Connection Design in the New AISC Manual

Part 1 — Changes to the 2005 Specification

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This is the first in a two-part series of articles exploring the many changes to the design of connections in the 2005 AISC Specification and its accompanying Manual of Steel Construction, 13th Edition. In this first article changes to the Specification are discussed. The second part will discuss changes to the Manual.

Design Philosophy (B3.3 and B3.4)

The most sweeping change in the 2005 Specification is that it incorporates both Load and Resistance Factor Design (LRFD) and what is now termed Allowable Strength Design (ASD). By incorporating both design philosophies, the 2005 Specification replaces both the 9th Edition ASD and the 3rd Edition LRFD. The same nominal strengths are calculated regardless of whether the designer chooses to use LRFD or ASD. However, the resistance factors (factors of safety) are different to accommodate the different load combinations. In LRFD, the nominal strength is multiplied by a ϕ factor, as was done in all previous LRFD specifications. In ASD, the nominal strength is multiplied by $1/\Omega$. In all cases the ratio of ϕ to $1/\Omega$ is 1.5. In most cases, $1/\Omega$ will be the inverse of the safety coefficients ASD designers are accustomed to.

Bolts in Combination with Welds (J1.8)

Significant changes have been made in this item, which was J1.9 in the 3rd LRFD and J1.10 in the 9th ASD. The changes are based on recent research, which showed that sharing the load between welds and slip critical (SC) bolts, which was previously allowed, can be unconservative.

The new J1.8 does not allow sharing of load between bolts and welds in new work, except as follows: The bolts must be installed in standard holes or short slots perpendicular to the load, and the fillet welds must be loaded longitudinally. The bolts, which can be any bolt permitted in A3.3 (i.e. A307, A325, A490 and others) shall have an available strength not greater than 50% of their available bearing strength. Note that the bolts need not be considered to be slip critical, so A307 and other non-pretensioned bolts can be used. Note also that, in all earlier editions, if slip critical bolts were used, holes size and orientation, and weld orientation, were *not* limited.

In old work (alterations to existing structures), there is no change from previous editions.

Minimum Loads (J1.7, 3rd Edition)

The 2005 Specification does not contain any limitations on minimum loads. The 3rd Edition LRFD, and the 2nd Edition LRFD Specified 10 kips in J1.7, and the 9th Edition ASD, 6 kips in J1.6. These are not considered to be design requirements and have therefore been eliminated. Requirements such as minimum loads, maximum slenderness ratios, and the old 50% rule for truss internal members (9th Edition ASD J1.5) have been gradually eliminated because they are not design requirements and have led to abuse (i.e. a strict interpretation of these requirements without engineering judgment has led to expensive and unnecessary details.)

Compression Members with Bearing Joints (J1.4)

Previous specifications have required these joints to be designed for 50% of the required compressive strength of the member acting in tension. The 2005 Specification has a more realistic requirement as an alternative. Consider a transverse load acting at the joint location, say at the center of a truss compression chord panel. The transverse load is taken as 2% of the required compressive strength of the chord member. The chord between panel points is considered to be pinned at the panel points, and the resulting shears and moments at the joint location are used to design the splice at the bearing joint. This is a much more rational approach to the design. The old 50% rule is still allowed, if one wishes to use it.

Edge Distance (J3.10)

This is not new in the 2005 Specification. It was new in the 3rd Edition LRFD Manual Specification, but was not included in the 9th Edition Manual Specification. Those accustomed to using the 9th Edition Manual are in for a shock, because the new requirement, in most cases given by formula J3-6a as:

$$R_n = 1.2L_ctF_u \qquad \textit{Equation (1)}$$

where,

L_c is the clear edge distance
t is the plate or member thickness
F_u is the tensile strength

can result in significantly reduced capacities with the usual center of hole (L_e) edge distances of 1 ¾, 1 ½, and 1 ¼ inches. The limit state represented by *Equation (1)* is referred to as "tear-out", because it involves a tearing out of a slug of material between the bolt hole and the edge of material. *Equation (1)* replaces the 9th Edition ASD and 2nd Edition LRFD requirement that when $L_e \geq 1.5d$, where d is the bolt diameter, edge distance is not a design consideration for 2 or more bolts in line of force. The necessity to consider edge distance in every case has a profound effect on connection design, particularly for bolts that are eccentrically loaded.

Block Shear (J4.3)

This has changed from all previous formulations due to recent research which has shown that failure always occurs with tension fracture in the tension net area, followed by shear yielding on the gross shear area. But, to cover the cases where the net shear area is significantly reduced from the gross shear area, the lesser of the shear yielding and the shear fracture strengths is used. A concise way to represent the new block shear requirement is:

$$R_n = U_{bs}F_uA_{nt} + \min\{0.6F_yA_{gv}, 0.6F_uA_{nv}\} \qquad \textit{Equation (2)}$$

where,

F_y is the yield strength
F_u is the tensile strength
A_{nt} is the net tension area
A_{gv} is the gross shear area
A_{nv} is the net shear area
U_{bs} is 1.0 when the tension stress is uniform, 0.5 otherwise

Equation (2) is a simplification of AISC 2005 formula J4.5. U_{bs} is a block shear coefficient which is introduced to handle double columns of bolts and other cases with larger than normal eccentricities.

Effective Throat of Partial-Joint-Penetration Groove Welds (J2.1a)

Several changes have been made to the determination of the effective throat for partial-joint-penetration groove welds in Table J2.1. These changes primarily are concerned with the welding process and positions used.

Fillet Weld Directional Strength (J2.4)

This was new in the 2nd Edition LRFD Manual and was also in the 3rd Edition LRFD Manual. It has been in AWS D1.1 in ASD form since AWS D1.1-2000, so its use with the ASD 9th Edition ASD Manual was possible when project specifications included both AISC 9th Edition and AWS D1.1-2000. All of the eccentrically loaded weld group charts in the 2nd and 3rd Edition LRFD Manuals include the fillet weld directional strength.

A fillet weld loaded transversely has 50% more strength than one loaded longitudinally. Unfortunately, the ductility of the transversely loaded fillet weld is much less than the same fillet longitudinally loaded. Therefore, when transverse and longitudinal fillets are in the same group, their strengths cannot be directly added. For eccentrically loaded groups, this is addressed by the equations of J2.4(b). But for concentrically loaded fillet groups, many engineers and some AISC publications have simply added the transverse and longitudinal fillet strengths. This is unconservative. The 2005 Specification has prohibited this practice in J2.4(c) for groups that include both transverse and longitudinal welds by means of formulas J2-9a and J2-9b, which can be written as:

$$R_n = \max\{R_{wl} + R_{wt},\ 0.85_{wl} + 1.5R_{wt}\}$$

Equation (3)

where,

R_{wl} is the strength of the longitudinal welds

R_{wt} is the strength of the transverse welds

R_{wl} and R_{wt} are calculated as $0.6F_{EXX}A_{wl}$ and $0.6F_{EXX}A_{wt}$, respectively, where F_{EXX} is the electrode classification number (tensile strength) and A_w is the weld area.

Equation (3) allows the old method of using the same fillet weld strength for both the longitudinal and transverse welds without consideration of ductility. This is the first term in the brackets. The second term uses the increased transverse weld strength, $1.5R_{wt}$, but recognizes that when this strength of the transverse weld is reached, only 85% of the longitudinal strength has been achieved. This result can be derived from the equations of J2.4(b), recognizing that for a concentrically loaded weld group the instantaneous center of rotation is at infinity. Also Figure CJ2.13 of the Commentary can be used to derive a formula similar to J2.9b.

For concentrically loaded cases containing longitudinal, transverse, and oblique welds, the formulas of J2.4(b) or the Figure CJ2.13 can be used.

Fillet Welds – Minimum Size (J2.2b)

Previous AISC Specifications have always matched minimum fillet sizes to the *thicker* of the parts joined. The 2005 Specification changes this to the *thinner* of the parts joined. This brings AISC into line with AWS which has used the thinner part requirement for some time. The Commentary gives some reasons for the change, which is primarily due to the prevalence of low hydrogen electrodes.

Slip Critical Connections (J3.8)

In past specifications, all slip critical (SC) connections were designed to prevent slip at the service load level, whether they were designed at the service load level (ASD) or the factored load level (LRFD). The factor of safety against slip for these connections was generally 1.4 to 1.5 with respect to the service loads. Other modes of failure, such as yielding, buckling, and fracture, have factors of safety of at least 1.7 with respect to the service loads. These factors of safety are the same whether ASD or LRFD methods are used for the design.

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From the above discussion, it is obvious that bolts in SC connections will slip before any other limit state is reached. In the case of long span flat trusses assembled with SC bolts in oversized holes or slots parallel to the load, excessive deflections due to slip could cause ponding and ultimately collapse. To rectify thus situation, the AISC 2005 Specification introduces a limit state of slip at the required strength level. This yields a factor of safety of about 1.7 against service loads. The joint in a structure designed to this criterion will not slip until other failure modes are also reached.

There are now two design levels for SC connections: (1) design against slip as a serviceability limit state, and (2) design against slip as a strength limit state. The latter is appropriate where oversize holes or slots parallel to the load are used, and slip into bearing could cause a catastrophic collapse.

Shear Lag Coefficients (D3)

This was B3 in the 9th Edition ASD and the 3rd Edition LRFD. A new table D3.1 is now provided that expands the number of cases considered, and includes tubular member cases which were contained in the HSS Specification. The HSS Specification has been incorporated into the AISC 2005 Specification and no longer stands alone. Chapter K of the 2005 Specification is dedicated to HSS Connections.

Column Stiffeners for Strong Axis Moment Connections (J10.8)

The 2005 AISC Specification requires that column stiffeners be attached to the inside of the loaded flange for the "difference between the required strength and the available limit state strength". This is a return to the practice of the 9th Edition ASD Manual. The 2nd and 3rd Edition LRFD Manuals both required that the stiffener be welded to the inside of the loaded flange for the contact strength of the stiffener. The new requirement of J10.8, quoted above, will produce more economical designs.

Group 4 and 5 Shapes (A3.1c)

This is not strictly a connection design issue, but ASTM A6 no longer identifies W shapes by group. Therefore, the AISC 2005 Specification Section A3.1c replaces the requirements for Charpy V-notch testing for Group 4 and 5 members used as tension members or subject to tension due to flexure and spliced with CJP welds, with similar requirements for rolled shapes with flanges having a thickness exceeding 2 inches. The latest issue of ASTM A6 Supplement 30 provides Charpy V-notch information that is now required.

Shear Yielding Limit State (J4.1, G2.1a)

These two sections, the first dealing with connections and the second dealing with members, return the specification to the historic factor of safety for shear in rolled beams and connection plates of 1.5. The 9th Edition ASD has this factor of safety, but the intervening 2nd and 3rd Edition LRFD specifications used a factor of safety of 1.67 for no reason other than academic purity. The factor of safety of 1.5 has stood the test of time since 1923.

Buckling of Short Members (J4.4)

The 9th Edition ASD Specification for column strength allowed a factor of safety of 1.67 for very short members. The 2nd and 3rd Editions LRFD had a constant factor of safety of 1.5/0.85=1.76 for all columns, a much more conservative formulation. The 2005 Specification and the 13th Edition ASD/LRFD Manual allow the same factor of safety as the 9th Edition ASD when $kl/r \le 25$, i.e. Ω =1.67. This is another step back to a time-honored factor of safety.

Proportions of Beams and Columns (F13)

This was B10 in the 9th Edition ASD, and the 2nd and 3rd Editions LRFD. The new requirement is based on research and is much more economical than the old. The old requirement was not based on research but rather was a conservative rational approach to the effect of holes in tension flanges of flexural members. For A992 steel, the old requirement allowed only a 7.7% reduction in flange area before the holes had an effect. The new requirement allows a 23% reduction in flange area before holes reduce the flexural strength. This is an obvious step in the direction of economy.▪

Part 2

Part 2 of this series will explore how the changes in the 13th Edition Manual will affect connection design. It will also summarize the economic effects of the changes in both the 2005 Specification and the 13th Edition Manual.

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