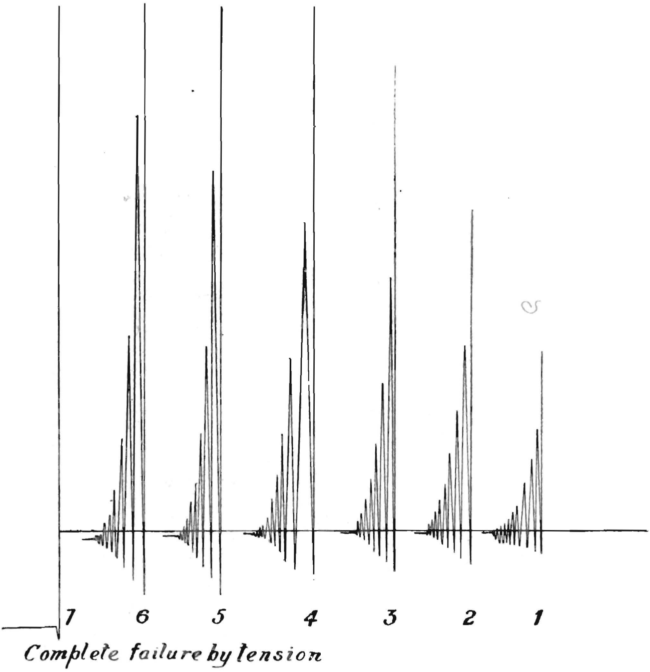
For axles l eq. 1.5 metres.

The deflection of both axles and rails is to be measured on the upper surface, and always in relation to the original distance between the bearings after each blow.

For rails, blows of 10,800, 7200, and 6400 ft., lb., are used when they exceed 48 pounds per yard. For axles 21,650 ft., lb. blows are given always on the same side of the test specimen. Locomotive axles are tested under blows of 39,750 ft., lb. (23 ft. x 1760 lb.), and tender axles under 30,280 ft., lb. blows (23 x 1320 lb.) Tyres are tested vertically under the drop with 21,630 foot lb. blows, and the vertical depression and lateral spreading is measured on the inside diameter by means of sliding callipers. When considered necessary the rupture of rails, axles, and tyres may be induced by nicking. Test pieces for the ordinary statical tension tests are usually cut out of the least injured pieces.

The heads and flanges of rails are divided into spaces near the centre, and generally spacing lines are marked on all test pieces in order to determine the compression or extension of the most strained portions. Riders are used to protect the divisions provided with grooves.

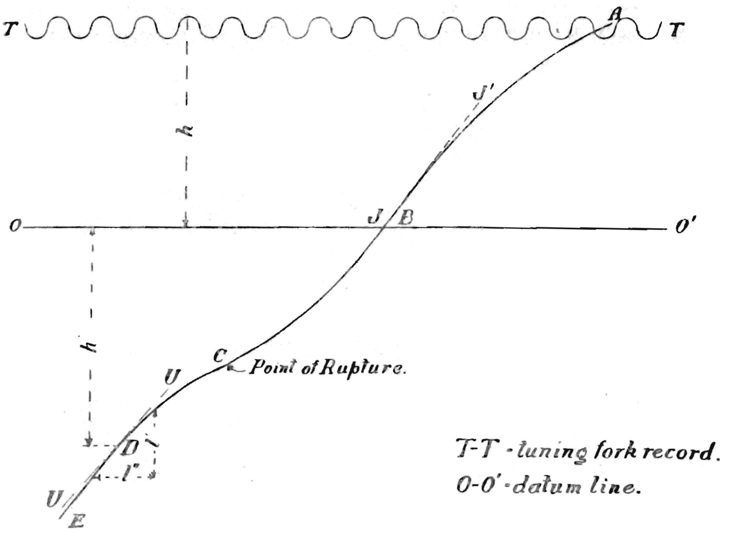
It is a great advantage to be able to record automatically the successive amounts of deformation and set, and the rebound of the hammer. A recording drum with its axis vertical may be connected to the fixed guides of the machine, and the length of the drum should be large enough to allow a pencil, attached to the falling hammer, to remain always in contact with it throughout the whole height of the drop. A tuning folk, attached to the frame-work supporting the drum spindle, is arranged to record the time as the drum revolves, producing a wave line, giving the data for calculating the velocity of the hammer at the instant of striking the blow; or, in some cases, where facture occurs, the velocity of the hammer, after fracture. When a specimen is subjected to a series of blows from a hammer falling from successively increasing heights, the record obtained for, say, 7 blows is similar to fig. 9. Whether the test is in connection with a beam, a prism subjected to compression, or a tension piece, the record enables the rebound of the hammer, the deformation, and set, of the specimen to be determined, and the tuning fork record provides the necessary data for calculating the velocity, although this is not so necessary with a number of blows as with a single blow causing fracture.



Record of Impact Bending Test.

FIG. 9.

The elastic limit in such tests is usually fixed at the point where the deflection suddenly increases, at this limit a sudden increase in the set of the specimen as well as a maximum rebound of the hammer usually occurs. In making the test the hammer is allowed barely to touch the specimen, and a light line is then drawn on the drum. The weight of the hammer is then allowed to rest upon the specimen, a zero or datum line is drawn, and the deflection under the dead weight of the hammer is noted.



Record of impact test. Specimen ruptured under single blow.

FIG. 10.

The blows of a weight dropped from increasing heights are delivered to the specimen, and a series of records are taken on the drum similar to fig. 9.

Let W eq. the weight of the hammer in pounds.
h eq. the height of drop in inches.
v eq. the deflection at elastic limit in inches below the zero line.
l eq. the length of the span in inches.
d eq. the depth of the beam in inches.
b eq. the width of the beam in inches.
v_1 eq. the deflection caused by a static load W.

$$\triangle = (v + V_1); \quad H = (h + v)\cdot$$

EL eq. the fibre stress at the elastic limit in pounds per sq. in.

E eq. the modulus of elasticity in pounds per sq. in.

M.Ri. eq. the modulus of resilience in pounds per cubic inch of the specimem, where volume eq. *lbd* cubic inches.

The elastic limit is determined by plotting H against $\triangle^2$, and noting on the diagram the point where the height of the drop ceases to be proportional to the square of the deflection|

From any height of drop below the elastic limit thus determined, we have:—

$$W(h + v) = \frac{P(v + v_1)}{2} = \frac{P\triangle}{2} \qquad (1.)$$

Where P eq. the total load on the beam at the elastic limit in pounds.

It may be shown that:—

$$P = \frac{48 \triangle EI}{l^3}$$

Where I is the moment of inertia of the cross-section of the beam $= \frac{1}{12} bd^3$ for rectangular cross-sections.

$$\therefore W(h + v) = \frac{24 EI \triangle^2}{l^3} \qquad (2.)$$

Fibre stress at elastic limit:—

If the beam is rectangular, and loaded in the centre:—

$$P = \frac{2.E.L \times bd^2}{l^3}$$

Substituting in equation (1)

$$WH = \frac{2 \times E\,L \times bd^2 \triangle}{3 \times 2 \times l} \qquad (3.)$$

$$\therefore E.L = \frac{3WHl}{bd^2 \triangle} \qquad (4.)$$

Modulus of elasticity:—

$$\text{Since :—} \quad \triangle = \frac{Pl^3}{48EI}$$

$$WH = \frac{2Ebd^3 \triangle^2}{l^3} \qquad (5.)$$

$$\therefore E = \frac{WHl^3}{2bd^3 \triangle^2} \qquad (6.)$$

In terms of E.L.

$$E = \frac{E.L \times l^2}{6d \triangle} \qquad (7.)$$

Modulus of resilience:—

$$M.Ri = \frac{WH}{lbd} \qquad (8.)$$

The following results, Table I., were obtained by Prof. W. K. Hatt, and are given to illustrate the method:—Timber "Pinus tœda," l eq. 34. in., b eq. 2.65 in., d eq. 2.04 in.; weight of hammer 50 pounds.

TABLE I.

No. of blow	Height of Drop. h	Deflection in inches. v	Rebound in inches.	Set in inches	Difference of Head inches. h	$(V + V_1)^2$
1	2.26	.30	1.73	.00	2.56	.102
2	4.26	.41	3.12	.01	4.67	.185
3	6.26	.52	4.32	.02	6.78	.292
4	8.26	.60	5.27	.03	8.86	.384
6	10.26	.70	6.53	.04	10.96	.518
5	12.26	.78	7.28	.05	13.04	.640
7	14.26	.88	8.06	.06	15.12	.774
8	16.26	.95	8.70	.08	17.21	.941
9	18.26	1.05	9.26	.10	19.31	1.145
10	20.26					

Complete failure in tension occurred at the ninth blow. The value of V was 0.02 inches.

IMPACT TESTS UNDER A SINGLE BLOW.

If it is desired to determine the energy necessary to produce rupture by a single blow, with a drop hammer impact machine, provided with a revolving drum, tuning fork and pencil on the hammer, the following method has been proposed by Prof. Hatt. The height of fall must be greater than that required to produce rupture, and the residual energy resident in the hammer after rupture is found from the diagram recorded on the revolving drum. Fig. 10 shows the kind of diagram obtained, where the zero datum line is determined as before.

Before contact of the hammer in falling upon the beam, the curve described is A.B., the hammer is then retarded by the resistance of the beam as shown by the curve, B.C., where the point C indicates the rupture of the beam, and the curve changes again to C.E., which is similar to A.B. Neglecting the loss of energy due to friction and yielding of the parts of the apparatus, we may assume that the hammer falls through a distance $(h + h_1)$ to some point D below C. A tangent to the curve, C.E., is drawn at D, and the vertical and horizontal components l^1 and l^{11} are determined as shown. The values of l^1 and l^{11} are deterbined by means of the tuning fork record, and the velocity at D is the distance l^1 divided by the time; call this V_d.

The total energy expended is $w\,(h + h_1)$, and this is equal to:—

a. The energy expended on the specimen.

b. The energy remaining in the hammer at D.

$W(h + h_1)$ = work done on specimen + $\frac{1}{2} M V_d^2$ where M = mass of W.

$\frac{MV_d^2}{2} = Wh_d$; where h_d = velocity head at d.

∴ Work expended on the specimen is:—

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

The rupture work per cubic inch is:—

$$M.Ri = \frac{W(h + h_1 - h_d)}{lbd}$$

IMPACT TESTS ON NOTCHED BARS.

Impact tests on notched specimens supported at each end, and struck with a hammer falling from a given height. may also be made by means of a number of blows, or by means of a single blow. The notches are made on the side of the test piece subjected to tension, and should be of definite geometrical form, triangular, rectangular, or circular. Figs. 11 and 12 represent two forms used by the author, recommended by the International Society for testing materials.