THERMAL BREAKS IN STRUCTURAL STEEL

Challenges and Suggested Practices

SEAC/RMSCA Steel Liaison Committee

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Executive Summary

Over the last 10 years, thermal breaks have become more common in building construction, and in the Rocky Mountain Region. In many applications proprietary thermal break products are incorporated into the structural building system. The types of products and applications vary, and proper specification, pricing, and construction of thermal break products can be challenging. The SEAC/RMSCA Steel Committee has researched the most common products and applications currently in use in the Rocky Mountain market and identified common challenges and best practices for use of Thermal Breaks in steel buildings.

Scope and Limitations: It is beyond the scope of this paper to quantify the benefits of thermal breaks with respect to the energy efficiency of buildings.

Contents

Introduction

Thermal bridging in structures is a condition where thermally conductive materials penetrate the building envelope, allowing heat energy to transfer between interior and exterior temperature zones. There are 3 different thermal bridging categories: *Point*, *Linear*, and *Planar*. Many common structural steel details demonstrate point and linear bridging and are the primary focus of this paper. Generally, architectural elements not included in structural steel scope exhibit planar thermal bridges.

A *point* thermal bridge is an isolated penetration of a structural member through the building envelope. Common examples in steel construction include beams cantilevered through the building envelope, canopy connections, and rooftop posts. Heat is transferred through the continuous member isolated by components of the building envelope.

Linear thermal bridging occurs when a continuous member is attached parallel to the building envelope, with surfaces contacting the building interior and exterior. Examples include girts, lintels, and ledgers. These components transfer heat along a linear separation in the building envelope.

Planar thermal bridges are characterized by components of the building envelope itself and mechanical systems such as windows, facades, and vents.

Localized points are generally the least impactful thermal bridge case because the small cross-sectional area of the member allows less thermal transmittance. Linear thermal bridges tend to be more impactful because there is a larger area contributing to thermal transmittance. Planar elements have the greatest impact on thermal efficiency.

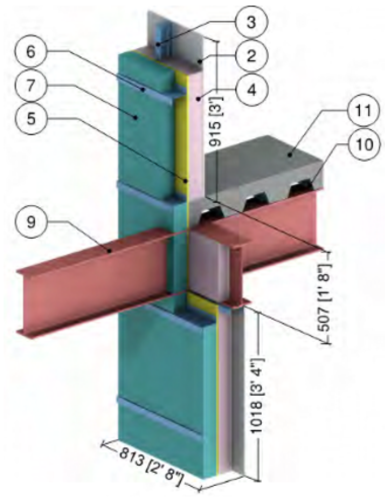
There are two major concerns with thermal bridging. First is the thermal efficiency of a building. Unmitigated thermal bridging can account for 20-70% of heat flow through a building envelope (ABTG, 2018). Building HVAC systems are a major consumer of energy and contributor to greenhouse gas emissions. Limiting thermal breaks reduces HVAC loading and in turn reduces upkeep cost. The second concern with thermal bridges is the risk of condensation which can result in mold, damage to interior finishes, and structural decay. Condensation is less of a concern in the Rocky Mountain Region but should not be ignored.

Energy conservation, carbon emission reduction, and the green building movement are all driving forces in the evolution of current local, national, and international building codes. Building codes requiring continuous insulation at the building envelope do not currently mandate the use of thermal breaks at structural connections, however incorporating breaks into the structure can help the design team achieve the goals of the governing building codes.

Products and Applications

There are many common applications for structural thermal breaks. At an exterior wall, steel thermal bridges can be created by elements such as balconies, canopies, and sign supports. The structural element for these building attachments includes a cantilevered beam element supporting an exterior feature passing through the thermal envelope and supported back to primary structure (Figure 1, left).

Thermal bridges can also occur at roofs as well. Common thermal bridges include platforms/dunnage supporting mechanical systems, screen wall posts, and fall protection or façade access anchors (Figure 1, right).



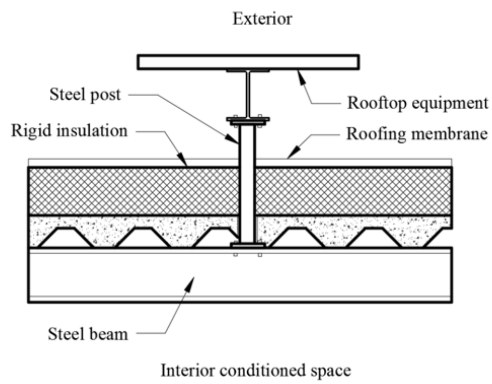


Figure 1: (left) Bending (Morrison Hershfield, 2020); (right) Column (Hamel, 2016)

Some thermal bridging conditions can be improved with thoughtful structural and architectural detailing. Otherwise, thermal bridges can be mitigated by interrupting the continuous steel member and creating a bolted splice connection with a thermal break pad or TBP (Figure 2).

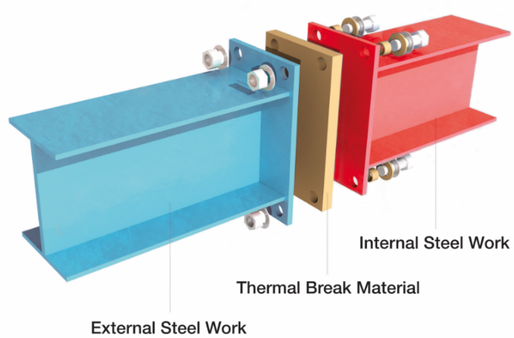


Figure 2: Typical thermal break assembly (Armatherm, 2022)

From a material strength standpoint there are generally two types of structural TBPs: high strength, and low strength. High strength pads are required for bending applications where the force within the connection is localized (Figure 1, left). Low strength pads may be appropriate for compression only elements not carrying moment-forces and consequently with highly distributed forces (Figure 1, right). Some high strength pads are rated for compressive strengths ranging from 38,000 psi to 43,000 psi. In contrast, some low strength pads have compressive strengths ranging from 200 to 2,000 psi. In all cases, the compressive modulus of the TBPs is much lower than steel, between 1% and 3%. The biggest issue regarding the use of TBPs in high strength steel connections is the creep behavior of the TBPs. Steel-to-steel connections do not creep. Introducing a non-steel material that does creep creates a new design challenge for connections subject to sustained loading.

The product market for structural thermal breaks is vast and growing. Although the scope of this paper is limited to a discussion about TBPs, other product types do exist. For example, some suppliers provide pre-manufactured structural thermal break assemblies composed of a stainless steel HSS member, wrapped in insulation, which connect to the primary structure with stainless steel threaded rods. Other manufacturers are marketing a "Thermal Break" paint. Although not technically a "break", a protective insulating coating may be a solution to prevent condensation in some applications, without introducing the structural challenge of a spliced member connection.

Specification and Detailing

TBPs are a part of the structural system and need to be clearly specified in the structural documents. At a minimum, TBP size and thickness should be identified, as well as any special fastener requirements. More comprehensively, a TBP specification should be included with the project documents. Manufacturers can provide sample specifications.

When specifying thermal break connections on a project, engineers and architects can help project estimators, fabricators, and erectors by presenting as much detailed information for the thermal breaks as available.

To be most effective, the thermal break should be located within the continuous insulation of the building envelope. This requires both structural and architectural details to be well coordinated. The more complex the building envelope, the greater the need for coordination among the design team. Designers should produce details and sections to ensure that components fit correctly in the building envelope and perform as intended.

Thermal break requirements can be shown in details (example, Figure 3), described in plan notes, and addressed in the specifications. The best approach for a project should be influenced by the quantity and complexity of thermal breaks required. In most cases, project documents should define pad type and manufacturer, pad thickness, pad location, thermal washer and bushing requirements, bolt size and type, and bolt pre-tension, if applicable

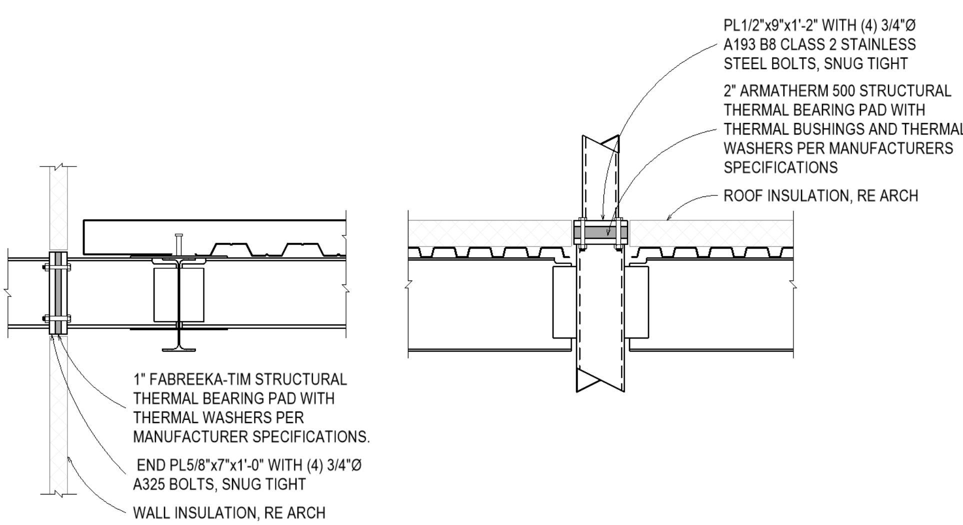


Figure 3: Example detail callouts for TBPs (for reference only)

Pad Thickness

Ideally the thickness of the TBPs should be determined by the project architect or building envelope consultant. The structural engineer needs to specify the thickness of the pad in their drawings and account for that thickness in the connection design.

Experimental (Hamel, 2017) and analytical (Morrison Hershfield, 2020) studies have shown that simply splicing a steel beam with a bolted end plate connection (without a TBP) increases the heat flow rate through the member, resulting in a more significant thermal bridge than the continuous beam condition. This is due to the increased cross-sectional area of the plates relative to the beam. Larger steel end plates equal a greater rate of heat flow. Including a thermal break pad at the splice improves the condition but if the pad is too thin, the overall thermal condition may still be worse than a continuous beam. Refer to Figure 4 for test results (Hamel, 2017) showing that a beam splice with a one-half inch thick FRP-TBP with steel bolts performs slightly worse than a continuous beam. Research has shown that for a TBP to be effective, the pad should be a minimum of one inch thick and ideally, the TBP thickness matches the thickness of the wall insulation.

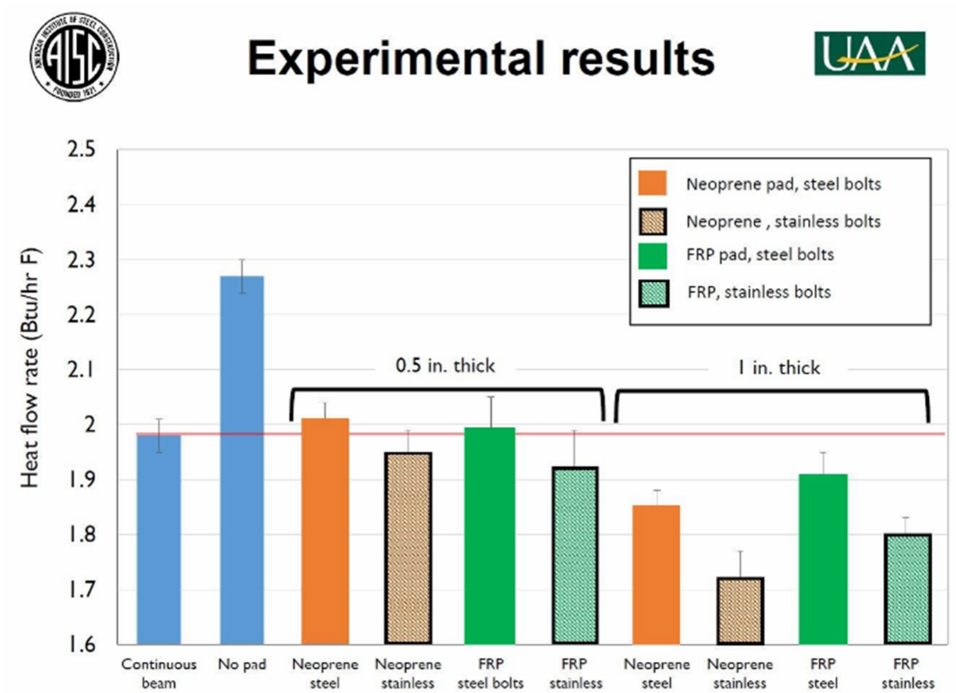


Figure 4: Hamel, UAA 2017 SEA Presentation

Thermal Washers and Bushings

Thermal washers and bushings are not necessarily required for every thermal break connection. Ideally, the architect or building envelope consultant should make that determination. If required, the washers and bushings need to be clearly specified on the project drawings or in the project specifications. Furthermore, some TBP manufacturers recommend special washer detailing when bushings are used.

Published studies indicate mixed conclusions as to the effectiveness of thermal bushings and washers. Some studies indicate significant improvement in thermal performance (Morrison Hershfield, 2020), while others conclude the impact is negligible (Peterman, 2017). The parameters of the analytical thermal models are complicated and beyond the scope of this paper.

Bolt Type and Installation

Stainless steel is roughly three times less conductive than carbon steel. Using stainless steel bolts in lieu of carbon steel bolts at a thermal break connection will improve the effectiveness of the break. However, stainless steel bolts are significantly more expensive than A325 bolts and can have less strength than carbon steel bolts. Specifying stainless steel requires special considerations such as galvanic corrosion, a bolt tightening qualification procedure if bolt pretension is specified (AISC *Design Guide 27*-Appendix A), and lubrication of bolts to prevent galling of the threaded surfaces.

Special Inspection

Special inspections of steel construction conform to IBC Chapter 17 requirements, which reference AISC 360 Chapter N to define what quality assurance inspections are completed by the third-party special inspector. The current AISC 360 Specification does not make reference to connections with thermal breaks, therefore the engineer should consider adding to their statement of special inspections within the Construction Documents. Items that may be listed within the required inspections include thermal break pad size, thickness, material specification, thermal bushing & washer installation (if applicable), and bolt size, grade, and installation. In addition to including TBP connections within the statement of special inspections, it is also beneficial to discuss these connections in a steel preconstruction meeting with the structural engineer, general contractor, steel fabricator, erector and third-party special inspector.

Structural Design

Currently formal building codes do not provide guidance for engineers designing connections with TBPs, including IBC or AISC. The Specification for Structural Joints Using High-Strength Bolts (RCSC, 2020) does include a discussion on thermal breaks in Section 1.1 commentary. In short, the commentary clarifies that the RCSC specification does not apply to thermal breaks, stating that "*Thermal break joints are not intended for primary load resisting systems*".

Commentary:

This Specification covers the design of bolted *joints* with collateral materials in the *grip* that are made of steel. These provisions do not apply when materials other than steel are included in the *grip*. These provisions are not applicable to anchor rods.

Recently, other types of *joints* that contain low-modulus materials in the *grip*, and most notably thermal break joints, have made an entrance in the market and questions on their use, chiefly for components, such as cladding, awnings, and roof posts, that are not part of a primary load-resisting system, have come forward. Thermal break joints are not intended for primary load resisting systems. Several research projects have been conducted (Peterman et al., 2017; Peterman et al., 2020; Hamel and White, 2016) investigating the structural properties of thermal break joints showing that the presence within the *grip* of compressible gaskets, insulation, or other materials or coatings will preclude the development and/or retention of the installation *pretension* in the bolts.

Figure 5: Excerpt RCSC Section 1.1 Commentary (RCSC, 2020)

There are several design methods that have been published by thermal break suppliers and academic researchers. Summarized below are some of the different methods of structural design and recommendations based on the current state of the industry. Steel-to-steel connections using thermal breaks are predominantly achieved using bolted end plate connections.

Below design methods focus on shear and moment transfer strategies through the thermal break pad. An in-depth discussion on the design of end plate connections is not provided here, however, AISC Design Guides 4, 13 and 39 are valuable resources for end plate connection design. End plate connections can be detailed as pinned connections with shear and zero moment transfer through the connection, or fixed end connections with both shear and moment transferred through the connection. The recommendations in the methods below can be applied to either connection type.

Method 1: Shear Force Transfer Through Bolt Bending

Method 1 is the recommended design method from *Thermal Break Strategies for Cladding Systems in Building Structures* (Peterman, 2017). To summarize, the shear force is resisted using single curvature bolt bending and neglecting the presence of the TBP. Note, the bolt will more likely behave in double curvature, however it is assumed that the researchers recommended single curvature bending to produce more conservative results.

The magnitude of the bending moment in the bolt is the bolt shear force times the TBP thickness. Therefore, thicker pads produce more demand on the bolt. The bending moment in the connecting element at the end plate connection is resolved by considering the moment as a compression-tension force couple in which tension is resisted by the bolts and compression is resisted in bearing between the end plates and through the TBP (Figure 6). Bolts are designed for the shear, tension and moment using the combined forces equations of AISC 360, Chapter H. To design the bolts for the single curvature bending, section J4.5 of the AISC 360 Specification can be used.

Peterman (2017) does not address if an elastic or plastic section modulus should be used to check the bolt bending strength or if any reductions should be applied to account for the bolt threads. Conservatively, the elastic section can be used, however if section F11 of the AISC Specification is applied for this bending capacity of a solid round section, the plastic section modulus is reasonable to use. If the thread planes are excluded from the shear plane and critical section for bending, then the full section modulus is appropriate to use. If the threads are within the shear plane and critical section for bending, the section modulus should be reduced to include the threads.

The compressive force of the moment force couple passes through the TBP and creates a compressive stress within the TBP. Peterman (2017) provides an elastic stress equation to determine the compressive stress in the TBP, however any rational method of mechanics, including finite element analysis or the method described below in Method 2 are suitable for determining the compressive stress in the pad.

Two other important recommendations from Peterman (2017) are also presented. First, compressive stresses in TBPs should be limited to 35% or less of the compressive strength of the material. This is based on considerations for creep due to compression in the pads in combination with their low modulus of elasticity. This recommendation is further validated based on material suppliers providing creep testing data at a stress of one third the material strength. Second, bolts should be installed snug tight and not pre-tensioned. Peterman (2017) states that pre-tensioned bolts were not part of their research and that their use in these connections is not recommended. Note, Peterman (2017) does not cover conditions with bushings or thermal washers. Given this, the engineer should consider the shear transfer mechanism and if bushings impact the ability to transfer the shear through bolt bending as well as bearing between the end plate and bolt.

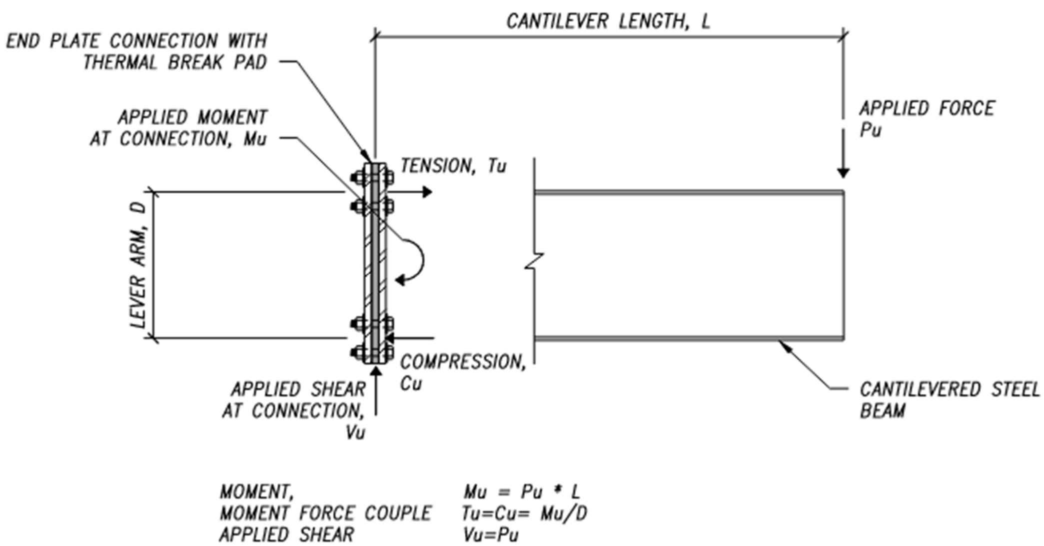


Figure 6: Free body diagram and force transfer with cantilevered beam and end plate connection

Method 2: Shear Force Transfer Based on Treating the Thermal Pad as a Filler

Method 2 is recommended by *Thermal Bridging in Steel Construction* (Way, 2016). This paper is based on European standards and references the Eurocode, but its principles can be applied to TBP connections using engineering principles and provisions of the AISC 360 specification.

In this method, the bending moment is resolved into the same tension/compression force couple described above in Method 1. The TBP must be checked to ensure the compressive stress is below the limits of the pad. Way (2016) does not provide recommendations on limits to the compressive stress within the pad, however it is reasonable to use the same 35% or less of the compressive strength of the pad as outlined in Method 1. Way (2016) does provide a simple method for determining the compressive stress in the pad by defining an effective area within the pad that resists the compression force. The effective area is determined by spreading the compression force at a 45-degree angle through the weld and end plate thickness (Figure 7).

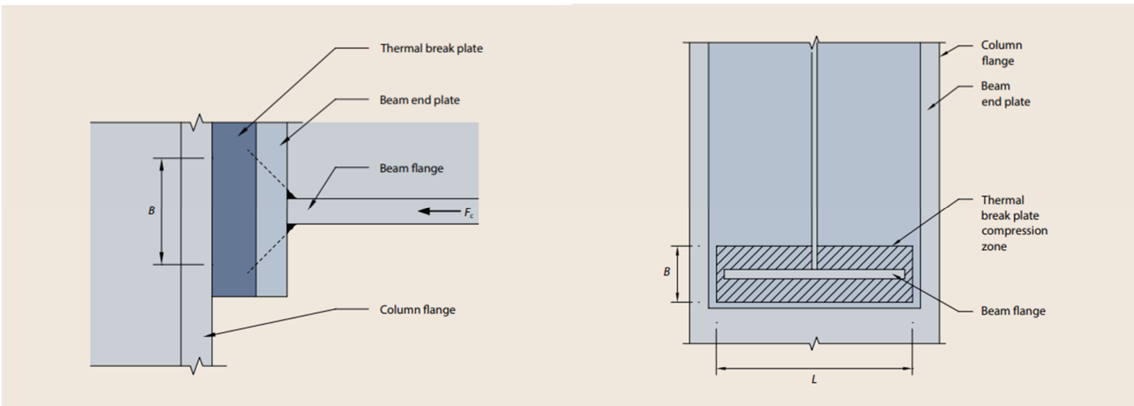


Figure 7: Effective area for determining compressive stress within thermal break pad (Way, 2016)

Shear is transferred by treating the TBP as a filler (or "packs" as defined by Way (2016)). To design this shear transfer using AISC 360, section J5.2 Fillers in Bolted Bearing-Type Connections, can be used to design the bolted connection. In this case, the shear is transferred using the shear capacity of the bolts, multiplied by a reduction factor based on the TBP thickness. This section of the AISC specification does not put an upper limit on the filler pad thickness, however Way (2016) states that "the total thickness of the packs (filler) should not exceed 4*d*/3, where *d* is the nominal diameter of the bolt". Using this recommendation, when using ¾" diameter bolts, the pad thickness should not exceed one inch.

Method 3: Shear Force Transfer Through Friction

Method 3 uses the compressive force of the tension/compression moment force couple and the frictional coefficient between steel and the TBP to provide shear resistance across the TBP (Figure 6). The manufacturer's product data provides a frictional coefficient; a value of between 0.25-0.30 can be expected. If pretension in the bolts is specified it can also create a clamping force with friction for additional shear resistance, however caution should be exercised when using bolt pretensioning due to lack of long-term research and potential loss of pretension due to pad deformation.

TBPs have a low modulus of elasticity and are therefore prone to larger deformations under axial loads. Localized high areas of compressive stress due to bolt pretension could cause the bolts to lose the effectiveness of pretension due to local thermal break material creep. Moment transfer across the thermal break joint is resolved using the same principles as described in Methods 1 and 2.

Additional Considerations

An important consideration to be aware of is the material properties of the TBPs. Most proprietary TBPs have compressive strengths above 30 ksi for applications that transfer bending moments, however the compressive modulus is significantly lower than that of steel. Pad deformation, and more importantly creep, are important considerations when evaluating the additional beam rotation that can occur at thermal break connections. When long cantilever members are used in a thermal break connection, the additional linear deflection at the tip of the cantilever should be considered in addition to the flexural deflection. Way (2016) provides a simple equation using Hooke's law to estimate the rotation at the connection due to the initial pad deformation. Most proprietary thermal break pad suppliers provide a creep plot within their literature.

If thermal washers are specified, the engineer should understand the localized compressive stress within the thermal washers. The compressive stress in the washer is the greater of the design bolt tension or the bolt pretension divided by the effective compressive area, the bearing area of the steel washer. As an example, if the design bolt tension in a ¾" A325 bolt is 25k using an LRFD load (29.8k LRFD capacity), the compressive stress in the thermal washer is approximately 21 ksi. There is no formal guidance for determining the capacity of the thermal washer, however it is reasonable to use the same 35% of the ultimate compressive stress from Method 1 to evaluate the applicability of the thermal washer in the connection. Further discussion on thermal washers is provided within the Fabricator and Erector section below and Appendix B.

The engineer also needs to verify and coordinate with the architect the wall assembly and location of thermal breaks. TBPs are most effective when placed in the plane of the exterior continuous insulation. It's important to consider the total thickness of the thermal connection assembly, including end plates, TBP, and bolt heads. In conditions where the continuous insulation is thin and the exterior wall finishes are close to the insulation, the thermal break connection assembly may not fit within the provided wall assembly. In this case, it may be more effective to use thermal break paint and avoid using a TBP assembly. In cases where the beam comes out of the exterior wall at a skew, the end plates could be specified as parallel with the exterior insulation/finishes, or other provisions should be made to conceal the connection with considerations to interior and exterior finishes.

Calculations Summary

The above methods of structural design are reasonable to use and are based on research or principles of mechanics. Method 1 will generally provide the most conservative results as it relates to bolt sizes. Method 2 has likely been used in practice most frequently, given its use in the Eurocode, however it does not have an upper bound thickness based on bolt diameter. Method 3 uses principals of mechanics and shear friction, but it is unknown if this method has been validated by research testing. Appendix A provides example calculations using the different methods outlined.

Thermal break connections will continue to gain prevalence and future research will help guide adoption into building codes. Until then, engineers will need to continue to rely on engineering judgement at locations where thermal break connections are proposed.

Fabrication and Erection

The main challenge for fabricators and erectors is properly estimating the cost of including thermal breaks in project bids. Clear details and specification of the TBPs and assemblies in the contract documents are critical for pricing. Recommendations are specifying a TBP manufacturer in the structural details along with any other assembly requirements, such as bushings, washers, bolt material and bolt installation methods. With long lead times, clear directives in the contract documents also allow for faster material procurement.

Thermal break assemblies also impact erector installation costs as they take more time and labor to install. A typical 4-bolt end plate connection can be assembled by just one iron worker. Adding thermal washers, bushings, and a pad to the connection complicates assembly. An improved thermal break connection can require two iron workers to keep all components in place during installation. Temporary erection aids such as tape or adhesives to hold bushings and pads in place are often employed in the field to install these assemblies.

A common field issue with these assemblies is failure of thermal washers during the bolting process, specifically when bushings are used due to the use of much larger holes in the end plates to accommodate bushings. To avoid this issue, manufacturers suggest using USS Grade 8 steel washers on both sides of the thermal washer to prevent crushing. This problem is accentuated when pretensioned bolts are specified. Engineers should specify the appropriate washers and refer to the manufacturers' recommendations. Erectors should confirm the required pretension through pre-installation verification. Manufacturers discourage the use of Tension Control Bolts in connections using thermal washers. Appendix B outlines experimental test results by the committee.

Shop and field modifications of TBPs can be difficult. Special safety precautions are required to cut, drill, or modify TBPs due to their composition leading to potential respiratory damage and special equipment may be required. In general, thermal break materials should be considered a final product rather than material that can be modified.

Conclusion

Expectations for energy efficient buildings are rising as jurisdictions set new targets and establish green standards. The design and construction communities have important roles to play in providing energy efficient buildings. Economically detailing thermal breaks to reduce thermal bridging in the building envelope is one of many small steps that can reduce future energy use.

Today, thermal breaks are becoming increasingly common in many projects in the Rocky Mountain Region and design codes are behind design practice – unlikely to catch up soon due to long code cycles. Engineers and builders must therefore exercise judgement in the use of TBPs. Understanding the function and the limits of these materials is critical for designing and building successfully.

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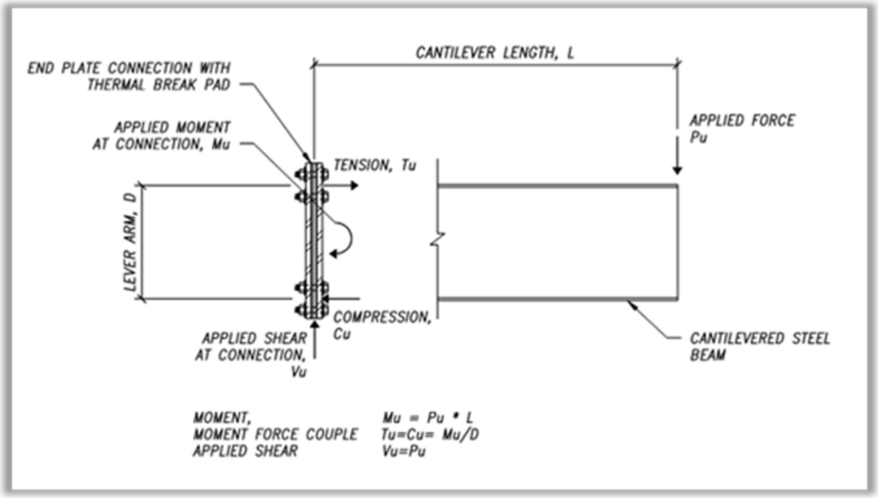
Appendix A – Sample Calculations



Method 1: Shear Force Transfer Through Bolt Bending

Beam: W12x26, d = 12.2”

Dead Load = 3k, Snow Load = 3k

Pu = 8.4 k

L = 8’

Mu = 67.2k-ft

Note: All limit states are not checked for this example calculation. Multiple approaches can be taken to sizing the end plate thickness and bolt design.

Determine end plate thickness and bolt tension:

Moment force couple: $Tu = Cu = \frac{Mu}{D}$

$D = 12.2" - .38" = 11.8"$

$Tu = Cu = \frac{67.2\ k{-}ft{*}12in}{11.8\ in} = 68\ kips$ / 4 bolts = 17k/bolt

Size the end plate to eliminate prying action based on Part 9 of AISC 360 Specification.

Bolt spacing above and below flange = 2” (thus center to center of bolts is 4.38”).

Bolt horizontal spacing is 4.5” with 1 ¼” edge distance (thus plate width = 7”).

$t_{np} = \sqrt{\frac{4T_u b\prime}{\emptyset p F_u}} = \sqrt{\frac{4*17k*1.625"}{0.9*3.5"*65ksi}} = .74"$ à Use ¾" end plate

Check bolt tension:

Tu = 17k/bolt, ØRn = 29.8k for ¾" A325 Bolt.

Check compressive stress on thermal break pad – Use SCI method described to determine effective area:

$A_{br} = B * L = 2.38"*7" = 16.66\ in^2$

$L = 7"$

$B = t_f + 2t_w + 2t_p = .38"+2*.25 + 2 * .75" = 2.38"$

$\sigma_{tbp} = \frac{C_u}{A_{br}} = \frac{68k}{16.66in^2} = 4.1ksi$

30% of thermal break pad ultimate compressive stress = 0.3*35ksi = 10.5ksi à Thermal break pad compressive stress is within the guidance of academic research.

Shear transfer through bolt bending:

$V_u = \frac{8.4k}{8\ bolts} = 1.05k\ per\ bolt$, bolt shear < 30% of shear capacity, effects of combined shear and tension not required to be checked.

Single curvature bolt bending neglecting the thermal break pad:

$M_u = 1.05\ k * 1" = 1.05k - in$

Bolt bending capacity using reduced area of bolt due to threads:

$\emptyset M_n = Z * Fy \leq Fy * 1.6S = 0.9 * 90ksi * 1.6 * 0.0257in^3 = 3.33\ k - in$

Combined moment and tension in bolts using Chapter H of AISC 360 Specification.

à ¾" A325 bolts OK for combined forces.

Check deflection of cantilever, including effect of thermal break pad compressive deformation and creep:

Dead load plus snow load deflection due to flexure = 0.298"

Deformation of pad under compression using Hooke's Law and 1" thermal break pad thickness. Use 400 ksi compressive modulus, compressive modulus to be provided by manufacturer.

$\Delta L = \frac{\sigma_{tbp}*t_{tbp}}{E_{tbp}} = \frac{4.1ksi*1"}{400\ ksi} = 0.01"$ Deformation of pad under compressive load.

Rotation of beam due to pad deformation:

$$\theta = \sin^{-1}(\frac{\Delta L}{d}) = \sin^{-1}\left(\frac{.01"}{12.2"}\right) = 0.047\ degrees$$

Additional linear deflection of beam due to rotation under full load:

$$\Delta_{TL} = L * \tan\theta = 8' * 12" * \tan(0.047) = .079"$$

Long term creep due to sustained loading – Creep plot to be provided by manufacturer's data. For calculation purposes, assumed creep = 150% of initial load. Creep occurs under sustained load, which is taken as dead load only.

Additional Deflection at tip due long-term creep of dead load only:

$$\Delta_{DLcreep} = (\frac{3k}{6k} * 0.079")(1.5 - 1.0)\ =\ 0.0198"$$

Total deflection of beam including flexural, thermal pad deformation and creep effects.

$\Delta = 0.298$+.079"+.0198 $= 0.397"$à   33% increase in deflection due to thermal break connection.

Method 2: Shear Force Transfer Through Bolt Bending

All aspects of connection design are the same as shown in method 1 except shear transfer.

Pad size is limited to 4/3d where d is bolt diameter. Using 3/4" A325 bolts and 1" thermal break pad.

Treat the thermal break pad as a filler and reduce bolt shear strength as required by AISC 360 J5.

Bolt shear strength reduction $= 1 - 0.4(t - 0.25) = 1 - .4(1 - .25) = 0.7$

Bolt shear strength with reduction as filler:

$$\emptyset R_n = 0.7 * 17.9k = 12.5k\ /bolt$$

Bolt Shear demand to capacity $\frac{1.05k}{12.5k} = 0.084$

Bolt Tension demand to capacity $\frac{17k}{29.8k} = 0.57$

bolt shear < 30% of shear capacity, effects of combined shear and tension not required to be checked.

Comparing the bolt design results in this example between Method 1 and Method 2 indicates that Method 1 produced 50% more demand on the bolt than Method 2.

Method 3: Shear Force Transfer Through Friction

All aspects of connection design are the same as shown in method 1 except shear transfer.

Use compressive component of tension/compression force couple and frictional coefficient between steel and thermal break pad to resist shear. Frictional coefficient to be provided by manufacturer's data. For this example, assume a coefficient of friction of 0.27.

$F_f \leq \mu F_n$, where μ is coefficient of friction and F_n is the normal force or compressive force and F_f is the friction resistance between the surfaces.

$$Vu \leq F_f = 0.25 * 68kips = 17kips$$

$V_u = 8.4k$ therefore, the shear force demand to capacity ratio is $\frac{8.4k}{17k} = 0.49$

Bolt Tension demand to capacity is the same as Method 2.

Appendix B – Washer Testing

Metro Steel fabricated a simple mockup of a typical bolted splice plate connection for testing purposes, and four bolts were attempted to be pre-tensioned. The purpose of this testing was to explore the process of assembling the connection and tightening the bolts.

Bolt and washer types were varied, while all four bolts included thermal bushings and sandwiched thermal washers on each side. The intended pretension of each bolt was 29 kips.

Bolt 1: A325 hex head with regular oversized washers.

Bolts 2 and 3: A325 hex head with grade 8 washers.

Bolt 4: Twist-off PT bolt with grade 8 washers.

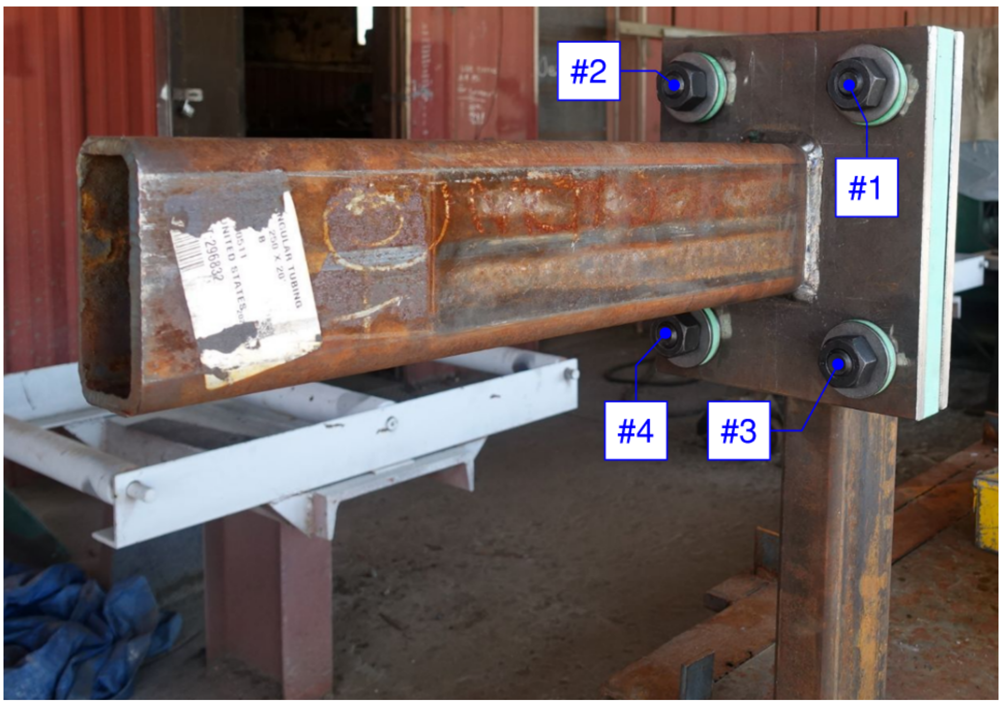


Photo 1: Test setup with bolt labels

The thermal washers on Bolts #1 and #2 failed prior to full pre-tensioning.

Bolts #3 and #4 were successfully installed to full pre-tension.

Torque-tension values were calibrated prior to installation. However, thermal washers introduce variability and the actual in-place tension values achieved are unknown. It is possible that Bolts #1 and #2 were simply over-tightened.

Photo 2: Thermal washer failure at Bolt #1 with regular oversized washer

Photo 3: Thermal washer failure at Bolt #1 with regular oversized washer