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The Whitmore Section

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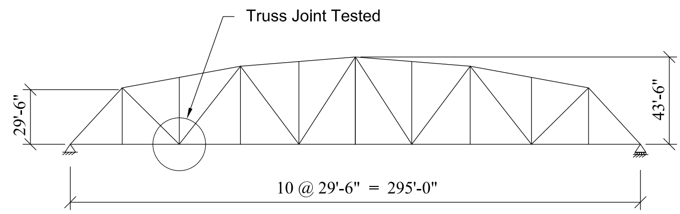
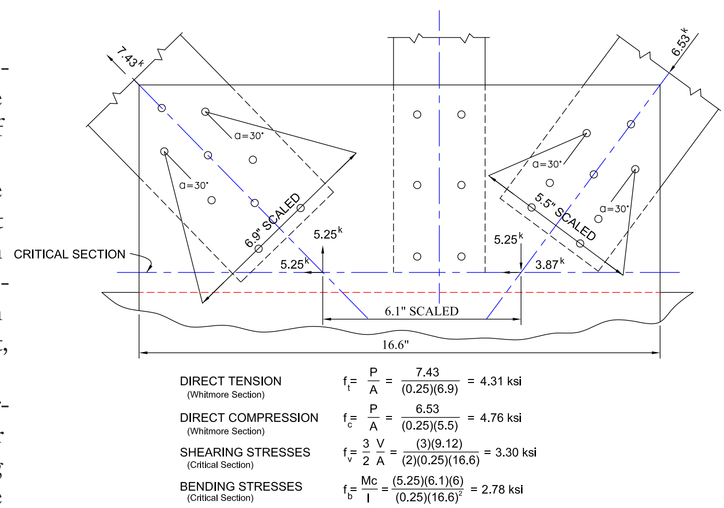
How to use the Whitmore method for tension and compression strength checks.

ANYONE WHO HAS HAD THE TASK of designing a bracing or truss connection has probably come across the Whitmore section. For most cases, the method is simple and straightforward. However, there are situations where determining the Whitmore section along with the tension and/or compression checks that follow are not quite so clear. This article addresses potential areas of confusion, and provides the reader with background information on the development of this approach.



▲ **Fig. 1:** Truss outline (Whitmore, 1952).

▼ **Fig. 2:** Stress distribution using Whitmore method (Whitmore, 1952).



Whitmore 101

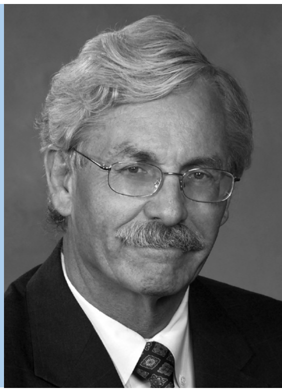
First, it's important to recognize what the Whitmore section is. It is a simple way to determine how force from a brace spreads through a gusset plate. It's used to make checks of gusset plate yielding and buckling possible.

Gusset plates have been used in steel structures since the earliest metal trusses. However, research in the early part of the 20th century regarding the distribution of stresses in gusset plates under tension or compression loading was limited. R.E. Whitmore made note of this lack of knowledge in 1952, providing the following 1941 quote from T.H. Rust, who had conducted earlier tests on gusset plates:

> "It is difficult to believe that there is a more important or more fundamental problem in need of further investigation in the field of structural engineering than steel gusset plates. They constitute a formidable problem in stress analysis capable of further exploitation in the laboratory…"

In an attempt to better understand gusset plates, Whitmore conducted a test on a mock-up of a truss joint connection for a 295-ft truss that was constructed at quarter scale (see Figure 1). Armour T. Granger, head of the Civil Engineering Department at the University of Tennessee during that time, had been interested in gusset plate stresses, most likely as a result of his work experience in bridge design while at Ash, Howard-Needles and Tammen. It was upon Granger's suggestion, and under his supervision, that Whitmore conducted this test. Based on the test results, Whitmore concluded that stresses occurred on the gusset plate as shown in Figure 2.

This article focuses on the direct tension and compression stresses on the Whitmore section. It is also important to note that some of the conditions presented in this article were not tested by Whitmore, but are what we believe are reasonable answers to questions we have received.



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Although Whitmore's findings were published in May, 1952, widespread use of the Whitmore section did not occur until the late 1970s. In fact, the method was not widely presented to the engineering community until 1974, when it was discussed in Fisher and Struik's *Guide to Design Criteria for Bolted and Riveted Joints*.

These Days, It's in the *Manual*

An explanation of how to calculate the Whitmore section is provided in Part 9 of the 14th Edition AISC *Manual*. A figure is also provided in the *Manual* (Figure 9-1) to aid the user and is shown here in Figure 3.

The Whitmore section is used to determine the peak tension or compression stress of an uneven stress distribution at the end of the joint. It does this by establishing an effective length, which Whitmore determined could be calculated by spreading the force from the start of the joint, 30° to each side in the connecting element along the line of force. The most common application of the Whitmore section is in gusset plates for bracing and truss connections. Figure 4 shows a gusset plate that has failed in tension rupture after significant tension yielding at the Whitmore section. The predicted strength was in good agreement with the measured failure load.

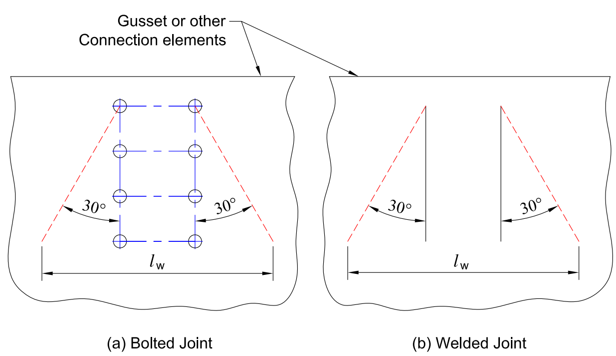


Fig. 3: Illustration of the width of the Whitmore section.

Fig. 4: Tension rupture of Whitmore section.

Tom Murray/Virginia Tech

The AISC Design Examples that complement the 14th Edition AISC *Manual* contain numerous examples of how to calculate the Whitmore section, along with how it is used in determining the tension yielding or compression buckling strengths of the gusset plate. These examples are also available online at **www.aisc.org/epubs**. To calculate the tension yielding and compression buckling strengths of a gusset plate, where the Whitmore section occurs over both the gusset and beam web, Example II.C-2 in the AISC Design Examples illustrates the process. Additionally, Examples II.C-1, II.C-2, II.C-5, II.C-6, II.D-1 and II.D-3 all contain calculations for the Whitmore section.

Areas of Possible Confusion

There are several predictable areas where confusion can arise in dealing with a Whitmore section. We will address these individually.

When the effective width crosses a connected edge. Part 9 of the 14th Edition AISC *Manual* states, "The Whitmore section may spread across the joint between connecting elements, but cannot spread beyond an unconnected edge." All of the examples provided in the Design Examples where the Whitmore section spreads across the joint also happen to be cases where the gusset plate edge is welded to the beam flange. While it may be stating the obvious, any connection that has been properly designed, such as a bolted-bolted or bolted-welded double-angle or single-plate connection, can be considered a connected edge when the Whitmore section passes through it.

When the effective width crosses a joint between 36 ksi and 50 ksi material. There may be some confusion as to how to use the Whitmore section for tension and compression checks when the Whitmore section spreads across a joint between a gusset plate and a beam or column that have different strength levels. One might expect that the stress distribution is uniform and that there is no way to have two separate levels of stress. However, as shown in Example II.C-2 in the Design Examples, we can take advantage of the higher strength material.

Once the lower strength material (typically the gusset plate) reaches its yield strength, it will strain and allow the load to distribute to the higher strength material (see Figure 6 on the following page). Note that the amount of strain involved for this to occur is negligible, as shown in Figure 5. This is an inelastic but self-limiting deformation much like that used in the design of "simple connections," and in this case, any tendency to rotate due to the uneven stress distribution on the Whitmore section is limited by the surrounding material that does not participate in load resistance, but would have to shear for rotation to occur. See the next question for more on this. The hybrid section may change the stress distribution but use of a design stress calculated from the hybrid Whitmore section will provide a gusset that performs in an acceptable fashion.

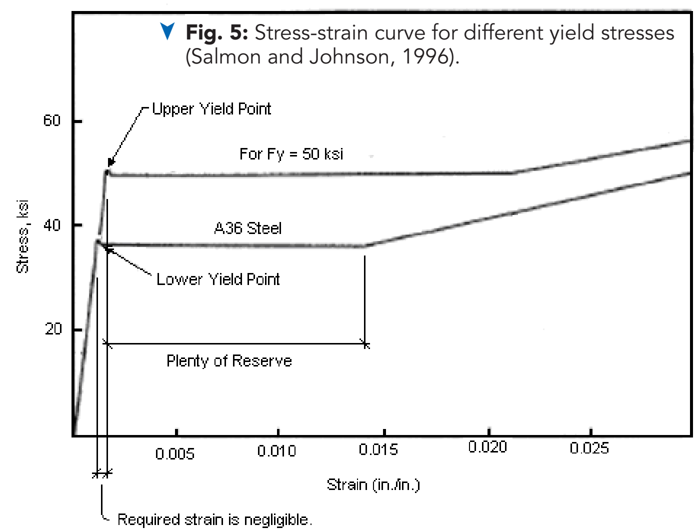
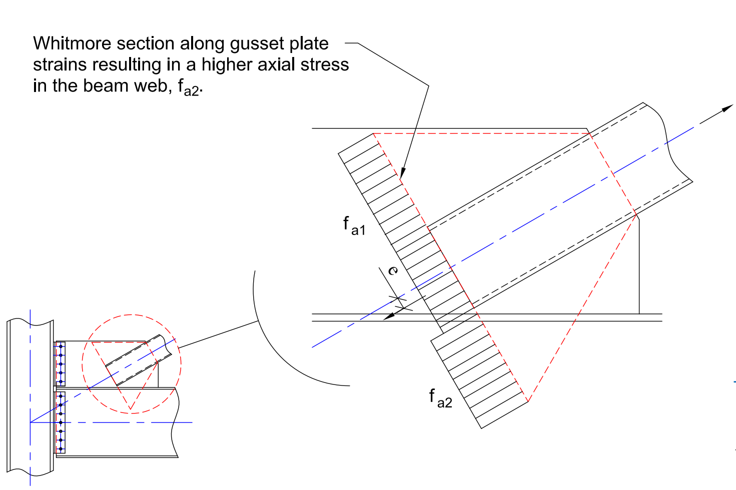
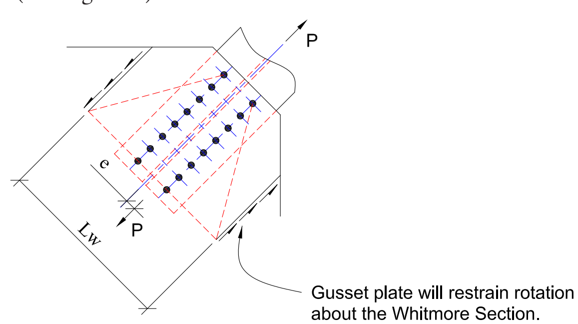


Fig. 5: Stress-strain curve for different yield stresses (Salmon and Johnson, 1996).



▲ **Fig. 6:** Eccentric loading on Whitmore section due to differing material strengths.

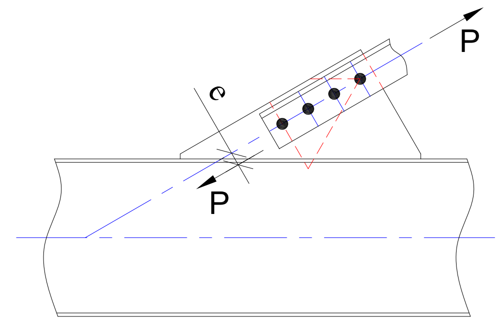
Eccentricity when the distribution isn't balanced. Another possible concern with taking advantage of the higher strength material is eccentricity. That is, what if doing so means that the resultant force is no longer centered on the work line as in Figure 6? The effects of this eccentricity can be ignored. The gusset plate is very rigid and the surrounding metal will restrain any rotation that would otherwise occur on the Whitmore section (see Figure 7).



▲ **Fig. 7:** Gusset plate rigidity.

Gusset plate and member web of different thicknesses. When the Whitmore section spreads across the joint of two components of differing thicknesses, the distribution of force similarly may not be uniform as for the case of materials of different strength. As explained above, the same conclusion (for the same reasons) may be stated here in that eccentricity about the Whitmore section is not a concern and its effects need not be calculated.

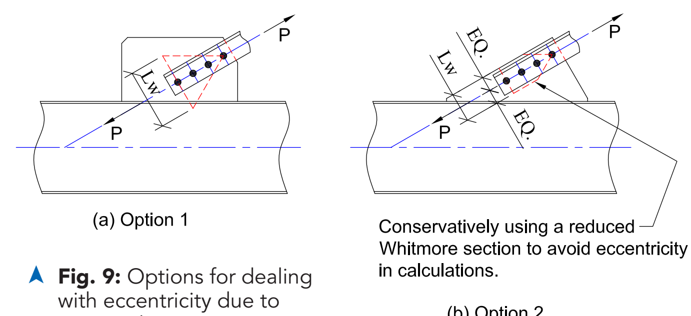
Gusset plates of restricted geometry. Gusset plate geometry may have a significant impact on the tension and compression strengths available on the Whitmore section. While eccentricity as a result of differing plate thicknesses and material strengths is not a concern when using the Whitmore method, eccentricity due to plate geometry may be important to consider because often the geometry limit also eliminates some of the stabilizing effect illustrated in Figure 7. Plate geometry may result in a non-uniform tensile stress distribution across the Whitmore section and no side material to restrain the rotation (see Figure 8).



▲ **Fig. 8:** Eccentricity due to gusset plate geometry.

Two options for treating an eccentric loading condition due to gusset plate geometry include:

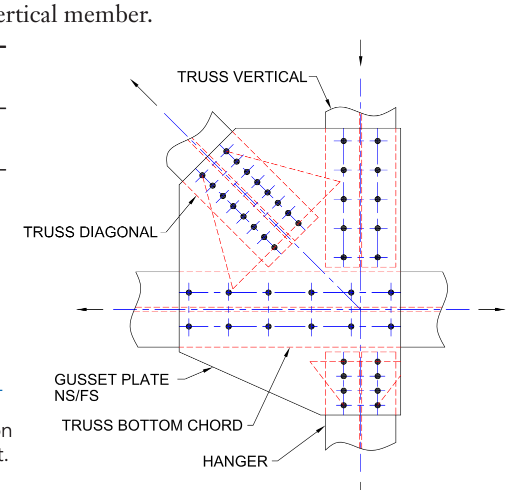
- Option 1: Adjust the gusset plate geometry to avoid eccentricity as shown in Figure 9 (a). This is the preferred solution if it is possible to do so.
- Option 2: Conservatively analyze the gusset plate for a reduced Whitmore section effective width that is balanced along the work line, as per Figure 9 (b). While this approach is conservative, it is a quick and easy solution.



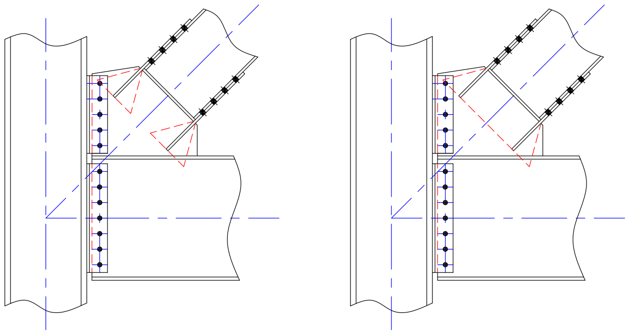
▲ **Fig. 9:** Options for dealing with eccentricity due to gusset plate geometry.

Another example of when geometry could be an issue is the hanger to truss panel point connection shown in Figure 10. The Whitmore method is not necessary for the vertical member to gusset plate connection. Most of the load will be transferred to the diagonal member through shear in the gusset plate. Calculations for a similar connection detail are shown in Design Example II.C-6 that works with the 14th Edition AISC *Manual*. This example does not include any Whitmore section calculations for the truss vertical member.

Overestimating the Whitmore section. Depending on the brace connection configuration, there are occasions where the calculated length of the Whitmore section could be less than what one



➤ **Fig. 10:** Connection at truss panel point.



(a) Correct Whitmore length. (b) Incorrect Whitmore length.

Fig. 11: Overestimating the Whitmore length.

would initially expect. This depends on the depth of the brace, how it is connected, and the length of the overall connection. Figure 11 provides an example of one case where the Whitmore length could be calculated incorrectly.

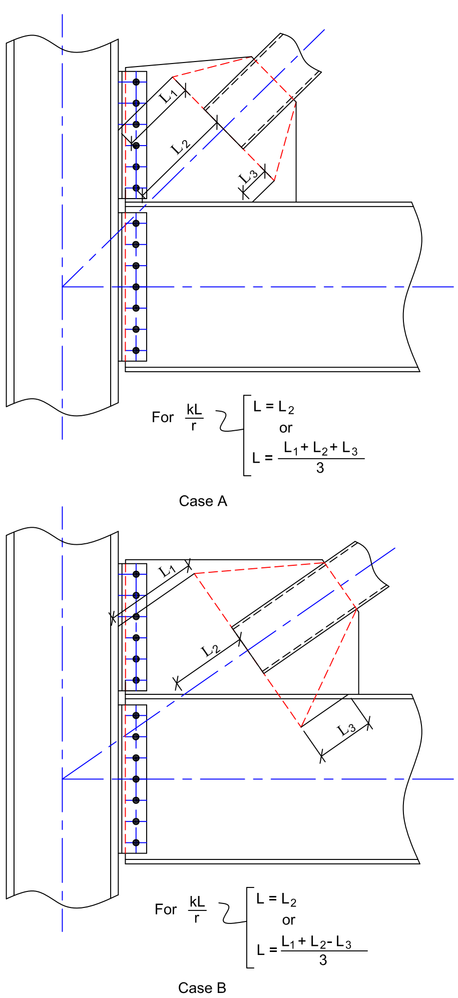


Fig. 12: Gusset plate buckling length determination.

Unbraced length for compression strength calculations. When calculating the buckling strength of a gusset plate, the approximate length of the gusset plate that will buckle must be determined. The two most common methods for determining this length are shown in Figure 12. Both methods are permitted.

Note that when computing the buckling length using an average of the three lengths (L_1, L_2 and L_3), L_1 or L_3 may be subtracted if the Whitmore section spreads across the joint into the beam or column as illustrated in Figure 12, Case B. Design example II.C-2 from the Design Examples also covers both of these methods.

The People Behind the Theory

Who was Armour T. Granger?

Armour T. Granger came to the University of Tennessee in 1939 after working for Ash, Howard-Needles & Tammen in New York City. According to David W. Goodpasture, professor emeritus in the Civil and Environmental Engineering Department at the University of Tennessee, Granger was "very interested in the behavior of joints in a Warren truss."

Goodpasture said that Granger asked Whitmore and another graduate student to study the joint in the early 1950s. "Whitmore made an aluminum model of the joint and . . . used electrical strain gages," Goodpasture said. "I can still remember seeing the model in the basement of Perkins Hall. It was about five feet tall. Whitmore wrote the engineering experiment publication based on both students' (M.S.) theses."

Who was R.E. Whitmore?

According to Edwin Burdette, a professor of civil engineering at the University of Tennessee, Whitmore was an assistant professor in the early 1960s at the University of Tennessee where he taught a materials course. He was a popular teacher, winning the first "Faculty Man of the Year" award given by the student chapter of ASCE in 1964. He also went on to be a successful road builder, though he is perhaps best remembered for his gusset plate article.

Whitmore doesn't just affect gusset plates. While most of this discussion has focused on Whitmore sections in gusset plates, there are other types of connections where this section should be calculated. One example is the truss connection shown earlier in Figure 10. Another example is a WT hanger connection, which is shown in Figure 13 below. If a connection is being designed to transfer axial load, an engineer will need to determine if a Whitmore section check is required.

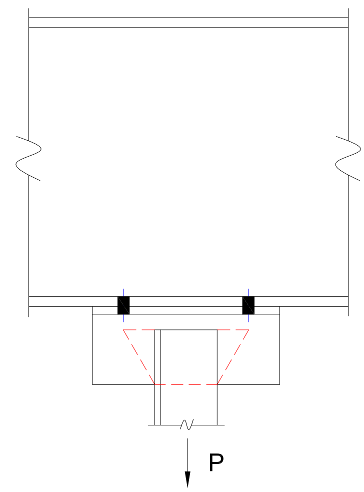


Fig. 13: WT hanger connection.

One Final Note

The 2011 AISC T.R. Higgins Lectureship Award winner, Charles W. Roeder, P.E., Ph.D., has introduced a very practical approach to the design of seismic gusset plates in special concentrically braced frames. While there are no changes to the Whitmore section, this new approach lets the gusset plate bend line occur in an elliptical pattern, allowing the gusset plate connection to be more compact, which helps reduce the size and cost of the bracing frame connection. The Whitmore section calculations for compression on these gussets will benefit greatly from the shorter buckling lengths. MSC

The authors would like to thank Tom Murray, Charlie Carter, Tom Schlafly and Leigh Arber for reviewing this article and for providing valuable feedback. The quality of the article benefited greatly from their involvement.