Practical Solutions

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Designing Column Base Plates for Uplift

45-Degree-Progression Bending Planes vs AISC HSS Base Plate Bending Planes

By Dan Mazzei, P.E.

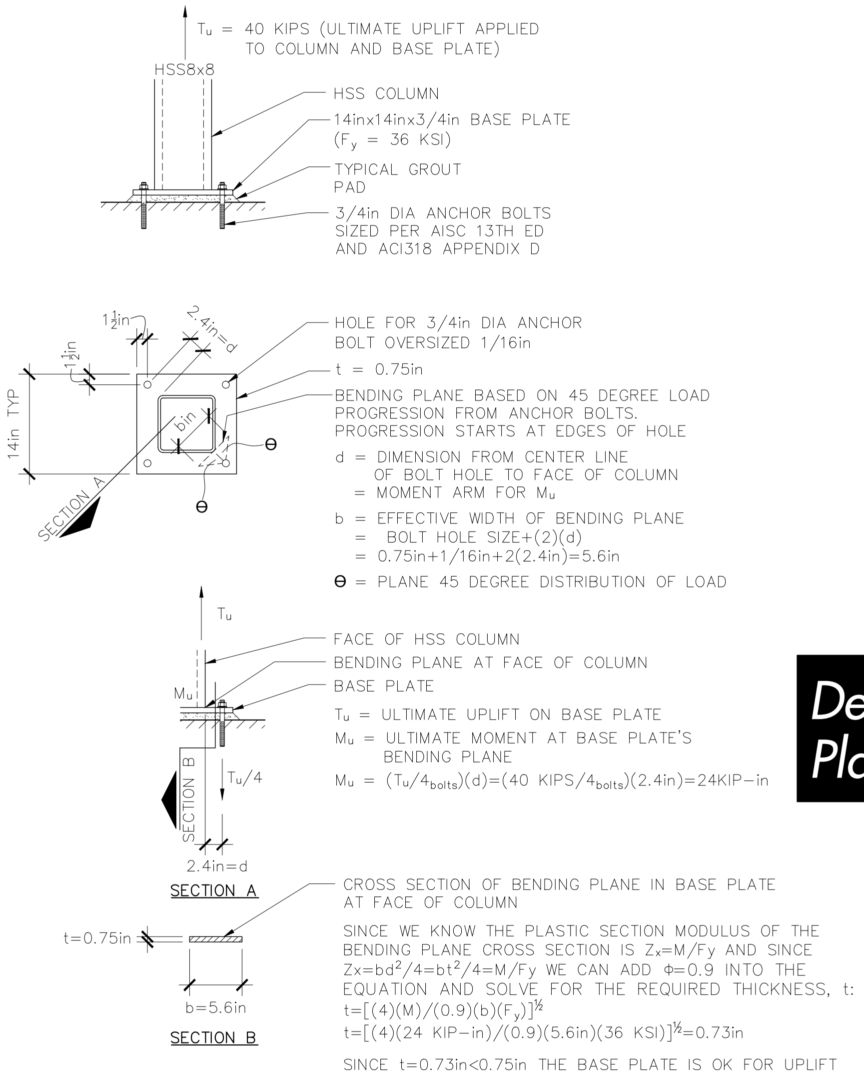

Figure 1: 45-degree-progression bending plane.

According to the father of the atomic age, Albert Einstein, we should all try to "Make everything as simple as possible, but not simpler." In the spirit of this admonition, the following article describes a simple way to analyze steel in bending, and specifically a steel base plate supporting an HSS column subject to uplift forces. Once properly understood, the method can be used for most conceivable configurations of steel components where a flat-plate-bending, bending plane can be identified. For comparison purposes, a corresponding base plate analysis will also be performed using the AISC procedure for locating the bending plane of a base plate supporting an HSS column.

We will analyze a 14-inch x 14-inch base plate, supporting an HSS 8x8 column resisting a net ultimate uplift of 40 kips. The steel design reference will be the 13th Edition of the AISC *Steel Construction Manual* (AISC 13th Edition).

The anchor bolts, that secure the base plate to the foundation, are symmetrically placed at the column corners. Following clear spacing guidance in Table J3.4 of the AISC 13th Edition, each anchor bolt is located as shown in *Figure 1*. Since the anchor bolts are symmetrically placed, and the base plate is a uniform thickness, they share the 40 kips equally. Therefore, each bolt resists 40 kips / 4 or 10 kips of uplift. The more difficult challenge is to locate the bending plane, and corresponding effective width, in the base plate as the column is pulled upward. If we assume that the bending plane is located at the column corners and the area of steel developed is based on a 45 degree distribution of the tension force from each bolt, the base plate's bending plane can be visualized as shown in *Figure 1*. Using this approach, the required base plate thickness based on the flexural strength of the bending plane is just under 0.75 inches.

continued on next page

Dan Mazzei, P.E. is an Associate at Wallace Engineering, headquartered in Tulsa, OK. He is a member of the American Concrete Institute and a member of the Oklahoma Structural Engineers Association. Dan can be reached at ***dmazzei@wallacesc.com****.*

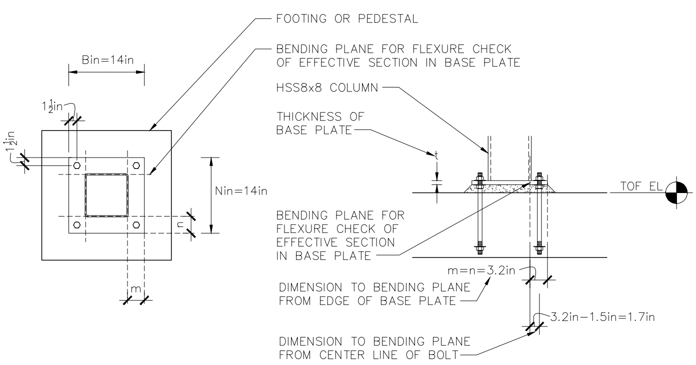

Figure 2: AISC HSS base plate bending plane.

For comparison purposes, our next step would be to locate the bending plane per the AISC 13th Edition, Chapter 14. It is important to note that this procedure is based on a base plate designed for gravity loads, but it can still be used to locate the bending plane for net uplift. Using the same base plate configuration, we will identify the plate width (B) = 14 inches and the base plate length (N) = 14 inches. With the base plate's bending plane being near the face of the column and considering the portion of the base plate beyond the face of the column as cantilevered out to the edge of the base plate, the actual location of the bending plane is the greatest of m, n and λn' from the edge of the base plate.

As shown in *Figure 2* and per AISC 13th Edition, Chapter 14, for a square HSS shape m = n = [N – (0.95)(column width)] / 2 = [14–(0.95)(8 inches)]/2 = 3.2 inches This dimension is the distance from the edge of the base plate to the bending plane in the base plate near the face of the column. For a base plate subjected to gravity loads, the 3.2 inch dimension must then be compared to the theoretical location of the bending plane based on yield line theory, λn'. However, the calculation for λn' is not applicable for a net uplift condition since it is dependent on the capacity of the base plate with respect to concrete crushing (i.e. Pu / ϕ Pp). See *Punching Shear In Thin Foundations* in the April 2012 issue of STRUCTURE Magazine.

Therefore, the bending plane for uplift loads is at m = n = 3.2 inches. In other words, this calculation shows that the bending plane is 3.2 inches from the edge of the base plate. Up to this point, the AISC procedure for determining the dimensions m and n is essentially the same as what is used when designing a base plate in bearing with continuous support by a footing (i.e. what is shown in AISC 13th Edition, Chapter 14). However, since the base plate is supported in the reverse direction by the heads of the anchor bolts, the bearing plate procedure cannot be used to solve for the moment in the effective section nor for the required base plate thickness. Instead, the location of the bending plane from the center line of the anchor bolts can be found by subtracting the bolt's clear space (1½ inches for the edge of the plate) from the 3.2 inch dimension determined above, giving 3.2 inches – 1.5 inches = 1.7 inches. This is the dimension between the bolt's centerline and the bending plane, and is also the moment arm needed to solve for the moment at the bending plane. The moment at the bending plane is simply the tension load on two bolts multiplied by the 1.7 inch moment arm. Since both sides resist the load equally, the moment at the bending plane is, M = Tu/2 x 1.7 inches = 40 kip/2 x 1.7 inches = 34 kip-inches. Using the same logic as shown in *Figure 1,* the effective section for this case is the full length of the base plate and the required thickness can be determined as follows:

$t = [(4)(M) / (0.9)(b)(Fy)]^{1/2}$

$t = [(4)(34 \text{ kip-inches}) / (0.9)(14 \text{ inches})(36)]^{1/2}$

$t = 0.55$ inches

As you can see, the required thickness, based on the AISC HSS base plate bending plane, is less than that based on the 45-degree-progression bending plane. This is because the latter accounts for unbraced base plate corners by using a reduced effective section. Therefore, the 45-degree-progression procedure is both simpler, more accurate, and will result in a more conservative design (i.e. a thicker base plate) when designing for uplift.

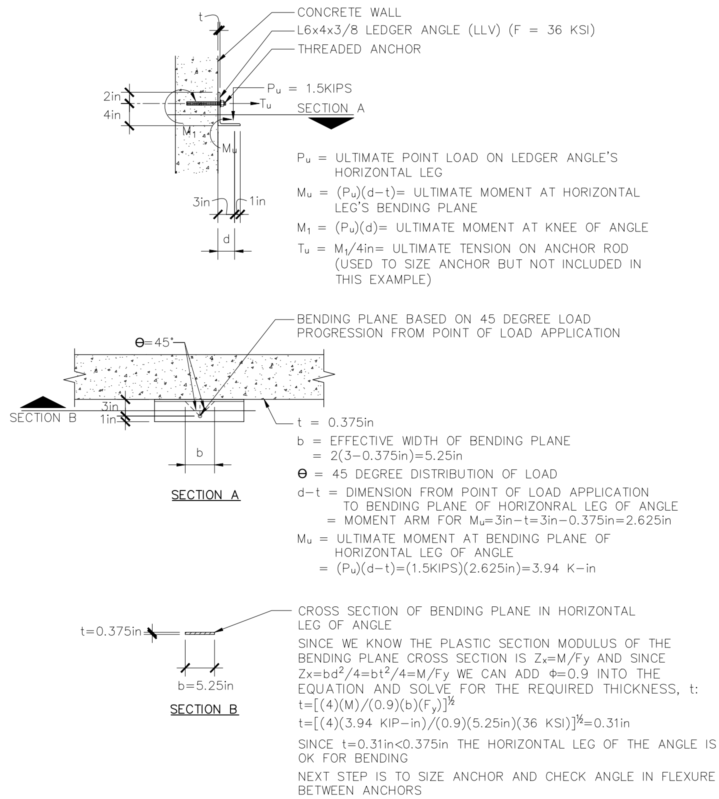

Figure 3: Bending at horizontal leg of ledger angle example.

Another example of how useful the 45-degree-progression bending plane procedure can be is shown in *Figure 3*. This calculation checks a ledger angle's ability to support a load applied near the toe of its horizontal leg. The procedure is the same as that outlined in *Figure 1* and simply shows that the required thickness of a steel component is easily determined by identifying the bending plane, calculating its section modulus, calculating the applied bending moment at the bending plane and then determining how much steel is necessary to resist the bending moment.

In conclusion, I hope that the reader can see how useful and simple the 45-degree-bending plane procedure can be when checking the capacity of steel components. It has helped me, on several occasions, check the capacities of structural components for which there was no clearly defined design procedure.▪