Welded Connections for Vierendeel Trusses

1. ADVANTAGES OF VIERENDEEL TRUSSES

A Vierendeel truss is in effect a rigid frame. It differs from the simple truss (Sect. 5.9), but it also differs in some respects from the usual rigid frame (Sect. 5.11).

Although the Vierendeel truss has been used widely in European bridge design, the relatively high cost of riveted construction precluded its early popularity in this country. Modern welding processes have changed the economics and several structures using the welded Vierendeel truss have been built here in recent years.

Currently the major field for welded Vierendeel trusses is in building design; Figure 1. For example, they have been used as roof supports to carry the extra load of a superstructure, as exterior floor-high members for rigid support of heavy masonry walls, and in exterior wall grid systems for aesthetic value as well as construction advantages.

In exterior use, the large panel areas provide adequate window area to be filled in by glass or translucent materials; chord and web members are sometimes faced with masonry. When used as interior members, the web openings permit savings in space since piping, conduits, and ducts may be fed through them.

Some Vierendeel trusses are fabricated from wide-flange beams, as shown at the top in Figure 2. Here the top and bottom chord members, as well as the verticals, are standard rolled beams. Additional plates are used to join these members.

At the center in Figure 2, the vertical rolled sections are extended all the way to the top and bottom members. A triangular gusset section or bracket is insected on each side of the connection. These gussets are flame cut from standard rolled sections, usually having the same flange width as the other members. This is a simpler method and therefore is widely used. However, it does not result in as smooth stress distribution at points of high bending moment as does a design with curved corners.

Another method of achieving these curved corners is illustrated at the bottom in Figure 2. Here the truss is flame cut from flat plate with flanges welded to it around the web openings and across top and bottom edges. Also see Open-Web Expanded Beams, Section 4.7.

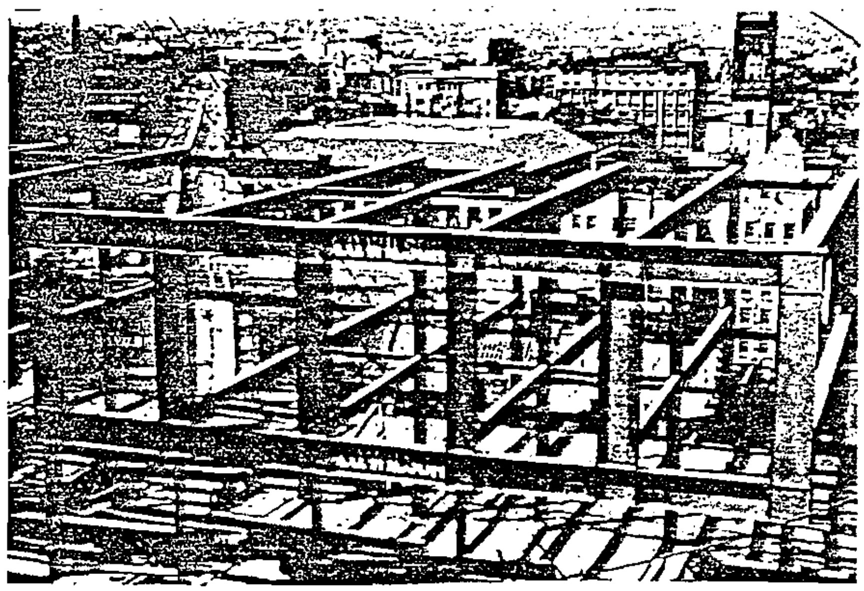


FIGURE 1

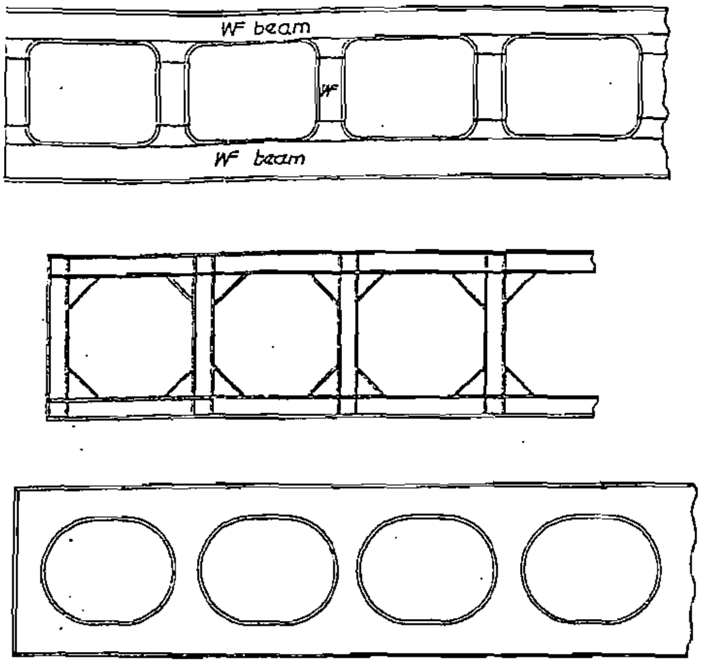


FIGURE 2

2. BASIC CONNECTION REQUIREMENTS

In the usual rigid-frame design certain assumptions are made: the beams and columns deflect, and the connections rotate; but within the connection itself, there is no appreciable movement. Of course the connection does undergo some movement (not to be confused with rotation). However, the distances over which this movement takes place are small compared with the lengths of the beams and columns. Consequently the movement within the joint has little effect on the final moment distribution in the frame.

The Vierendeel truss on the other hand is more compact; for example, the lengths of the vertical members often are relatively shorter. See Figure 3. The more massive connections thus occupy a larger portion of this frame than most others. Any angular movement of vertical members due to yielding within the connection itself will greatly increase the moments in horizontal members. There is no method of computing or predicting how much the connection will yield; therefore, every effort must be made to provide a connection at least as rigid as the adjoining members.

It might be thought that the simple square type of connection would naturally be as rigid as the members, since it is a continuation of the same section. In many cases this is true. However, it might be well to remember that stress causes strain, and the accumulation of strain over a distance results in appreciable movement of some kind: deflection, angular movement, etc. The sharp corner of this connection increases the stress in this area by several times. This stress concentration results in a higher strain and therefore greater movement in this small area. Since only flange stiffeners are added to this square-cornered connection, it is difficult to exceed the stiffness of the member. In most cases, it will just equal the member, and in some cases it will be less.

3. PLASTIC DATA HAS APPLICATION

There is little test data on the connections used in the Vierendeel truss. However, data available on the plastic design of corner connections or knees will be helpful.

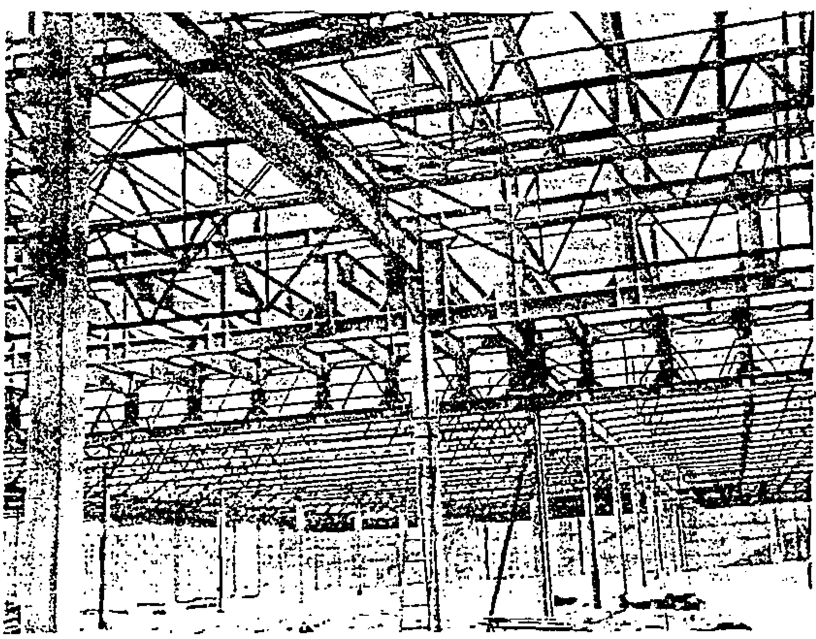


FIG. 3—In this building addition, use of Vierendeel trusses will provide a column-free area of about 30′ x 60′ for large trucks and trailers to load and unload communications equipment.

FIGURE 4

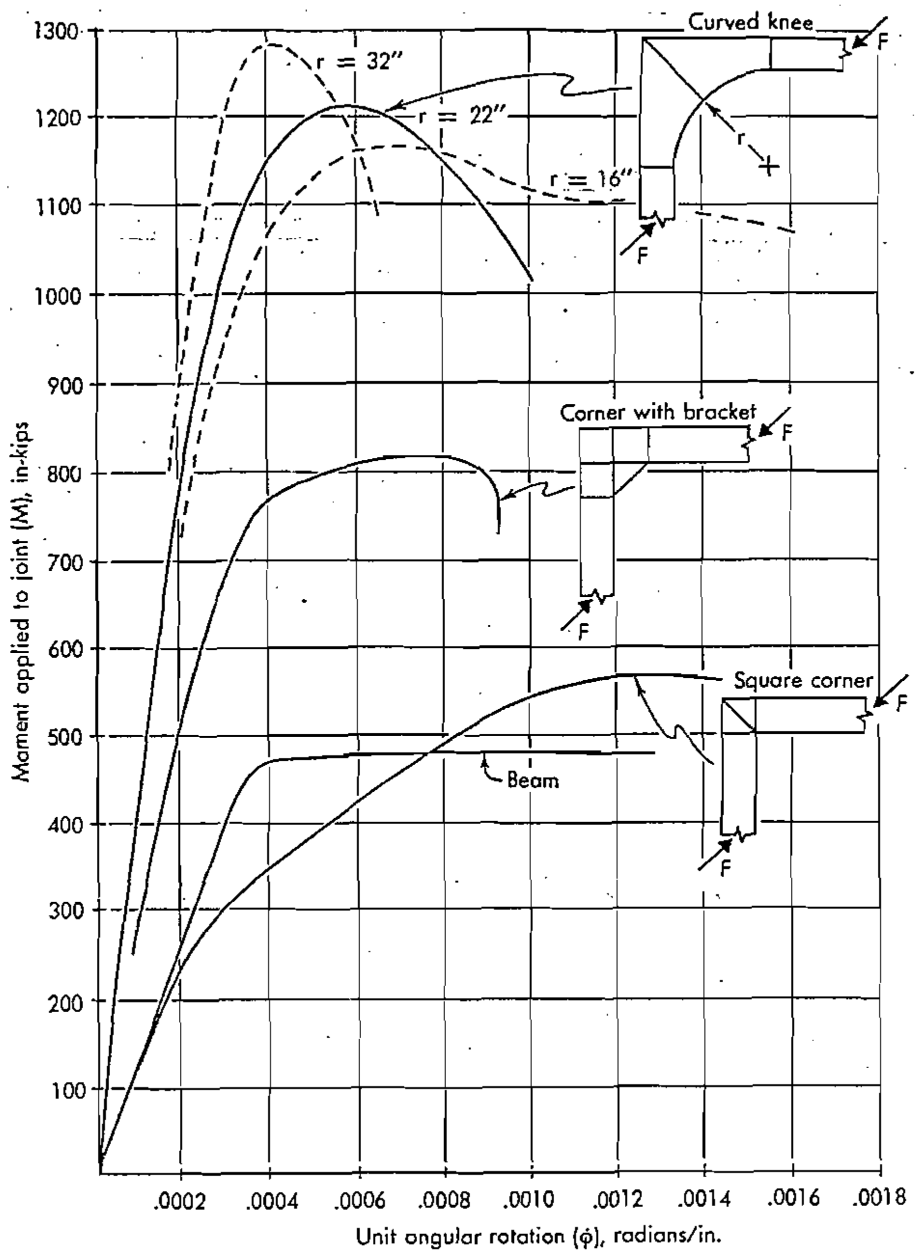


Figure 4 shows moment-rotation curves of various corner connections.* The vertical axis is the applied moment; the horizontal axis is the resulting rotation of the connection. The vertical height of the curve represents the maximum or ultimate strength moment of the connection. The slope of the straight portion of the curve represents the stiffness of the connection, with the more nearly vertical curves representing the stiffer connections. The right-hand extremity of the curve represents the rotational capacity of the connection.

In plastic design, it is necessary that the connection have high rotational capacity in addition to exceeding the moment capacity of the member. In Vierendeel trusses, it is more important that the connection have a stiffness equal to or exceeding that of the member, and a high moment capacity in order to safely carry accidental overloads. Here the extra rotational capacity would not be as important because it is an elastic design rather than a plastic design.

In Figure 4 notice that the square-corner connection is the most flexible. It falls slightly short of the beam itself, but does have the greatest rotational capacity. The corner with the bracket has greater stiffness and higher moment capacity, but less rotational capacity. Tapered haunch knees, not shown here, were found

* Figure 1 adapted from "Connections for Welded Continuous Portal Frames", Beedle, Topractsoglou and Johnston; AWS Journal; Part I July 1951, Part II August 1951, and Part III November 1952.

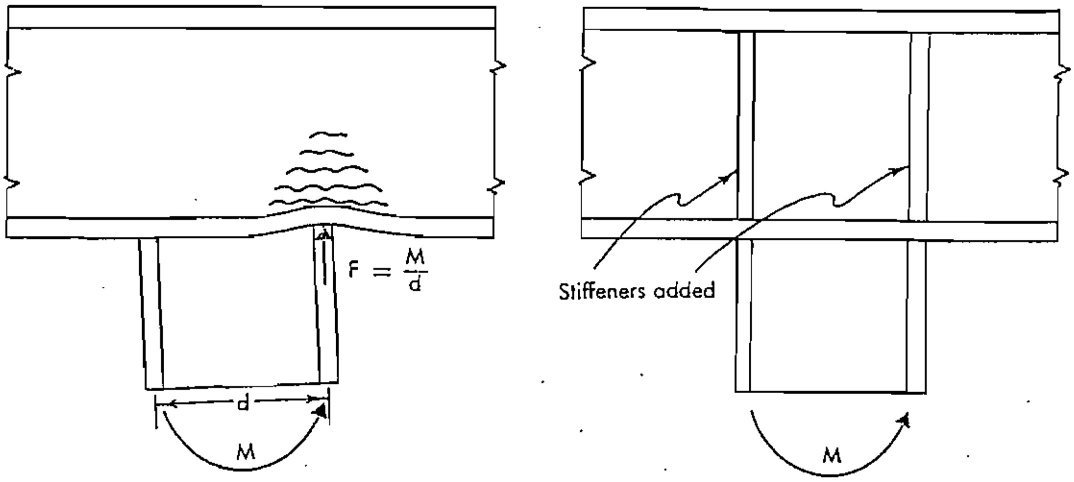


FIGURE 4

to behave similarly. The curved knees are the most rigid, have the highest moment capacity, and have a rotational capacity somewhere in between the simple square corner and the haunched knee. As the radius of curvature of this inner flange is increased, the stiffness and moment capacity increase slightly, with slightly lower rotational capacity.

4. SQUARE CONNECTIONS

When the flanges of one member intersect the flange of another, stiffeners should be added in line with the intersecting flanges. The stiffeners transfer the forces of the flange back into the web of the other member. See Figure 5. These flange forces are distributed as shear into the web along the full web depth. This will prevent the web from buckling due to the concentrated flange forces.

The unbalanced moment about a connection will cause shear forces around the periphery of the connection web, Figure 6. The vertical shear force and the horizontal shear force will result in a diagonal compressive force applied to the connection web. Unless the web has sufficient thickness or is reinforced, it may buckle. According to plastic design (and this may be used in elastic design), the required thickness of the joint web must be—

$$\tau\, t_w = f_v = \frac{F_h}{d_v} = \frac{M}{d_h\, d_v}$$

and:

$$\boxed{t_w = \frac{M}{d_h\, d_v\, \tau}} \qquad \text{(1)}$$

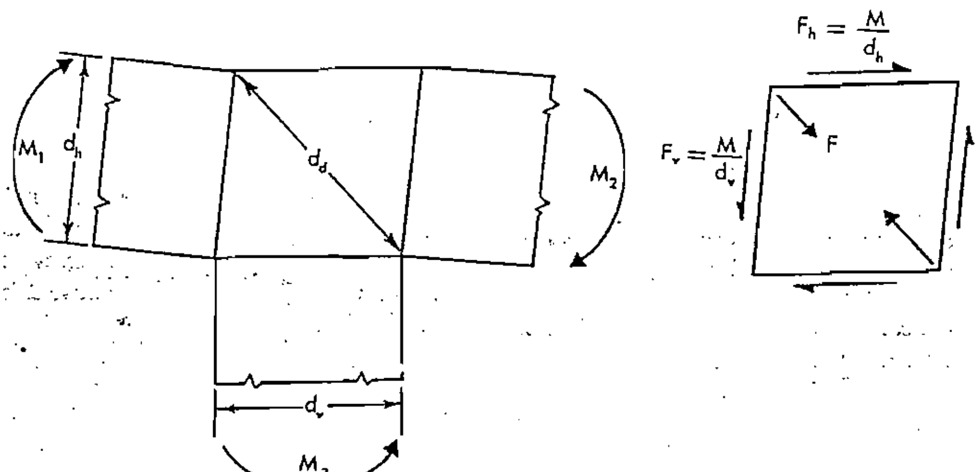


FIGURE 6

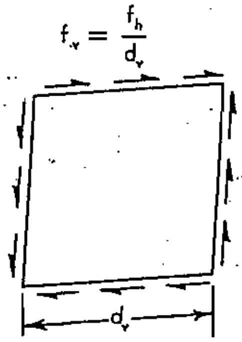


FIGURE 7

where:

t_w = thickness of connection web, inches

f_v = unit shear force, lbs/linear inch = $\tau\, t_w$

d_h = depth of horizontal member, inches

d_v = depth of vertical member, inches

M = algebraic sum of clockwise and counterclockwise moments applied by members framing to opposite sides of the joint web boundary at ultimate load, inch-pounds

For a panel subjected to shear forces and having a ratio of width to thickness up to about 70 (the connection webs will almost always be within this value), the critical shear stress (τ_{cr}) equals the yield shear stress (τ_y), or—

$$\tau_{cr} = \tau_y \quad \text{and}$$

$$\tau_y = \frac{\sigma_y}{\sqrt{3}} \quad \text{or:}$$

$$\boxed{t_w \geqq \frac{\sqrt{3}\, M}{d_h\, d_v\, \sigma_y}} \qquad (2)$$

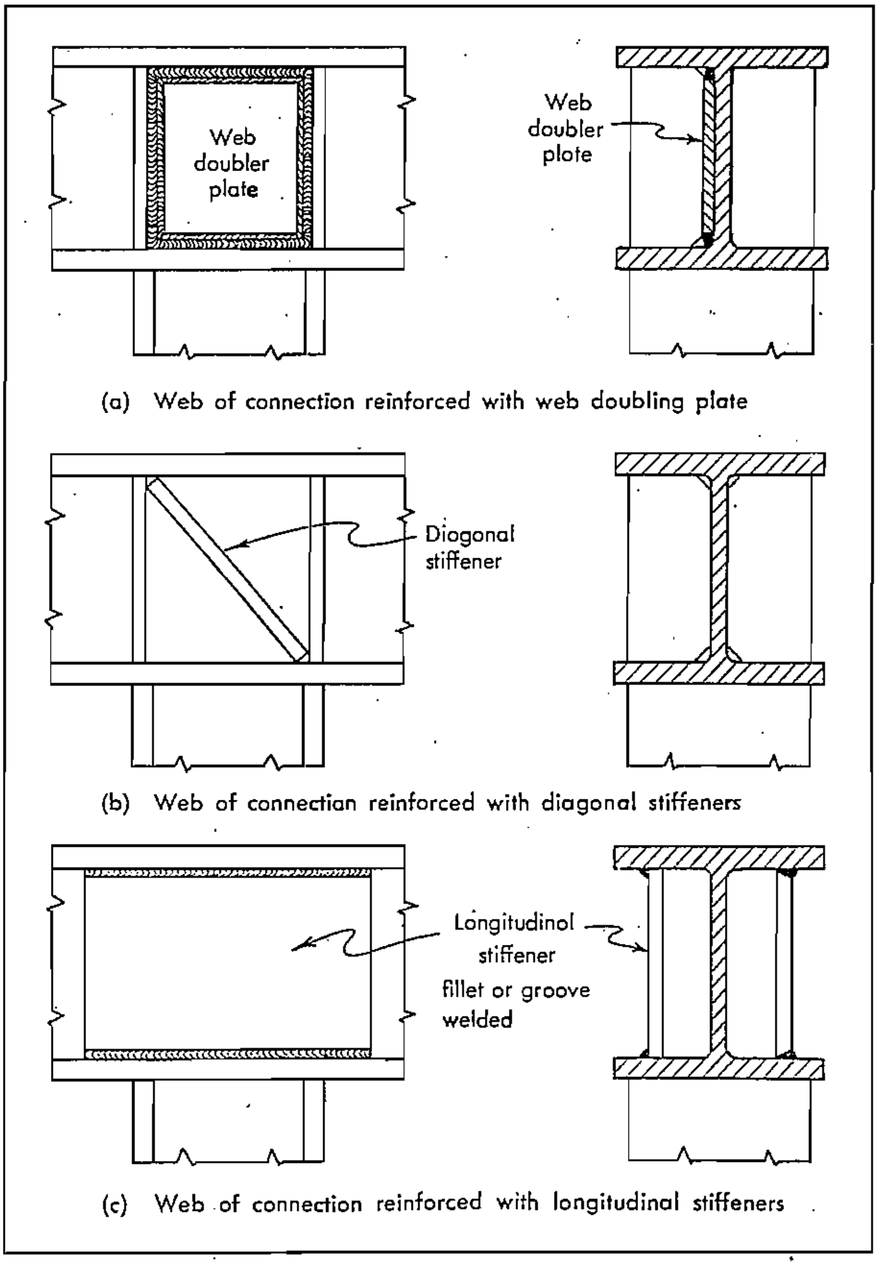


FIG. 8 Methods of obtaining web thickness to meet requirement of Formula #2.

If the thickness of the connection web should be less than this required value, AISC in their work on Plastic Design (which may also be used in Elastic Design) recommends adding either (a) a doubler plate to the web to get this required thickness, see Figure 8, or (b) a pair of diagonal stiffeners to carry this diagonal compression, the area of these stiffeners to be sufficient for just the additional requirements.

It seems reasonable that (c) a pair of longitudinal stiffeners extending through the connection area would be sufficient to resist this web shear. These stiffeners would be flat plates standing vertically between flanges of the chord member and welded to the flanges near their outer edges.

5. CURVED-KNEE CONNECTIONS

Tensile stress (σ_{mean}) in the inner flange of a curved knee tends to pull the flange away from the web, and to bend the curved flange as shown at the lower right of Figure 9. Because of the slight yielding of the flange's outer edge, there is a non-uniform distribution of flange stress (σ). This stress is maximum in line with the web.

In addition there is a transverse tensile bending stress (σ_t) in the curved flange. If this value is too high, stiffeners should be welded between this flange and the web. These keep the flange from bending and pulling away from the web. These stiffeners usually need not extend all the way between flanges, but may be a series of short triangular plates connecting with the curved flange.

In the following formulas, the values of factors α and β come from the graph, Figure 10.*

longitudinal tensile stress in flange

$$\boxed{\sigma_{max} = \frac{\sigma_{mean}}{\alpha}}^{\,*} \qquad (3)$$

transverse tensile bending stress in flange

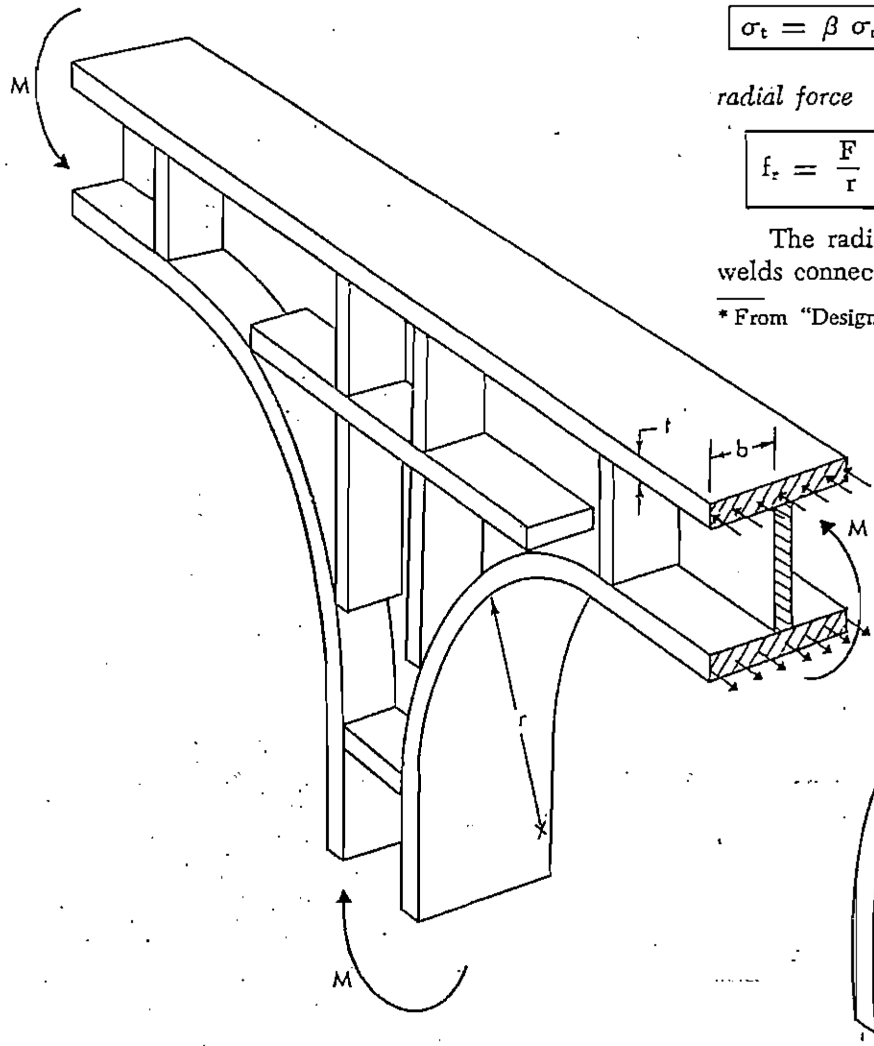
$$\boxed{\sigma_t = \beta\ \sigma_{max}}^{\,*} \qquad (4)$$

radial force

$$\boxed{f_r = \frac{F}{r}} \qquad (5)$$

The radial force (f_r) acts transverse to the fillet welds connecting the flange and the web.

* From "Design of Rigid Frame Knees", by F. Bleich, AISC.



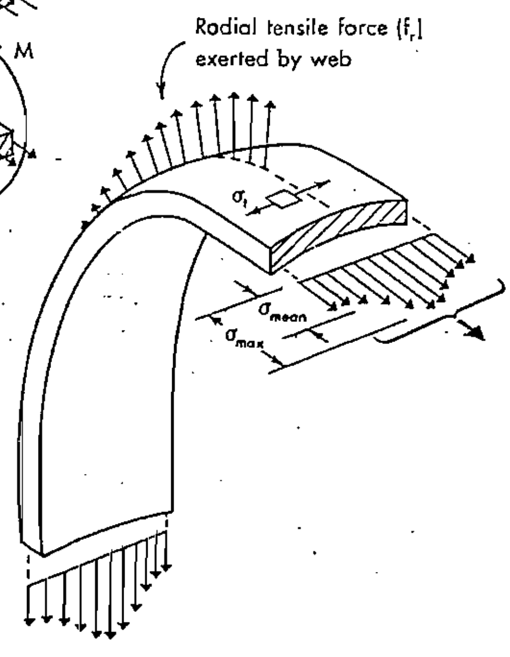


FIGURE 9

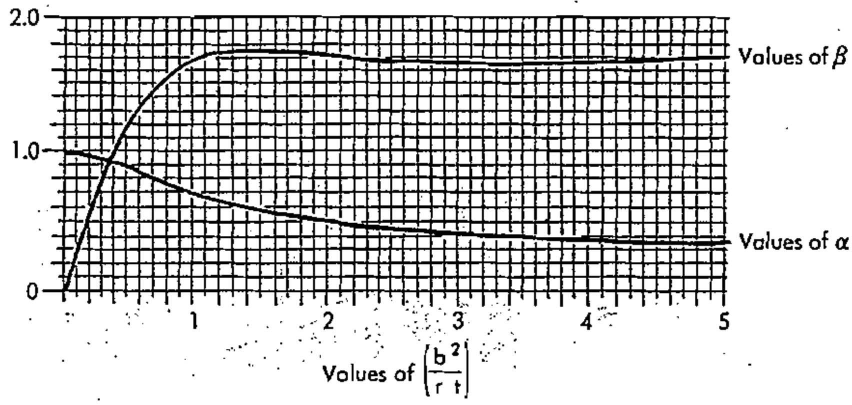


FIGURE 10

6. SUMMARY OF REQUIREMENTS

Here is a summary of the general requirements for these Vierendeel truss connections:

1. The bottom chord is in tension and the connections here must provide continuity of the member for this tensile force; the top chord is in compression and the connections here must provide continuity of the member for this compressive force. For these reasons, the inside flanges of the horizontal chords should be made continuous throughout the connection.

2. There may be some axial tension or compression in the vertical member, but this is usually of a smaller magnitude.

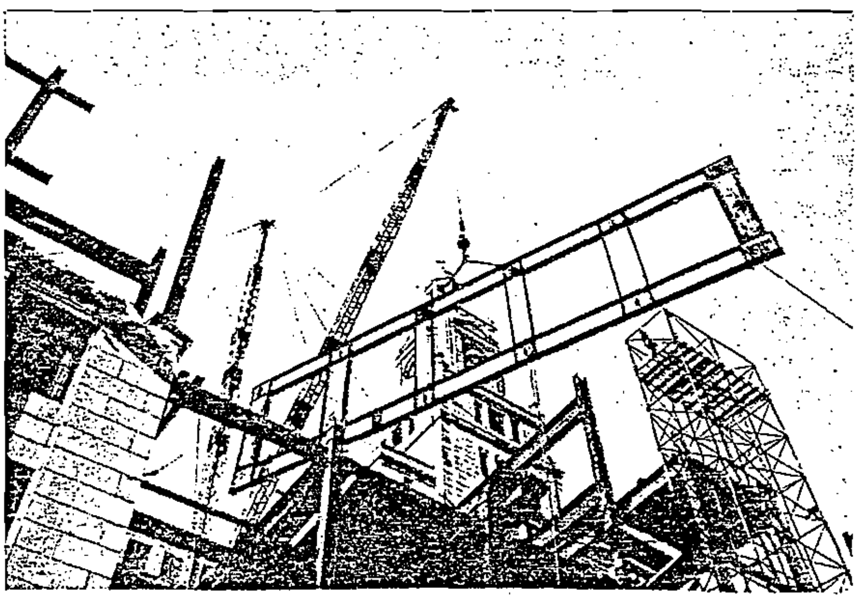
3. Large moments are applied by the horizontal and vertical legs to each connection.

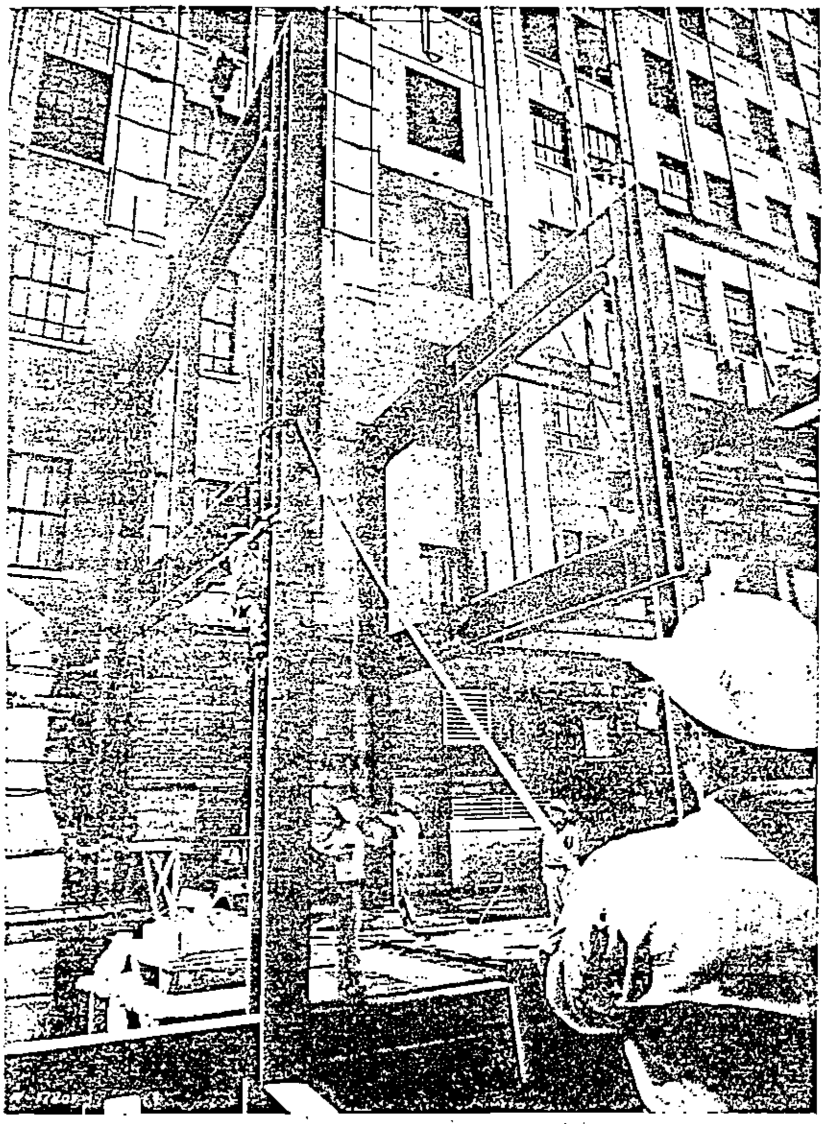
4. A pair of connections, one above the other, tend to be restrained from rotation by the vertical member which connects them. The rotation of these connections due to deflection of horizontal and vertical members is taken into consideration when the truss is designed. However, yielding within the connection itself is not considered in the design and this could alter the moment distribution of the truss, therefore it is important that the connection have equal or greater stiffness than the members connecting to it.

5. The web of the connection must be stiffened against buckling due to the high shear stress resulting from the unbalanced moment of the two horizontal members connecting at the joint. This difference in moment is equal to the moment applied by the vertical member also connected there. This web must either have sufficient thickness or be reinforced with a doubler plate or some type of stiffeners.

6. Flange stiffeners should be used whenever there is an abrupt change in direction or curvature of the flange.

Vierendeel trusses in this addition to the New England Life Insurance Co. home office building permitted architect to match window openings in original buildings, yet accomplish significant savings in steel and in floor space. Design also provided stiffer construction, reducing danger of cracked masonry.





Use of Vierendeel trusses here provided a column-free area of about 30′ x 60′ for large trucks and trailers to load and unload communications equipment.