Aug. 16, 1949. C. P. CUENI 2,479,475

COMPOSITE STRUCTURE WITH TRIANGULAR SHEAR CONNECTORS

Filed March 16, 1944

Fig. 1

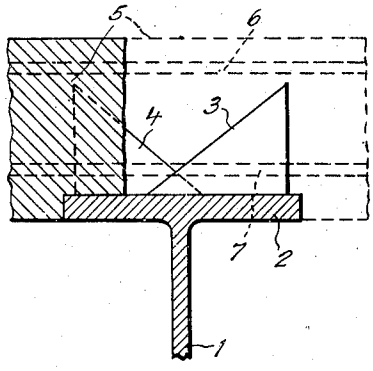


Fig. 2

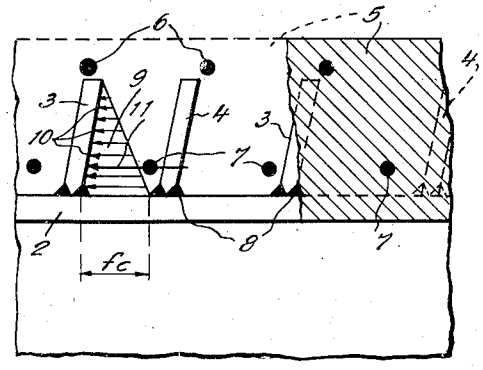


Fig. 3

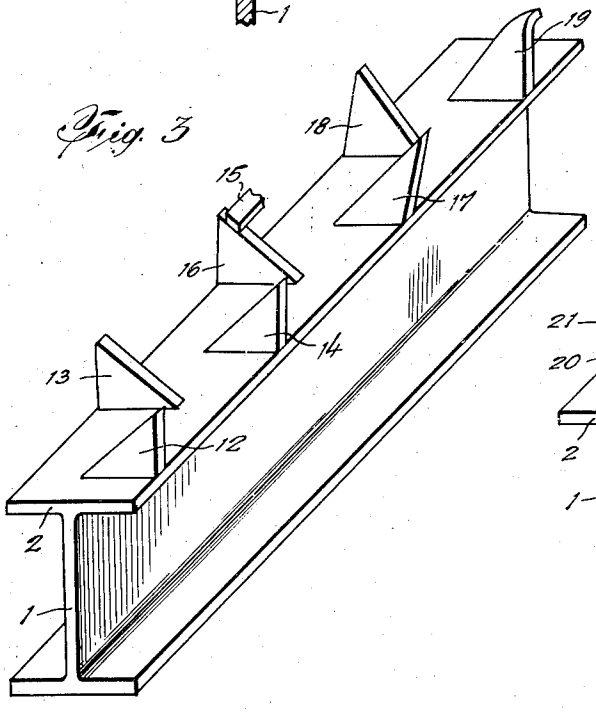
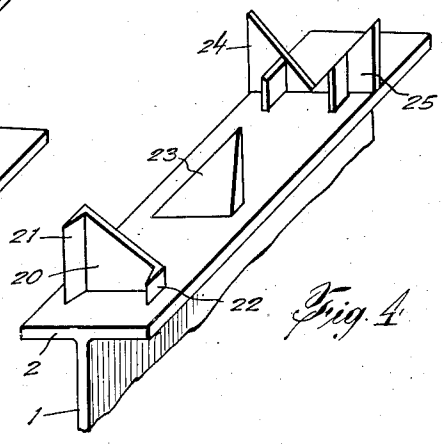


Fig. 4



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COMPOSITE STRUCTURE WITH TRIANGULAR SHEAR CONNECTORS

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5 Claims. (Cl. 72—70)

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This invention is directed to composite structures consisting essentially of steel or other beams and a reinforced concrete slab supported by the same and united thereto by the use of shear reinforcements extending from said beam into said concrete.

More particularly, the present invention is directed to shear connectors to anchor the slab to the beams, and thus providing a unitary structure which is characterized by lightness and great strength.

It has been customary for a number of years to provide structures of this kind wherein the upper flanges of the steel beams were provided with shear connectors, consisting of steel bars bent into helical shape and welded to the top flange of the steel beams, as is described in the patent to Schaub No. 2,016,616. Such a construction has numerous advantages, and is used extensively. However, because of the use of sinuous rods, it sometimes becomes difficult to insert, in their proper positions, the steel reinforcement for the concrete slab. Another disadvantage of the bent rod connectors is their vulnerability. If they are welded in the shop to the top flange of the steel beams, the connectors may be damaged or deformed during shipping or erection. Also, the connectors on top of the beams may interfere with walking on the beams during erection or make difficult the erection of a working platform on top of the erected beams. For this reason, the bar connectors are usually welded in the field after the beams are erected. This is much more expensive and the field welding is not as reliable as the shop welding.

There have also been used shear connectors for steel beams wherein a number of spaced elements consisting of an angle section were welded to the top flange of the beam with one of the faces lying flat on said flange. This construction allowed the placing of the reinforcements for the concrete slabs, but had the disadvantage that there was no great resistance to a certain bending moment set up by the horizontal shear on the erect member of the angle. The erect member has therefore to be designed on bending which makes such a connector prohibitive. The same is true of a plate connector, consisting of a square or rectangular plate standing on one edge and welded to the beam.

There have also been used shear connectors consisting of structural shapes standing upright on the top flange of the steel beams, and welded thereto in such a way that they were stiff enough to transmit the shear forces without bending, and also effectively prevented the slab from lifting upwardly from the beam, as described in my Patent No. 2,340,176. These connectors take more space, longitudinally of the beam, than an angle or a plain rectangular plate standing on its edge,

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and therefore may interfere with the placing of the slab reinforcement. In structures with heavy unit horizontal shear these stiff connectors may be so close together that the placing of the bottom slab reinforcing becomes difficult. Furthermore, in such structures the small space between the connectors makes it difficult to transmit the shear stresses into the concrete. This transmission of the shear stresses into the concrete is effected by the compression of the connector against the concrete. If the space between two connectors is small the shear value of the concrete will be the governing factor and not the compression value. If the shear strength of the concrete, which is much smaller than its compressive strength, is exceeded, the concrete protruding between two connectors will be sheared off before the allowable compressive strength of the concrete is reached.

This disadvantage applies even more to angle and plate connectors, and channel and z bar connectors standing with one flange on top of the beam.

The present invention is intended and adapted to overcome the disadvantages of prior structures and provide shear connectors secured to the steel or other beams which will have adequate stiffness, yet will provide sufficient space between two adjacent connectors to transmit the stresses into the concrete.

Accordingly, it is among the objects of the present invention to provide a composite structure wherein the beam has shear reinforcements providing an adequate resistance against shear and, at the same time, provide for the use of reinforcements in the lower part of the concrete slab.

It is also among the objects of the present invention to provide a composite structure in which the shear connectors are of such form and arrangement as to give the maximum resistance to shear while, at the same time, utilizing a minimum weight of metal.

In practicing the present invention, the same is based upon the fact that with all shear connectors that transmit the stresses into the concrete by compression the stresses acting on the compression face of the connector form a diagram of parabolic shape, which is well approached by a triangle, the stress at the top being zero and at the bottom, near the top fiber of the steel beam, reaching the maximum.

The point of attack of the resultant of all stresses is therefore one-third up from the base of the connector. The lever arm for the computation of the bending moment produced by the horizontal shear for any connector with a compression face of rectangular shape is therefore one-third of the depth of the connector. According to the present invention, by using a plate

shear connector of roughly triangular shape, most of the less effective top part of the plate is eliminated and the lever arm for the computation of the bending moment is reduced from one-third to one-fourth of the depth of the connector, that is, the height upwardly from the beam. These two seemingly small differences make a triangular connector much more economical than a rectangular one and provide more space for the introduction of the compressive stresses into the concrete.

To prevent uplift of the concrete slab, the connectors may be provided with a hook at the upper corner, or may be inclined toward the center of the beam.

In the accompanying drawing constituting a part hereof, and in which like reference characters indicate like parts:

Figure 1 is a transverse vertical cross-sectional view of the steel section and shear connectors of a composite section, some parts being broken away for clearness;

Figure 2 is a longitudinal cross-sectional view of the structure of Figure 1, part of the concrete slab being broken away to show the connectors;

Figure 3 is a perspective view of a beam with shear connectors thereon prior to the pouring of the concrete slab; and

Figure 4 is a view similar to Figure 3, but showing different forms of connectors.

The structure according to the present invention consists generally of a steel or other beam **1**, only partly shown in Figure 1, with a top flange **2**, shear connectors **3** and **4** and a concrete slab **5**. As shown in Figure 1, the shear connectors **3** and **4** consist of plates of triangular shape which are welded to the top flange **2** of the steel beam, and are well embedded in concrete slab **5**. Top reinforcing bars **6** and bottom reinforcing bars **7** of the concrete slab are also shown. Shear connectors **3** and **4** may be of the same shape and dimensions, but are placed alternately on opposite sides of the flange. The spacing may increase toward the center of the beam according to the actual stress.

In Figure 2 the top flange **2** to which the shear connectors **3** and **4** are attached by welds **8**, supports concrete slab **5**. The connectors are welded to the flange in inclined positions, providing resistance against stresses tending to lift the slab from the beam.

With the shear connector **3** in Figure 2 is shown stress diagram **9** with the arrows **10** indicating the direction and magnitude of the stresses. Because the stress diagram is of triangular form from both sides, in other words, forms a pyramid the point of attack of the resultant **11** of all stresses is at one-fourth of the depth of the connector from the base. f_c shows the maximum concrete stress. An example will illustrate what advantage a triangular connector has as compared with heretofore used connectors. Assuming the unit horizontal shear per lineal inch is 2,500 pounds, the thickness of the concrete slab 7½'' and the required height of the connector is 4¾''. This does not mean that the whole connector has to reach 4¾'' up into the slab, part of it is sufficient. The allowable stress for the concrete is assumed to be f_c=1,000 p. s. i., and for the steel f_s=20,000 p. s. i.

The allowable load per shear connector has to be computed with respect to concrete and steel stresses, the lower one governing the design.

1. *Design of triangular plate*

Assumptions: plate of ¾'' thickness, 6'' base and 4¾'' height.

a. Allowable load for one connector with respect to concrete stress:

$$F=f_c\times 6\times 4.75/3=9.5\ f_c=9{,}500\ p$$

b. Allowable load with respect to steel stress: The section modulus of the plate at the base

$$S_s=6\times 0.75^{2}/6=0.5625\text{ in.}^3$$

The bending moment produced by the resultant of the shear stresses:

$$M=f_c\times 6\times 4.75/3\times 4.75/4=11.28\ f_c$$
$$f_s=20{,}000=M/S_s=f_c\times 11.28/0.5625=20\ f_c$$
$$f_c=20{,}000/20=1{,}000\text{ p. s. i.}$$
$$F=9.5\times 1{,}000=9{,}500\ p$$

Both *a* and *b* give the same value.

Spacing required=9,500/2,500=3.8 in.

Weight of connectors per ft. of beam:

$$6/2\times 12.11/3.8=9.58\ p.$$

2. *Design of rectangular plate*

Assumption: plate of ¾'' thickness, 6'' base and 4¾'' height.

a. Allowable load with respect to concrete stress:

$$F=f_c\times 6\times 4.75/2=14.25\ f_c=14{,}250\ p$$

b. Allowable load with respect to steel stress: The section modulus is the same as under 1*b*.

$$S_s=0.5625\text{ in.}^3$$

The bending moment produced by the shear stresses:

$$M=f_c\times 6\times 4.75/2\times 4.75/3=22.675\ f_c$$
$$f_s=20{,}000=f_c\times 22.675/0.5625=40.0\ f_c$$
$$f_c=20{,}000/40.0=500\text{ p. s. i.}$$
$$F=14.25\times 500=7{,}125\ p$$

Therefore the steel stress governs, and the spacing required=7,125/2,500=2.85 in.

Weight of connector per ft. of beam:

$$6\times 12.11/2.85=25.5\ p$$

The triangular plate connector saves 62% in weight as compared with the rectangular plate connector. Besides the rectangular plate connectors are spaced only 2.85'' apart which is by far not enough to transmit the stresses safely into the concrete. No doubt the concrete protruding into the space between two plates would shear off. With the triangular plates the spacing is 3.8'' which still would not be enough for rectangular plates, but it is sufficient for a triangular plate because if placed as shown in Figure 1, the spacing for most of the compressive area is 2×3.8=7.6 in.

The triangular plate connector has another advantage. A timber, such as a 4'' x 4'' or 3'' x 3'', can easily be placed on top of the connector in the center, along the beam, and will be held well in place by the two inclined edges of the shear connectors. A working platform can easily be built on top and nailed to these longitudinal wood supports. These connectors do not at all interfere with the placing of the slab reinforcement, as is well shown by Figs. 1 and 2. They are also much less vulnerable to damage than, for instance, a spiral connector.

Figure 3 shows triangular shear connectors **12**, **13** and **14** welded perpendicularly to the top flange **2** of beam **1**. Connectors **12** and **14** are welded on one side of the beam and on the other side, in the center between them, is welded con-

nector 13. This arragnement doubles the shearing area of the concrete and makes for better lateral distribution of the compressive stresses in the concrete.

Because the direction of the horizontal shear near the supports is at an angle to the horizontal, the shear has a vertical component and the connectors must be able to take care of it. With triangular connectors this can be done by welding a horizontal bar 15 to connector 16, or by placing the connector at an acute angle to the top flange 2, as shown by connectors 17 and 18 and in Figure 2. For the same purpose the top of the triangular connector can be bent to form a hook, as shown by connector 19. Instead of straight bar 15 a hooked bar may be welded to the connector.

Figure 4 shows I-beam 1 which may be a rolled section with or without a cover plate or a built-up section, and having a top flange 2. Shear connector 20 has the shape of a channel with flanges 21 and 22, and to take advantage of the section modulus of the web and both flanges, the triangular section is modified to become a trapezoid. This reduces in part the advantages of the purely triangular section, but makes the channel still more economical than any other way. The channel could also be used with the flange 21 sitting on top of the beam flange 2 and flange 22 would reach into the concrete and form an anchor to resist uplift forces. However, this would be a more expensive channel connector than the one shown in Figures 1 to 3.

Connector 23 is in the shape of a pyramid, and, therefore, its cross-section is better adjusted to the bending moment than a connector of triangular shape. Compared with connectors 3 and 4 or 12 to 14 it has one-third less weight, but cannot be cut from standard rolled sections.

24 and 25 show connectors cut in triangular shape from T sections. The triangular shape of a T connector is more economical if the T connector is governed by the steel stresses, and not the concrete stresses. The upper part of connector 25 is bent to provide effective anchorage in the concrete slab.

If the unit shear is not very high or connectors are used that have a great section modulus, the spacing will be increased enough to place the connectors in the center of the beams, as shown by connector 20. If the width of the connectors is small two may be placed at the same level, as shown by connectors 24 and 25.

Although the invention has been described by several specific examples of various connectors, the invention is not limited thereto, since any shear connector, the design of which is governed by the bending moment produced by the shear stresses will profit by a triangular shape. Other forms than those specifically described may be used, as, for instance, the shape of the triangles may be different from those shown, as, for example, they may be equilateral, scalene, or other forms. The connectors need not be true triangles, but the benefits of the present invention are obtained when connectors are approximately or roughly triangular, as, for example, the sides need not be straight, but there may be some curvature therein either concave, convex or combinations.

In the claims the term "beam" is intended to include not only the standard commercial shapes, but any built up welded or riveted beam section, as well as trussed joists that may be rolled or welded, and the term "triangular" is intended to include an approximately triangular form and also shapes wherein the edges are other than straight lines.

What I claim is:

1. A composite structure comprising a beam having a top flange, said flange having an unbroken surface and having parallel side edges, a plurality of shear connectors of triangular form, one edge of each connector resting on said flange and extending from the side edge of said flange to at least the center-line of said beam at right angles to said side edges, said connectors being adjacent both of said side edges and being welded to said flange.

2. A composite structure comprising a beam having a top flange, said flange having an unbroken surface and having parallel side edges, a plurality of shear connectors of triangular form, one edge of each connector resting on said flange and extending from the side edge of said flange to at least the center-line of said beam at right angles to said side edges, said connectors being adjacent both of said side edges and being welded to said flange, the face of said connectors being inclined to the surface of said flange.

3. A composite structure comprising a beam having a top flange, said flange having an unbroken surface and having parallel side edges, a plurality of shear connectors of triangular form, one edge of each connector resting on said flange and extending from the side edge of said flange to at least the center-line of said beam at right angles to said side edges, said connectors being adjacent both of said side edges and being welded to said flange, an extension on said connectors at right angles to the face thereof fixed on said flange.

4. A composite structure comprising a beam having a top flange, said flange having an unbroken surface and having parallel side edges, a plurality of shear connectors of triangular form, one edge of each connector resting on said flange and extending from the side edge of said flange to at least the center-line of said beam at right angles to said side edges, said connectors being adjacent both of said side edges and being welded to said flange, pairs of said connectors being in alinement transversely of said flange and in substantial contact with each other.

5. A composite structure comprising a beam having a top flange, said flange having an unbroken surface and having parallel side edges, a plurality of shear connectors of triangular form, one edge of each connector resting on said flange and extending from the side edge of said flange to at least the center-line of said beam at right angles to said side edges, said connectors being adjacent both of said side edges and being welded to said flange, the highest point of said connectors being above said side edge, said connectors sloping from said point to said surface.

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