The Examination & Repair of Simple Highway Bridges

WITH PRINCIPLES RELATING TO THEIR DESIGN

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Adopted by Direction of the Commandant for Use in the Army Service Schools at Fort Leavenworth

1909

ERRATA

Page 9, 12th line, read "strut" for "struct."

Page 13, line 6, read "the" for "tne"; 2d Par. line 2 read "trusses" for "tresses."

Page 16, line 7 from bottom read "components" for "compononents."

Page 18, 2d line read "$\frac{W}{\cos A}$" for "cosA."

Page 21, line 7 from bottom read "compression" for "tension." Omit the words "as for cable."

Page 28, line 20 omit "be."

Page 33, line 11 from bottom read "25" for "36."

Page 37, line 11 read "spans" for "spars."

INTRODUCTION

The purpose of this pamphlet is not to teach bridge building, but to cover a subject of much greater importance to the line officer. Bridges of all types have in the past and will in the future be built by line officers. Such work is, however, rarely the duty of the line officer, while the subject here treated, ' 'The Examination and Repair of Simple Bridges", is apt to be of importance to any line officer in any day's marching in time of war or peace.

It is true that repair may in extreme eases amount to replacement, but such replacement will generally be of the simplest types of bridges. When there has been a systematic destruction of all bridges, a rapid restoration of communications will require that the bridge work be done by specially trained men, and the engineer troops will naturally assume charge of the work. In the march of large armies, bridges will be examined and repaired, when repair is necessary, by the engineers; but in the march of detachments, even of considerable size, this work will most frequently fall to the line.

Bridges may be too weak for military loads, due (1) to original lack of strength, wear and tear, lack of proper attention; or (2), because of damage deliberately done by a retreating enemy. As mentioned above, the latter cause may result in a condition of affairs which will bring all marching to a standstill and be best remedied by calling in the specially trained forces.

, The first class of damage or weakness is one which is ever present on country roads, and the most trouble will be found with the least important bridges and those of the simplest type, for it seems to be the rule to make these bridges just about strong enough to carry the average load when they are first built and to consider the only urgent necessity for repair to be indicated by the falling down of the bridge. This is not a good way to tell when a bridge needs repair from a civilian standpoint, and its bad features are tremendously magnified from a military point of view. A bridge known to be too weak may often be made efficient by fifteen minutes' repair, while an entire rebuilding is necessary after it has broken down under a load too heavy for it. The officer in charge of a baggage train or a battery must then know how to rapidly- determine whether the bridges will carry his loads, and, if not, how to strengthen them to efficiency with the least loss of time.

The second class of repair is made necessary by hasty demolition. such as can be made by a closely pursued rear guard. Such damage rarely amounts to total destruction. It is very easy in problems to state that a bridge was blown up, but it is only necessary to witness attempts at demolition made by unskilled men, to understand that the total destruction of a bridge is not an easy matter. Even when the demolition detachment knows its duty well, time and material for effective work are frequently wanting. Wooden bridges of the trestle or pile type are most certainly destroyed by fire, but this takes time. Kerosene or other inflammable substance is of assistance but would very rarely be available. A great deal of explosive may be used, unless it can be carefully placed, without doing more than local damage. The demolitions to be effective must be prepared carefully before the rear guard comes up and neither time nor materials are apt to be available unless the retreat has been deliberately planned.

Under the usual conditions of retreat, the damage even to the more important bridges, is apt to be partial and local and an officer skilled in determining weakness in bridges and knowing how to counteract it can greatly expedite the march of his column.

Abutments and piers are rarely destroyed. Of ten much of the material is in good shape, trestles unharmed, some piles standing, etc., Piles may be cut with explosives and the broken ends abut on each other. The compression members of trusses may act similarly. Some of both the tension and compression members of trusses may be broken and yet the bridge may not fall by its own weight. In such cases, an officer with a knowledge of the stresses in the different members and with ingenuity in handling timbers, jacks and tackle, will be able to save the bridge for the use of his column. A simple treatment, free from mathematics, is also given in this pamphlet on the subject of stresses in beams and on simple bridges, to familiarize officers of the line with the most important principles of bridge construction. A thorough knowledge of these principles is necessary for an intelligent examination and repair of existing bridges and will be of much assistance in indicating to the officer of a demolition detachment, the best points for placing. explosives for destroying or disabling a bridge.

The author desires to acknowledge assistance received from Captain Edwin T. Cole, 6th Infantry, Senior Instructor, Department of Engineering, for many suggestions as to the matter herein.

Computations Relating to the Design of Simple Military Bridges

The bridges here considered are the pile, trestle, spar and floating bridges. The first problem encountered is the calculation of the dimensions of the different parts of the bridge to meet the conditions imposed in a particular case, and involves the determination of the strength of a beam resting on two points of support and subjected to a transverse load.

The Beam

Let such a beam, as A-B, figure 1, be assumed and let it be subjected to a load W concentrated at the center. It is evident that the beam, under the influence of the load, will bend down to some such position as shown in broken lines in the figure. If, before applying the load, two notches were cut in the beam as shown in figure 1, and a load were then applied, the upper notch would close up and the lower one open out as shown in the figure. This indicates that the effect of the load is to compress the fibres of the upper half of the beam and to extend those of the lower half. It is also a matter of common observation that a beam bent in this manner will give way, if at all, by the tearing apart of the fibres on the convex edge of the beam and the crushing of the fibres on the concave edge of the beam. By experiment the law governing the resistance of beams, under the influence 0f loads such as described above, has been found to be expressed approximately by' the formula $W = \frac{1}{3} \times \frac{bd^2}{l} \times C$, in which the quantities are as follows :

W is the safe load applied to the beam at the center, including the weight of the beam.

3 is a factor of safety suitable for temporary bridges.

b is the breadth of the beam in inches.

d is the depth of the beam in inches.

1 is the length of the beam in feet.

C is a constant for a given material. It is the dead (or quiescent) load concentrated at the center (including the weight of the beam) which will just break a beam one inch square by one foot long between supports.

It was noted above that W includes the weight of the beam itself; therefore to get the clear load that may be applied to the beam, ½ the weight of the beam must be subtracted from the value of W found. One-half the weight of the beam is subtracted from W because experiment shows that the effect of a load uniformly distributed over the entire beam is ½ that of a concentrated load at the center.

There are in the/formula five quantities, any four of which may be assumed and a fifth determined. But since C is a known quantity for any given material and may be found tabulated in any engineering manual, we have left four unknown quantities and from the conditions of the problem we may assume three and determine the fourth. The usual problem met with is to find b and d, having given W, C and 1. When dimension stuff is available the number of beams is fixed by the designer and the corresponding values of b and d are then determined. In military bridges th'e values of b and d are apt to be fixed by the timber at hand and the number of timbers required to give necessary strength is to be determined. If it should happen that we do not know the value of C for the material at hand, it may be found as follows: Take a convenient sized beam, place it on two supports and gradually apply a load at the center until the beam begins to break. A test load usually &ail-able consists of boxes of commissary and quarter-master supplies on which the weight is marked. Having measured b, d, 1, and knowing W, substitute these quantities in the formula and (omitting fraction $\frac{1}{3}$), solve for C. C for the common woods varies from 400 to 800; for steel it is 12,000. Values of C for a few common woods: Oak 600, Spruce 450, Pine 500, Hemlock 400.

If the ‘student will become thoroughly familiar with this formula he will be able to solve most of the problems that arise in the design of a simple bridge, without the knowledge of the complicated subjects of bending moments, curve of mean fibre, etc.

A further examination of the formula shows that the strength of the beams varies inversely as the length. For instance if a balk ten feet long of given breadth and depth will carry 500 pounds, then one of the same breadth and depth and five feet long will ‘carry 1,000 pounds. A simple way to strengthen a transom,. balk or floor plank is to increase the number of its supports, that is, shorten the unsupported length of the piece.

Next considering the cross section, the strength of a beam of given length varies directly as the breadth and as the square of the depth. (Dimensions will be written as follows: breadth in inches by depth in inches by length in feet). The capacity of a beam to support a load, therefore, increases very rapidly as its depth increases, A balk 4 inches × 12 inches × 15 feet is only $\frac{1}{2}$ as strong as one of the same material 8 inches × 12 inches × 15 feet; but, if in-stead of doubling the breadth, we double the depth, using the same amount of material, we have a beam four times as strong as the first one. If the beam of cross section 4 inches × 12 inches is placed on edge it will carry three times as great a load as it would if laid flat on its side. In the former case b = 4, $d^2=144$, $bd^2=576$. In the latter' case $b=12$, $d^2=16$, bd" = 192. The measure of the relative strength of the two beams is bd^2, and therefore the beam on edge is three times as strong as when laid flat.

To further illustrate the principle stated: If we place six 2 inch × 12 inch plank as shown in figure 2, they form a beam practically as strong as the solid beam 12 inches × 12 inches cross section, from which 'they are cut. If, however, we place them as in figure 3, we have a beam $\frac{1}{6}$ as strong as the 12 × 12 beam.

A very narrow beam with respect to its depth may fail, due to lateral strain tending to tip over the beam and it must be braced to' prevent this tendency. A common method of doing this is the familiar bridging used to stiffen the floor joists of a house. The combination shown in figure 3 contains approximately as much material as the solid beam from which the planks are sawed; the difference in strength being due only to the loss of natural cementation of the fibres between the plank on account of sawing. It is possible to very considerably strengthen such a combination by imitating the original condition by the application of adhesive between the adjacent surfaces and bolting the plank firmly together so that the combination will act as a solid beam: This method may be used to advantage in the construction of curved chords of trusses because of the ease with which the desired shape may be secured by the use of thin plank. .

It has been shown that in a simple beam the fibres of the upper half are in compression and those of the lower half in tension, and that the maximum of each stress occurs at the ed.ge of the beam. The compressive stress, therefore, is greatest at the top and decreases uniformly to zero at the center, where the tensile stress begins and increases uniformly to a maximum at the bottom edge. All the fibres are assumed capable of the same resistance, so that when the beam breaks it is because the fibres at the edge have passed the limit of their resisting power, while those nearer the center are not doing all the work of which they are capable. The breaking continues toward the center by the rupture of each fibre successively as it becomes the outer one. If the beam were composed of a set of small rods which could be massed toward the edges where their maximum resistance would be offered to supture. the beam would be capable of doing more work and the breaking would take place under a greater load. The strength of built up beams and beams of special shapes, depends on an arrangement of the fibres according to this principle.

The following are some of the ordinary standard shapes as manufactured: I beams; channels; T's, and box girders as shown in figures 10 to 13.

The amount of metal saved by adopting one of these shapes is well illustrated by the I beam in the following example, figure 10; Assume an I beam with dimentions as shown in the figure and 10 feet in length. The maximum concentrated central load which the beam will support, including its own weight, is 94,080 lbs. (Trautwine, page 523a). A rectangular beam of the same depth, area and span, 'besides its deficient resistance to lateral stress, will sustain a maximum load of only 51,840 lbs.

Economy of the Truss as Opposed to the Rectangular Beam

A simple beam supporting a load resists tensile, compresive and bending stresses. By means of the triangular frames of a truss it is possible to largely eliminate the bending stress from all the members of the structure and to limit the stress in any particular member to a simple tension or compression. This results in a large economy of material in the construction of a bridge of a given span to support a given load. There is also a saving of material due the greater safe load that a timber will support under tension as compared with its safe load under compression. Suppose that we have a piece of pine timber, figures 10a, 10b, and 10c, 12 inches x 12 inches x 12 feet. As a beam resting on two supports this will carry a maximum load of 64,800 pounds. As a struct it will carry a maximum compressive load of 408,000 pounds. As a tension member it will carry a maximum load of 1,444,000 pounds. The tensile load sustained by the piece is 20 times the bending load; the compressive load is 7 times the bending load; the tensile load is 3' times the compressive load. These results give a fair idea of the economy possible when the character of the stress is definitely known. Another economy resulting from the truss form of construction depends on the principle that the strength of a beam rapidly increases as its depth increases, a condition which applies equally to trusses. The economical height of trusses is about one-fourth of the length of the span.

There is also an economy in choosing for the different members, materials and shapes of cross sections, which are best suited to resist a particular stress. A small rod of steel, or a steel cable is well adapted to carrying a tensile stress, but would be useless for resisting one of compression. A hollow, square, east iron pillar is well suited to carrying a heavy compressive load, but, due to its structure, is weak in tensile strength.

We have, therefore, four economies in the modern truss over the old style rectangular simple beam: (1) The elimination of bending stresses in the members;

(2) The concentration of a large part of the material al0ng the upper and lower edges of the truss, thereby largely increasing its resisting power with a given fiber stress in the material; (3) The selection of that class of material whichis best adapted to the stress to be resisted; (4) The design of the member in cross section and the method of securing the joints, so as to best adapt it to the particular kind of stress to which it will be subjected.

Flooring

For foot bridges the floor plank should be one half inch thick for each foot apart of stringers. For cavalry, wagons and light artillery, the flooring should be one inch thick for each foot apart of stringers. If round poles are used their diameter should be one and a half times the thickness ok' the plank required.

Trestles

The upper transom is calculated as a beam supporting the load on an entire bay, uniformly distributed for other than wheel loads which are considered as concentrated at the center.

The uprights are subjected to compression and there is little danger 'of their failure. If the height of the upper transom does not exceed 12 feet, use the formula W =300A, in which W is the safe load on the upright in lbs. A is the area of cross section of upright in inches. Decrease the coefficient 300 by 10 for every foot of increase in the height above 12 feet. For a bridge 10 feet wide, with 15 foot bays, the two legs should be about 5 inches square, assuming diagonal 'braces to prevent bending stresses.

Pile Bents

A pile bent must resist crushing, for which the calculation is as for the legs of a trestle. The piles must also be driven sufficiently to prevent a considerable sinking under the applied load. Piles from 8 to 12 inches' in diameter at the butt (upper end) and driven until the penetration is ½ inch under the last blow of a 150 lb. hammer, will be found safe for the ordinary military loads. If the loading is , unusual, employ the following formula: $W=\frac{2wh}{s+1}$, in which W is the safe load in lbs. ; w is the weight of the hammer in lbs. ; h is the average fall of the hammer during the last few blows, in feet; s is the average penetration in inches during the last few blows. The formula includes a factor of safety of 6.

The legs of trestle and pile bents should be braced with diagonals about two to four inches in diameter to prevent lateral strains and to- provide stiffness. Successive bents should also be similarly braced to provide longitudinal stiffness.

Simple Trusses

Forms of trusses here considered are types of compound beams in which the lower chord A-C-B, figures 4, 5 and 6, is in tension and the upper chord A-D-B is in compression, in the, same way that the upper half of a simple beam is compressed and the lower half is extended. The analogy between the simple beam and the truss is complete.

A -truss is composed of a series of triangular frames, the members of which are designed to resist tension or compression, or both. The triangle is the basis of construction because it is the only geometrical figure which cannot change its shape without the rupture of one of its joints. The quadrilateral, on the other hand, can be warped indefinitely and still have its sides the same length and its joints intact. This is shown in figures 7 and 8. The truss in figure 7 would be stable as long as the load was uniformly distributed along A-B, but if an additional load were applied at C, the truss would assume such a position as in figure 8. The triangular parts A-D-C and E-B-F retain their figure, but E-C is lengthened to E′-C′ and D-F is shortened to D’F’. If an iron rod were inserted from E to C to take the resulting pull, the rectangle would be divided into two triangles and warping could not occur, The same result would be accomplished by placing a wooden strut between D and F to take the resulting compression. This strut then becomes a counter brace for the load at C.

The Determination of the Character and Amount of Stress in the Members of a Simple Truss

The character of stress in the members of a simple truss may usually be determined by imagining different members omitted and observing the natural tendency of the remaining structure to fall. If in Fig. 4, A-C were removed it can be seen that the entire weight of tne truss falls on A-D. D tends to fall, producing a thrust outward at A, which can be resisted only by a tension in A-C. If A-D were removed, the entire weight of the bridge would fall on A-C, as a beam resting on two supports. C tends to fall, bringing D toward A. This tendency is re-, sisted by a compression in A-D. If the king post, C-D, were cut, C would tend to fall, increasing the distance from D to C. This tendency is prevented by the tension in D-C.

In the same way the character of stresses in the members of the Queen post and Howe tresses may be determined by inspection. If A-F, Fig. 6, were . removed, all the weight of the truss would fall on A-E. The resulting tendency of E is to fall toward A, thrusting A away from F and hence A-F is in tension. If E-A were removed, A-F would support the total load as a beam; F tending to fall, bringing E toward A and hence compressing A-E. E-F, as in the King post, is under tension, due to the total load at F. If F-G were removed, H tends to fall, thrusting F away from G and F-G is in tension to resist this tendency. If F-H were removed, the rectangle E-H-G-F, would support the truss, but since the weight to the right of H-G (i.e. on H) is greater than that to the left of E-F (i.e. on E), the rectangle is warped as shown in E'-F'-G'-H', thus shortening H-F, which must therefore be under compression. In this way the character of stress in any member of a simple truss may usually be determined.

When the amount of stress in a mernber as well as its character is to be determined, both can be written out by inspection when the following principles are understood.

Preliminary Principles

(*a*) A stress (or force) may be laid off as a right line, showing its direction, point of application and amount to scale. Thus, in figure 14, AB represents a force of 1,500 pounds to the scale of one inch equals 1,000 pounds. A represents the point at which the force is applied, and the line AB shows the direction in which the force acts. If the point A be taken as one of the joints of a truss as B, figure 15, the forces transmitted through that point and tending to rupture the joint have' their directions along the members BC, BE, BA, and BD, respectively. These forces may act toward or away from the joint and it can readily be seen that the former must be resisted by an equal tension and the latter by an equal compression in the corresponding members; and, likewise, in. every structure all the forces due to'applied loads must be opposed by equal and opposite resistences in the mernbers concerned.

(*b*) Any force such as AB, figure 14, may be resolved into two components as AD and AC, which in direction, point of application and amount are represented by the sides of a parallelogram, whose diagonal is the force A% thus resolved. That is to say, AB could be removed entirely and the two forces AC and AD would produce exactly the same effect on the joint as was produced by AB. Therefore, we have the principle that any force may be resolved into any other two forces which are represented by the sides of the parallelogram whose diagonal is the given force.

(*c*) Every joint of a structure must be in equilibrium under the applied loads, and to have equilibrium at any joint, the sum of the horizontal components of the forces acting at the joint must equal zero and the sum of the vertical components likewise equal zero. If the forces acting at B, figure 15, be resolved according to principle (bj above, into components in both directions along AE and BC perpendicular to each other, then will the sum of the components along AE equal zero and the sum of the components along the direction of BC equal zero.

The above principles are essential to an understanding of the following '"method of sections" for 'determining the stresses in the members of any truss with parallel chords and with web members (verticals and diagonals) which make the same angles with each other. The following explanation is somewhat long due to the necessity for simplicity required by those not having previous engineering knowledge, but the method, as will be seen later, is rapid and easy in any particular case.

Assume a six panel Howe Truss, figure 15, with a load of 2W at each panel point as shown. The two abutments, A and M support the entire load and therefore the reaction at each of these two points is equal to 5W, one half the entire load. Since the load on the truss is composed entirely of weights acting downward, the two abutments can be replaced by two forces at A and M, each equal to 5W, and acting vertically upward, thus exactly balancing the weight of 10W on the truss.

According to principle (cj above, the forces acting at any point must be balanced by resistences in the members at that point. Taking the point A, the applied force at that point is AP=5W. This force must be balanced by the resistance offered by members AC and AB. Since the entire force applied at A must be opposed by two resistances, one in AC and the other in A%, therefore, in order to determine how much resistance each member will be required to offer to maintain equilibrium, the force AP must be resolved into components in the directions of these two members. This is done in accordance with principle (bj and is shown in AR and AS, figure 15. It will be noted that the force AR acts along the line AB, and tends to pull the joint away from B. To secure equilibrium, this tendency must, therefore, be opposed by a resistance in AB equal to and opposite in direction to AR, i. e., a tension. Calling the angle P-A-C, A; $\frac{RA}{PA}=\text{Tan}A$ or $RA=PA\tan A=5W\tan A$, for the total tension in AB. Similarly the component of AP along AC is equal to AS, and tends to pull the joint A toward C. This tendency must be opposed by an equal resistance in the member AC acting toward the point A, i. e., a compression. $\frac{AP}{AS}=\cos A$ or $AS=\frac{AP}{\cos A}=\frac{5W}{\cos A}$, which is the total compression to be sustained by the member AS. We have thus established equilibrium at the joint A and in so doing have transmitted from A to C a thrust of $\frac{5W}{\cos A}$ and to B a pull of 5Wtan A.

Considering the joint C, the transmitted force here is, as we have just seen, $\frac{5W}{\cos A}=CV$, due to the upward thrust of AC. This force, therefore, must be resolved' into two compononents along the other members at the joint, viz. CD and CB, as follows: $\frac{TC}{CV}=\cos A$ or $TC=CV\cos A$. But $CV=\frac{5W}{\cos A}$, hence $TC=\frac{5W\cos A}{\cos A}=5W$, the total stress upward. on C. This must be resisted by an equal tension in CB. In the same way $\frac{WC}{CV}=\sin A$, or $WC=CV\sin A=5W\tan A$. Hence there must be a compression of 5Wtan A in CD to give equilibrium. Taking the joint B, there is a stress of tension transmitted through CR, pulling upward, and there is an applied load of 2W acting downward at B, the resultant of the two being 3W acting upward. This force is resolved as shown in the figure giving $\frac{3W}{\cos A}$ in BD and 3W tanA in AB. There is in addition, a tension of 5 W tanA transmitted from A to B and to this is added, the component 3W tanA which came down from C, making a total of 8W tanA to be resisted by an equal tension in BE. In the same way the stresses in all the members may be determined by considering each joint in succession to the right, but using a much shorter and simpler method based on the above discussion the stresses may be written out by inspection as will be shown below. It is well to note here that a resistance of tension in a member is a force acting away from the joints at both of its ends, and compression a force acting toward the joints at both its ends, as indicated by the arrows on the members of all the trusses. By examining the truss solved above, it can be seen (1) that the stresses in the *web members* are alternately compression and tension and the numerical coefficients of their stresses, starting with that of the abutment reaction, decrease gradually toward the center. This decrease occurs only in passing the joints where loads are applied and the reduction in coefficient is equal to the coefficient of the applied load at the particular point.

(2) That the value of the stress in any diagonal is $\frac{W}{\cos A}$ into the coefficient of the member, and in any upright is W into the particular coefficient.

(3) That all the members of the upper chord are in compression and of the lower chord are in tension and each equal to the expression W tan A into the coefficient of the member, which gradually increases to a maximum at the center of the truss. The stress in

each member in heavy line equals its coefficient into W tanA that in fine line into $\frac{}{\cos A}$ and that in broken line its coefficient into W.

(4) It will be noted that at each panel point the sum of the numerical coefficients of the stresses tending to move the joint upward is equal to the sum of the coefficients tending to move the joint downward; and similarly that the sum of the coefficients tending to move the joint to the right and left is zero. This makes it possible to write by inspection the numerical coefficients of the stresses of all the members of trusses whose upper and lower chords are parallel and whose web members make the same angles with each other.

(5) It will also be seen that in any- section of the truss containing one *diagonal only*, the sum of the coefficients of the compressive stresses in the members thus cut is equal to the sum of the coefficients of the tensile stresses, as in a-b or c-d, in the figure. And where such section cuts two horizontals and no diagonals as e-f, the coefficients of the horizontal members are equal and of opposite stress.[1]

We are now prepared to write out the stresses in a King Post, Queen Post, Howe, Pratt or Warren Truss, or indeed any form of truss with parallel chords and web members making equal angles with each other.

The King Post Truss (Fig. 16.) Suppose a load of 2W is acting on the truss at B. The reactions at A and B are 1W each, and passing the section a-b, we see that the coefficients of AC and AB are each equal to 1, and that of AC acts toward the joint to oppose the vertical coefficient of the reaction, while that in AB is tension to oppose the compression in AC (principle 5). CM and BM are at once. known by similarity of the two halves of the truss and BC is

[1] In determining the stress in a truss by the method of sections the counter members are omitted, being later determined as shown below p 21.

two to oppose the applied load of 2W at B. The actual values are found by multiplying the above coefficients by the proper functions of W and A, as in the Howe Truss above.

Pratt Truss, figure 17.

Assume a total load on the truss of 4W at each pannel point. Each reaction will be 10 W, from which the stresses are written out at once, as shown in the figure. Coefficient 10 of reaction is opposed by 10 of eompression in AC. This vertical coefficient at C is opposed by 10 of tension in CB. The horizontal puil from C in CB is opposed by the coefficient 10 in CD (principle 4). Now, cutting the section a-b, the coefficients in CB and CD exactly balance each other and there is zero stress in AB. Cutting the section e-d, the coefficient of BE must equal 10 by principle (5). And so on to the right abutment the stresses may be written out at once. It will be found easier to write out the stresses in all the web members first, and afterwards in the chord members, because the coefficients of the web members are only reduced at each point from abutment to center by the coefficient of the applied load at that point (principle 4).

Warren Truss, Fig. 18.

Assume a load of 1W at each panel point. The reactions are then 2W and we may write out the stresses in the *web* members as shown. AC has a coefficient of two compression to oppose the 2 upward of the abutment. At C the coefficients in both AC and CB will be seen to act to the right, hence the coefficient of CD equals their sum or is 4 (principle 4). Cutting the section a-b gives a tension of 2 in AB to add to that in CB, their sum balancing'the 4 of compression in CD (principle 5). Similarly the 4 compression of CD, added to 1 compression of BD, is balanced by 5 tension in BE, and so on to the end of the truss. The actual values of the stresses follow the rule given under the Howe truss, i. e., the co-efficient into W tan A for horizontal members; into $\frac{W}{\cos A}$ for diagonals.

With the stresses determined as above, the members of these trusses can be designed, when the load on the bridge is the distributed dead load (weight of bridge itself), and, a distributed applied load. In this case add the coefficient in each member due to the two loads and their sum gives the maximum coefficient for the member.

If the applied load is concentrated, the maximum stress in any member is determined by applying this concentrated load to the panel points in succession, and finding the total coefficients due to the two loads *for each position of the concentrated load,* and taking the greatest resulting coefficient in any member for its maximum stress. The part of the concentrated load going to each abutment is inversely proportional to the distance of the load from that abutment. For instance, figure 15, an applied load of 6 W at E is taken up at the abutments as follows:

$$\frac{4}{6} \text{ of } 6 \text{ W at A}; \quad \frac{2}{6} \text{ of } 6 \text{ W at M}.$$

By making the tests for the applied concentrated load at each panel point successively and adding the coefficients due to the dead distributed load to those due to the concentrated load, the following principles are determined: (1) The maximum stress in either *chord* occurs when the concentrated load is at the center of. the truss. (2) In any *web member* the stress is a maximum when the concentrated load is between the member and the middle point of the truss and as near the member as the method of loading will permit; the stress is a minimum when the load is between the member and the nearer abutment and as near the member as the method of loading will permit.

Having determined the character of the stress in each member of a truss, the best point, at which to place a charge of explosive for its demolition becomes known.

In destroying a truss bridge, the member chosen for demolition should be under tension, for the reason that if a member under compression be cut by an explosive, its two ends are very liable to' fall together and abutting against each other still be able to support the compressions required to hold up the structure. If, however, a principal tension member be cut, the truss will collapse. The best place to cut a member of a truss bridge is at the center of the lower chord, since there the greatest tension occurs. If the truss is of steel it is safest to cut all the members in the entire cross section to insure a complete fall. The charge should be placed at a point to secure the maximum destructive effect.

Counter Members

In any except the end panels of' a simple truss such as shown in figures 15, 17 and 18, a concentrated load at. the joint of *a* panel toward the nearer abutment may cause in the diagonal a stress opposite in kind to that produced by the dead load. For instance, in the panel F, G, H, I; Fig 15, a concentrated load of 6 W at I (in addition to the distributed load) causes a stress of tension of coefficient 1 instead of a stress of compression in FI due to distributed load alone. If FI were designed to resist tension alone, as for a cable, a counter brace would be necessary between H and G to relieve FI from this stress. Similarly in panel G, H, I, K, Fig. 17, a concentrated load of 12 W at K (in. addition to the distributed load) would produce a tension of coefficient 2 instead of a compression in IK. A counter tension member between

H and K would relieve IK from tension. It is seen from the two above illustrations of counter bracing, that to counter brace' a panel the counter member must be designed to resist the same kind of stress as the main diagonal of the panel.

If therefore the web member in any panel has a reversal of stress i. e. a change from compression to tension or the reverse, under the effect of applied loads at one or more panel points between the panel and the, nearer abutment, counter braces will be necessary. Hence to test for counter braces, apply the concentrated load at th.e joint of the panel nearest an abutment and see if there is a reversal of stress, if so a counter member is necessary and the test should also be made in the next panels toward the nearer abutment, until there is no reversal. A web member liable to reversed stress requires a counterbrace when it has a coefficient due to the dead load equal to or less than the coefficient of the concentrated load *going to the farther abutment.*

The Cantilever

A Cantilever is a beam fixed at one end and supporting a weight at the other. The principle of the cantilever may be used in the construction of military bridges where the depth of opening is too great for trestles or piles and where the span is too great for a single beam. Let C-B, Fig. 9 be a cantilever, supporting the weight W at the end. Under the influence of the load the beam will bend downward to same position as shown in broken lines If before applying the load, two notehes were cut in the beam, as shown in the figure, the application of the load would bring together the edges of the lower notch and open out the upper one. It is also evident that the greatest tendency to break is at the fixed end of the beam. If it becomes necessary to design such a beam, the formula for beams supported at both ends may be used if the value of W found be divided by 4. The beam supported at two ends and loaded at the center is equivalent to two cantilevers fixed at the point C Fig. 1 supporting the pull of two forces acting upward at the ends, each force W' equal to ½ W; the length of the cantilever, l', being equal to ½ of l, the length 'of the original beam. Substituting in the formula 2W' for W, and 2l' for l, we have:

$$2w' = \frac{\frac{1}{3} \times bd^2 \times C}{El'}, \text{ or } W' = \frac{\frac{1}{12} \times bd^2 \times C}{l'}$$

(For military cantilever bridges see Engineer Field Manual page 79).

Loads On Military Bridges

For infantry in fours or cavalry in twos allow 500 lbs. per'linear foot over the entire span.

For escort wagons and field artillery allow a concentrated load of 5,000 lbs. at the center of the span.

For army wagons allow a load of 7,000 lbs. at the center.

For siege guns allow 10,000 lbs. at the center.

The greatest load that would ever come on a military bridge is probably the weight of dismounted men massed over the entire span for which allow 133 lbs. per square foot of surface of the floor.

The dangerous point may be taken at the center of the span. Moving loads have a greater breaking effect than quiescent loads, and for this reason as well as to prevent vibrations, bridges should be crosssed at a slow gait, and marching men should break step.

In calculating the safe load on round timbers, use $\frac{6}{10}$ of the load on a square beam of side equal to mean diameter of the round timber in use. The mean, rather than smaller diameter, is taken because the lesser strain on the end of the beam usually more than compensates for the smaller diameter. This would not be a safe rule, however, where the smaller end is very much less than the larger, as such a condition usually indicates that the log is cut from near the top of the tree and the wood of the small end is not of as good quality as the large end and is much more likely to deteriorate. In such ease use. the diameter of the small end.

Problems

1. What concentrated dead load can be safely placed on five. 8 inch × 12 inch ×15 foot stringers of poplar? C=550 lbs.

Solution :

$$W=\frac{1}{3}\frac{bd^2}{l}\times C;\quad W=\frac{1}{3}\ \frac{8\times144\times550}{15}=14080$$

Poplar weighs 30 lbs. per cu. ft.

$$\frac{8\times12\times15\times30}{144}=300 \text{ lbs., weight of one stringer.}$$

14080-150-13930, applied load on one stringer; 69650=applied load on five stringers.

Problem 2.

You have pieces of red oak (C =550 lbs.) 4 × 4 cross section. How many are required to safely carry a concentrated dead load, including weight of timbers, of 5,000 lbs., over a span of 12 feet?

Solution :

$$W=\frac{1}{3}\frac{bd^2}{l}\times C;\quad W=\frac{1}{3}\frac{4\times16\times550}{12}=977.$$

$\frac{5000}{977}=5+$, or use six balk. The same result would be obtained if the applied load of 5000 lbs. were exclusive of the weight of the beam, for the weight of one beam is about 53 pounds distributed or 26 concentrated. Subtracting from 977 gives 951; $\frac{5000}{951}=5+$.

(Weight of red oak is 40 lbs. per cu. ft.)

Problem 3.

You are required to haul a ten ton road roller over a bridge which has four $4 \times 12 \times 16$ yellow pine stringers. Is the bridge safe for the load neglecting weight of flooring?

$$W = \frac{\frac{1}{3} \times 4 \times 144 \times 500}{16} = 6000;\ 6000 \times 4 = 24000 \text{ lbs.}$$

total load supported by the four stringers.

Weight of stringers:

Weight of yellow pine per cu. ft. = 40 lbs.

$\frac{4 \times 12 \times 16}{144}$ -213 lbs. per stringer, or for four, 852 lbs.

The concentrated dead load to be substracted, is therefore, 426 lbs. $24000 - 426 = 23574$ lbs. allowable applied concentrated load; the bridge is therefore safe.

Problem 4.

You are required to construct a bridge for infantry 'in fours, over a span of 20 feet. There are only hemlock poles 4 inches mean diameter available. How many poles are required? $C = 400$.

Solution :

$$W = \frac{\frac{1}{3} \times 4 \times 16 \times 400}{20} = 426 \text{ lbs.}$$

For round timbers take $\frac{6}{10}$ the value of W : $\frac{6}{10} \times 426 = 255$ lbs. total concentrated load on one pole including its weight. Hemlock weighs 25 lbs. per cu. ft. ;

The volume of log= $\frac{7854x16x2!\&}{144}$ 7453 cu. ft.;

$1.7453 \times 25 = 44$ lbs. weight of one log. 255-22 lbs. $= 233$ lbs. =applied load on one log. Total applied load is $500 \times 20 = 10000$ lbs. 5000 lbs. = load concentrated at the center, $\frac{5000}{233} = 21+$ or 22 poles are required.

Methods of Testing the Strength of Existing Bridges, and Some Expedients for Strengthening Them

In all classes of bridges, the first point to examine in testing their strength is general condition of the timbers and metal parts for soundness. Any rotteness, breaks, warping or undue bent condition of wood work should be noted and an estimate of the remaining strength of the member made. The threads especially and rivets of plates in iron members should be carefully considered. The apparent age of the bridge will often show whether a detailed examination for condition of members is necessary. For the careful examination of the timbers of an old bridge a hatchet, an augur, and a few long nails are necessary. Usually the condition of a doubtful piece can be determined by striking it with a hammer and noting the sound produced by the blows. Hollow or decayed parts usually can at once be detected by the hollow sound. If decay is found, a hole should be bored or cut in the piece to determine the amount of material still in good condition. This may often'be determined by driving in a wire nail to the solid part. The degree of decay will be evident from the ease with which the nail is driven, and the diameter of the solid part becomes known from the length of nail driven before striking the undecayed timber. In piles these tests are especially necessary just below the ground line, or, if the bottom is under water, at the part alternately wet and dry.

Stringer Bridges

The strength of the stringers may be readily tested by use of the formula for beams $W = \frac{1}{3} \frac{bd^2}{l} \times C$

From the value of W found, subtract ½ the weight of the balks and fiooring to get the load that may safely be passed over the span. For this purpose, C may be taken at 400 for ordinary timber, and the weight of a cu. ft. of timber at 40 lbs. The flooring, if of 2 inch stuff, or thicker will generally be sufficient, but if a siege gun or' army wagon is to be passed over the span, it is well to lay a track over two stringers for the wheels. This not only strengthens the floor, but also has the effect of increasing the size and strength of the balk. .

To strengthen the stringers if found too weak for the proposed load, one or more additional uprights may be inserted under the weak member, or an additional trestle may be similarly inserted to strengthen all the stringers. Such re-enforcing should be tied to the bridge with diagonal braces, as shown in figure 19,to assist in keeping the trestle or post in position and to aid in stiffening the .balks by the additional supports thus provided. To secure uniform and. maximum strengthening effect these brackets should be applied to each balk. When their application is impossible or difficult these diagonal braces 'could be used to further strengthen all of the balks by having transoms extending across the bridge at d and e. These transoms would be lashed or spiked to the balk and the diagonal then spiked on. The efficiency of these transoms could be still further increased by additional struts to the bank as shown. All or part of this work may be done according to the amount of additional strength required, a gain being made according to how far the process is carried and the strength of the materials used, up to four times the original strength. In case the opening is of such a nature that re-enforcing by means of additional trestles or posts is not possible, such for instance as deep water, mud or excessive depth of opening, then two braces, ab and cd, figure 20, may be used. A firm footing at a and d would be necessary and might be secured directly on the bank, or, in soft earth, a larger bearing might be secured by a platform of planks or a log laid as footing for all the braces.

The braces may be lashed, nailed or secured with iron dogs or drift bolts to the balks to be strengthened. If several of the stringers require re-enforcement, the bracing would be done by means of trestles, the transoms of which would be secured to the stringers. In placing these trestles they should be forced into position to give them an initial compression. To secure a still greater re-enforcement, the form in figure 21 may be used. The straining beam be renders unnecessary the secure fastenings required by the simple trestles to'prevent the load from tearing loose and throwing the ends of the braces toward the center of the span. The straining beam also strengthens the balk itself near its center where the danger of breaking is greatest. This tvpe of re-enforcement, it will be seen, forms a queen post truss, with the load applied on top; the thrust ordinarily taken up by the lower chord is here taken up by the abutments. Such a queen post truss may often in original construction be built over an opening where conditions are suitable.

Where sufficient timber is not available for the form in figure 21, or where no footing is practicable the method shown in figure 22 may be used to advantage, forming an inverted king post. In trussing a single beam two rods are used one on each side, bearing on a plate which extends across the end of the beam. In trussing a double beam a single rod may be placed between the two pieces. The wire or rope ab could be led up under the mud sill and secured ,to it or to a post or tree, the slack being taken up by means of block and tackle or direct pull. The brace c may be a small framed trestle or a single beam extending across the width of the bridge. A similar arrangement entirely of timber would frequently be possible, the wire ab being replaced by two scantlings, which should be so attached as to give an initial tension in the diagonals. An inverted queen post can be put up in the same way as the inverted king post above described.

A good method of re-enforcing stringers or of relieving a trestle of its load, where short logs or cross-ties are available, is by means of a crib, figure 23. On dry ground the crib can be built without fastenings, on the site. The ground should be levelled for the bottom timbers. If the pieces are round timbers, their ends should be adzed off flat to give good bearing surfaces and prevent rocking. The pieces of the second and succeeding courses should be laid on with crossings in good bearing,' keeping the top constantly about level. The sides should be kept vertical or with a slight batter toward the center. If squared timber is used, small wedges, securely fastened, may be placed where necessary to give good bearing. The top pieces should be securely fastened to the balks. On soft ground or mud a platform will be required for the footing of the crib to give sufficient bearing surface. This may be of riprap, mattress or plank. A crib is also very serviceable for replacing on its abutments a span of a bridge which has been thrown down, by alternately jacking up the span "and adding to the crib. A temporary crib can often be made of boxes of quartermaster or commissary supplies.

When none of the above methods can be used and the flooring can be taken up, additional stringers may be inserted, or those present may be spaced so as to give greater strength under the wheels of the loads to be passed. When time is not available for taking up the floor, additional stringers may be laid on top of the floor and another floor or runways for the wheels placed on these. In this case, however, these stringers should be lashed, bblted or nailed to . the floor or the underlying balk, so that the two sets will act together. Merely laying the additional balk and flooring on top of the floor will assist if the ends of the stringers rest on the abutments or transoms, but if shorter than this they are of small value, although in the case of concentrated loads such as heavy% guns they assist by distributing the load, and may enable such a load to be carried over a bridge which would otherwise give way when -the load is at the center. Diagonal (sway) bracing across the lower edges of the stringers will add considerably to the strength of the span by preventing lateral bending and vibrations.

In marching over country where standing timber is not available a supply'of timbers should be carried with the wagon train. A supply of jacks and tackles, rope and steel wire should also be carried. With such an outfit repairs could often be made temporarily without wasting the materials in the repair outfit. The jacks would be of material assistance in raising and supporting broken spans or placing supports under weak ones. They would generally be used in connectibn with cribs, or of pillars built up of boxes of army supplies carried by the train. With the tackles and a few stout poles, it would frequently be possible to put in an additional transom suspended by tackles to lashed shears. The tackles may also be used for putting in broken tension pieces on truss bridges, or in strengthening by the inverted King Post Truss method. After the train has passed, these repair materials may be taken up again.

Pile and Trestle Bridges

To test such a bridge, first see if it is in alignment horizontally and vertically. If not in horizontal alignment (floor with changing slopes) it is probable that there has been undue settling of a trestle at the lowest point of the flooring; or the base of the trestle at that point may have been displaced in the direction of the length of the bridge due to a washout, thus causing the floor to drop. , Having noted the probable weak point from above the bridge, a closer examination should be made on the ground under that point to determine the exact weakness. A settlement must be remedied by taking the load off the trestle on a new support, or the trestle may be given a new and stable footing by means of logs, stones, or a grillage of crossed poles. If the base is secure in its present position, the top of the trestle may be elevated by inserting additional timbers on top of and secured to the transom.

If the bridge is out of vertical alignment, it is probably due to unequal settlement of the trestle or pile bent, or a warping of the members of the trestle due to lack of diagonal bracing on the trestle. In this case there is danger of a collapse sideways. The point of the bridge farthest out of alignment should be examined to determine the cause of the trouble. A trestle warped sidewise should be pulled into position with tackle and then braced with diagonals. Where it is not possible to correct the position of the trestle, additional supports may be placed on the weak side. Posts thus placed to support a trestle should be given a batter toward the bridge and particular attention given to their footing to see that it is stable; the

/top of the post should be securely fastened to the top of the trestle. Frequently a bridge will have no longitudinal braces between the different trestles, and the addition of these adds materially to the strength, especially if the bridge is subjected to rapidly moving loads.

In driving piles the smaller end of the pile (top of tree) is placed in the ground. This is the least developed and most inferior part of the pile and decays most. rapidly. The higher thk pile bent the poorer is this driven part. That part just below the ground line is also liable to the most severe attacks by insects and the elements and is the point where decay or wet rot first sets in. A careful examination; should therefore be made here to determine the remaining strength of the timber. If the piles are driven in fresh water and kept constantly wet, the wet portion will last indefinitely. Those portions alternately wet and dry are readily attacked by decay and must be carefully inspected.

Truss Bridges

Truss bridges will usually be of sufficient strength for military loads, except siege guns, provided that the materials of which they are constructed are in average condi t-ion. It is of first importance, therefore, to see if the timber and metal parts of the bridge are in a good state of preservation. The metal parts should, especially, be examined as to rust, sheared rivets and bent members. All of the tension members should be unifortnily strained and where one is slack and another taut the strength of the truss is much diminished. The compression members should be straight without bulges and all joints should bear closely against each other. The counter rods should not hang loose. The hangers by which stringers or floor beams are suspended should be examined for fractures or loose nuts.

Loose bolts and rivets can be detected by blows of a hammer. The action of a bridge under a moving load is one of the best tests of its strength and stability. If it vibrates or deflects excessively, collapse would be liable under the repeated strain due to the passing of the carriages of batteries or trains.

To determine the safe load for a truss bridge, first consider the end braces and the compression chord at the center of the truss, for these will have a greater load than any other compression members. It is customary to make the tension chord, of the same depth and width as the compression chord, and when this is the case the tension chord will have the greater factor of safety and need not be tested.

The compression members are tested as follows; (1.) Find the dead load carried by each panel point of the truss. (For sufficiently close results, the dead load on one *truss* may be assumed as 120 lbs. per running foot for spans up to 36 feet; and 140 lbs. per running foot for spans of 25 feet up to 50 feet. This is where the width of roadway is 10 feet in the clear). (2.) Find the load which the member will safely support. (3.) Find the stress in the member due to the dead load; (4.) The difference between these two loads will be the allowable live load on the member, from which the allowable live load on the bridge is found. A test of this character would be necessary on the bridges of the lines of communications along which heavy supply trains are to pass.

[APPENDIX]

The following tables will be of value in the rapid examination of bridges as well as in their design. Distance in feet, center to center, between stringers or beams to carry a distributed load of 100 lbs. per sq. ft. of roadway, including its own weight. For other loads divide the tabular number by the assumed load per sq. ft. and multiply by 100.

TABLE I.

ROUND	RECTANG-ULAR	SPAN IN FEET											
D	b x d	9	10	11	12	13	14	15	16	18	20	22	24
Ins.	Ins.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
5	2 x 6	1.2	1.0										
6	8												
7	10	3.2	1.2	2.1.1	1.1	1.5	1.3	1.1	1.0				
	12	4.7	3.8	3.1	2.6	2.2	1.9	1.7	1.5	1.2	1.0		
	3 x 6	1.7	1.4	1.2	1.0								
	8	3.1	2.5	2.1	1.8	1.5	1.3	1.1	1.0				
8	10												
9	4 x 6	2.3.4	1.9.3	1.5 2	1.3 2	1.1	1.0	2.1	1.2.2	1.7	1.4	1.2	1.0
	10	4.2	3.4	2.8	2.4	2.0	1.7	1.5	1.3	1.0			
	12	6.9	5.7	4.6	3.5.4	3.0	3.8	2.3	2.3.0	2.4	1.9	1.5	1.0
	6 x 6	3.4	2.8	2.4	2.0	1.7	1.4	1.2	1.1				
	10	6.2	5.0	4.2	3.6	3.0	2.6	2.2	2.0	1.6	1.2	1.0	
10	12	14.2	11.9	8.9.6	8.5.4	6.8	6.0	5.0	3.1	3.4	2.6	2.4	1.3
	8 x 8	8.4	6.8	5.6	4.8	4.0	3.4	3.0	2.6	2.0	1.7	1.4	1.1
11	10	13.2	10.6	8.8	7.2	6.0	5.2	4.4	4.0	3.2	2.6	2.2	2.0
	12	18.8	15.2	12.4	10.4	8.8	7.6	6.6	6.0	4.8	3.8	3.0	2.6
	10 x 10	16.4	13.3	11.0	9.2	7.9	6.8	5.9	5.2	4.1	3.3	2.7	2.3
	12	23.7	19.2	15.8	13.3	11.3	9.8	8.5	7.5	5.9	4.6	4.0	3.3
12		17.0	13.8	11.4	9.6	8.1	7.0	6.1	5.4	4.2	3.4	2.8	2.4

EXAMPLES

(1) The span between roadway bearers of a bridge is 16 ft. and the timber available for balks is 4 x 12 ins. How many balks will be required in each bay for a 12-ft. roadway? The table under span 16 and opposite size 4 x 12 gives a spacing, center to

center, of 3 ft. between balks, therefore there will be 4 spaces 'and 5 balks in each bay. If 11-in. round timbers were available, the spacing would be 4 ft. and there would be 3 spaces and 4 balks in each bay.

(2) The bays of a bridge are to have a span of 12 ft. 'and the balks' are to be spaced 4 ft. center to center. What sizes of balks may be used?

Answer. Either 9-in. round timbers or 3 by 12 in. rectangular. beams.

(3) The cap of a pile bent is supported'. on two piles, 10 ft. center to center, and the bents are spaced 15 ft. center to center. What size of cap is required? Opposite "15.2 ft." in column "10 ft." is found the required size, 8 x 12 ins., for the cap. Intermediate sizes, spans, and spaces may be found by simple interpolation;

Wagons and artillery carriages bring concentrated wheel loads on the bridge, and for such loads the foregoing table is not applicable.

The following assumptions simplify the problem, give safe results, and are in accord with the usual eonditions. The balks are' assumed to be so spaced that the load of any one wheel is transmitted by the flooring to at least 2 balks.

When the span of the balks is less than twice the length of wheel base of the carriage the greatest strain occurs when the' heaviest wheel loads are at the middle of the span. When the span of the balks is more than twice the length of wheel base of the carriage each wheel is supposed to have a load equal to the greatest wheel load of the carriage, and the strain is greatest when the center of the carriage is at the middle of the span.

For light artillery and army wagons the heaviest wheel load is 1,750 lbs. Add one-half the weight of the flooring carried by 2 balks, and 2,000 Ibs. may be taken as the concentrated load on 2 balks, giving

1000 lbs. on 1 balk, applied at the middle point if the span is less than twice the wheel base, and applied at two points, 6 ft. apart and equidistant from the middle point, if the span is more than twice the wheel base. In the same way 2,000 lbs. may be taken as the concentrated load on 1 balk for siege artillery applied in like manner with a wheel base of 8 ft.

TABLE II.

Sizes of round and rectangular balks and maximum safe spans in feet for wagons and artillery.

ROUND	RECTANGUL'R	Maximum safe spars in feet for four or more balks	
D	b x d	Wagons and light artillery	Siege artillery
Ins.	Ins.		
5	2 x 6	4.8	....
6	8	11.2	5.6
7	10	12.6	6.6
	12	15.6	9.6
	3 x 6	7.2	3.6
8	8	12.6	6.4
	10	16.0	10.0
9	12	20.4	14.4
	4 x 6	9.6	4.8
	8	14.5	18.5
	10	19.3	
	12	25.2	17.6
	6 x 6	13.2	7.2
	8	18.8	12.8
10	10	26.0	18.0
	12	34.8	22.4
	8 x 8	23.0	16.5
11	10	32.5	21.2
	12	44.4	27.2
12	10 x 10	39.3	24.6
	12	52.0	32.0

[Engineer Field Manual]

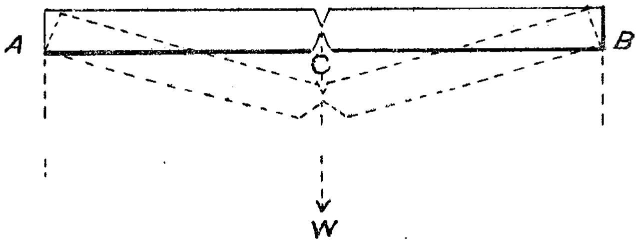

Fig. 1

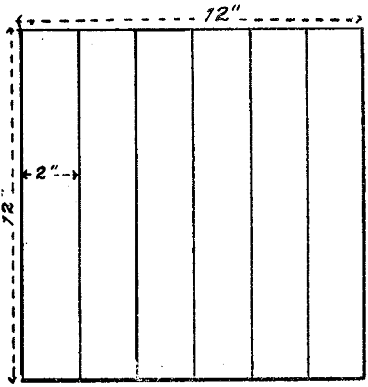

Fig. 2

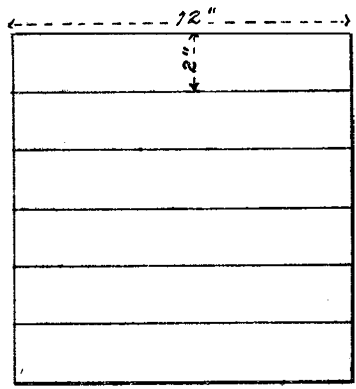

Fig. 3

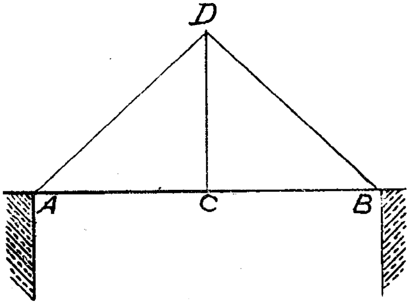

Fig. 4

KING POST

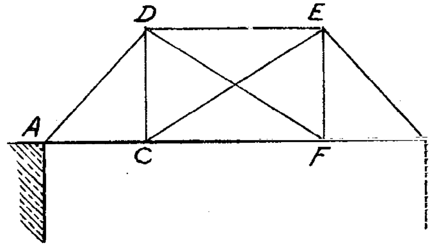

Fig. 5

QUEEN POST

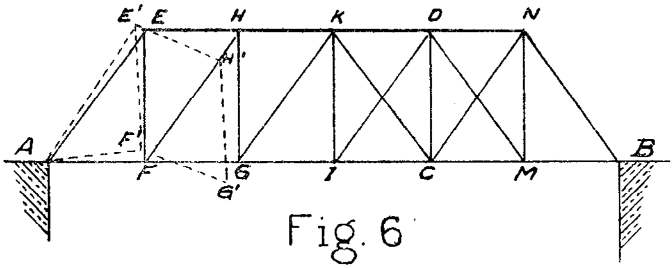

Fig. 6

HOWE TRUSS

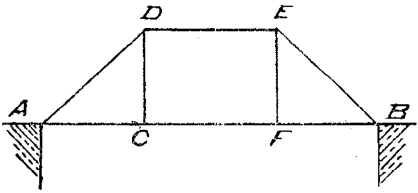

Fig. 7

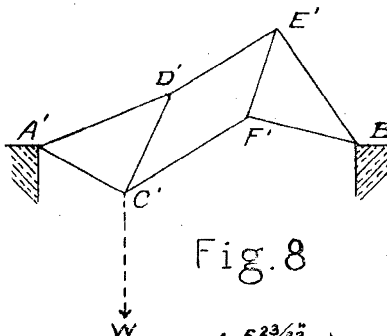

Fig. 8

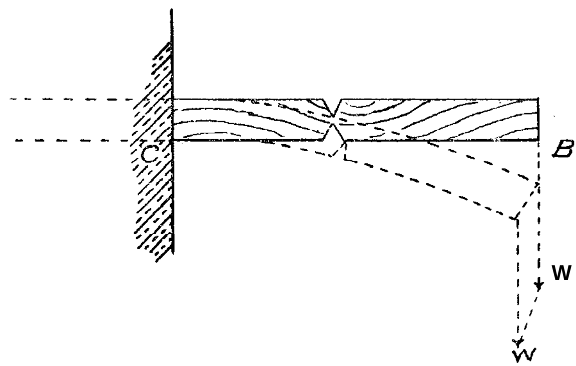

Fig 9

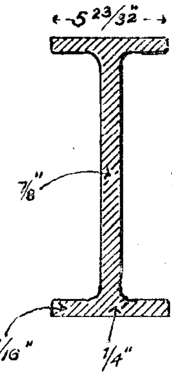

Fig. 10

I BEAM

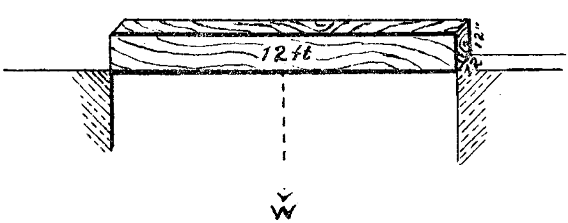

Fig. 10 a.

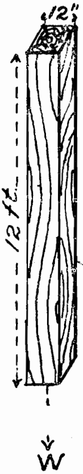

Fig.10.b.

Fig.10.c.

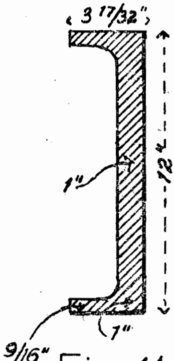

Fig. 11.

CHANNEL

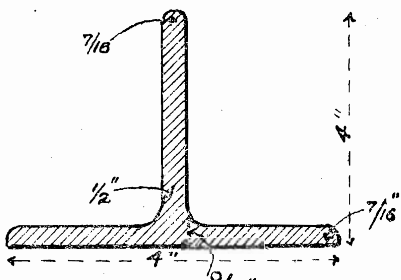

Fig.12

T BAR

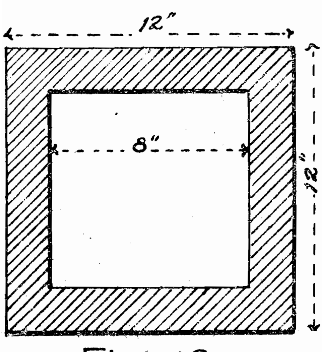

Fig. 13

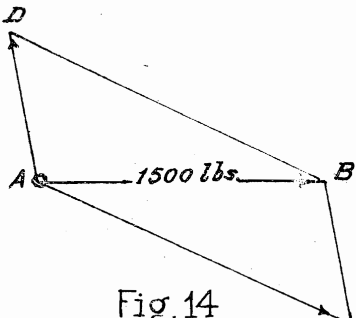

Fig.14

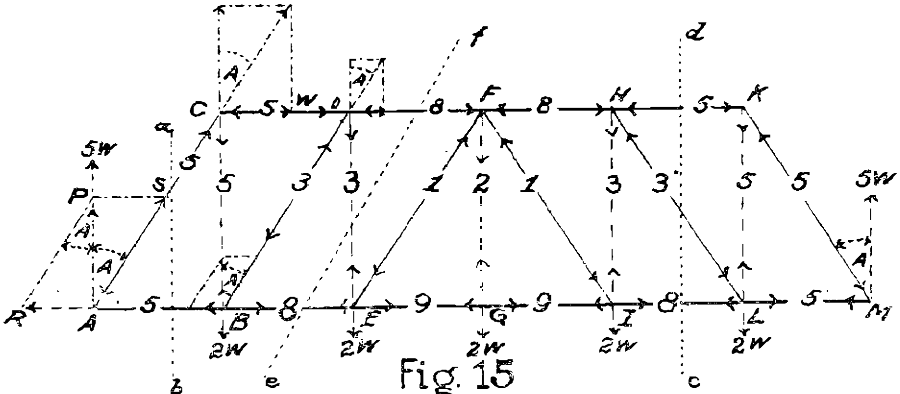

Fig. 15

HOWE TRUSS

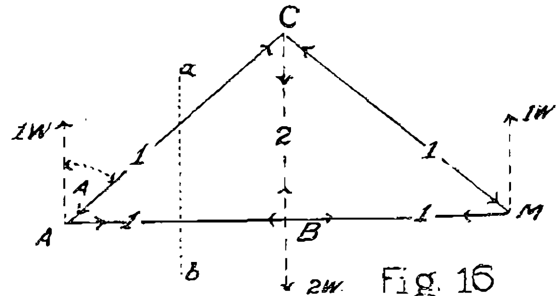

Fig. 16

KING POST TRUSS

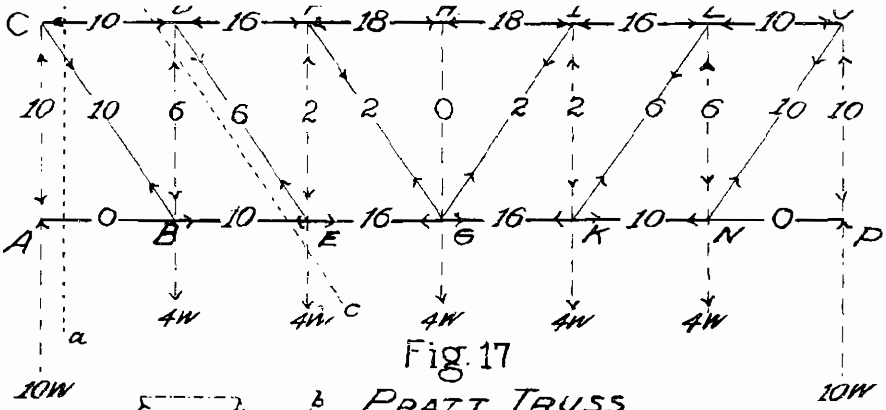

Fig. 17
PRATT TRUSS

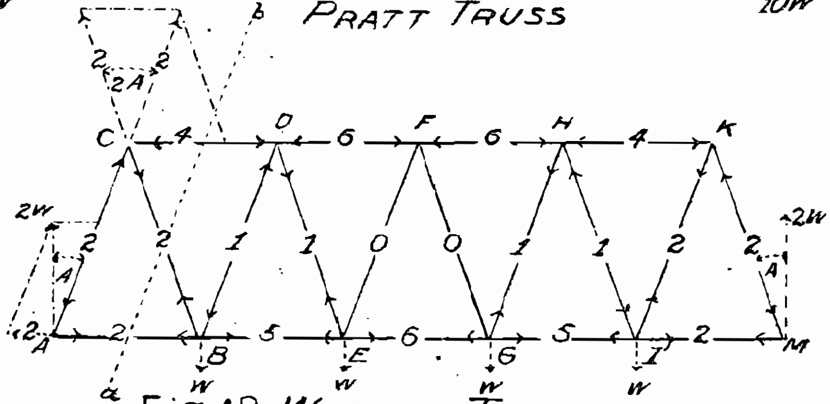

Fig. 18 *WARREN TRUSS*

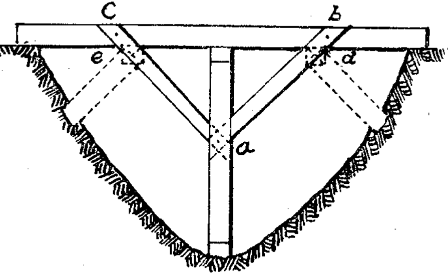

Fig. 19

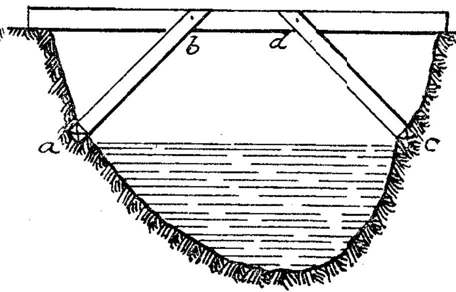

Fig. 2°

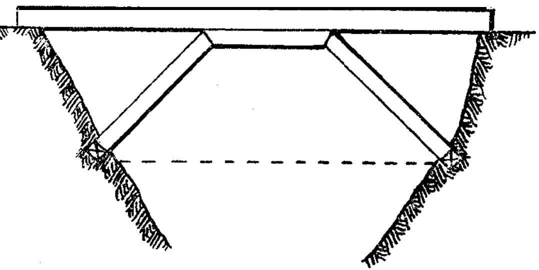
Fig. 21

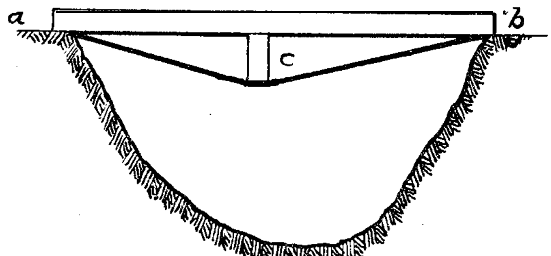

Fig. 22

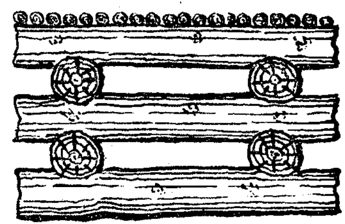
Fig. 23