減弱式梁柱接頭銲接孔之細部與施工

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銲接孔（或稱扇形孔）的主要目的，是允許銲道施工時穿越梁腹板等阻礙，而銲接孔同時可以降低銲道正交方向的束制。研究結果顯示，當梁柱間以翼板全滲透銲腹板栓接連接時，銲接孔的幾何形狀、施工方式及施工品質，對梁強度與韌性的發展有顯著的影響。國內對於銲接孔之幾何形狀有很多的討論，也有不少的爭議，本文試著提供一些想法，讓讀者參考。

美國 AISC 341-10[5] Seismic Provisions for Structural Steel Buildings 有如下的規定：

（1） OMF 的梁柱接頭：並不需要使用 AISC 358[6]規定之預檢定梁柱接頭型式，但是其銲接孔形狀需符合 AWS D1.8[4]中 6.10.1.2 之規定，如圖 1 所示。

（2） IMF 及 SMF 的梁柱接頭：應使用符合 AISC 358 規範規定之預檢定梁柱接頭型式。AISC 358 第 5.5 節（如圖 2）則規定，使用減弱式梁柱接頭時，銲接孔形狀不需符合 AWS D1.8 中 6.10.1.2（即圖 1）之規定，但須符合 AISC 360 J1.6（簡稱 J1.6）[2]之規定（詳圖 3 方框中之文字）。

OMF 對梁柱接頭韌性的需求不高，不需使用預檢定梁柱接頭，而使用傳統的梁柱接頭即可。因此梁柱接頭之銲接孔，一方面要考慮到裂縫的抑制，另一方面也要考慮某些程度韌性的提供。就韌性之提供而言，圖 1 中②這一段是一個重點，②越長降伏段越長，所能提供的韌性也越高，但是②太長時會導致翼板挫屈，所以也不可以過長。總之，OMF 所需之韌性由圖 1 之細部來提供即可，不需使用到預檢定梁柱接頭型式。

由於處於地震帶，國內房屋結構大多使用 SMF 及減弱式接頭，此時韌性由翼板切削段提供，而銲接孔則以抑制裂縫為首要考量，因此銲接孔形狀不需符合 AWS D1.8（即圖 1）之規定。至於裂縫的抑制，重點在幾何形狀的漸變、加工面的平順、熱循環的減少及銲接束制的降低。其中幾何形狀漸變及銲接束制的降低與銲接孔的幾何形狀有關，而加工面的平順及熱循環的減少則與施工比較有關。

在幾何形狀方面，AISC 358 規定幾何形狀需要符合 AISC 360 J1.6 之規定，如圖 3 之文字敘述。這個規定主要包括銲接孔的最小寬度、最小高度，以及切割線最小彎轉半徑等。圖 4 為 AISC 360 J1.6 解說中提出之可能銲接孔型式。而

日本「建築鐵骨設計基準及解說」則提出如圖 5 所示之幾何形狀（以下簡稱弧形銲接孔），國內對於圖 5 所示銲接孔幾何形狀（即 ABDE 曲線），一般根據下述準則決定之[8]：

（1）AB 為一段以 E 點（上翼板）或 G 點（下翼板）為圓心、r_1 為半徑之圓弧。當翼板厚度較小時 r_1 採用 35 mm，隨著翼板厚度增加下翼板之 DE 線段逐漸變小，當 DE 線段之長度小於 10 mm 時，r_1 應改採用較大的數值，通常採用 45 mm。

（2）BD 為一段以 C 為圓心、r_2 為半徑之四分之一圓弧。r_2 固定為 10 mm。

（3）DE 為一直線段且為 BD 圓弧之切線。

根據 J1.6(2005)的規定，銲接孔的寬度（W）不得小於 1.5 倍腹板厚度（即 1.5 t_w），銲接孔的高度（H）不得小於 1.5 倍腹板厚度（即 1.5 t_w）及 25 mm 之大者，此外切割線最小彎轉半徑不得小於 10 mm。根據 J1.6 的規定，檢討弧形銲接孔，由於上翼板不會控制，因此檢討下翼板如下：

（1） 弧形銲接孔最小彎轉半徑為 10 mm（即 r_2），所以不論 r_1 為 35 mm 或 45 mm，彎轉半徑都合乎 J1.6 之規定。

（2a）當 r_1 為 35 mm 時，DE 段保持 10 mm 以上，也就是寬度 W 保持 20 mm 以上，此時腹板厚度不得大於 13 mm。為了讓 DE 段保持 10 mm 以上，翼板厚度必需受到限制，當翼板使用 30^o 開槽角度，翼板厚度不得大於 23 mm。

（2b）當 r_1 為 45 mm 時，以 DE 段保持 14 mm 為例，寬度 W 保持 24 mm 以上，此時腹板厚度不得大於 16 mm。為了讓 DE 段保持 14 mm 以上，翼板厚度必需受到限制，當翼板使用 30^o 開槽角度，翼板厚度不得大於 34 mm。若 DE 段採用其他數值時，梁腹板及翼板厚度之限制如表 1 所示。

（3）銲接孔高度 H 等於 r_1，不論 r_1 為 35 mm 或 45 mm，H 都大於 25 mm，也都可以大於 1.5 倍由寬度決定之腹板厚度，因此銲接孔高度都可以合乎 J1.6(2005)之規定。

綜合上述，弧形銲接孔在下述限制下可以合乎 J1.6(2005)之規定：

（1） 當 r_1 為 35 mm 時，梁翼板厚度不超過 23 mm，梁腹板厚度不超過 13 mm。

（2） 當 r_1 為 45 mm 時，梁翼板厚度及梁腹板厚度之限制互為消長，其容許值如表 1 所示。

AISC 360 J1.6(2005)解說中所提出之銲接孔型式中(即圖 4a)，銲接孔寬度多了一個不小於 38 mm 的要求，2010 年版則將不小於 38 mm 的規定納入規範主文中。就力學的觀點而言，為了降低銲接束制，銲接孔寬度至少需有 1.5 倍腹板厚度，這個觀點出現在 2005 年及 2010 年版的解說條文中。至於 2010 年版規範主文中增加銲接孔寬度不小於 38 mm 的要求，其原因解說並沒有說明，可能與施工性比較有關，銲接孔採用手動方式（即火焰切割加上切割面研磨）製作時，比

較需要考慮這個要求，如果銲接孔採用自動銑刀設備施作，則這個要求的需要性不高。

在施工方面，AISC 360 J1.6 解說所提出的銲接孔型式（即圖 4 Alternate 1 及 Alternate 2）中，Alternate 2 基本上無法採用機械加工的方式來製作，Alternate 1 或許可以但是國內沒有可用的機具，因此只能以火焰切割及切割面研磨等手動方式施工。AWS D1.8 建議之銲接孔，國內也無法採用機械加工的方式製作。目前國內可以採用機械加工方式製作的銲接孔，為弧形銲接孔。

減弱式梁柱接頭的試驗，有採用圖 1 所示銲接孔形狀者，也有採用弧形銲接孔者，而兩者基本上都可以讓梁柱接頭發展出足夠的韌性，合乎規範對於樓層變位角不小於 0.04 的要求，因此兩種作法都可以被接受。不過考慮到實際工程施工品質之控制，使用機械加工者品質穩定性高出手動加工甚多。基於目前國內施工設備的條件，建議梁斷面在施工機具容量可及之範圍時，採用弧形銲接孔並以機械加工方式製作；當梁斷面超出施工機具能夠施作的範圍時，採用火焰切割及切割面研磨的方式施作，而銲接孔的幾何形狀可以採用 AWS D1.8 之規定者（圖 1）或弧形銲接孔，不過弧形銲接孔的 r_1 應該根據 J1.6 的規定調整之，不應拘泥於 45 mm。

參考文獻：

[1]AISC(2005), Specification for Structural Steel Buildings, ANSI/AISC 360-05, American Institute of Steel Construction.

[2]AISC(2010), Specification for Structural Steel Buildings, ANSI/AISC 360-10, American Institute of Steel Construction.

[3] AWS (2010), Structural Welding Code-Steel, AWS D1.1/D1.1M:2010, American Welding Society.

[4] AWS (2009), Structural Welding Code-Seismic Supplement, ANSI/AWS D1.8/D1.8M:2009, American Welding Society.

[5]AISC(2010), Seismic Provisions for Structural Steel Buildings, ANSI/AISC 341-10, American Institute of Steel Construction.

[6]AISC(2010), Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications, ANSI/AISC 358-10, American Institute of Steel Construction.

[7] 日本財團法人公共建築協會，建築鐵骨設計基準及解說，平成10 年。

[8] 中華民國鋼結構協會技術委員會，”技術備忘錄第002號： H 梁扇形孔細部設計與施工”，中華民國鋼結構協會，民國一百年十二日

表 1 弧形銲接孔 r_1 為 45 mm 時翼板及腹板厚度之容許值

DE 段距離 (mm)	銲接孔寬度 (mm)	容許最大翼板厚度 (mm)	容許最大腹板厚度 (mm)
12	22	38	15
13	23	36	15
14	24	34	16
15	25	33	17

6.10 Weld Access Holes

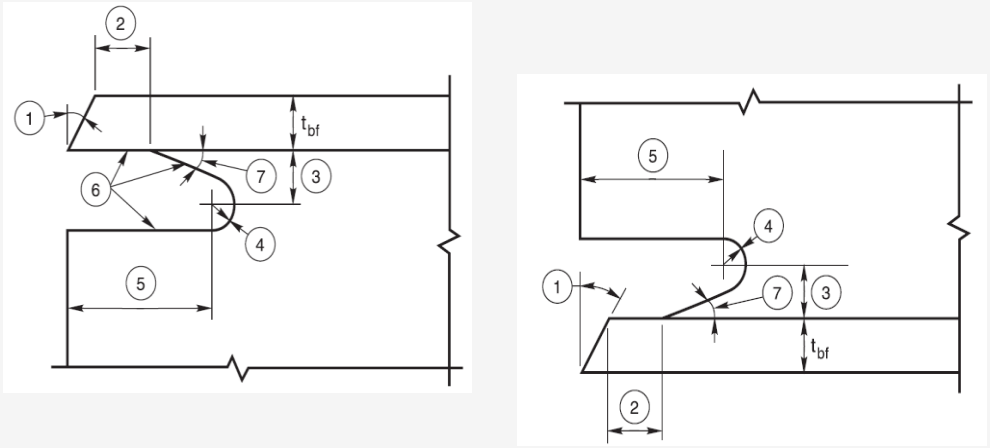
Weld access holes for all Demand Critical welds shall conform to the following:

6.10.1 Shape

6.10.1.1 Standard AWS D1.1/D1.1M Geometry. Unless otherwise specified in Contract Documents, all weld access holes shall meet the dimensions and tolerances of AWS D1.1/D1.1M or AISC 360. At the option of the Contractor, the geometry of 6.10.1.2 may be substituted for the 6.10.1.1 geometry.

6.10.1.2 Alternate Geometry. When required by Contract Documents, the weld access hole dimensions and tolerances, and geometry shall comply with Figure 6.2.

6.10.1.3 Special Geometry. When a special geometry is required by Contract Documents, the weld access hole geometry shall comply with those dimensions and tolerances specified.



Notes:
1. Bevel as required for the WPS.
2. t_{bf} or 1/2 in [12 mm], whichever is larger (plus 1/2 t_{bf}, or minus 1/4 t_{bf}).
3. The minimum dimension shall be 3/4 t_{bf}, or 3/4 in [20 mm], whichever is greater. The maximum dimension shall be t_{bf} (+1/4 in [6 mm]).
4. 3/8 in [10 mm] minimum radius (–0, +unlimited).
5. 3 t_{bf} (±1/2 in [12 mm]).
6. See 6.10.2.1 for surface roughness requirements.
7. Tolerances shall not accumulate to the extent that the angle of the access hole cut to the flange surface exceeds 25°.

Figure 6.2—Alternate Geometry—Beam Flange Weld Access Hole Detail (see 6.10.1.2)

圖 1 AWS D1.8 [4]耐震補充規定之銲接孔型式

AISC 358-10 CHAPTER 5 **REDUCED BEAM SECTION (RBS) MOMENT**

5.5. BEAM FLANGE-TO-COLUMN FLANGE WELD LIMITATIONS

Beam flange to column flange connections shall satisfy the following limitations:

(1) Beam flanges shall be connected to column flanges using complete-joint-penetration (CJP) groove welds. Beam flange welds shall conform to the requirements for demand critical welds in the AISC *Seismic Provisions*.

(2) Weld access hole geometry shall conform to the requirements of the AISC *Specification*.

5.5. BEAM FLANGE-TO-COLUMN FLANGE WELD LIMITATIONS

Complete-joint-penetration groove welds joining the beam flanges to the column flanges provided on the majority of RBS test specimens have been made by the self-shielded flux cored arc welding process (FCAW-S) using electrodes with a minimum specified Charpy V-notch toughness. Three different electrode designations have commonly been used in these tests: E71T-8, E70TG-K2 and E70T-6. Further, for most specimens, the bottom flange backing was removed and a reinforcing fillet added, top flange backing was fillet welded to the column, and weld tabs were removed at both the top and bottom flanges.

Test specimens have employed a range of weld access-hole geometries, and results suggest that connection performance is not highly sensitive to the weld access-hole geometry. Consequently, prequalified RBS connections do not require specific access-hole geometry. Weld access holes should satisfy the requirements of Section 6.10 of AWS D1.8/D1.8M (AWS, 2009). The alternative geometry for weld access holes specified in Section 6.10.1.2 of AWS D1.8/D1.8M is not required for RBS connections.

圖 2 AISC 358-10 [6]預檢定減弱式梁柱接頭銲接孔之規定

6. Beam Copes and Weld Access Holes

All weld access holes required to facilitate welding operations shall have a length from the toe of the weld preparation not less than $1^1/_2$ times the thickness of the material in which the hole is made. The height of the access hole shall be $1^1/_2$ times the thickness of the material with the access hole, t_w, but not less than 1 in. (25 mm) nor does it need to exceed 2 in. (50 mm). The access hole shall be detailed to provide room for weld backing as needed.

For sections that are rolled or welded prior to cutting, the edge of the web shall be sloped or curved from the surface of the flange to the *reentrant* surface of the access hole. In hot-rolled shapes, and built-up shapes with CJP *groove welds* that join the web-to-flange, all *beam copes* and weld access holes shall be free of notches and sharp reentrant corners. No arc of the weld access hole shall have a radius less than $^3/_8$ in. (10 mm).

In built-up shapes with fillet or *partial-joint-penetration groove welds* that join the web-to-flange, all beam copes and weld access holes shall be free of notches and sharp reentrant corners. The access hole shall be permitted to terminate perpendicular to the flange, providing the weld is terminated at least a distance equal to the weld size away from the access hole.

For heavy sections as defined in A3.1c and A3.1d, the *thermally cut* surfaces of beam copes and weld access holes shall be ground to bright metal and inspected by either magnetic particle or dye penetrant methods prior to deposition of *splice* welds. If the curved transition portion of weld access holes and beam copes are formed by predrilled or sawed holes, that portion of the access hole or cope need not be ground. Weld access holes and beam copes in other shapes need not be ground nor inspected by dye penetrant or magnetic particle methods.

圖 3a　AISC 360-05[1] 對銲接孔之規定

6. Weld Access Holes

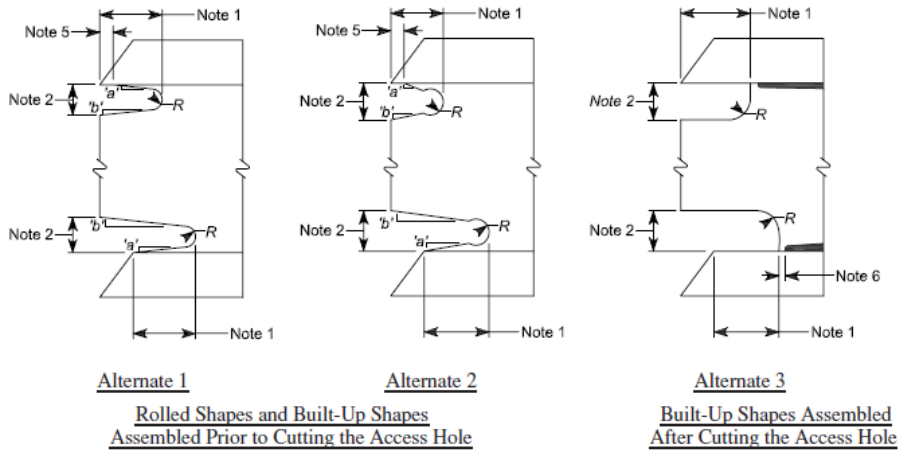
All weld access holes required to facilitate welding operations shall be detailed to provide room for weld backing as needed. The access hole shall have a length from the toe of the weld preparation not less than $1^1/_2$ times the thickness of the material in which the hole is made, nor less than $1^1/_2$ in. (38 mm). The access hole shall have a height not less than the thickness of the material with the access hole, nor less than $^3/_4$ in. (19 mm), nor does it need to exceed 2 in. (50 mm).

For sections that are rolled or welded prior to cutting, the edge of the web shall be sloped or curved from the surface of the flange to the *reentrant* surface of the access hole. In hot-rolled shapes, and *built-up shapes* with CJP *groove welds* that join the web-to-flange, weld access holes shall be free of notches and sharp reentrant corners. No arc of the weld access hole shall have a radius less than $^3/_8$ in. (10 mm).

In built-up shapes with fillet or *partial-joint-penetration groove welds* that join the web-to-flange, weld access holes shall be free of notches and sharp reentrant corners. The access hole shall be permitted to terminate perpendicular to the flange, providing the weld is terminated at least a distance equal to the weld size away from the access hole.

For heavy sections as defined in Sections A3.1c and A3.1d, the *thermally cut* surfaces of weld access holes shall be ground to bright metal and inspected by either magnetic particle or dye penetrant methods prior to deposition of *splice* welds. If the curved transition portion of weld access holes is formed by predrilled or sawed holes, that portion of the access hole need not be ground. Weld access holes in other shapes need not be ground nor inspected by dye penetrant or magnetic particle methods.

圖 3b　AISC 360-10[2] 對銲接孔之規定



Notes: There are typical details for joints welded from one side against steel backing. Alternative details are discussed in the commentary text.

(1) Width: Greater of 1.5 × t_w or $1^1/_2$ in. (38 mm). Tolerance is ± $^1/_4$ in. (6 mm).

(2) Height: Greater of 1.5 t_w or 1 in. (25 mm) but need not exceed 2 in. (50 mm).

(3) R: $^3/_8$ in. min. (8 mm). Grind the thermally cut surfaces of access holes in heavy shapes as defined in Section A3.1c and A3.1d.

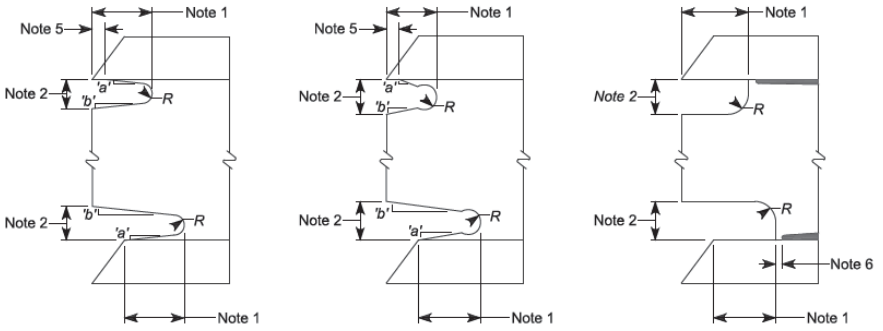
(4) Slope 'a' forms a transition from the web to the flange. Slope 'b' may be horizontal.

(5) The bottom of the top flange is to be contoured to permit the tight fit of backing bars where they are to be used.

(6) The web-to-flange weld of built-up members is to be held back a distance of at least the weld size from the edge of the access hole.

Fig. C-J1.2. Weld access hole geometry.

圖 4a　AISC 360-05[1] 建議之銲接孔幾何形狀



Rolled shapes and built-up shapes assembled prior to cutting the weld access hole.

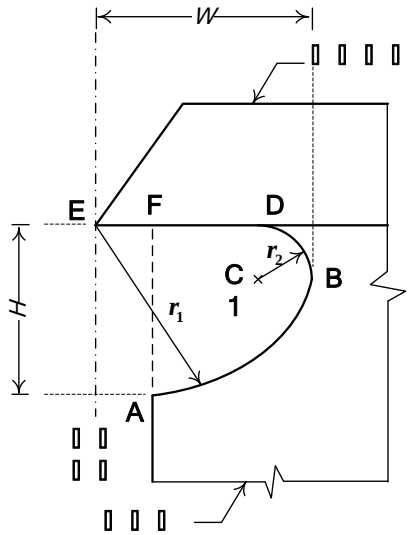
Built-up shapes assembled after cutting the weld access hole.

Notes: These are typical details for joints welded from one side against steel backing. Alternative details are discussed in the commentary text.

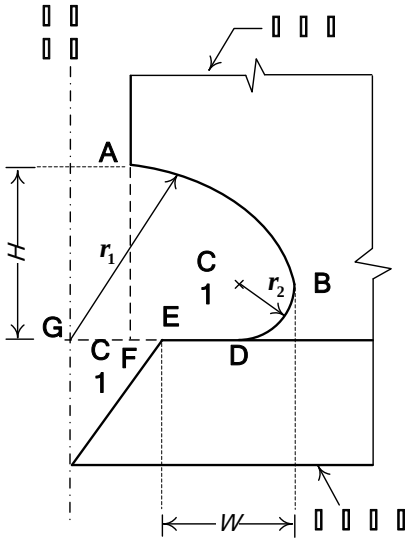
1) Length: Greater of 1.5t_w or $1^1/_2$ in. (38 mm)
2) Height: Greater of 1.0t_w or $^3/_4$ in. (19 mm) but need not exceed 2 in. (50 mm)
3) *R*: 3/8 in. min. (10 mm). Grind the thermally cut surfaces of weld access holes in heavy shapes as defined in Sections A3.1(c) and (d).
4) Slope *'a'* forms a transition from the web to the flange. Slope *'b'* may be horizontal.
5) The bottom of the top flange is to be contoured to permit the tight fit of backing bars where they are to be used.
6) The web-to-flange weld of built-up members is to be held back a distance of at least the weld size from the edge of the access hole.

Fig. C-J1.2. Weld access hole geometry.

圖 4b　AISC 360-10[2] 建議之銲接孔幾何形狀



(a) 上翼板



(b) 下翼板

圖 5 弧形銲接孔幾何形狀