

Horizontal Bracing

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An overview of lateral load resisting systems and how to implement them.

IN MOST COMMERCIAL BUILDINGS, floor and roof diaphragms are used to distribute loads in the horizontal plane of the structure to the lateral load resisting system. Due to the open nature of most industrial structures, diaphragms are not present, and horizontal bracing is often used to distribute the loads in the horizontal plane. Horizontal bracing is also used in heavily-loaded commercial structures, where a diaphragm is not present, or where the strength or stiffness of the diaphragm is not adequate.

When horizontal bracing is used, the beams at that elevation become members in a horizontal truss system, carrying axial loads in addition to the normal bending and shear gravity loads. Careful attention should be paid to the beam end connections within the truss system because the axial loads transferring through the connections can be large.

Selection of Structural Shapes

The most common shapes used for horizontal bracing are single angles and WT-shapes. Single angles are the most economical shape for resisting small and medium loads, because WT-shapes must be split from W-shapes and straightened by the fabricator. WT-shapes can be used to resist larger loads and where long spans are required.

Double-angles can be used in lieu of WT-shapes, but corrosion of the steel in the area between the angles can be a problem for exposed structures. If the original protective coating fails, it is difficult to recoat the area between the angles. In exposed

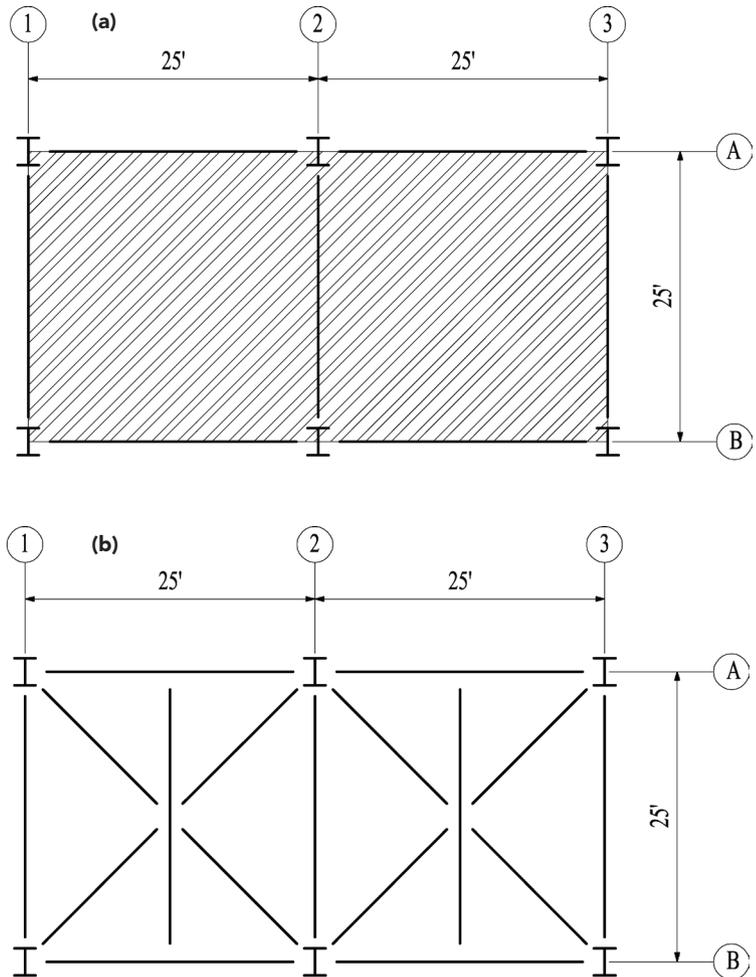


Fig. 1: (a) Horizontal diaphragm and (b) bracing systems.



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structures, stitch plates in double-angle braces should be bolted, due to limited access for welding between the angles. With bolted stitch plates, the angles are bolted together after they have been coated (painted or galvanized).

For very large loads, W-shapes can be used. For buildings with very light loads, rod bracing is commonly used. Sometimes, architects prefer the use of HSS when the bracing is exposed to view.

In open structures, the member should be rotated to the position that is least likely to collect dust, debris, and/or rainwater. Angle legs and WT stems usually are oriented downward, and W-shapes normally are designed with the web oriented vertically.

Design Considerations

Although the dominant load in a horizontal brace is axial load, the effect of bending moments should be accounted for in the design. The moment due to self weight can be significant for long, slender braces.

The details of the connections also may result in moments. It is preferable to bolt single-angle braces through the horizontal leg and WT braces through the flange as shown in Figure 2. Because there is an offset between the centroid of the brace and the gusset plate, the eccentric moment, $M = Pe$, must be accounted for in the member design, and this can significantly lower the member strength. For preliminary design of WT braces connected through the flange, a good starting assumption is that the moment consumes half the strength of a concentrically loaded brace.

Because the length-to-depth ratio for horizontal bracing members can be very high, large deflections under self weight are possible. This can lead to large second order moments, and serviceability problems due to sagging of the brace as shown in exaggerated fashion in Figure 3. Also, in industrial structures with vibrating machinery, large length-to-depth ratios can lead to vibration problems. A rule of thumb that can be used to determine an approximate preliminary brace depth is that the depth in inches should equal or exceed $0.006F_y$ times the span in ft.

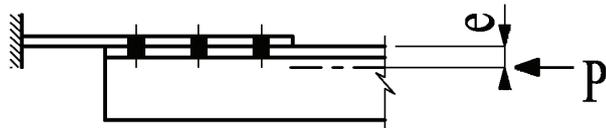


Fig. 2: Brace with an eccentric connection.

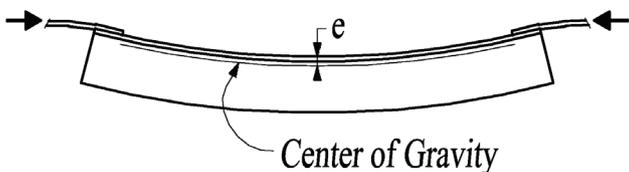


Fig. 3: Sagging brace member.

Brace Configurations

Bracing is most efficient when placed at angles between 30° and 60° . With steeper bevels, the end connections can be cumbersome. Any brace configuration can be used to make up a horizontal bracing system, as long as a complete load path is available to transfer the load into the lateral load resisting system. In most structures, the configuration is a secondary consideration, determined after the location of the main gravity load-carrying members is set.

Under most conditions, a single brace system is adequate; however, an x-bracing system can be used to reduce the buckling length of the compression brace in systems with long brace spans. If the braces are designed as a tension-compression system and are connected at the intersection, the intersection can be considered a brace point for both in-plane and out-of-plane buckling. If the braces are designed using a tension-only philosophy, it is recommended that they be connected at the intersection to reduce the possibility of serviceability problems due to the flexibility of the braces.

Minus Dimension

Horizontal braces typically are not located at the top of steel, because the connections can interfere with grating and decking. To indicate the elevation of the brace, a “minus dimension” is usually shown on the design drawings. The minus dimension is the distance from the reference elevation (top of steel, top of grating, top of concrete, etc.) to the top of the brace. Theoretically, the best location for the bracing is at the centroid of the beams, because this is where it is located in the structural analysis model (unless offsets are used in the model). However, this usually is not practical, because most structures are built with multiple beam depths within each bay. The minus dimensions are usually determined by the connection details and the depth of filler beams. In practice, the moments caused by the offsets between the brace centroid and beam centroid usually are neglected. The best practice for design drawings is to list the nominal minus dimension, which will allow some flexibility for the detailer to make minor adjustments where beam depths are slightly different within the brace span.

A simple example is illustrated in Figure 4 (following page). If the brace is placed 6 in. below the top of steel as shown in Figure 4a, gusset plates are required at the W14 web. The more economical solution is shown in Figure 4b, where the nominal minus dimension is 14 in., and the brace passes under the W14. The W14 filler beam in Figure 4a is more expensive to fabricate due to the gusset plates shop welded to the web. The extra bolts and extra shipping piece for the system in Figure 4a also make the arrangement more expensive to erect. Where braces pass under filler beams, they are usually connected to the bottom flange of the beam with two bolts as shown in Figure 4b. This reduces the buckling length of the brace and acts as a support to reduce the dead load moment and deflection.

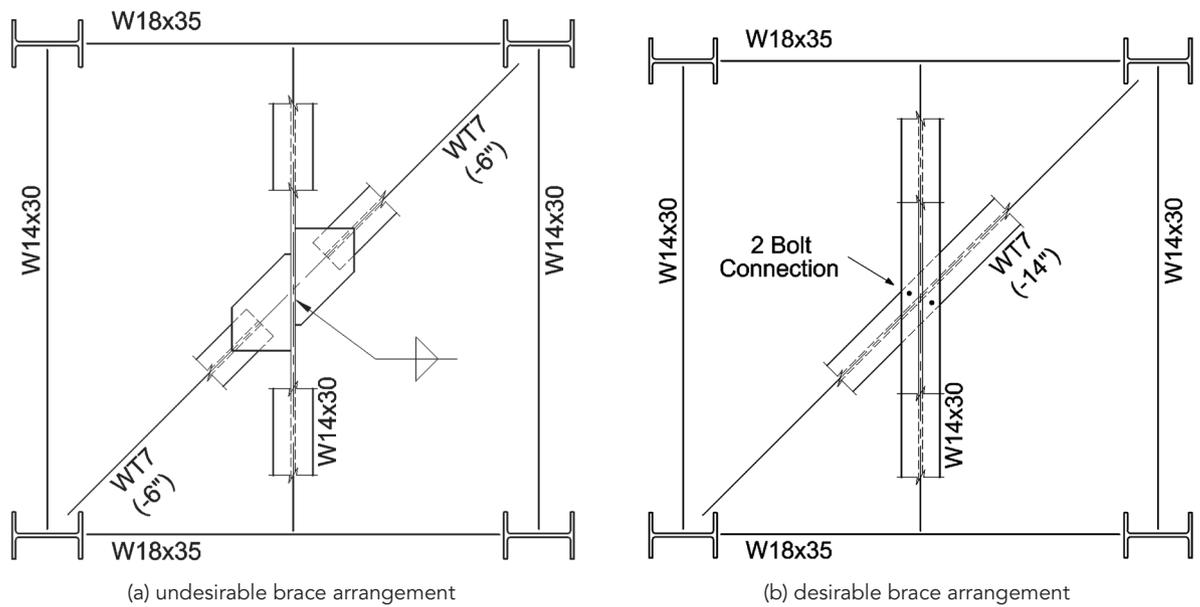


Fig. 4: Typical plan with horizontal bracing.

Connection Details

Figure 5a shows a typical horizontal bracing connection at a beam-to-beam intersection. Where horizontal bracing is located at a beam-to-column intersection, the gusset plate must be cut out around the column as shown in Figure 5b. These are called wrap-around gusset plates. At locations with large columns and heavy beam connection angles, a large area of the gusset plate must be cut out as shown in Figure 6 (opposite page). It is more economical for shops to cut square openings, but the optional diagonal cut shown at the inside corner of the plate can significantly increase the bending strength of the gusset plate legs. The optional cut at the outside corner is used to ensure that the maximum edge distance requirements in the AISC *Specification* are met.

Connections at the gusset-to-beam interface typically

are made with single clip angles on one side of the gusset. Usually the field bolts are easier to access when the clip angles are placed on the top side of the gusset. For larger loads, double clip-angles (one on each side of the gusset) are common. Figure 7 shows a detail where the nominal minus dimension is 14 in. A single clip angle is used to connect the gusset plate to the W18 beam. On the opposite interface, the gusset plate is bolted directly to the flange of the W14 beam. In practice, filler plates are common where the gusset is bolted directly to the beam flange, due to the varying depths of the beams within a braced bay.

Gusset plates usually are shop bolted to the brace for shipping to the field. This is more efficient for erection, because the single assembly can be located and oriented easier than if the brace were shipped separately from the

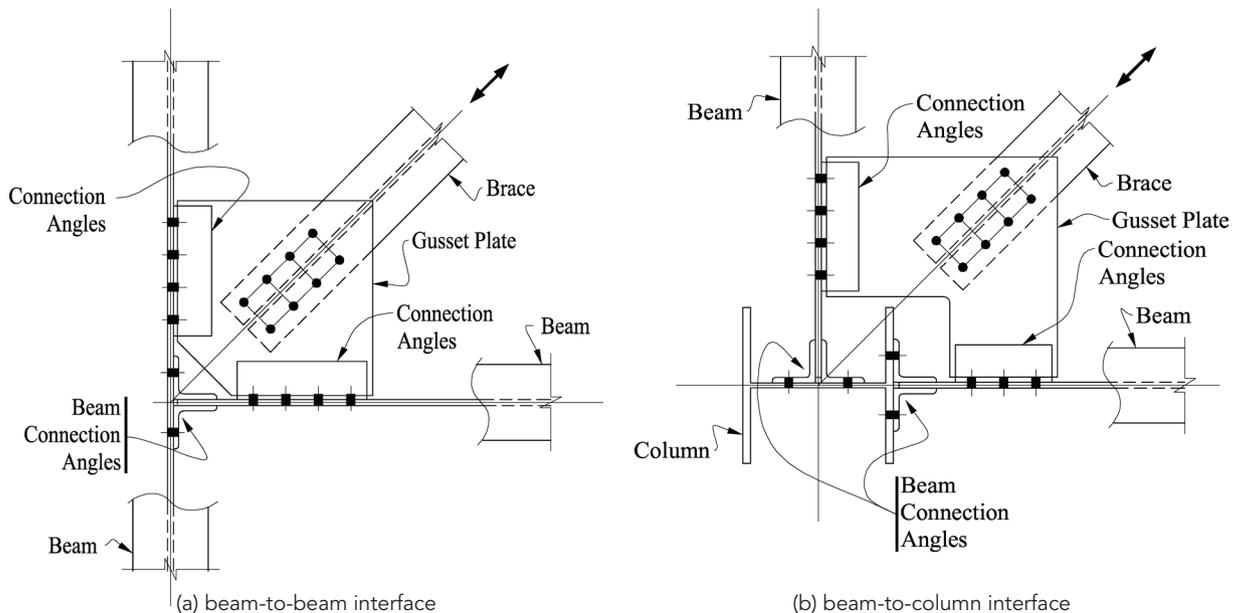


Fig. 5: Standard horizontal brace connections.

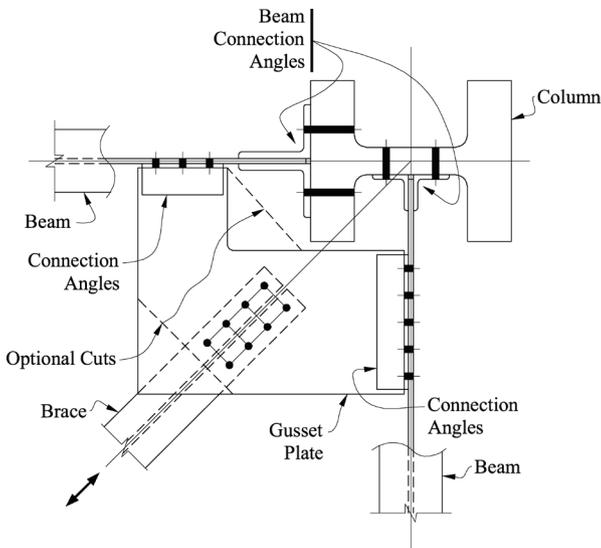


Fig. 6: Wrap-around gusset plate with a large cutout.

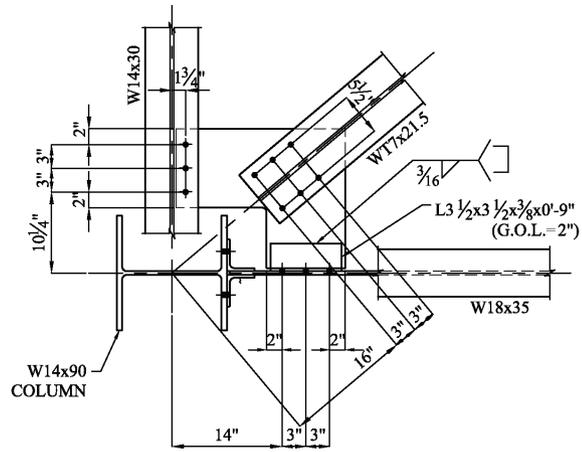


Fig. 7

Wrap-around gusset plate bolted to bottom flange of W14 beam.

gussets. On rare occasions, such as where shipping space is at a premium, it may be better to ship the pieces separately so they can be nested.

Connection Design

Although the force distribution in horizontal brace connections is indeterminate, the gusset-to-beam interface forces can be determined easily. Figure 8 shows a plan view of a horizontal brace connection at a beam-to-beam intersection. The engineer must assign a force path to distribute the axial load in the brace to the gusset-plate to beam-web interfaces. Using a deflection compatibility approach, the interface forces shown in Figure 8a are incorrect because the stiffness parallel to the beam webs is much greater than

the stiffness perpendicular to the beam webs. The small load entering the web in the transverse direction can be neglected, which results in the interface forces shown in Figure 8b. Additionally, the force distribution in Figure 8b uses the simplest and most direct path to get the components of the brace force directly into the beams.

Gusset plates are designed so the stresses on any cross section of the plate are lower than the design stresses. The selection of the most highly stressed section is at the discretion of the Engineer-of-Record and is based on judgment and experience. Traditionally, beam equations have been used to determine the stresses at the critical sections, and the normal stress and shear stress are usually considered separately. **MSC**

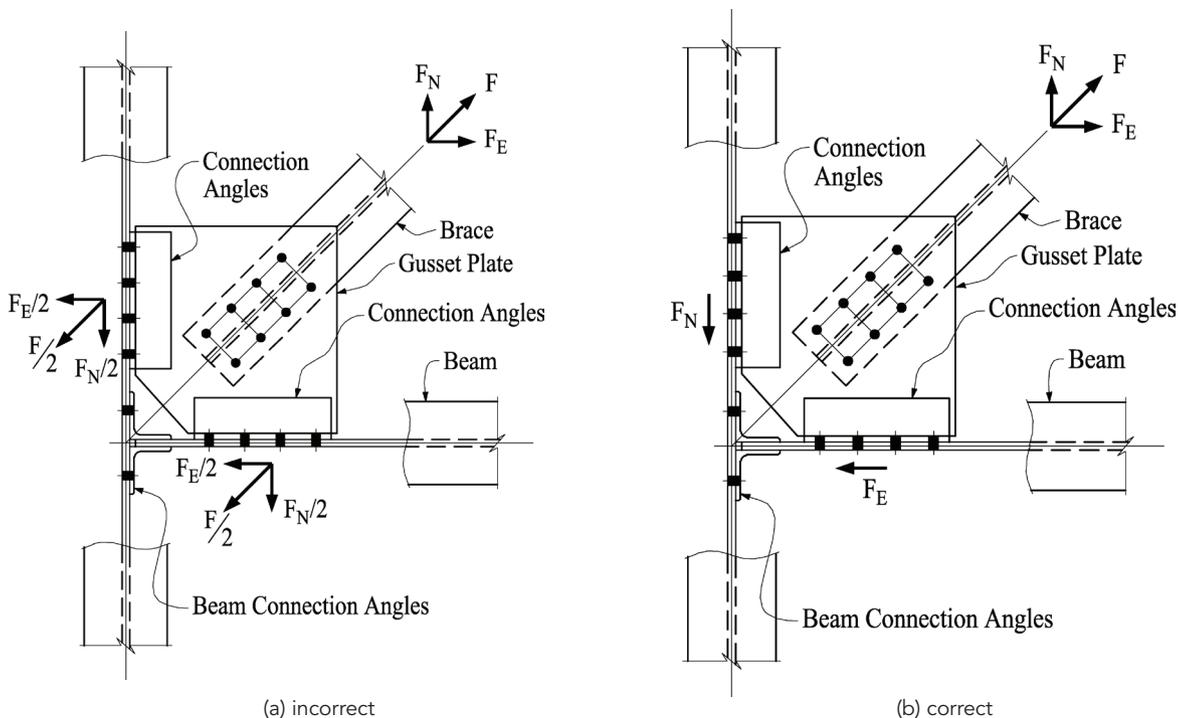


Fig. 8: Horizontal brace connection with incorrect and correct force distribution.