with coarser clay added in a frame, and this is solidified in a screw-press. Then comes the filling in of the design, which the maker does by spreading the coloured clay in a creamy or slip state on the indented surface. After a few days' evaporation, the surface is scraped or planed, and the tile passes successively to the drying house and the oven. The colours desired in encaustic tiles are sometimes those given by the clay in ordinary treatment, sometimes they are obtained by staining with manganese, cobalt, &c. The products of this branch of manufacture are much admired.

The fine ornamental bricks of various shape and colour known as *terra cotta* have of late been much used, especially in the facing of public buildings, and with the happiest effects. (A. B. M.)

BRIDAINE, Jacques, a celebrated French preacher and home-missionary, was born in 1701 at Chuslan in the department of Gard. Though a rigid Catholic in principle, he gained the good-will of the Protestants of France by the boldness with which he advocated their cause on many occasions, and the personal kindness which he displayed towards many of their number during the persecutions to which they were exposed under the Regent Orléans and Louis XV. He accomplished no fewer than 250 evangelizing journeys through various parts of France, in the course of which he made himself universally popular, being possessed of a powerful though rugged eloquence. He was the author of a collection of *Cantiques Spirituels*, which has been frequently reprinted, and of five volumes of sermons, printed at Avignon in 1825. In the neighbourhood of this town he died in 1767.

BRIDGENORTH, a parliamentary and municipal borough and market town of England, in the county of Shropshire, on both sides of the Severn, 18 miles S.E. by E. of Shrewsbury. The river, which is here crossed by a handsome stone bridge of six arches, separates the upper from the lower town. The former is built on the acclivities and summit of a rock which rises abruptly from the river to the height of 180 feet, and gives the town a very picturesque appearance. The railway passes under by a long tunnel. On the summit is the tower of the old castle, leaning about 17 degrees from the perpendicular; two parish churches, one of which, St Leonard's, was rebuilt in 1862; and a large public reservoir. There are in the town a mechanics' institute, a public library—founded by the Rev. Mr Stackhouse, an infirmary, a jail, a theatre (1824), a market hall (1855), and a considerable number of schools and charities. It has manufactures of carpets, worsted, and tobacco-pipes, and some trade in agricultural produce. It returns one member to parliament. The population of the parliamentary borough amounted in 1871 to 7317; that of the municipal borough to 5876.

Arms of Bridgenorth.

Bridgenorth, or Brigge, is said to have been founded by Ethelfleda, the daughter of Alfred, and it was fortified with a castle and walls by Robert de Belesme, earl of Shrewsbury. On the earl's rebellion the town was besieged and taken by Henry I. in 1102; and in the reign of Henry II. the castle was dismantled. In 1646 the town, being held by a Royal garrison, sustained a remarkable siege by the Parliamentary forces, who at last obtained possession.

BRIDGEPORT, a seaport town in the county of Fairfield, Connecticut, United States, is situated on an arm of Long Island Sound, 58 miles N.E. of New York, in 41° 10′ N. lat. and 73° 11′ W. long. It has several iron-foundries and manufactures fire-arms, metallic cartridges, sewing-machines, carriages, harness, locks, blinds, &c. The coasting trade and the fisheries are both extensive. The bar at the mouth of the harbour, which is formed by the Pequonnock Creek, has 13 feet at high water. Bridgeport is the centre of an extensive system of railways, and steam-boats ply between it and New York. The township was separated from Stratford in 1821, and the city, formerly called Newfield, was incorporated in 1836. Population in 1870, 19,835.

BRIDGES

§ 1. *Definitions and General Considerations.*—Bridges are structures designed to carry roads across streams, gullies, or roads. A viaduct may be distinguished from a bridge, inasmuch as the object of the former is to carry a road at a considerable elevation above the surrounding country, by means of structures, similar indeed to bridges, but in which the object of the open spans is to save expense rather than to cross some obstacle which could not be passed by a level road or embankment. The aqueduct is a structure similar to the viaduct, but employed to convey or support water. A culvert may be distinguished from a bridge as an opening, the primary object of which is to let water flow past a road or other obstacle, the object being similar to that of a large drain. A large culvert might be called a small bridge, and a bridge having long approaches with many spans might be called a viaduct. The present article will treat only of Bridges.

Every bridge may be divided into two parts, the *substructure* and the *superstructure*. The substructure of a bridge consists of foundations, abutments, and piers. The end supports of the bridge are the abutments, and the intermediate supports are called piers. Piers and abutments rest on foundations in the ground. A bridge of one span has no piers. The superstructure of a bridge consists of the roadway and the beam, arch, or chain used to carry the roadway from support to support.

The dimensions and design of a bridge depend on the nature of the obstacle to be crossed and on the traffic to which the road over the bridge is subject. The engineer is usually bound to design the cheapest structure which will perform the required duties; he has, therefore, in each case to consider whether a small number of large spans or a large number of small spans will be cheaper. Large spans will be desirable where foundations cannot be easily obtained, or where the height of the structure is great. The engineer has also to determine whether, considering the prices of materials, labour, and transport, one or other form of superstructure is to be preferred. The traffic to be accommodated will determine the width of the bridge and the load which the superstructure must bear. In many cases it will also be the duty of the designer to endeavour to combine beauty with utility. Beauty does not require ornament or expense, but demands, what may be more difficult to supply, correct taste in the designer.

In Great Britain law prescribes the following minimum dimensions for the over and under bridges of railways. (An *over bridge* is one in which the road goes over the railway; an *under bridge* one in which the road goes under the railway.) *Over bridges.*—Width: turnpike road, 35 feet; other public carriage road, 25 feet; private road, 12 feet. Span over two lines (narrow gauge), generally about 26 feet; head room, 14 feet 6 inches above outer rail. *Under bridges.*—Spans: turnpike road, 35 feet; other public carriage road, 25 feet; private road, 12 feet. Head-room: turnpike road, 12 feet at springing of arch, and 16 feet throughout a breadth of 12 feet in the middle; for

public road, 12 feet, 15 feet, and 10 feet in the same places; private road, 14 feet for 9 feet in the middle; for exceptions the Acts must be consulted. In designing a bridge to cross a stream care must be taken to insure that the openings are suitable for the maximum floods.

The *load* which the superstructure of a bridge has to carry in additicn to its own mass may be estimated as follows:—

1. For a *public road;* one hundredweight per square foot will represent the weight of a very dense crowd. This is greater than any load which ordinary carts or vans will bring on the bridge, but of late years traction engines and road rollers have been introduced, and a weight of perhaps 10 tons on each wheel on one line across the bridge ought in future designs to be provided for. The bridge must be strong enough to bear this maximum weight applied at any point, and also to bear all possible distributions of the crowd. A bridge might be fit to carry the crowd uniformly distributed over its surface, and yet fail when the crowd covered one-half of its length or width.

2. For a *railway;* the maximum passing load on each line of rails may be taken as the weight of a train composed exclusively of locomotives. The bridge must be fit to bear this load distributed in all possible ways along the line. For spans above 60 feet on the usual 4 feet $8\frac{1}{2}$ inches gauge this load may generally be taken as equivalent to 1 ton for each foot in length of each line of way, or in engineering language, "one ton per foot run." Where a very heavy class of locomotives is in use $1\frac{1}{4}$ tons per foot run must be provided for. For small spans the distribution of the load as a locomotive passes is such that the above allowance is barely sufficient. For very small spans of 8 or 10 feet the maximum passing load is a little more than the weight on the driving axle of the locomotive, or say 14 tons.

§ 2. *Classification.*—Bridges are classed, according to the design of their superstructure, as *girders, arches,* and *suspension bridges.* A beam of wood crossing a stream, a brick arch, and a platform hung to a flexible wire rope are common examples of the three types. The essential distinction between the three types may be said to be, that in all forms of the suspension bridge the supporting structure (*i.e.,* the wire rope in the above example) is *extended* by the stress due to the load; in all forms of the arch the supporting structure (*i.e.,* the ring of bricks in the above example) is *compressed* by the stress due to the load; and in all forms of the beam or girder the material is partly extended and partly compressed by the flexure which it undergoes as it bends under the load,—thus when a beam of wood carrying a load bends, the upper side of the beam is thereby shortened and the fibres compressed, while the lower side of the beam is lengthened and the fibres extended.

Beams or *Girders* may be of various materials,—wrought iron, cast-iron, and wood being chiefly employed.

Arches may be of masonry, or they may be of wrought or cast iron or steel, in which case the compressed sector of a ring is usually a continuous and stiff structure.

Suspension bridges are made of wire ropes or of separate links of wrought iron or steel pinned together so as to form a chain. The metal beam, arch, or suspension bridge may be a continuous structure or an open frame; we shall also find that in some designs the several simple types are combined so as almost to defy classification.

Whatever design be adopted, the strength or efficiency to carry a given load depends on similar considerations. The designer selects that form of superstructure which the principles of statics show to be most desirable; he calculates the maximum stress which the load can produce on each part, and then so distributes his material that the maximum intensity of stress on every part shall be a definite fraction of the ultimate strength of the material. In metal structures, where the above principle can be very perfectly carried out, this fraction varies from one-sixth to one-third, according to the certainty with which the stresses and strength of the materials are known. In stone structures the engineer has greater difficulty in calculating the stresses on each part, and relies more on empirical rules based on long experience.

I. Strength and other Properties of Materials employed in Bridges.

§ 3. *Classes of Stress.*—There are three kinds of stress, due to tension, compression, and shearing. Tension tends to cause failure by the extension or lengthening of the part strained; compression tends to cause failure by the crushing of the part strained; and shearing stress tends to cause failure by the sliding of one part of the piece across the other from which it is shorn off.

§ 4. *Tenacity, or Strength to resist Tension.*—When tension is applied to a rod or link of any material so as to be resisted equally by each element of any imaginary section in a plane normal to the direction of the pull, this section, which is called a *cross section,* is said to be subject to a stress of *uniform intensity.* This intensity p is equal to the quotient of the whole pull P divided by the area S of the cross section, or

$$1. \quad p = \frac{P}{S}.$$

The ultimate strength of a rod subject to uniform stress is proportional to the section S, and the ultimate strength of the material is measured by the maximum intensity of stress which it can bear, or in other words, by the stress which the unit area of cross section can bear; for example, if the unit of force employed be the weight of a ton, and the unit of area the square inch, the strength of materials will be measured in tons per square inch, or by the number of tons which will just tear asunder a rod one inch square, great care being taken that the load is so hung on the rod as to bear equally on all parts of the cross section.

The following table gives in tons or lbs. per square inch the ultimate strength f_t of some of the materials used in bridges:—

Table I.—*Tensile Strength of Materials* $= f_t$.

Name of Material.	Tons per sq. inch.
Wrought Iron Plates	20 to 25
„ „ Bars and Bolts	25 to 30
„ „ Wire	30 to 45
Steel Plates	30 to 40
Steel Rivets	41 to 48
Steel Wire	50 to 100
Cast-iron	6 to 8
Red Pine	5·1 to 6·3
Larch	4 to 5·5
Oak	4·5 to 8·5
Teak	6 to 9
	Lbs. per sq. inch.
Brick (specimens of)	250 to 300
Basalt „	1000
Sandstone „	285
Common Mortar	10 to 50
Hydraulic Mortar	85 to 140
Roman Cement, 12 months old	46
Portland Cement, 7 days old	270
„ „ 12 months old	350 to 470

The ultimate strength P_1 of a bar with the cross section S to resist a stress uniformly distributed over that section is given in terms of f_t by the expression—

$$2. \quad P_1 = S f_t.$$

Table I. gives some idea of the tensile strength of the materials, but for a full comprehension of the subject special treatises, or the article on the Strength of Materials.

must be consulted. No two specimens of any material ever give exactly similar results. The various brands of iron differ much; different specimens of steel differ still more; the strength is greater when the stress is applied along than when it is applied across the fibres. Iron or steel forged or drawn down to a small cross section is stronger than when in large masses; the material in small castings is stronger than in large castings run from the same batch of metal; the skin is stronger than the rest of a casting. The variations to be expected in timber are still greater than those in metals, and the values for stones or bricks must in each case be specially determined by experiment on the special kind to be used. These warnings are applicable to the subsequent tables, which give the strength of materials to resist other kinds of stress.

§ 5. *Strength to resist Crushing.*—The law given for tension applies to the compression of blocks, so that the strength f_c of a material to resist crushing may also be measured in tons per square inch. Thus the ultimate strength P_1 of a block of the cross section S, subject to a uniform stress, is given in terms of f_c the strength of the material per unit of section by the expression—

1. . . . . $P_1 = Sf_c$.

This equation is not applicable to blocks or struts of iron in which the ratio of the shortest side of the cross section to the length is less than about 1 to 5, nor to struts of timber in which this ratio is less than about 1 to 10. When this limit is passed the strut bends before failing (*vide* § 57), and whenever this occurs the essential condition that the stress shall be uniformly distributed no longer obtains. The flexure increases the stress on the inside of the curve assumed by the strut or pillar, and diminishes it on the outside; but the strut will fail as soon as *any part* of the cross section is subject to a crushing stress of greater intensity than f_c.

TABLE II.—*Ultimate Strength to resist Crushing* $= f_c$.

Name of Material.	Tons per sq. inch.
Wrought Iron	15 to 18
Cast-iron	37 to 65
Steel Plates	90
Red Pine	2·4 to 2·76
Larch	2·5
Oak	2·7 to 4·5
Teak	5·4
Bricks—	Lbs. per sq. inch.
Portland Cement, 3 months old.	2460
" " 9 "	3750
Gault Bricks	710 to 930
Best Whites	300
" poor quality	60
Best Reds	490
Best Fire Bricks	930
Best Blue	1260
Stones (specimens)—	
Portland Stone (on bed)	2630
" " (against bed)	2390
Bramley Fall (on bed)	5100
" " (against bed)	2950
Yorkshire Landing (on bed)	5380
" " (against bed)	5850
Granite	5500 to 11,000
Scotch Basalt	8300
Greenstone	17,200
Sandstones (ordinary)	3300 to 4000
Chalk	330 to 500
Béton	420 to 580

§ 6. *Strength to resist Shearing.*—Let a bar AD of any material be firmly supported on C, as shown in fig 1, and let a strong tool B, say of steel, descend upon it in the direction of the arrow, with force sufficient to sever the part D from the part A, so that the surface dividing the two parts is in the plane of the face of C. This tool is said to *shear* the bar, and the resistance which the bar opposes to this stress is called its strength to resist shearing. The tools practically used to shear are not quite square at the edge, and therefore *cut* slightly, but for true shearing the lower face ought to be square, and the tool should come down close

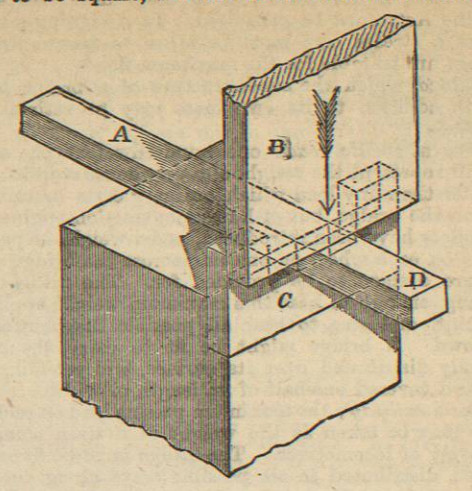

Fig. 1.

to the support, so that the inner face of the tool slides on the outer face of the support.

Fig 2. represents two iron links joined by an iron pin. If the links are pulled asunder the pin will be shorn

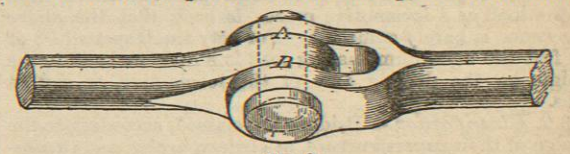

Fig. 2.

at two places, A and B, and the whole section shorn will be twice the cross section of the pin.

Fig 3 shows a joint where the pin would be shorn in four places—A, B, C, and D.

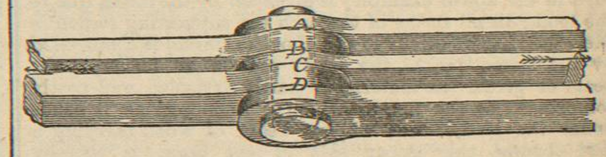

Fig. 3.

The strength of a piece of any material to resist shearing is usually assumed by engineers to be proportional to the cross section to be shorn through, and each material may consequently be said to have a certain shearing strength per square inch; in other words, the ultimate shearing strength of the material is the *intensity* of stress required to shear it asunder. If, therefore, P_1 be the ultimate strength of a bar of cross section S to resist shearing in *n* places, and if f_s be the ultimate strength of the material, we have the expression—

1. . . . . $P_1 = nSf_s$.

The assumption on which this equation is founded is not strictly correct; indeed, the actual shearing described does not correspond with any simple homogeneous stress, and the form of the cross section shorn through must exercise considerable influence on the strength of the piece to resist shearing. In a round pin the maximum intensity of shearing stress is $\frac{4}{3}$ of the mean intensity, and in a rect-

angular pin $\frac{3}{2}$ of the mean intensity. See STRENGTH OF MATERIALS.

The pins which join the links of suspension bridges, and the rivets which join the wrought iron plates of girder bridges, are subject to shearing stress, and the area to be shorn through must be made sufficient to bear the total shearing stress on that part of the structure. Wood is strong to resist tension, and would be much employed for ties but for the difficulty of taking hold of the ends of the tie in such a way that these ends shall not fail by being shorn.

Fig 4 shows the end of a balk of wood with a strap bolted to it. This strap would be torn off by the shearing

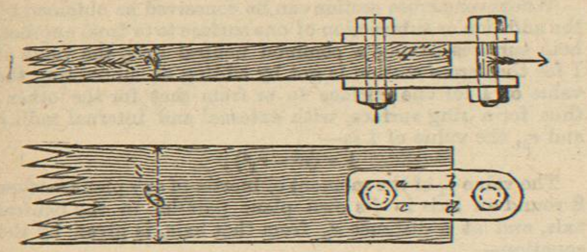

Fig. 4.

of the wood along the dotted lines *ab* and *cd*, with a stress which would be much less than that required to overcome the tenacity of the wood; for if the dimensions of the balk of pine are 6 in. by 2 in. with an inch hole, its tensile strength will be 10 × 5 or 50 tons, while if the bolt be 1 inch diameter, and be placed 4 inches from one end, it could be torn out by shearing 16 inches of the wood; now each inch will only resist a shearing stress of say 600 lb, so that the bolt would be torn out with only 4·3 tons. Thus at least eleven such bolts, each 4 inches from its neighbour, and occupying 3 feet 8 inches in length of this balk, with an iron strap of corresponding length, would be required to render the full strength of the balk as a tie available. A similar difficulty is met with when timber is joined, as in fig. 5, where shearing would take place along the dotted lines AB or CD.

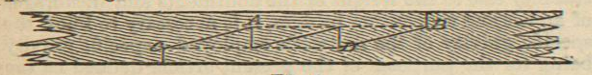

Fig. 5.

TABLE III.—*Ultimate Strength to resist Shearing* $= f_s$

Name of Material.	Tons per sq. inch.
Cast-iron	14·5
Wrought Iron	22
Steel Rivets	30 to 36
Red Pine	·22 to ·35
Larch	·43 to ·75
Oak (British)	1

The strengths given here for wood are those obtained by testing the resistance to shearing along the grain.

The strength of wrought iron to resist shearing may be taken as practically equal to its strength to resist tension—an assumption which facilitates the design of rivetted and other joints.

The strength of steel to resist shearing is less than its strength to resist tearing in the ratio of three to four approximately. Rivets employed to joint steel plates require, therefore, to be larger or more numerous than those employed for iron plates of equal dimensions.

§ 7. *Elasticity.*—When a piece of any material is under tension or compression, it is lengthened or shortened by the stress, and the amount of extension or compression for the same length and stress varies with different materials. Approximately correct results are obtained by assuming that the extension or compression of a given piece of the material of uniform cross section, under a uniformly distributed stress constant throughout its length, is proportional to the length of the piece and to the intensity of the stress.

Let p be the intensity of the stress in tons per square inch, let l be the length of a specimen of a given material in any unit, and let e be the extension or compression observed in the same unit. Then the expression $\frac{pl}{e}$ is, on the above assumption, a constant quantity, and this ratio is experimentally found for many materials to be sensibly constant for stresses which do not approach the ultimate strength. This constant ratio E has received the name of modulus of elasticity, and is generally expressed in tons per square inch, this being the unit in which p is measured. Thomson and Tait (*Elements of Nat. Phil.*) call E the "measure of longitudinal rigidity," a better name than the modulus of elasticity. The actual extension or compression e of any piece of a structure is given by the expression—

1. . . . . $e = \frac{pl}{E}$,

where p is in tons per square inch; e will be given in terms of the unit in which l is expressed.

TABLE IV.—*Modulus of Elasticity* = E.

Name of Material	Tons per sq. inch.	Name of Material.	Tons per sq. inch.
Wrought Iron	10,000 to 13,000	Slate	5800 to 7100
Iron Wire	11,500	Red Pine	650 to 850
Wire Ropes	6700	Larch	400 to 600
Steel Bars	13,000 to 19,000	Oak	535 to 780
Cast-iron	5250 to 10,000	Teak	1070

The modulus of elasticity is very generally assumed as equal for extension and compression, which is nearly true for wrought iron and steel under any stress to which these materials can be safely subjected. The principle of continuity shows that there can be no difference in the value of E for positive and negative stresses so long as these are small. The law according to which E varies as p changes is not accurately known for any material. When the stress is small the value of E appears to be more nearly constant in wrought iron than in cast-iron, but the change in the value of E corresponding to a change from a small stress to the ultimate stress is greater in wrought iron than in cast-iron. The values in the table cannot be depended upon to give very exact results, as the elasticity of different specimens of the same material varies considerably; the theory is wholly inapplicable when the breaking strain is approached; the engineer, however, seldom requires to calculate the extensions or compressions when the stress is even so great as one-third of the ultimate strength. For the same reason the engineer need seldom take account of the permanent set caused by stresses exceeding those within which the material may be considered perfectly elastic. B. D. Stoney, in his work on the theory of strains on girders, gives an excellent summary of what is known experimentally concerning *set* and the modulus of elasticity.

§ 8. *Strength to resist Tension or Crushing when the Stress is not Axial.*—When the resultant of a stress passes through the centre of surface of the cross section of the piece of a structure, and is normal to the cross section, the stress is called *axial*, and it is usually assumed that this stress will be borne uniformly by all the elements into which the surface of the cross section may be conceived as divided. This is not necessarily true, but it is approximately true for the forms usually employed by engineers. When the stress is not axial it cannot be considered, even approximately, as uniformly distributed; the greatest intensity of stress will occur towards that edge of the cross section which is nearest to the point where the resultant meets the plane of the cross section. The following considerations allow the maximum intensity of stress to be approximately calculated in most of the cases which are practically met with. 1. Let the cross section (fig. 6) have an axis of symmetry XX_1, and let YY_1 be an axis passing through the centre of gravity of the surface at right angles to XX_1; the axis YY_1 will be called the *neutral axis.* 2. Let the resultant stress pass through some point A in the axis XX_1, at a distance x_0 from the axis YY_1. 3. Let the material be such that its modulus of elasticity is constant under all the intensities of stress which result from the given total stress; then calling the whole force P, the area of the cross section S, the mean intensity of stress p_0, the maximum intensity of stress p_1, the maximum distance of any point of the cross section from the axis x_1, and representing by I the moment of inertia (*vide* § 9) of the surface of the cross section round the axis YY_1, we observe—first, that

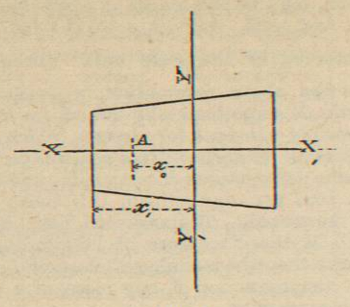

Fig. 6.

$$p_0 = \frac{P}{S};$$

and secondly, that the non-axial force may be assumed to produce a uniformly varying stress, the maximum intensity of which will occur at the distance x_1 from the neutral axis on the same side as x_0 is taken. This uniformly varying stress is equivalent to a uniformly distributed stress of the intensity p_0 and a couple of the moment aI, where a is the constant rate of increase of the tress. We also know by the principles of mechanics that the force P applied at a distance x_0 from the centre might be replaced by an equal force P at the centre and a couple of the moment Px_0. Hence we have—

$$1. \quad . \quad . \quad . \quad . \quad Px_0 = aI, \text{ or } a = \frac{Px_0}{I}.$$

But the maximum intensity of stress due to the couple will be $x_1 a$, *i.e.*, $\frac{Px_0x_1}{I}$, and the maximum stress p_1 may be considered as consisting of two parts,—first, the mean intensity of stress p_0, and secondly, the maximum stress due to the couple. Hence we have—

$$2. \quad . \quad . \quad . \quad p_1 = p_0 + \frac{Px_0x_1}{I} = p_0\left(1 + \frac{x_0x_1S}{I}\right).$$

This equation shows that the maximum intensity of stress increases very rapidly as x_0 increases, and it must be borne in mind that the ultimate strength of any member of a structure is determined, not by the mean stress, but by the maximum stress on any part, for when the part most strained yields the structure is weakened thereby, and this failure must continue to extend until the whole yields.

§ 9. *Note on the Value of* I, *the Moment of Inertia of the Cross Section.*—Suppose the cross section divided into a very large number of rectangles, so small that the distance x of the centre of each from the neutral axis may be taken as sensibly expressing the distance of every part of the rectangle; then I is the sum of the products of the areas of all the elementary rectangles each multiplied into the square of its distance from the neutral axis; or calling the area of the elementary rectangle $\Delta x \Delta y$,—

$$1. \quad . \quad . \quad . \quad . \quad . \quad I = \Sigma x^2 \Delta x \Delta y.$$

The subjoined table gives the values of I for some simple geometrical forms; the axis in all cases passes through the centre of gravity of the surface.

TABLE V.—*Moment of Inertia* = I.

Surface.	Neutral Axis.	I.
Circle, radius r	Diameter	$\frac{1}{4}\pi r^4$
Square, side d	Parallel to one side	$\frac{1}{12}d^4$
Square, side d	Diagonal	$\frac{1}{12}d^4$
Rectangle with sides d and b	Parallel to b	$\frac{1}{12}bd^3$
Triangle, base b, height d	Parallel to b	$\frac{1}{36}bd^3$

Whenever a cross section can be conceived as obtained by the addition or subtraction of one surface to or from another, both surfaces having a common neutral axis, the value of I for that cross section is got by adding or subtracting the value of I for one surface to or from that for the other; thus for a ring surface, with external and internal radii r and r_1, the value of I is—

$$\tfrac{1}{4}\pi(r^4 - r_1^4).$$

The value I_1 of the moment of inertia of any plane surface S round an axis in its own plane parallel to the neutral axis, and at a distance x_0 from that axis, is given by the equation—

$$2. \quad . \quad . \quad . \quad . \quad . \quad I_1 = I + Sx_0^2,$$

where I is the moment of inertia of the surface round a neutral axis, *i.e.*, round a parallel axis passing through the centre of gravity of the section. We can thus obtain the value of the moment of inertia I of complicated cross sections whenever we can divide these into rectangles, circles, or triangles; for then, calling s_1, s_2, s_3, &c., the surfaces of each elementary part, x_1, x_2, x_3 the distances of the centre of each part from the neutral axis of the whole cross section, and $I_{\prime}$, $I_{\prime\prime}$, $I_{\prime\prime\prime}$ the moments of inertia of each element calculated round its own neutral axis, we have the moment of inertia of the whole round its neutral axis—

$$3. \quad . \quad . \quad . \quad . \quad . \quad I_0 = \Sigma I + \Sigma s x^2.$$

§ 10. *Specific Gravity of Materials.*—In order to calculate the load due to the superstructure of a bridge, and the stability due to the weight of the abutments and anchorages of arches and suspension bridges, it is necessary to know the specific gravity of the materials employed—specific gravity being for the purposes of the present article defined as the weight of the material in lbs. per cubic foot. The following are the most useful numbers:—

TABLE VI.—*Weight per Cubic Foot of Different Materials.*

Name of Material.	Weight of cubic foot in lbs.
Water (pure) at 39°·4. Fahr.	62·425
Basalt	187·3
Brick	100 to 135
Brickwork (ordinary)	112
Chalk	117 to 174
Clay	120
Granite	164 to 172
Limestone and Marble	169 to 175
Masonry	116 to 144
Mortar	86 to 119
Mud	102
Sandstone	130 to 157
Sand (damp)	118
Sand (dry)	88·6
Asphalt	156
Concrete (ordinary)	119
Concrete in cement	137
Earth	77 to 125
Slate	175 to 181
Trap	170
Cast-iron (average)	444
Wrought Iron (average)	480
Red Pine	30 to 44
Larch	31 to 35
Oak (European)	43 to 62