SECTION II.

FINISHED STEEL.

CHAPTER XIV.

MECHANICAL TESTING OF MATERIALS.

THE great developments in all branches of engineering during recent years and the consequent demand for material of the highest quality necessitate the most exhaustive testing by all manufacturers of the steel made at their works, if they desire to maintain a reputation for producing a thoroughly reliable material. All steel used for structural and general engineering purposes should be subject to such tests, before leaving the works, that it may be reasonably certain that there will be no risk of failure after it has once left the manufacturer's hands. The special tests which it is advisable to make will largely depend upon the purpose for which the material is required, and in most cases the engineers specify their requirements in these respects, quite apart from such tests as the manufacturer may choose to make for his own satisfaction. It must be remembered that the object of testing materials under the conditions which we are considering is not to arrive at any *absolute* results, but simply to see if the material is good of its kind and suitable for the particular purpose for which it is required. It is sufficient, therefore, to compare it with some more or less arbitrary standard which has been selected, and which varies with different individual opinions and with varying classes of material. Thus, some engineers, having found as the result of experience that steel with 45 to 50 tons breaking-load gives the best results for tires, specify that their tire steels shall have a tensile strength within these limits, while others again specify from 48 to 52 tons.

Broadly speaking, the tests applied may be divided into two classes:—(1) Hot tests to insure that the metal is free from all red shortness at all temperatures above a red heat, and is of good welding qualities; and (2) cold tests to insure that the metal possesses the required strength, elasticity, ductility, &c., and is free from cold shortness or tendency to brittleness when cold.

The ordinary welding and hot plating tests have already been, to some extent, referred to under the Bessemer and Siemens processes, and these are described more fully at the end of this chapter. What we have more especially to consider now are the systematic methods for investigating the properties of steel by the application of stress and the deductions to be drawn from the results obtained.

The stress may be applied gradually in the form of a direct pull, or may be applied gradually as a direct thrust, to test the resistance of the material to crushing. Torsional or twisting stresses and shearing stresses may also be applied, and each of the several methods adopted furnishes different information as to the qualities of the material under trial. Instead of applying the load gradually, it may be applied suddenly by means of a falling weight or the blow of a hammer to test the resistance of the material to deformation or fracture by sudden shock.

In the case of a gradually-applied load, the most usual test for steel is to determine the maximum stress or tensile strength, as, incidentally, in carrying out this test a considerable amount of other information as to the general properties of the material is obtained. Before describing in detail the methods and machines used for testing, it will be advisable to define certain terms which are used to express the results obtained in ordinary testing machines—viz., tensile strength, elastic limit, elongation, reduction of area, and yield-point.

The Tensile Strength — *Ultimate or Maximum Stress; Maximum Load*—may be defined as the maximum stress which a bar of the material can sustain without rupture when a pulling force is applied gradually in the direction of its length. It is expressed in tons, pounds, or kilogrammes per unit area of the cross-section of the test bar, usually per square inch or per square millimetre.

Elastic Limit is the maximum stress a material can bear without suffering permanent distortion or set. This is likewise expressed in tons, pounds, or kilogrammes per unit area of cross-section, usually per square inch or per square millimetre. Within certain limits steel is an elastic body, and, on being elongated by a tensile stress, returns to its original dimensions when the force ceases to be applied.

When the applied force exceeds a certain amount, the material becomes permanently distorted, and *permanent set* takes place. Within the limits of elasticity, under equal variation of loading, a metal bar of uniform section lengthens or shortens equally through its entire length, and on removal of the load returns to its original size; and such loading may be repeated indefinitely, subject to the condition known as fatigue, without deterioration of the material in any way. If, however, the material is once subjected to stresses in excess of its elastic limit, it is permanently altered, and under a series of such stresses it becomes more or less plastic and finally breaks down. Professor Unwin[*] distinguished the two deformations referred to as "elastic deformation," that which disappears when the load is removed, and "plastic deformation," that permanent distortion which remains after the load is removed, and these probably give as correct an idea of the physical state of the material when subjected to the two stresses as it is possible to convey; the elastic limit seems to mark the boundary between the elastic and plastic conditions.

Modulus of Elasticity (Young's Modulus).—As a perfectly elastic body shortens or lengthens equally under equal additions of stress, it is therefore obvious there must be some force which would stretch such a body to twice its length, and this stress expressed in tons, pounds, or kilogrammes per unit area of cross-section is termed the modulus of elasticity. Thus, assuming a steel bar 3 inches long and 1 square inch in sectional area is stretched, by a force of 13 tons, ·003 of an inch without permanent set, by a simple proportion sum we are able to find the force which will be required to stretch it 3 inches. Thus—

$$\begin{array}{ccccccc} \text{Extension.} & & \text{Inches.} & & \text{Tons.} & & \text{Tons.} \\ \cdot 003 & : & 3 & :: & 13 & : & x \end{array}$$

$$\therefore \quad x = \frac{39}{\cdot 003} = 13{,}000 \text{ tons per sq. in.},$$

and this is known as Young's modulus.

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[*] "Testing of Materials of Construction," p. 18.

Young's modulus may be defined as the force which, acting in the direction of the length of a bar, when applied to one end of it, the other end being fixed, would double the length of the bar, the cross-section being of the unit area (say 1 square inch). As no metallic substance can thus be doubled in length, the modulus may be defined as 1,000 times the force, which would increase the length by the $\frac{1}{1000}$ part of the whole, or 1,000.000 times the force, which would increase the length by the $\frac{1}{1000000}$ part of the whole.

In wrought iron and mild steel the value of Young's modulus is about 13,000 tons per square inch; in other words, a stress of 1 ton per square inch produces an extension which is $\frac{1}{13000}$ of the original length of the bar.

Young's modulus can be calculated by the following formula:—

$$\frac{p \times \mathrm{L}}{\omega \times l} = \mathrm{E},$$

where p = stress, L = original length of sample,
ω = original sectional area, l = extension measured.

Elongation.—This is the increase in length which a metal bar undergoes when subjected to a gradually applied tensile stress, in the direction of its length, sufficient to cause fracture. It is usually expressed as the percentage increase on the original length of the bar. This elongation of the bar takes place equally throughout its entire length so long as the load is maintained well within the elastic limit, but as soon as this is much exceeded the bar elongates somewhat unequally in different parts, and the ultimate elongation expressed in percentages is simply the sum of these variable local elongations. It is of the greatest importance when referring to elongation to state always the *length of the sample* on which the experiment has been made, as owing to a great local extension always taking place at the point of fracture, unless this is done the results are most misleading. Thus, a good *local* extension on a length of 3 inches would make the ultimate percentage of elongation appear very much higher than if the results were obtained on an 8 or 10-inch sample.

Reduction of Area.—This is the amount of contraction of area which takes place at the point of fracture when a metal bar is broken by a direct pulling force. It is usually expressed in percentages of contraction of area as compared with the original sectional area of the bar. Both the elongation and reduction of area furnish valuable indications of the ductility of the material under examination, and the greater they are for the same class of material—*i.e.*, for material having approximately the same tensile strength and elastic limit—the softer and more ductile the material may as a rule be considered.

Yield Point.—This is a very noticeable point in rolled or hammered iron or steel, which occurs just when the elastic limit has been exceeded, and which apparently marks the breaking down of the original molecular arrangement. At this point, without any increase of stress, the bar suddenly and permanently elongates by a considerable amount, often equal to 100 times its whole previous elongation, and then again recovers somewhat its original rigidity, and a greater load has to be applied before there is any further elongation or the bar can be fractured.

In ordinary commercial testing this point is generally taken as the elastic limit, and is very noticeable by the "drop of the beam" of the testing machine; but this is incorrect, as it is not identical with the elastic limit, although very near it.

In investigating the properties of a material and its suitability for structural work or other engineering purposes, in which it will be subjected to varied stresses, probably nothing is of greater importance than the elastic limit and the yield point, as however great the ultimate breaking load may be, when once this elastic limit is passed we are dealing with a plastic material which, under the action of stress, will continue to go on deforming, and consequently must be an unsafe material to use. In actual practice, however, this determination is often omitted by steel makers, and is frequently not specified by engineers, the ultimate breaking load, elongation, and contraction of area being considered sufficient.

Stress Diagrams.—A stress-strain diagram with vernier readings will probably make clearer what takes place during the testing of an ordinary steel bar. Fig. 210 is from an automatic record diagram taken by the machine at Cooper's Hill. On the horizontal line are set out the percentage extensions or elongations of the bar, and on the vertical line the stress in tons. The extensions on the original diagram before reduction, were shown as 3·025 times the actual extension, but for convenience are divided into percentages of elongation on the original length of the bar. As the stress gradually increases the bar slightly elongates along its entire length, but very slightly, until it registers a load of 13·5 tons. This point marks the elastic limit, and it will be noticed that the elongation up to this point has been almost inappreciable and quite uniform for every equal increment of the load, an extension of about ·0011 of an inch taking place for each increase of 1 ton. At a load of 13·5 tons this regularity vanishes, and between 13·5 and 14 tons there is a very noticeable and sudden increase in the extension of the bar, and at the point D this is equal to ·038 of an inch, or nearly 33 times that produced by any previous increment of 1 ton in the load.

ORDINARY OR COMMERCIAL TESTS MADE ON BAR OF OPEN HEARTH MILD STEEL.—READINGS TAKEN FROM SCALE ON THE TESTING MACHINE.

Original Dimensions.	Dimensions after Testing.	Percentages of Extension, &c.
Length, 10 inches, . . .	12·658	26·58 per cent. extension.
Sectional area, ·6320, . .	·2678	57·62 per cent. contraction of area.

Elastic limit, 13·5 tons, equal to 21·36 tons per square inch; maximum stress, 19·86 tons, equal to 31·42 tons per square inch.

OPEN HEARTH MILD STEEL—RESULTS OBTAINED FROM A SERIES OF VERNIER READINGS.

Loads in Tons.	Vernier Readings.	Vernier Extensions. 3·025 actual.	Total Extension. 3·025 actual.	
1	1·7534	...	...	
2	1·7566	·0032	·0032	
3	1·7599	·0033	·0065	
4	1·7632	·0033	·0098	
5	1·7665	·0033	·0131	Modulus of elasticity.
6	1·7699	·0034	·0165	
7	1·7732	·0033	·0198	$E = \frac{12 \times 10}{\cdot632 \times \cdot0396} \times 3\cdot025 = 14,504$ tons per sq. in
8	1·7765	·0033	·0231	
9	1·7797	·0032	·0263	
10	1·7830	·0033	·0296	
11	1·7863	·0033	·0329	
12	1·7896	·0033	·0362	
13	1·7930	·0034	·0396	Elastic limit.
14	1·9076	·1146	...	Yield point.

N.B.—The vernier readings are 3·025 times the actual extension.

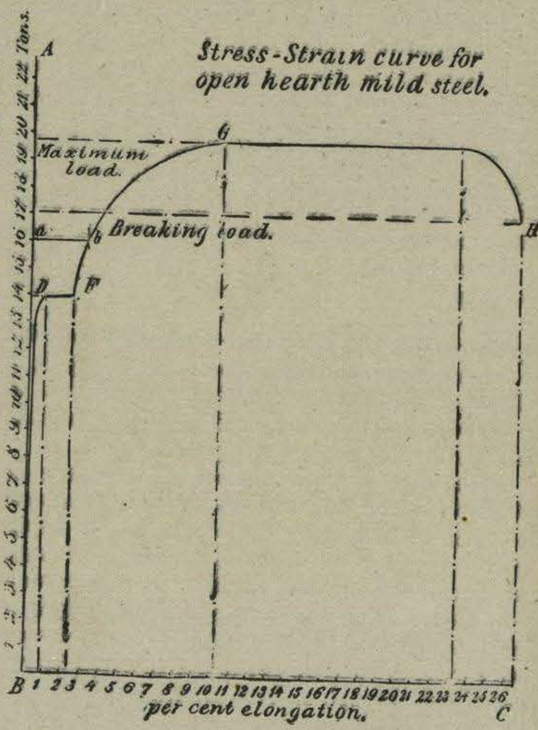

Fig. 210.—Elastic limit, 13·5 tons; D, yield point; F to G, curve of extension between yield point and maximum load; G, maximum load, 19·86 tons; H, breaking load, 17 tons. By dropping perpendiculars from any point in the curve, as at D, F, G, or H, to cut the base line, we get the percentage elongation for any particular load. Thus, at D it is rather under 1 per cent., at F just under 2·5 per cent., at G 10·25 per cent., and at H 26·65 per cent. Similarly, by drawing lines from any point in the curve parallel to the base line to cut the perpendicular load line, we can get the load on the specimen for any particular point in the curve.

At this point suddenly, without any increase in the load, there is a further most marked increase in the elongation from D to F, equal to 60 or 70 times the uniform elongation which has previously taken place; this marks the yield point. At the point F this elongation suddenly stops until a further load is applied, when the specimen gradually elongates as the stress increases up to the point G, which marks the maximum load the sample will bear. From this point the specimen still goes on elongating notwithstanding the decreasing load, and finally breaks at H. This diagram shows that the maximum tensile stress and the actual breaking load are very different things, the latter being considerably less (viz., 17 tons against 19·86 tons) owing to the fracture taking place on a much reduced sectional area due to the "necking" of the specimen at the point of local contraction. From G to H gives the history of the specimen from the time the maximum load is applied until local contraction takes place and it is drawn out and finally ruptured. By plotting out the actual loads and extensions as shown, the amount of extension for any given load can be obtained. Thus, suppose we want the elongation, say, at 16 tons, we draw a horizontal line at *a* to intersect the curve at *b*, when the extension will be given by the length of *a b*. By the same means we can find the extension for any given load. Although the above curve was taken with a recorder, curves can thus be plotted, for any given specimen, by taking a number of readings and by placing the loads along the vertical and some multiple of the actual elongation along the horizontal, and joining up the points obtained. The elongation can be expressed in actual or percentage elongations.

Testing Machines.

The simplest mode of testing materials is to suspend a dead load from the specimen, but, except for very small sections, it is impossible to handle the large weights necessary. To overcome this difficulty a smaller weight with a lever interposed can be employed, and the earliest forms of testing machines were constructed in this way. A difficulty arises, however, as the lever becomes inclined when the bar stretches, and it is then necessary to arrange to take up the elongation of the sample by a screw or hydraulic press and ram, or some similar device, to keep the lever horizontal, and some arrangement of this kind is now always adopted.

Machines may be either horizontal or vertical, and each has its own advantages according to the special work required. For ordinary work the vertical type is probably the more useful. The modern lever machine may be regarded as a weighing machine, in which the ram to which the specimen is fixed, and which produces the pull, represents the body to be weighed on the platform, and tends to pull the lever carrying the weights up against the top stop until these are sufficient to balance the pull, which it then measures and registers.

One mode of applying the weight is to use a scale pan and place separate weights in it, and this is in actual use in some machines; but the more usual plan, instead of varying the weights, is to keep the weight constant and vary the leverage by means of a jockey or travelling weight, which rolls upon the lever beam, and can thus be readily moved to or from the fulcrum of the lever. Another form of machine which is in use in France, is the Maillard machine, in which the lever-weighing apparatus is entirely dispensed with, the pull on the specimen being exerted by a hydraulic ram, and transmitted through a bent crosshead holding the specimen, to another chamber containing an incompressible fluid, the pressure on which is registered by an ordinary pressure gauge, or by a column of Mercury.

In England the Wicksteed machine, and for a cheaper form the Adamson, may be taken as fairly representative types of the single and multiple lever machines in use in modern steel works, and therefore a sketch and short description of these two types are given to enable the student to grasp the essential details of these machines which he may have to use.

Fig. 211 is a diagram prepared by Mr. Hopps, superintendent of the workshops at Cooper's Hill for illustrating the *principle* of the Wicksteed machine. U and S are two crossheads connected by strong screws, T T, to the hydraulic ram. The test piece is held at one end by grips in the top crosshead, U, the other end being gripped by the end of the shackle supported on a knife-edge on the main lever. Water, from the pump or accumulator, is forced into the cylinder through the pipe shown, and the ram in the cylinder tends to move down in the direction indicated by the arrow, and this downward pull is then counterbalanced by advancing a movable weight along the main lever which exerts a pulling force on the specimen in an upward direction. The main lever or beam is graduated in tons and tenths of tons, and at any particular moment therefore the pull on the sample under stress can be obtained. As the stress is gradually increased the balance weight on the lever is advanced to keep the latter floating in a horizontal position until the elastic limit, maximum stress, or breaking load, as the case may be, is determined. This is the principle of all single lever machines.

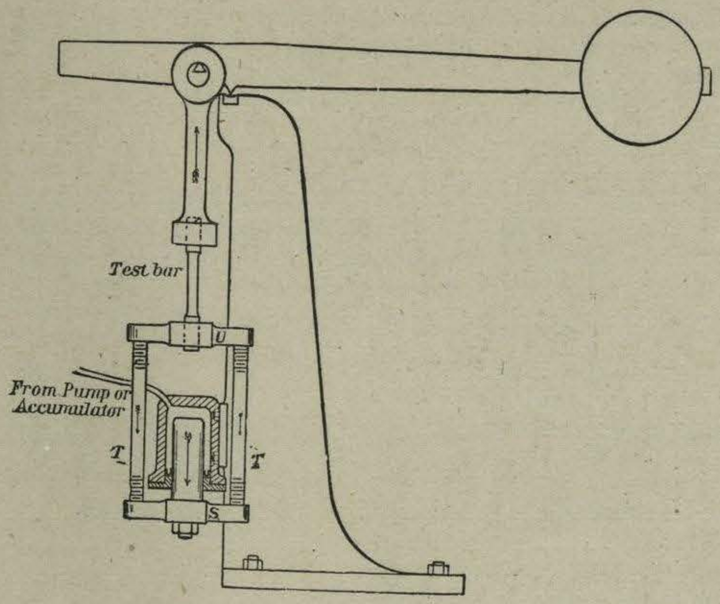

Fig. 211.

Wicksteed Testing Machine.—This testing machine (fig. 212) consists essentially of a beam resting, by means of a knife-edge, on a standard of cast-iron. In connection with the beam is a screwed bar, O, running the whole length of the beam, and by rotating this bar motion is imparted to a weight of exactly 30 cwts., which moves by means of four rollers along the beam. This beam is about 21 feet in length, and is supported by a knife-edge of hardened steel.

The bar to be tested is attached to the shackles of cast steel, which latter rest on a similar knife-edge to the one for the beam. Thus, by moving the weight of 30 cwts. towards the longer end of the beam, any required weight or stress can be placed on the specimen up to 100 tons.

In fig. 212 is shown a general view of the latest form of Wicksteed testing machine, built a few years ago for the Bradford Technical College by

Messrs. Buckton, and described by Mr. G. F. Charnock, head of the engineering department. Both the drawing and description are taken from *Engineering* with some details supplied by Messrs. Buckton.

The Wicksteed machine is often worked from a screw pump or compressor, but there are several distinct advantages secured by the employment of an accumulator. This is shown at G, and the ram, H, having a diameter of 4½ inches, is loaded to a pressure of 3,000 lbs. per square inch, from a crosshead, I, fixed at its upper extremity from which is suspended by means of four rods a load of about 24 tons of cast-iron slabs, I^1, 18 inches by 9 inches by 2¾ inches, bonded together in courses round a square opening left in the centre for the cylinder, K. The whole is neatly cased in with a wooden frame filled in with boarding. The foundation for the accumulator consists of a stone 6 feet by 6 feet by 2 feet, weighing about 5¾ tons. The accumulator is supplied by an automatic belt-driven pump, L, supported upon a frame which also forms the tank from which the supply is drawn. The pump is arranged on the well-known differential principle, to give a continuous delivery during both strokes, although single-acting. In this case, however, there are two plungers, each working in its own barrel, one above and the other below the crank, from which motion is imparted by means of a slotted cross-slide. The lower plunger has twice the sectional area of the upper one, and there is only one suction and one delivery valve, both in connection with the bottom barrel. Therefore during the down-stroke, of the whole cylinder volume discharged through the delivery valve, half returns to fill the upper barrel by the pipe shown, and the other half goes direct to the accumulator, whereas during the up-stroke a whole volume is drawn through the suction valve, and the half volume in the upper barrel is delivered to the accumulator. The belt is thrown on to the loose pulley, M, by means of the tappet-rod, N, and lever, when the accumulator reaches the upper limit of its stroke. The whole arrangement has been found to work in a highly satisfactory manner, and gives no trouble whatever. The pressure and exhaust pipes, O, P, from the accumulator to the machine and return, are laid in a brick-lined trench formed in the floor, and covered in with 3-inch boards, so that the joints are easy of inspection.

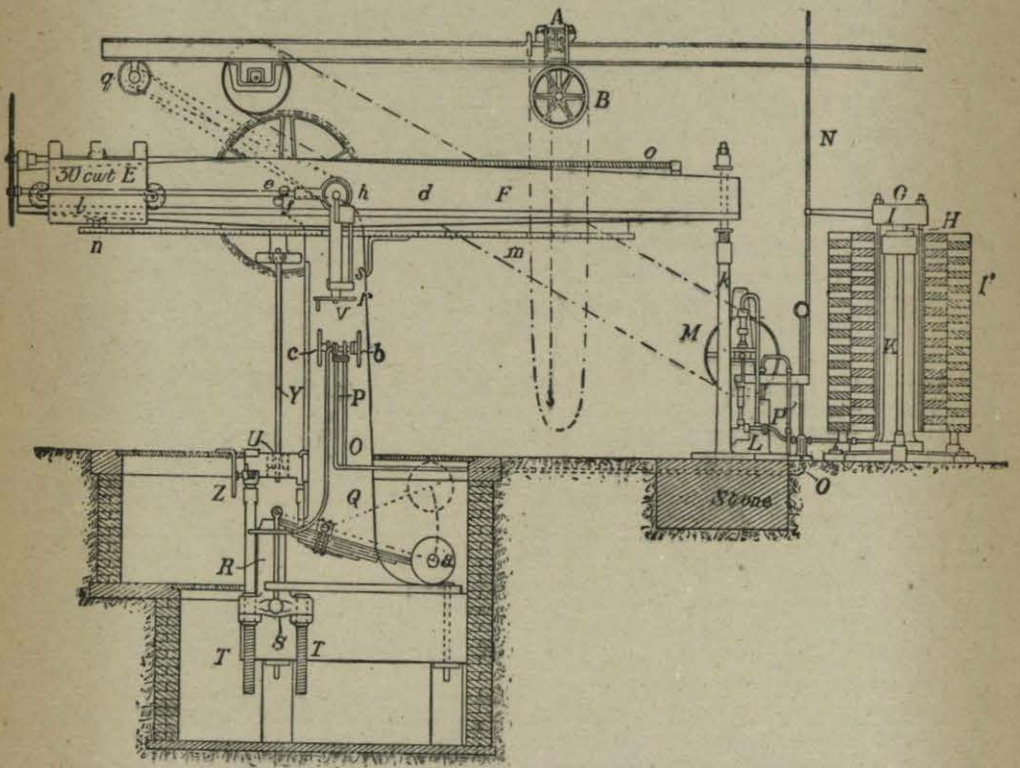

Fig. 212.—Wicksteed Testing Machine, Bradford College—A, Small overhead traveller; B, 2 ton pulley blocks; E, travelling poise-weight; F, main lever; G, accumulator; H, accumulator ram; I, crosshead to ram carrying weights; K, cylinder of accumulator; L, pump for supplying accumulator; O, pressure pipe from accumulator; P, exhaust pipe to accumulator; Q, main cast-iron standard; R, hydraulic straining cylinder; S and U, crossheads attached to hydraulic ram; T T, strong screws connecting crossheads, S and U; Z, worm gearing for operating screws, T; *a*, balance-weight; Y, specimen; *b*, pressure valve; *c*, exhaust valve; *e*, knife-edge fulcrum for F; *f*, knife-edge for shackles; *m*, graduated scale; *n*, vernier; *o*, screw for moving poise-weight; *q*, counter shaft; *r*, hand-wheel for slow movement of E; *s*, reversing handle.

The machine itself consists of the main standard, Q, a heavy box casting, firmly secured to a massive stone foundation contained in a brick-lined pit, covered in with a removable flooring of 3-inch hard wood boards. The latter can easily be lifted for testing long specimens, when the lower platform, accessible by steps, becomes the working floor. The hydraulic straining cylinder, R, of 10 inches diameter and 12 inches stroke, is securely fixed in an inverted position to the base of the standard. The ram thus acts downwards, its crosshead, S, being connected by the two strong side screws, T, to the upper crosshead, U, which is guided by **V**-slides on the face of the main standard, and in which is formed (1) the gripping-box for the lower end of a tension specimen, Y, as shown in fig. 212; (2) a face for the upper end of a compression specimen, W, as seen in figs. 213 and 214; or (3) a presser foot to apply the load at the centre of a beam specimen. The screws, T, are operated by worm gearing, worked by the handle, Z, and enable the adjustment to any length of either tension or compression specimen up to 6 feet to be effected. The balance-weight, *a*, carried upon the end of spring levers, causes the return stroke of the ram to be made after the conclusion of a test. The valve, *b*, admitting pressure from the accumulator, and the exhaust valve, *c*, for return to tank, are of the screw pattern worked by hand-wheels instead of levers, as usual, and are easily adjustable to suit any speed of testing desired.

The main lever or steelyard, F, is double-ended, one of the distinguishing features of this type of machine, and in the present instance is of cast iron, probably possessing greater rigidity than if built up of wrought-iron plates. It turns upon a knife-edged main fulcrum, *e*, on the top of the main standard, and from a second knife-edge, *f*, hangs the upper shackle, *g*, which carries the gripping-box for the upper end of a tension specimen (see fig. 212), or from it may be suspended by the four strong rods, *h*, the lower table, *i*, having a face for the bottom end of a compression specimen as in figs. 213 and 214. The knife-edges are of hardened steel, 20 inches long, or 1 inch for every 5 tons of load, and the fulcrum distance between them is 3 inches. The motion of the end of the lever is limited by stops, fitted with strong steel springs, on the post, *k*. The travelling poise-weight, E, of 30 cwts., is of rectangular form, overhanging the sides of the main lever so that its centre of gravity may be kept on the plane passing through the knife-edges. The graduated scale, *m*, is 200 inches long, reading 2 inches to the ton, and is carried upon brackets depending from the side of the lever, instead of being placed upon the lever itself as in some previous machines. This is a great improvement, vastly increasing the legibility of the scale. The vernier, *n*, which easily reads to $\frac{1}{100}$ ton, is as usual carried by the poise-weight, and its position is adjustable, so that when the lever has been put in balance, it may be set to zero on the scale. A peculiarity should be noticed in connection with the lever of Mr. Wicksteed's machine. If this were balanced by a counterweight in the ordinary manner, the poise would indicate zero when on the fulcrum, and as the long arm would be of the same length as the scale, the leverage ratio would be

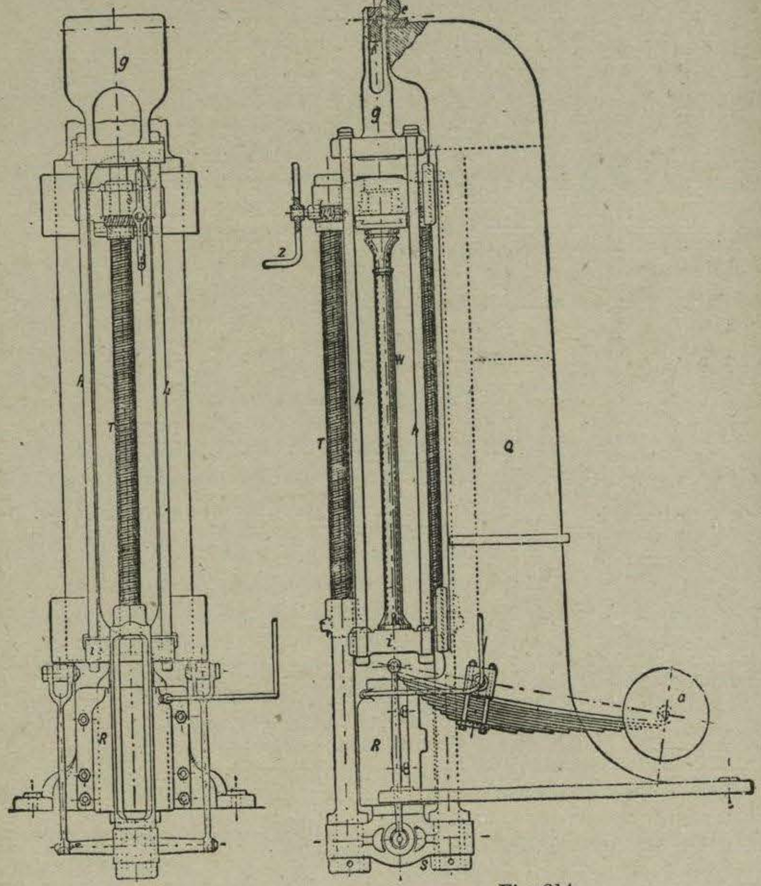

Fig. 213. Fig. 214.

Arrangement for making Compression Tests on long Cast-iron or other Bars or Columns—*g*, Shackle; *h*, rods carrying compression table, *i*; *i*, compression table.

$$\frac{\text{200 inches length of scale}}{\text{3 inches fulcrum distance}} = 66{\cdot}6 \text{ to } 1.$$

The steelyard is, however, double-ended, and the poise must be travelled back over the short arm until the lever is in equilibrium, and at this point the zero of the scale must be taken. Hence the poise when at zero on the negative end of the lever is balancing weight of equal moment on the positive end, and as it travels towards the fulcrum, the effect is to deliver back again to the long arm the weight previously balanced. Therefore the actual weight used for measuring the stress is really double the weight of the poise—viz., 3 tons—or the virtual long arm is half the length of the scale, giving a leverage ratio of only 33·3 to 1. This great weight and low velocity ratio is highly favourable to rapid and accurate testing, because it minimises the unrecorded effects of inertia due to vertical oscillations of the lever, and at the same time gives the advantage of a large scale reading, and a comparatively light travelling poise.

The poise-weight is mounted on four rollers, which run on rails cast on the sides of the lever, and it is moved by a quick-threaded screw, *o*, which is rotated by spur-wheels from a shaft fitted with Hooke's joint to allow of the motion of the lever, in connection with reversing gear, *p*, driven by open and crossed belts from the countershaft, *q*. A hand-wheel, *r*, is also provided for very slow motion or fine adjustment, and this, together with the reversing handle, *s*, and hydraulic valves, *b* and *c*, is placed within easy reach of the operator, who, without moving from his place, has the specimen in full sight, and can easily observe the movement of the lever.

A is a small overhead traveller actuated by hand-chains fitted with a 2-ton pulley block, B, for moving large specimens and for lifting different parts of the machine.

The arrangement for making compression tests, shown in figs. 213 and 214, is capable of dealing with specimens up to 6 feet high and 9 by 9 inches in cross-section, and the convenience of a vertical machine probably ends when lengths greater than this or about the height of a man have to be tested.

Adamson Machine.—This is a multiple lever testing machine, and a skeleton sketch of the system of levers is shown in fig. 215. The first right-hand lever, A′, is made of 10 powers, so that the force on the lever is $\frac{1}{10}$ of that on the specimen, and, in passing to the end of the second 10-power lever, B′, the load becomes $\frac{1}{100}$ of that on the specimen; it then passes forward to C′, which is 12 powers, at the end of which the load is reduced to $\frac{1}{1200}$ of the force on the specimen, passing finally from the third lever to the end of the fourth, D, of 12 powers, where the force is $\frac{1}{14400}$ of that on the sample, and where the scale plate is fixed for receiving the 3-lb. weights.

Referring to fig. 215, the specimen, L, is held in the crossheads, H and K, by wedges which fit into grip-boxes having cylindrical bushes, as shown in separate sketch (fig. 217). The load is put upon the specimen by means of a hydraulic ram, D, working in the cast-steel cylinder, C, actuated by a pair of small ram pumps, E, worked with double crank-shaft, F, driven either by hand or other power, with a friction clutch to stop or start as required. The centres of motion of the pumps are directly opposite each other, so that one pump is constantly forcing whilst the other draws water or other fluid from the cistern, G, under the hydraulic ram cylinder. This gives a steady outward action on the ram, while the force is transmitted to the crosshead or grip-box, H, holding one end of the specimen under test, through two steel side bolts, I, with adjustable screw ends, so as to regulate the distance between the two sets of crosshead grip-boxes, in order to suit the varying lengths of test pieces and to transmit the stress in a direct horizontal line. The opposite end of the test piece, L, is held in similar manner in crosshead, K, attached to the main lever system, and the entire force is passed through the lever pins resting on hardened knife-edges. The registered lever is divided into main divisions, which show an increased stress of 1,000 lbs. on the specimen, and these divisions are subdivided to show an increase or decrease of 20

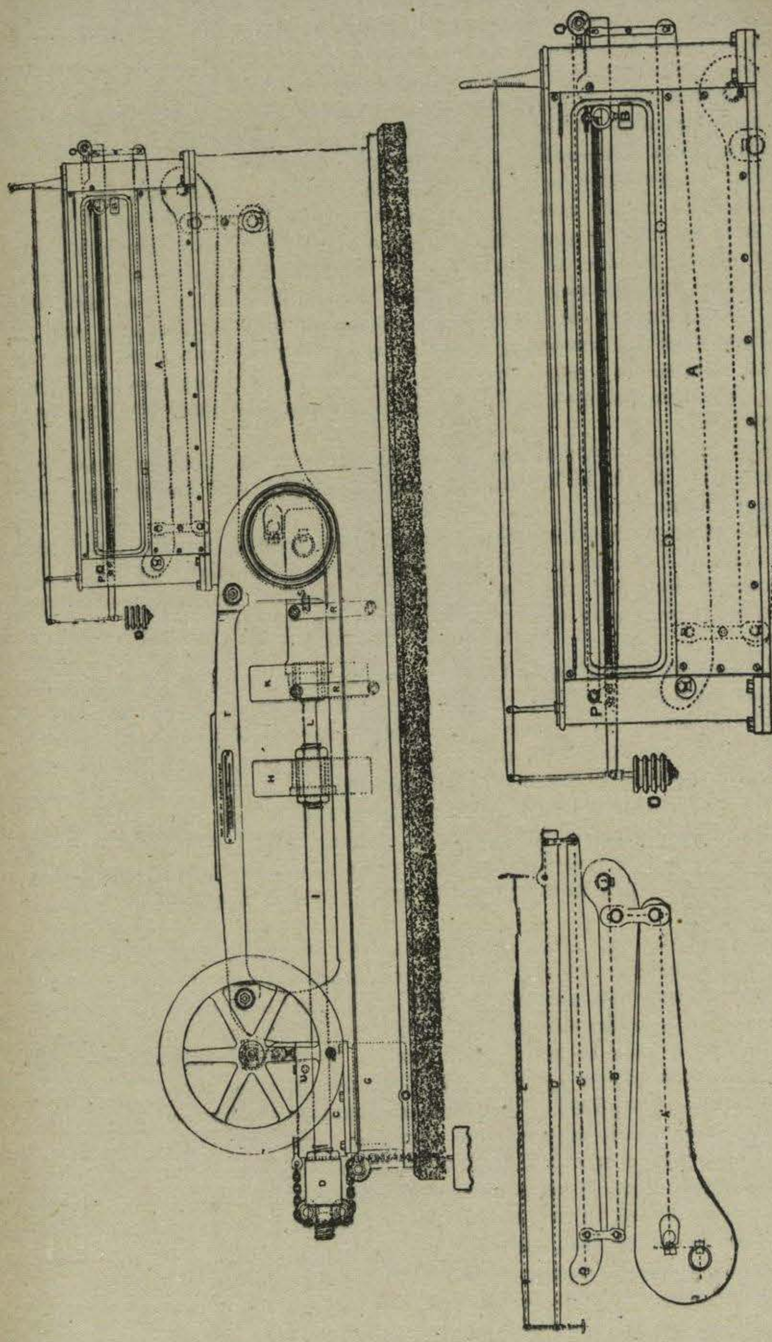

Fig. 215.—Adamson Lever Testing Machine.

lbs., so that great refinement is obtained by the movement of a very light jockey-weight along the beam. The total weights required to register

230,000 lbs. are four 3-lb. weights, used at the end of the 14,400-power lever, and one floating weight of 4 lbs., the aggregate of the weights being only 16 lbs.

The jockey or floating weight, B, is moved along the lever beam by a light cord having a pulley, P, fixed on the outer end of the lever, and another pulley, Q, against the outer end of the lever box. By turning the latter pulley by a hand-wheel, the weight is moved to and fro to maintain the load on the test piece at any given moment of time.

In commencing to test, the jockey-weight is run back to zero and the pump put in motion, and, when the strain comes upon the specimen, the weight is advanced along the beam to keep it floating evenly between the stops and just balance the load on the specimen.

The hydraulic ram, when forced out by the pumps after the rupture of the specimen, is brought back into position by a weight suspended by a chain passing over two pulleys fixed on the head of the ram, one end of the chain being fixed to the upper portion of the cylinder. U is a hand screw for releasing the water from the cylinder, which passes back into the cistern below.

For ordinary work, this machine gives good results, is very rapid, and, if used with care, does not readily get out of order.

It is more especially adapted for tensile testing, but, with some modifications and an additional apparatus, can be used for compression tests and punching.

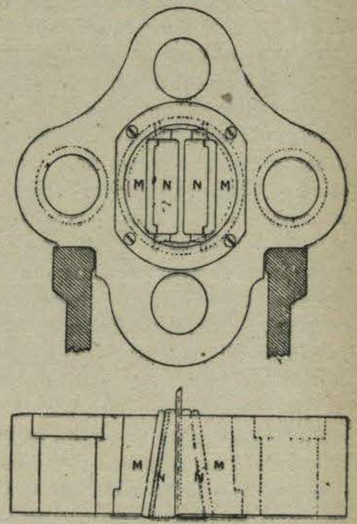

Fig. 216.—Gripping-box Showing Taper Wedges for Holding Specimen.

Calibrating Testing Machines.—In these days, when materials required for structural work are constantly being tested by engineers at machines away from the works as a check upon the works' results, the necessity of tests being reliable from a business point of view, apart from any consideration as to the great importance of obtaining accuracy in the absolute sense, is too obvious to need emphasising. Testing, like other machines, even assuming they are quite accurate at first, are liable to get out of order, which renders their verification an important matter.

The calibration of a testing machine is perhaps one of the most useful lessons a student can have, and, if done carefully, will give him an intelligent grasp of the principle and details of the machine he has to use, which he can hardly gain in any other way.

Professor Unwin * considers the three essential points to test are :—

(1) If the jockey-weight is of the weight indicated.

(2) To determine the leverage of the machine—that is, to see if the fulcrum distance agrees with the unit length taken on the scale.

(3) To determine what error, if any, is introduced by the centres of gravity of the jockey-weight and of the lever not coinciding with a line drawn through their knife edges.

In testing the weight in a type of machine like the Wicksteed, the

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* Cantor Lecture, March 28, 1887, p. 15.

first thing to be done is to travel the jockey-weight back a little behind the fixed knife edge until the lever is exactly balanced, and then adjust the vernier attached to the weight so as to read zero on the scale which extends along the arm of the lever. In the machine shown in the sketch (fig. 212), the weight is 30 cwts. In the Cooper's Hill College machine it is 1 ton, and the fulcrum distance—the short arm of the lever—is 4 inches. We will consider the latter. On the scale extending along the level is one division which coincides exactly with the principal knife-edge, and, if the jockey-weight is run back past this principal knife-edge to the position of - 1 division, it ought to balance a 56-lb. weight hung at a leverage of 40 on the other side of the principal fulcrum, and this is a test very easily applied. This may seem a totally unnecessary precaution, but sometimes after repairs it is by no means superfluous, and Professor Unwin states that, a weight for his first machine having been sent to be standardised, in adjusting the weight the officials forgot to take into their calculation the four little rollers on which the weight runs, and consequently the weight was made wrong, and, had he not tested it himself, might have led to serious errors.

The next calibration necessary is to test whether the fulcrum distance agrees with the unit length on the scale. The most convenient way of doing this is to have a special 1-ton weight made which can be hung in the shackles of the machine. This 1-ton weight in the shackles ought to balance the 1-ton jockey-weight at the first scale distance on the machine, or, what is still more accurate, it ought to balance a 56-lb. weight at a leverage of 40 to 1. This test of the fulcrum distance is one that ought to be applied to every testing machine from time to time.

The third test is of less importance, as the error introduced is likely to be at most only a small one, the whole movement of the lever being through a very small arc, often not more than 1°. If, however, the centre of gravity of the jockey-weight is below the line drawn through the knife-edges, then the pull on the specimen will increase as the lever moves downwards, and, if the centre of gravity of the jockey-weight is above that line, the pull on the specimen will increase as the lever moves upwards. An easy way of testing the machine is to place in the shackles an ordinary suspended weighing machine capable of registering 1 ton. This must first be balanced by the jockey-weight with the lever horizontal, and afterwards with the lever inclined upwards and downwards. It does not matter about the weighing machine being very accurate, as all that is wanted is to find the variation of the pull with the movement of the lever. Professor Unwin found, in testing his machine with a movement of the end of the lever 3 inches upwards and 3 inches downwards, that the error introduced by the movement of the lever in the pull on the specimen was 12 lbs., which, as he remarks, is practically unimportant for most testing, but, as in a badly-adjusted machine this might be much more, it should not be altogether overlooked.

The Test Piece.—The test bar may be of any convenient size, and either round or rectangular in section. For testing, a bar of circular section is distinctly the best, as it can be more accurately gauged after fracture and the contraction of area more exactly determined. The contraction is also more regular with such a section, as the mass of metal is equally distributed on all sides where local contraction commences. In the case of plates and bars, circular test bars are generally impracticable, and it is usual to test a parallel strip of plate as rolled, which may be shouldered down from each end or not.

The following sketches show the forms of test piece in common use. They may have screwed ends, or be held in the shackles by wedge grips:—

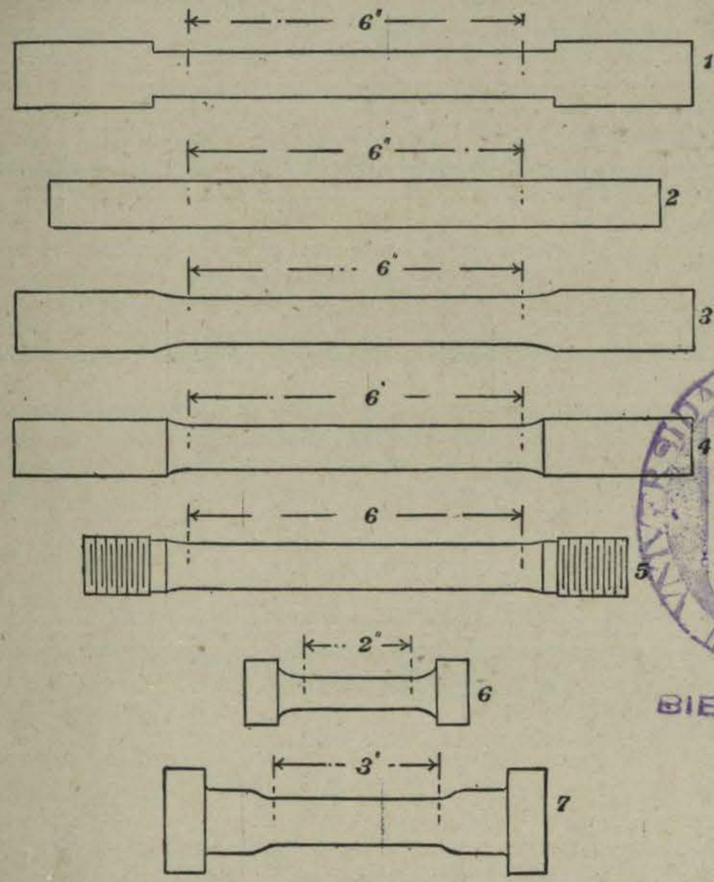

Fig. 217.—Bars for Tensile Tests.—Nos. 1, 2, and 3 are flat bars; Nos. 4, 5, 6, and 7 round. No. 1, showing sharp corners where the section is reduced is a form to be avoided; the shoulders should be shaped as shown in No. 3.

The Shape and Form of Test Piece.—That the form or shape of the test piece has considerable influence on the ultimate tensile strength, and also on the elongation, has long been known, and this was first investigated by Kirkaldy.* The most important point is to avoid any sudden change in the section of the specimen and all sharp angles should be avoided, the change from the larger section to the smaller being gradual, as shown in fig. 217, Nos. 3, 4, 5, 6, and 7.

The following sketches, which are taken from Mr. W. G. Kirkaldy's "System of Testing," very clearly show the influence of shape on ultimate tensile strength. A, which has a parallel portion with gradually-reduced section, may be regarded as the sample which gives the normal or true strength of the material; B, with the square corners, giving the lowest result; and D, with the groove, giving the highest. The results obtained with different shapes will vary considerably with the ductility of the sample, and thus

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* "Experiments on Wrought Iron and Steel," and "Experimental Enquiry into the Mechanical Properties of Fagersta Steel."