adjustable cut-off plates. The same diagram may also be used in an elementary way for the attainment of the same purpose.

I hope that this new deduction of the theory of the diagram may tend to make the use of this geometrical method more popular among the engine-builders.

BRIDGE-BUILDING CONSIDERED NORMALLY.

BY JOHN W. MURPHY.

Darwin says we are a race that has descended from a long line of magnificent Apes. Whether I agree with Darwin or not will make no difference in the subject I propose to discuss. I know that the first bridge-builders that were of kin to humanity were the monkey race. Travellers who have been through the wilds of Africa, South America and portions of India tell us how the monkey is a bridge-builder. The traveller has frequently described how he has seen a convoy of monkeys making the attempt to cross a stream, and succeeding by a process which he describes in this wise: The leading monkey climbs a tree as close to the shore as he can make choice of, holding by his forearms to the limb of the tree. He gives opportunity to each succeeding monkey to entwine himself with his prehensile tail, until one after the other they have become so attached, head and tail (the height of the tree being equal to the width of the stream); that the lower monkey, starting forward from the ground, by a pendulum movement swings himself to the opposite side of the stream. He then climbs the nearest tree, and when he has gained the height of the first monkey it will be easy to understand that there will be formed a catenary curve of monkeys from tree to tree across the stream. On this curve the youthful monkeys, the comparatively infantile monkeys and the aged monkeys cross over in perfect safety, and no monkey, either youthful, infantile or aged, wets his feet in the water in crossing.

Now let us see how our catenary bridge is removed when its work is done. The first monkey, by a signal from the other side of the stream, lets go his hold of the limb and swings gracefully to the other side. Now, if Darwin be correct and we are descendants of a race of monkeys, then it must be truthfully said that our ancestors have given us the best thoughts and principles of bridge construction.

There is no doubt that the suspension curve, where the material acts by tension, is the most *economic* form, the *safest* form, and the

most artistic form for the support of moving or stationary bodies over space.

The Peruvian, with his grass ropes, throws across the gorges of the Andes a primitive bridge, which is no more nor less than the monkey bridge just described, with this difference, that the monkey uses his own *body* to make the chain, while the *Peruvian* uses long grass from the Pampas. Another difference is that the monkey uses but one rope or cable, while the Peruvian uses two. See how easy it is to do as the Peruvian does. We have only to take the material at our hands, make a chain, connect it from point to point, from shore to shore, put some plank upon the two cables that lie side by side, at at any practicable distance apart, and we can make a bridge that we can walk over, if we descend from the summit of the abutment down to the bottom of the deflection of the catenary curve of our rope.

It is plain that, if our ropes are reliable, we can erect staunchions upon them at practicable distances apart, and that we can manage and truss these staunchions so that we may be enabled to construct a roadway on a horizontal line, notwithstanding that this roadway is dependent upon the catenary curve that bellies below it.

Our ancestors (according to Darwin) have therefore given us a magnificent thought. Charles Ellett and John A. Roebling have copied this principle in their great forms of construction, such as the bridge at Niagara Falls, the largest span for railroad purposes in the world—810 feet from shore to shore; the bridge at Cincinnati, the central span of 1110 feet, with two co-ordinate spans of 500 feet each; also the bridge at Fairmount, 342 feet span, designed by Charles Ellett, the first suspension bridge built in the United States.

If I could cast aside all the prejudices of the engineering fraternity regarding bridges, I would build them on the same principle that the monkey builds his.

I am free to say that Whipple, Linville and Murphy are all wrong in the principles they evolve in the construction of bridges. While

their works show skill and aptitude in the sustenance of bodies moving and stationary over space, I declare that the suspension form is the only *true* form for *any* structure that relies for the conserver of weights that are carried or impinged upon it.

In 1853 I erected a bridge across the Delaware river at Easton, Pa. It was obligatory by my contract that I should execute this work during the spring and summer months. I found that the rafts that came floating down the river made it impossible for me to erect this bridge in the ordinary manner, that is to say, by placing trestles or false works in the stream, upon which the superstructure would ordinarily be erected. I therefore devised the following plan:

I took some wire ropes and suspended them from pier to pier, and placed staunchions upon them, braced them in the manner which will be understood from the drawing, and made a temporary bridge, upon which I erected the main superstructure.

I never will forget the pleasure it afforded me, in the erection of this work, to see the rafts passing freely underneath, and the feeling of security that I had in devising a plan by which I was enabled to erect this bridge without danger to myself, to my men, or to the raftsmen, who were obliged to float upon the high currents of the Delaware, and of course liable to injury to themselves or to my workmen.

Bridge construction, it seems to me, must ultimately come to the natural suspension curve. It is a natural curve. It is as though we were to take a rope or cable and swing it across the space to be spanned. If we examine into the lines of the curve formed by this cable when stretched across such space, we will discover that it hangs in obedience to the law provided by lines resolved into three forms:

First. Resistance to gravity.

Second. The diagonal value due to that resistance over space.

Third. The horizontal component of these two values, which make the elements of stable equilibrium.

To take this principle and construct mechanically a stable and comparatively permanent structure, demands that we should understand most thoroughly the value of three nodal points of the curve.

I have said that there is one positive line, resistance to which must be provided against, and that is the line in the direction of gravity. The other is the diagonal, which is represented by the curve of our cable.

Material in the direction of gravity in a suspension bridge will be represented by the suspenders that hang from the cable, they supporting the roadway. The one representing diagonal and the other vertical forces, it follows that we have but one force to provide for, viz., the horizontal.

Material proportionate to the value of the strains in the direction of the three forces named must be employed.

Strains upon a suspension bridge are widely different from the strains upon rectangular forms of trusses.

A body supported over space by two lines acting by tension, requires no lateral bracing to hold it in equilibrium from side swinging, provided that care is taken that the width of the bridge at the towers is greater than the width at the centre of the roadway.

The suspension bridge at Fairmount is illustrative of this resistance to side motion; it having, if I remember right, some fifteen feet greater width between cables at the top of the towers than at the centre of the bridge.

The suspension bridge at Fairmount has no lateral bracing in it, and relies for its resistance to a side swinging motion, to the splay of the cables at the towers, and the compression or tightening of the curve at the centre of the bridge.

If we use the suspension principle in contradistinction to the direct arch, and all the rectangular systems of truss framing, we have at least *one* advantage, that the lateral bracing, both at top and bottom, may in a great degree be dispensed with.

Fig. 4.

When I have turned my suspension bridge upside down, it requires a new order of material to hold in line this arch.

The rectangular truss, in all its forms, involves material acting by thrust, and any form of construction which shall dispense with material acting by thrust is the best form, for this reason, material acting by tension depends for its value only upon the section.

Material acting by thrust depends for its value not only upon the section but it also depends upon the diameter, if it be a column of any form that may be devised. A No. 10 wire of 10,000 feet long, if sustained in a horizontal line, will maintain a strain, acting by tension, of 1400 pounds; while the same wire, acting by compression, will not sustain a single pound.

In all rectangular forms of bridge construction thrust values exist. The top chord must be kept in line, to resist horizontal strain, in two ways:

First. In and of itself.

Second. By lateral bracing, in order that it maintain itself like a pillar or column.

It follows that when that form of construction that demands the majority of its parts to act by thrust, as is the case of the rectangular bridge, that there are faulty principles in the construction of bridges, *per se*.

In order that material shall resist a thrust strain, it is necessary that three conditions shall be fulfilled:

First. Quantity of material; in other words, cross section.

Second. Diameter; and

Third. That the length of the section shall have some definite relation to the diameter, and the quantity of the material in the cross section thereof.

Now, since parts acting by thrust must have a value equal to the cube of their diameters, directly and inversely as the square of their lengths, it follows that, in all rectangular forms of bridge construction, when that form of construction that demands the majority of its parts shall act by thrust, as is the case of the rectangular bridge—it follows that there are faulty principles in the construction of bridges *per se*.

That form of structure that shall best sustain, support and maintain bodies moving or stationary over space, should be such an one as will have the least amount of material acting by thrust.

If we examine any of the suspension forms, we will find that the primary condition is the hitching fast of a cable into the ground, the anchorage of which serves the part of our horizontal strains.

By making fast our cable into the solid masonry and into the earth itself, we do away in the suspension bridge with all horizontal values except those that are due to vibration.

The objection heretofore existing against suspension forms has been that under variable loads they undulate.

It has been found that where long spans have been constructed, from the great weight of the superstructure, bodies of lighter weight than the superstructure, have produced no undulations destructive or injurious to the superstructure.

Fig. 5.

A bridge can be constructed on the suspension principle that shall fulfil all the conditions of stability, freedom from vibrations, and absolute integrity as to strength.

It is not necessary, in the practical construction of a bridge based upon a suspension principle, to consider the suspension curve that of the catenary; indeed, it is better to consider the curve as consisting of a series of straight lines from nodal point to nodal point, in fact, a funicular polygon, of as many sides as there are points to be supported.

Fig. 6.

Suppose, for the sake of illustration, that we begin with a bridge that shall have but one weight suspended over space; the

Fig. 7.

weight, W , to be suspended by two chord lines from A to B . Suppose, again, that we have the same chord line supporting two weights, W and W' , dividing the space into what we would call three

Fig. 8.

panels. We might go forward practically and divide the space between our abutments, as will be seen, into a large number of panels. If we do, the greater the number of panels the greater will be the number of nodal points, and the greater the number of *nodal points* the more

closely will our suspension line approximate to the curve of the true catenary.

In the determination of what is requisite for the support of moving loads, it must be understood that if these loads are to be sustained upon a flexible cable or chain, or suspended from a flexible cable or chain, material must be used which shall act in the direction of tension.

The motive of this paper being to show that the suspension bridge, in any form that it can be constructed, demands *less* material in the lines of thrust strains than any other form, it will be our business to examine how *much* of the suspension bridge acts by thrust.

It will be plainly seen that the main supporting part of a suspension bridge is the cable or chain acting by tension, and that all parts that are to be supplied to resist undulations must act by thrust.

Fig. 9.

Suppose, in the above diagram (Fig. 3), that weights are supported on three nodal points, and that one of these weights is greater than either of the other two; it will be clear that our suspension cable will deflect in the direction of the greater weight and rise in the direction of the lesser weight. It is plain that the nodal points must be placed in equilibrium by material in the direction of a line forming the side of a triangle, which shall satisfy the conditions of equilibrium.

Now, suppose *this* case: a bridge divided into *three* panels (Fig. 3), weights hung upon a chord essentially at *two* nodal points. It is easy to see how we can fasten a chord line from a nodal point on the right to the abutment, and the nodal point to the *left* to the abutment, and thus secure an absolute stability and equilibrium of the nodal points at which places the weights act.

Fig. 10.

If we increase the number of panels, and consequently the number of nodal points, we will not change the principle that I have already demonstrated.

The suspension curve is the natural form for the construction of *any* bridge. It is that form, when placed mechanically exact, gives to us the very *purity* of theoretic bridge-building. It eliminates horizontal values if the cables be hitched on shore. The principle eliminates, furthermore, all lateral bracing.

Out of the three forces that we are to provide material against—the vertical, the horizontal and the diagonal—the suspension principle eliminates most easily the horizontal value, by means of the anchorage at each shore end of the work. The vertical value represented by the little threads that hang the roadway to the cable.

In truth, the suspension principle leaves us the necessity for only the diagonal value for the sustainment of bodies over space, and that is the cable itself.

In a future paper I propose to discuss the mathematics of the forms which I have described.

SOMETHING NEW CONCERNING THE PHYSICAL PROPERTIES OF STEAM.

By JOHN LOWE, First Assistant Engineer U. S. N.

The volume, temperature, pressure, etc., of steam mutually depend the one upon the other, and vary simultaneously with each other. For example: the volume of one temperature and pressure cannot have the temperature and pressure of another volume; but these relations are strictly defined and are unchangeable.

These relations are well known, and may be found tabulated in Isherwood's works with critical exactness.

They are also expressed in the formula $\frac{V_p}{V'p'} = \frac{1+(t-39).0025}{1+(t'-39).0025}$ equation (1). In which V= volume of steam, (t) its temperature, (p) its pressure.