

Gusset Plate Load Rating

Before 2007, most truss load ratings checked members and assumed the connections were stronger than the members they joined. The collapse of the I-35W bridge in Minneapolis on August 1, 2007, which the National Transportation Safety Board attributed to undersized gusset plates, ended that assumption. This course explains how gusset plate rating became a national priority, the five minimum resistance checks in the FHWA guidance document FHWA-IF-09-014 (fasteners, shear yielding and fracture, Whitmore compression, Whitmore tension, block shear), how to handle section loss and plate buckling, and what the later NCHRP Project 12-84 research changed. Equations and factors are taken from FHWA-IF-09-014 and from FHWA TechBrief FHWA-HRT-14-063, which summarizes NCHRP 12-84. Example numbers are illustrative teaching values unless a source is named.

Learning objectives

- Explain why gusset rating became a priority
- List gusset limit states
- Apply FHWA guidance resistance checks
- Account for section loss and plate buckling

Why gusset plate rating became a priority

On August 1, 2007, the I-35W bridge over the Mississippi River in Minneapolis collapsed. It was a three-span (255 by 456 by 255 ft) continuous subdivided Warren deck truss. The NTSB, with technical assistance from FHWA, determined that the collapse was due to undersized gusset plates at a particular node of the main truss. According to the FHWA TechBrief summarizing the investigation, the plates "should have been twice as thick or should have had twice the yield strength to provide adequate resistance to prevent the collapse."

On January 15, 2008, the NTSB recommended that FHWA require owners of all non-load-path-redundant steel truss bridges in the National Bridge Inventory to "conduct load capacity calculations to verify that the stress levels in all structural elements, including gusset plates, remain within applicable requirements whenever planned modifications or operational changes may significantly increase stresses." The same day FHWA issued Technical Advisory T 5140.29, which strongly encouraged owners to check the capacity of gusset plates in their inventory.

A paradigm shift

The TechBrief describes the state of practice at the time plainly: "bridge load ratings were member-centric and did not require connection elements to be rated." The AASHTO design specifications were "vague on the subject, leaving room for considerable engineering discretion and judgment." There was no consensus on what to check. FHWA responded in February 2009 with *Load Rating Guidance and Examples for Bolted and Riveted Gusset Plates in Truss Bridges*, FHWA-IF-09-014, which set out "the minimum number of resistance equations that must be checked to adequately load rate a gusset plate."

What this means for a rating engineer today

- A truss rating that checks members only is incomplete. Gusset plates are rated as part of the connection.
- Dead load matters more than in many girder ratings. The I-35W investigation drew attention to added dead load from deck overlays and construction materials staged on the deck, which is why the NTSB recommendation focuses on

"planned modifications or operational changes."

- Gusset ratings are sensitive to section loss, especially at the chord level where debris and water collect.
- The MBE system factor for riveted and bolted gusset plates and their connections is 0.90 for all force effects (MBE 6A.4.2.4), consistent with their role in nonredundant load paths.

The five minimum checks in FHWA-IF-09-014

The FHWA guide gives procedures for both LRFR and load factor rating. As summarized in FHWA-HRT-14-063, it "recommends five resistance checks at a minimum":

1. **Fasteners.** Shear resistance of the fasteners for each connected member, plus bearing resistance of the plate material at the fastener holes. The guide refers to the existing LRFD checks, and, because the current AASHTO specifications do not give values for old rivets, it provides recommended rivet shear strengths based on the rivets' age.
2. **Shear yielding and shear fracture** on the relevant planes through the gusset.
3. **Compression (local stability)** of the plate around compression members, using the Whitmore section as an equivalent column.
4. **Tension** of the plate at the ends of tension members: gross yielding and net section fracture on the Whitmore section.
5. **Block shear** around tension members.

The guide also suggests that compression and tension chord splices be checked with the Whitmore compression and tension approach; later research refined that check (see the NCHRP 12-84 section).

Shear: the governing equations

In the LRFR format of FHWA-IF-09-014, the factored shear resistance V_r is the lesser of:

$$V_r = \phi_{vy} 0.58 F_y A_g \Omega \text{ (shear yield, gross section)}$$

$$V_r = \phi_{vu} 0.58 F_u A_n \text{ (shear fracture, net section)}$$

with $\phi_{vy} = 0.95$ and $\phi_{vu} = 0.80$. A_g and A_n are the gross and net areas of the plates resisting shear, and F_y and F_u are the minimum yield and tensile strengths of the plates. The guide takes Ω as:

- $\Omega = 1.00$ "when the gusset plates are of ample stiffness to prevent buckling and develop the plastic shear force of the plates," or
- $\Omega = 0.74$ "in the absence of a more rigorous analysis or criterion to assure and quantify the stiffness requirements to develop the plastic shear force of the plates."

The TechBrief explains the origin of Ω : it was introduced in the 1985 AASHTO *Guide Specifications for Strength Design of Truss Bridges*. A plate acting like a beam in bending along the shear plane would have a parabolic shear stress distribution ($\Omega = 0.74$); a stiff or braced plate could redistribute yielding until the whole plane was mobilized ($\Omega = 1.00$). The resistance factors 0.95 and 0.80 are the tension yielding and fracture factors, applied because "for ductile materials, shear failures are technically tensile failures on inclined planes."

The guide states that shear analysis "involves the evaluation of several shear sections to arrive at the governing section." In practice that means horizontal planes along the chord, vertical planes through the plate, and planes that pass between members.

Compression: the Whitmore section and the equivalent column

The FHWA guide notes that "the proximity of connected members, complex state of stress, and boundary conditions can influence the resistance of gusset plates in compression," and that "special care must be exercised to properly assess the buckled shape." In the absence of a more rigorous analysis, the plate is treated as an idealized compression member under AASHTO LRFD Articles 6.9.2.1 and 6.9.4.

Effective width

The effective width is the Whitmore width. Per the TechBrief: "the stress spreads out from the member into the gusset plate by dispersing at 30-degree angles from the first to the last row of fasteners. The width of the section is defined along the end row of fasteners and extending out to the dispersion lines." The Whitmore method dates to R.E. Whitmore's 1952 University of Tennessee experiment station bulletin, *Experimental Investigation of Stresses in Gusset Plates*.

Unbraced length

FHWA-IF-09-014 takes the unbraced length L_c as the average of three distances:

- L_2 : from the last row of fasteners in the compression member to the first row of fasteners in the closest adjacent member, measured along the line of action of the compressive force.
- L_1, L_3 : from each end of the Whitmore width to the first row of fasteners in the closest adjacent member, measured parallel to the line of action. "When the Whitmore width enters into the adjacent member, the associated distance at that end should be set to zero."

Effective length factor K

The guide's Table 2 gives K values by buckled shape. When lateral sway of the gusset is possible, K is taken from cases (d), (e) or (f); when sway is not possible, from cases (a), (b) or (c). The design values tabulated are 0.65, 0.80, 1.0, 1.2, 2.1 and 2.0 (theoretical 0.5, 0.7, 1.0, 1.0, 2.0 and 2.0) for the respective cases. The choice is a matter of engineering judgment about rotational restraint and sway. The TechBrief notes the engineer "is given leeway to select an appropriate equivalent column length, or K-factor, depending on the likely buckling mode shape."

The section of the course on NCHRP 12-84 explains how later research simplified both L_c and K.

Tension checks and block shear

For tension members, FHWA-IF-09-014 uses the same Whitmore construction at the end of the member. The TechBrief summary is: "for tension members, the same Whitmore section is defined at the end of the tension members. On this section, both gross yielding and net section fracture must be checked. In addition, the fifth check is block shear resistance around tension members."

Gross yielding and net fracture on the Whitmore section

The two checks mirror the familiar member tension checks of AASHTO LRFD Article 6.8.2, applied to the plate:

- **Gross section yielding** uses the gross area of the Whitmore section (Whitmore width times plate thickness, summed over the plates).
- **Net section fracture** uses the net area after deducting fastener holes along the Whitmore line.

Because the Whitmore width is measured at the last row of fasteners, the hole deduction is taken along that row. Engineers should also consider whether a staggered path or a path through more holes might give a lower net area; the Whitmore line is the starting point, not a guarantee that it is the critical net section.

Block shear

Block shear is a tearing failure in which a block of plate around the fastener group of a tension member pulls out, with tension on one face and shear on the others. FHWA-IF-09-014 shows examples of potential block shear rupture planes for gusset plates in tension, and the check follows the LRFD block shear provisions. For a gusset plate with several closely spaced tension members, look at blocks that include fasteners of more than one member: the TechBrief notes that block shear "needs to be validated when failure planes can be merged between closely spaced tension members."

What the later research said about tension

The NCHRP 12-84 research did not change the tension checks. According to the TechBrief, only three analytical models showed pure tensile failure modes, so "there were no data available to provide a statistically significant sample to derive changes," and "no changes were recommended to the FHWA guide for Whitmore tension checks." Block shear was not studied experimentally because abundant data already existed. The TechBrief cites a summary of 133 block shear experiments from 8 sources (Huns, Grondin and Driver, 2006). The research also observed that in some models a combined tension and shear failure along the plate boundary with the chord and vertical occurred, which "the application of the block shear check did not predict well." This is identified as an area for future work, and it is a reason for care at heavily loaded tension joints.

Fasteners: rivets, bolts and plate bearing

The first of the five checks is the fasteners. FHWA-IF-09-014 directs that fasteners be checked for adequate shear resistance for each connected member and that bearing of the plate material at the holes be checked as part of the fastener checks, using the LRFD provisions.

Rivets

Most trusses in the inventory that need gusset ratings are riveted. Modern AASHTO specifications do not give rivet strengths, so the FHWA guide provides recommended rivet shear strengths based on the rivets' age, as noted in the TechBrief. The rating engineer must therefore establish:

- **The rivet era or material**, from plans, specifications, mill records or the construction date. If unknown, use the owner's policy for default values.
- **The number of shear planes**. A member connected between two gusset plates puts its rivets in double shear.
- **The grip**. Long-grip rivets have historically been treated with reductions in some specifications; check the guide and the owner's manual for how to handle them.
- **Condition**. Missing, loose or corroded rivet heads reduce the effective count. A rivet with a head corroded away should not be counted.

Bolts

Where rivets have been replaced by high-strength bolts, which is common after repairs, use the LRFD bolt shear provisions and note whether threads are included in the shear plane. Mixed rivet and bolt groups require judgment about load sharing; document the assumption.

Plate bearing at holes

Bearing on the plate at fastener holes depends on plate thickness, so section loss around fastener rows lowers bearing resistance directly. Thin outer gussets with heavy corrosion around the rivet heads can be controlled by bearing rather than by any of the plate checks.

Why fastener checks matter for the rating

The TechBrief notes that early in implementation of the FHWA guide, "some gusset plates were not attaining desirable rating factors," and that the guide was thought to be "overly conservative, particularly for fastener shear, gusset shear yielding, and Whitmore compression checks." The NCHRP research focused on the plate checks; for fasteners, the engineer's best tool for avoiding unduly low ratings is accurate information on rivet material and a careful count of sound rivets.

What NCHRP Project 12-84 changed

Because some States were retrofitting or restricting trusses with no history of performance problems after applying the FHWA guide, AASHTO and FHWA sponsored NCHRP Project 12-84, *Guidelines for the Load and Resistance Factor Design and Rating of Riveted, Bolted, and Welded Gusset-Plate Connections for Steel Bridges*. FHWA summarized the results in TechBrief FHWA-HRT-14-063 (August 2014).

The research program

- 12 full-scale gusset plate connections were tested at FHWA's Turner-Fairbank laboratory, with five members (two collinear chords, a compression diagonal and a tension diagonal at 45 degrees, and a vertical). Plates were roughly 60 in. wide by 36 in. tall.
- A second phase used the same geometries with artificial section loss, edge stiffening and multi-layered gussets.
- Calibrated nonlinear shell finite element models extended the study to 201 models covering other angles, non-collinear chords, corner joints, Warren and Pratt configurations, and joints over piers, at midspan and near inflection points.

Shear yielding

From 44 observed shear-yielding failures, the actual load averaged 2 percent above the predicted $0.58F_yA$ value, implying Ω of about 1.00 in a nominal sense. To account for scatter, Ω was selected as **0.88**. The TechBrief explains that this value "is an artifact of the calibration" chosen so that the resistance factors rounded cleanly to the nearest 0.05.

Buckling and partial shear planes

Compression diagonals often have chamfered ends so they can sit close to adjoining members. The research found that for joints with closely spaced members, "the buckling strength was found to be coupled to the shear strength of the planes around the compression member." These planes do not cross the full plate and are called **partial shear planes**. Buckling resistance therefore became a two-part check: Whitmore buckling, and shear yielding on a partial plane around the compression member.

The research also found better correlation when the effective column length was the length at the **middle** of the Whitmore width rather than the average of three lengths, and that "a fixed K-factor of 0.5 was found applicable for all gusset plates in predicting the minimum buckling resistance." In general, plates 3/8 in. thick or less were controlled by Whitmore buckling, and thicker plates by partial plane shear yielding.

Chord splices

In models that failed at the chord splice, stress patterns did not match the assumed Whitmore section. The research identified a check that treats the gusset and splice plates as a single cross-section, including axial and bending effects from eccentric chord loads.

Edge stiffening and free-edge slenderness

No correlation was found between buckling resistance and free-edge slenderness. Properly detailed stiffeners that add out-of-plane stiffness to the compression member can raise buckling resistance, but "conventional edge stiffeners stiffen only the free edge and therefore offer no additional gains." The researchers recommended "not to rate gusset plates based on edge slenderness."

Calibrated resistance factors

The TechBrief's Table 1 lists the recommended factors. For the MBE (rating, calibrated at a reliability index of 3.5 and a dead-to-live load ratio of 1.0): full and partial plane shear yielding 1.00 (with $\Omega = 0.88$), Whitmore buckling 0.95, block shear 1.00, chord splice 0.85. For the design specifications (reliability index 4.5, DL/LL of 6.0): shear yielding 0.80, Whitmore buckling 0.75 and chord splice 0.65 (both neglecting plates thinner than 3/8 in.), block shear 0.80. The TechBrief notes that "the use of system reliability factors for gusset plate rating was mandated" and that an additional reduction was provided for long-span trusses with high dead-to-live load ratios.

These were the recommendations made to AASHTO. The resistance factors, equations and any additional reduction factors in force for your rating are those in the MBE edition and interims your owner has adopted. Verify them there before use.

How the resistance factors were calibrated

Understanding the calibration helps you see why the rating and design factors differ and why long-span trusses get extra attention.

Monte Carlo reliability and the DL/LL ratio

The NCHRP 12-84 resistance factors were set by Monte Carlo reliability analysis following the philosophy of NCHRP 20-07(186). Rather than running live load analyses through many trusses, the researchers assumed dead-to-live load ratios. Twenty truss plans from eight States were used to define the variation: DL/LL ranged from 0.5 to 6.5, with an average of approximately 2.0. Strength I and Strength IV load combinations were both used. The required resistance factor decreases with DL/LL for Strength I and increases with DL/LL for Strength IV; the TechBrief notes that the two typically converge at a DL/LL between 6.0 and 8.0.

Different targets for design and rating

- **Design** factors were calibrated at a reliability index of 4.5 and a DL/LL of 6.0. The higher index was chosen because AASHTO already requires higher reliability for fastener, weld and block shear limit states, and the AISC Steel Construction Manual uses a higher index for connection limit states than for members. For design, data for plates thinner than 3/8 in. were excluded, on the assumption that a minimum thickness can be imposed on new plates.
- **Rating** factors were calibrated at a reliability index of 3.5 and a DL/LL of 1.0, and they include all the data, because the existing inventory contains thin plates. The TechBrief is explicit about the reason: "Using the design philosophy in rating would require posting of many trusses that have performed satisfactorily."

Two consequences for the rating engineer

1. **System factors are part of the method.** The TechBrief states that the use of system reliability factors for gusset plate rating "was mandated" as a condition of the more favorable rating calibration.
2. **Long spans need an added reduction.** Because the rating factors were calibrated at $DL/LL = 1.0$, long-span trusses with higher DL/LL ratios "would unconservatively be rated," and "an additional reduction factor was provided to account for the reduction in the resistance factor between DL/LL ratios of 1.0 and 6.0." Find this factor and its application in your adopted MBE edition. Do not omit it on a long span.

The existing design factor for block shear, 0.80, was found to have a reliability index of 4.5; for rating it was raised to 1.00 to reflect the rating index of 3.5.

Section loss, inspection data and multilayer plates

Gusset plate ratings are only as good as the thickness measurements behind them. Chord-level gussets in deck trusses and lower-chord gussets in through trusses tend to trap debris and water, and section loss is often concentrated along the top of the bottom chord, at the edges of chord angles, and around rivet heads.

Shear planes

NCHRP 12-84 tested localized section loss both experimentally and analytically. For shear limit states, "resistance was based on the total cross sectional area in the plane of failure. Therefore, there was no effect from section loss being unbalanced across the gusset plate or unbalanced between the two plates." In practice:

- Measure remaining thickness along each candidate shear plane, both full and partial planes.
- Compute the remaining area plane by plane, summed over both gussets (and any splice or fill plates that act on that plane).
- Do not average the loss over the whole plate. A band of heavy loss along the chord line controls the horizontal plane through that band.

Buckling

For Whitmore buckling with section loss, "any section loss occurring between the Whitmore width and the adjoining member fastener lines is projected onto the Whitmore section, and an equivalent plate thickness is derived on the Whitmore section." The TechBrief cautions that this approach "was found to be very conservative at times, but there were not enough failures to derive any better recommendation." If buckling with corrosion controls the rating and leads to posting, a refined analysis may be justified.

Multilayer plates

Many trusses have gussets made of more than one layer, either as built or from earlier repairs. For observed failures of multilayer gussets, "it was appropriate to add the individual resistances of each plate together." The caution is that "consideration should be given to determining whether enough fasteners are being provided to develop the strength of each plate at the plane of failure." A doubler plate attached with only a few fasteners near the failure plane cannot contribute its full resistance.

What to ask the inspection team for

- Ultrasonic thickness readings on a grid or along predefined plane lines, not just a single "typical" reading.
- Photos and sketches locating pack rust, pitting and holes, keyed to plate edges and fastener lines.
- Distortion or out-of-plane bowing of free edges, which may indicate prior overstress or pack rust.
- Missing, loose or deteriorated rivets and bolts, by member and row.
- Any repairs, added plates or field-drilled holes not shown on the plans.

Worked example (illustrative): shear and Whitmore checks

All numbers in this example are illustrative teaching values, not from any real bridge. The equations follow FHWA-IF-09-014 and the NCHRP 12-84 recommendations summarized in FHWA-HRT-14-063. A real rating must use the equations, factors and load model in your adopted MBE edition.

Given (illustrative)

- Two gusset plates, each 1/2 in. thick, $F_y = 36$ ksi, $F_u = 58$ ksi.
- Horizontal shear plane along the chord: gross length 60 in.; 12 rivet holes of 15/16 in. diameter (illustrative effective hole size) on the plane.
- Factored shear demand on the plane (illustrative, from a truss analysis): dead load 300 kips, HL-93 live load plus impact 150 kips. Use $\gamma_{DC} = 1.25$ and $\gamma_{LL} = 1.75$ (Strength I, design inventory), condition factor 1.0, system factor 0.90.

Step 1: areas

$$A_g = 2 \times 0.5 \times 60 = 60.0 \text{ in.}^2. A_n = 2 \times 0.5 \times (60 - 12 \times 0.9375) = 2 \times 0.5 \times 48.75 = 48.75 \text{ in.}^2.$$

Step 2: shear yield and fracture, FHWA-IF-09-014 format

Shear yield with $\Omega = 0.74$: $\phi 0.58 F_y A_g \Omega = 0.95 \times 0.58 \times 36 \times 60.0 \times 0.74 = 880$ kips.

Shear fracture: $0.80 \times 0.58 \times 58 \times 48.75 = 1,312$ kips.

Yield controls: $R_r = 880$ kips before system and condition factors.

Step 3: same plane, NCHRP 12-84 recommended rating factors

Shear yield with $\Omega = 0.88$ and $\phi = 1.00$: $1.00 \times 0.58 \times 36 \times 60.0 \times 0.88 = 1,103$ kips. That is about 25 percent higher than Step 2 for this plane, which illustrates why States saw improved ratings after the research.

Step 4: rating factor

Using the general LRFR rating equation, $RF = (\phi_c \phi_s R - \gamma_{DC} DC) / (\gamma_{LL} (LL + IM))$. With Step 3: capacity = $1.0 \times 0.90 \times 1,103 = 993$ kips. $RF = (993 - 1.25 \times 300) / (1.75 \times 150) = (993 - 375) / 262.5 = 2.35$ (illustrative). With Step 2: $0.90 \times 880 = 792$; $RF = (792 - 375) / 262.5 = 1.59$.

Step 5: section loss (illustrative)

Suppose inspection shows a 6 in. band along the chord with average remaining thickness of 0.375 in. on each plate, crossing the horizontal plane over its full 60 in. length. The plane's remaining gross area is $2 \times 0.375 \times 60 = 45.0 \text{ in.}^2$. Shear yield (12-84 factors) becomes $1.00 \times 0.58 \times 36 \times 45.0 \times 0.88 = 827$ kips; capacity $0.90 \times 827 = 744$ kips; $RF = (744 - 375) / 262.5 =$

1.41. A 25 percent loss in thickness reduced the rating factor by about 40 percent because dead load takes a fixed share of the capacity.

Step 6: Whitmore buckling (illustrative)

For a compression diagonal with two fastener lines 4 in. apart (gage) and 6 rows at 3 in. pitch (15 in. from first to last row), the Whitmore width is $4 + 2 \times 15 \times \tan 30^\circ = 4 + 17.3 = 21.3$ in. For two 1/2 in. plates, $A = 21.3 \text{ in.}^2$. If the middle distance to the adjacent fastener line is 10 in. and $K = 0.5$ (the 12-84 recommendation), $KL/r = 0.5 \times 10/(0.5/\sqrt{12}) = 34.6$. The nominal resistance then comes from the LRFD column equations of Article 6.9.4 with $\phi = 0.95$ for rating per the 12-84 recommendation. Check the partial-plane shear around the diagonal as well; for 1/2 in. plates with a chamfered diagonal, the research suggests partial-plane shear is likely to control.

A practical rating workflow

The steps below describe one reasonable order of work for rating a truss's gusset plates. It is a teaching outline, not a regulatory procedure. Your owner's load rating manual governs.

1. Gather documents

- Original design and shop drawings showing plate thicknesses, material grades, rivet patterns and member end details (including chamfers).
- Repair and rehabilitation plans, especially any added plates, replaced rivets or deck replacements that changed dead load.
- The latest inspection report with thickness data, plus any special gusset inspection.
- Material test data if available; otherwise use the owner's default steel and rivet properties by era.

2. Get member forces at each node

Gusset demands come from the member forces in the truss analysis, for dead load and for the governing live load positions. Because the critical live load position for a gusset plane can differ from the one for any individual member, plan the analysis to produce consistent sets of concurrent member forces. Many engineers resolve member forces into the shear plane force by free-body equilibrium of the plate portion on one side of the plane.

3. Screen nodes

A large truss can have dozens of distinct nodes. Group nodes that share geometry and plate thickness, then rate the most heavily loaded or most deteriorated node in each group. Nodes with significant section loss get their own calculation.

4. Run the checks

- Fasteners and plate bearing for each member.
- Full shear planes (horizontal and vertical) and partial planes around compression members.
- Whitmore buckling for each compression member.
- Whitmore tension yield and fracture, and block shear, for each tension member.
- Chord splice, if the node includes one.

5. Apply factors and compute rating factors

Apply the condition factor, the gusset system factor of 0.90, and any added reduction for long-span trusses in your adopted MBE edition. Compute inventory, operating and legal load rating factors as required by the owner.

6. Report

For each node, report the controlling limit state, plane or member, the rating factor, and the thickness data used. A reviewer should be able to trace every number back to a plan sheet or inspection reading.

LRFR, LFR and owner policy

FHWA-IF-09-014 gives procedures for both LRFR and load factor rating. The LRFR shear factors (0.95 yield, 0.80 fracture) are summarized above. The guide's LFR shear provisions use a fracture factor of 0.85. Because owners rate older trusses under both methods depending on policy and the bridge's design method, confirm which method your agency requires and use that set of equations consistently. Do not mix LRFR resistance factors with LFR load factors.

Which version of the checks to use

There are three generations of gusset guidance an engineer may encounter:

1. **FHWA-IF-09-014 (2009)**: five minimum checks, Ω of 0.74 or 1.00, average-of-three column length, K by buckled shape.
2. **NCHRP 12-84 recommendations (NCHRP Web-Only Document 197; summarized in FHWA-HRT-14-063, 2014)**: $\Omega = 0.88$, partial shear planes, middle-length column with $K = 0.5$, combined-section chord splice check, recalibrated resistance factors.
3. **The current MBE and LRFD specifications**, which AASHTO revised using the research results. The TechBrief states that the project's goal was to produce data that "could then be adopted into the AASHTO BDS and Manual for Bridge Evaluation."

For a new rating, use the provisions in the MBE edition your owner has adopted, and use the FHWA guide and TechBrief to understand the background. When reviewing an older rating, note which generation it used. A gusset that rated low under the 2009 guide with $\Omega = 0.74$ may rate quite differently under the later provisions, in either direction once partial planes and the long-span reduction are included.

Common pitfalls

- **Rating members only.** After TA 5140.29, a truss rating that omits gussets is incomplete.
- **Using the wrong Ω with the wrong ϕ .** $\Omega = 0.88$ belongs with the recalibrated factors; $\Omega = 0.74$ or 1.00 belongs with the 2009 guide's 0.95. Mixing them gives a number with no calibration behind it.
- **Missing partial planes.** With chamfered compression diagonals close to adjacent members, a partial shear plane around the diagonal can control even when full planes and the Whitmore check pass.
- **Rating on free-edge slenderness.** The research recommends against it. Edge slenderness limits are a detailing requirement, not a strength check.
- **Counting conventional edge stiffeners as buckling strength.** Only stiffening that adds out-of-plane stiffness to the compression member region helps.
- **Averaging section loss.** Shear depends on the total remaining area in each plane. Map loss to planes.

- **Counting doubler plates fully without enough fasteners** to develop them at the failure plane.
- **Ignoring dead load changes.** Overlays, deck replacements and staged construction materials raise dead load demand. The NTSB recommendation targets exactly these "planned modifications or operational changes."
- **Leaving out the system factor or the long-span reduction** that was a condition of the rating calibration.

Retrofit and posting decisions

When a gusset rates below the legal load, the owner's options include refined analysis, load posting, and retrofit. Some points to weigh:

- **Refined analysis.** The TechBrief describes calibrated nonlinear shell finite element models with initial imperfections as capable of predicting buckling, shear yielding and chord splice failures in the research. Such models take expertise and should be reviewed independently, but they can be justified when a simplified check, such as the conservative corrosion projection for buckling, controls.
- **Retrofit plates.** Added plates contribute only if enough fasteners develop them at the failure plane. If the deficiency is buckling, stiffening that braces the plate out of plane at the compression member can help; a free-edge angle alone may not.
- **Cleaning and coating.** Stopping further section loss protects the rating you have. Remove pack rust and debris at chord-level gussets as part of maintenance.
- **Monitoring.** Where a node is near its limit, more frequent thickness measurements may be part of the plan.

Example (illustrative): in the worked example, the corroded plane rated at $RF = 1.41$ under the recalibrated factors for HL-93 at the design level. Whether that is acceptable depends on the owner's inventory and operating criteria and the legal load ratings. The rating engineer reports the result; the owner decides on posting or retrofit.

Summary

The I-35W collapse moved gusset plates from an assumed-adequate detail to a required part of every steel truss rating. FHWA-IF-09-014 set five minimum checks. NCHRP 12-84 refined them with full-scale tests and 201 finite element models: $\Omega = 0.88$ with recalibrated factors, partial-plane shear, a middle-length Whitmore column with $K = 0.5$, a combined-section chord splice check, and clear rules for corrosion and multilayer plates. Good gusset ratings depend on accurate thickness data mapped to failure planes, consistent concurrent member forces, and the system and long-span factors that the calibration requires.

Worked example (illustrative): tension diagonal

Illustrative teaching values only. The equations follow the familiar LRFD tension member and block shear forms that FHWA-IF-09-014 applies to the plate. Use the exact equations and factors in your adopted specification and MBE edition.

Given (illustrative)

- Two 1/2 in. gusset plates, $F_y = 36$ ksi, $F_u = 58$ ksi.
- Tension diagonal connected by two lines of rivets at 5 in. gage, 5 rows at 3 in. pitch (12 in. from first to last row). Hole size for net area: 15/16 in. (illustrative).

Whitmore width

$W = 5 + 2 \times 12 \times \tan 30^\circ = 5 + 13.9 = 18.9$ in. Gross area $A_g = 2 \times 0.5 \times 18.9 = 18.9$ in.².

Net area on the Whitmore line

Two holes are on the last row: $A_n = 2 \times 0.5 \times (18.9 - 2 \times 0.9375) = 17.0$ in.². The engineer would also look for a lower net path, for example where the Whitmore line passes through holes of an adjacent member.

Nominal resistances

Gross yield nominal: $F_y A_g = 36 \times 18.9 = 680$ kips. Net fracture nominal (taking the shear lag factor as 1.0 for a plate in this illustration): $F_u A_n = 58 \times 17.0 = 986$ kips. Gross yield controls in nominal terms; the factored comparison uses the resistance factors for yield and fracture in your specification.

Block shear (concept)

Picture a block bounded by the two rivet lines and the end of the plate: two shear faces along the rivet lines, each about 12 in. plus edge distance, and a tension face across the 5 in. gage between the outer holes. The resistance combines tension rupture on the tension face with shear yielding or rupture on the shear faces, per the LRFD block shear equation. With closely spaced members, also try blocks that merge with an adjacent member's fasteners. The TechBrief identifies these merged surfaces as a check that "needs to be validated."

What the example shows

For a typical tension diagonal, the Whitmore checks seldom govern if the plates are sound, because the Whitmore width grows quickly with the length of the fastener group. Corrosion along the end row, or a short fastener group, changes that quickly.

Glossary

Gusset plate

A plate that connects truss members at a panel point (node), transferring member forces through fasteners and plate shear.

Whitmore section

An effective plate width at the end row of fasteners of a member, defined by 30-degree dispersion lines from the first row of fasteners.

Ω (shear reduction factor)

A factor on shear yield resistance. It is 0.74 or 1.00 in FHWA-IF-09-014, and 0.88 in the NCHRP 12-84 calibration.

Full shear plane

A plane crossing the full width or height of the gusset, such as the horizontal plane along the chord.

Partial shear plane

A shear plane around a compression member that does not cross the full plate. It is coupled with buckling for closely spaced members.

Chord splice

A splice of the chord at the node. NCHRP 12-84 checks it as a combined section of gusset and splice plates under axial load and bending.

Block shear

A tearing failure of a block of plate around a fastener group, with tension on one face and shear on the others.

Non-load-path-redundant

A structure in which failure of a single main element could lead to collapse. This is the class of truss bridges named in the NTSB recommendation.

DL/LL ratio

The ratio of dead load to live load effect. It is used in calibration because the needed resistance factor varies with it.

Reviewer's checklist for a gusset plate rating

Use this checklist when you check another engineer's gusset rating, or before you seal your own. It is a teaching aid built from the checks and research findings in this course, not an official checklist.

Inputs

- Are plate thicknesses, grades and fastener patterns traced to specific plan or shop drawing sheets?
- Is the rivet strength basis stated, with its era or source?
- Are the inspection thickness readings dated, located on a sketch and mapped to the planes and Whitmore sections used?
- Are repairs, added plates and replaced fasteners reflected in the model?
- Does the dead load reflect the current deck, overlay and utilities?

Demands

- Are concurrent member forces used for each plane, rather than the envelope maximum of each member combined arbitrarily?
- Is the free body used to find each plane's shear shown?
- Were the live load cases that govern each node identified?

Resistances

- Were all five FHWA minimum checks performed, plus partial planes and chord splice where present?
- Are Ω and ϕ from the same generation of provisions?
- Is the Whitmore width drawn with 30-degree dispersion from the first to the last row of fasteners?
- Are the column length and K consistent with the provisions used?
- Was section loss for buckling projected onto an equivalent Whitmore thickness, and for shear taken plane by plane?
- Were multilayer plates checked for enough fasteners to develop each layer?

Factors and results

- Are the condition factor, the gusset system factor (0.90) and any long-span reduction applied?
- Is the controlling limit state identified for each node, with inventory, operating and legal results as the owner requires?
- Are recommendations (posting, retrofit, cleaning, monitoring) separated from the rating results?

A rating that answers each question with a reference to a source sheet, reading or specification article is a rating that will hold up to review and to the next inspection cycle.

Key takeaways

- The I-35W collapse (August 1, 2007) was attributed by the NTSB to undersized gusset plates; FHWA TA 5140.29 (January 15, 2008) and FHWA-IF-09-014 (February 2009) made connection rating standard practice.
- FHWA-IF-09-014 sets five minimum checks: fasteners (with plate bearing), shear yield and fracture, Whitmore compression, Whitmore tension (gross yield and net fracture), and block shear.
- Shear yield is $\phi_v y 0.58 F_y A_g \Omega$ with $\phi_v y = 0.95$ and $\Omega = 0.74$ unless stiffness to develop plastic shear is shown (then 1.00); shear fracture is $\phi_v u 0.58 F_u A_n$ with $\phi_v u = 0.80$.
- Whitmore width uses 30-degree dispersion; FHWA-IF-09-014 averages L1, L2, L3 for the column length and offers K by buckled shape; NCHRP 12-84 later found the middle length with $K = 0.5$, plus a partial-plane shear check, correlated better.
- Section loss on a shear plane acts through the total remaining area; for buckling, loss between the Whitmore width and adjacent fastener lines is projected onto an equivalent Whitmore thickness. Use the MBE gusset system factor of 0.90 and check your adopted MBE edition.

References

1. FHWA, Load Rating Guidance and Examples for Bolted and Riveted Gusset Plates in Truss Bridges, FHWA-IF-09-014, 2009
2. AASHTO, The Manual for Bridge Evaluation, 3rd Edition, 2018 (with interim revisions)
3. FHWA, Guidelines for Design and Rating of Gusset-Plate Connections for Steel Truss Bridges (TechBrief), FHWA-HRT-14-063, August 2014
4. FHWA Technical Advisory T 5140.29, Load-Carrying Capacity Considerations of Gusset Plates in Non-Load-Path-Redundant Steel Truss Bridges, January 15, 2008
5. NTSB, Collapse of I-35W Highway Bridge, Minneapolis, Minnesota, August 1, 2007, Highway Accident Report NTSB/HAR-08/03, 2008
6. NCHRP Web-Only Document 197, Guidelines for the Load and Resistance Factor Design and Rating of Riveted, Bolted, and Welded Gusset-Plate Connections for Steel Bridges (NCHRP Project 12-84)

Study text only; the final quiz is taken online. Verify all references against the edition your agency has adopted.