Tangent Outlet Design For Welded Steel Pipe

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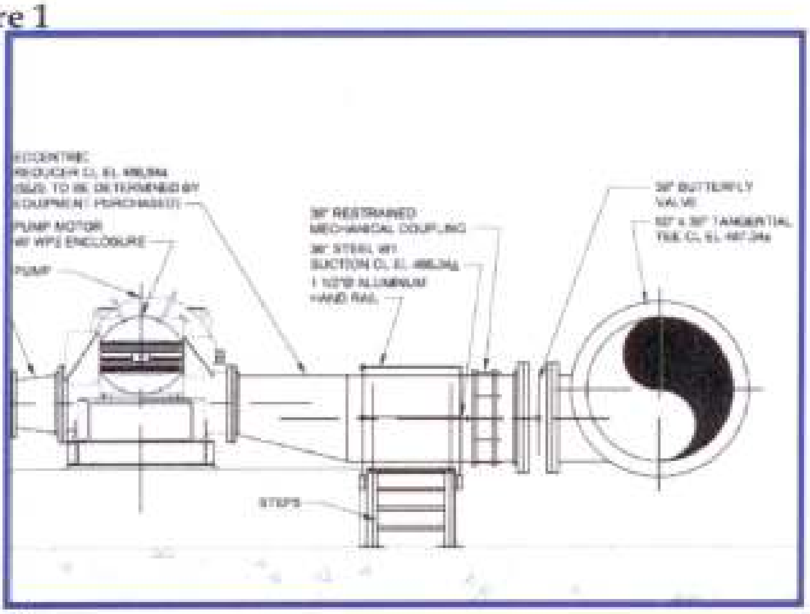
Abstract

Tangent outlet fittings are a key component of many pipelines. These fittings are typically used in water-works applications where complete drainage of a pipeline is desired or at pumping stations where necessary for the elimination of air that is troublesome to pumping equipment. Tangent outlets, because the branch pipe centerline is asymmetric with the main pipe centerline, are more complex geometrically than conventional nozzles and tees that are symmetrically oriented. The reinforcement of openings and stress analysis of tangent outlets has not been the topic of many texts. Also, welding details that are critical to the success of any steel fabrication are often ignored. Some design guidance can be obtained from several sources including the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC), Section VIII, Division 1 and the American Water Works Association (AWWA) Manual M11, *Steel Water Pipe: A Guide for Design and Installation*, however the analysis and design details of tangent outlet fittings for water-works applications could use some improvements for use in the design office.

This paper will address the fundamentals of design and fabrication of tangent outlet fittings for welded steel pipe and will explore the geometry and mathematics of typical fittings. The paper will also present welding code concepts and formulas that govern design. In addition, suggested welding details for ease of fabrication will be presented. The goal of this paper is to provide a useful tool to pipeline designers who may have struggled in the past with design issues related to tangent outlet fittings. An example problem is included.

Figure 1 indicates a typical tangent outlet fitting fabricated from weld steel pipe.

Figure 1



Geometry

Understanding of the geometry of welded steel tangent outlets is essential to accurate design and fabrication for dependable service. However, somewhat rigorous calculations are necessary to accurately design and detail components of tangent outlets. Analytic geometry and vector algebra play a significant role in determining templates for cutting and bending the steel plates and for developing groove welding details. The author has previously presented the equations and an example problem illustrating the geometry of intersecting cylinders in another ASCE Pipelines publication *Fabrication of Welded Steel Wye Branches.*

This paper focuses on tools for determining joint geometry of tangent outlets. Figures 2, 3 and 4 are useful tools in determining the geometry of intersecting pipes, specific to tangent outlets. Figure 3 is used to determine welding details, where angles between planes tangent to the branch and main pipes called "***local dihedral angle***" as indicated in ***AWS D1.1/1.1M:2010, Structural Welding Code-Steel, Annex P, Local Dihedral Angle*** are calculated. Note that Annex P is limited to outlets that are located on the same axis as the main pipe thus Annex P cannot be used for tangent outlets.

Further definition of "***Local Dihedral Angle***" is found in ***AWS D1.1, Annex K, Terms and Definitions***,

> *local dihedral angle, Ψ (tubular structures). The angle, measured in a plane perpendicular to the line of the weld, between tangents to the outside surfaces of the tubes being joined at the weld. The exterior dihedral angle, where one looks at a localized section of the connection, such that the intersecting surfaces may be treated as planes.*

Figure 2 indicates the relationship between branch end rotation angle, "***Rho***" (ρ) and local dihedral angle "***Psi***" (Ψ). Once a branch rotation angle, "***Rho***" has been selected, Figure 3 can be used to determine the dihedral angle "***Psi***" for any value of "***Beta***", a series of curves, where Beta=r/R, "***r***" is equal to the radius of the outlet, and "***R***" is equal to the radius of the main pipe. As an aid to the reader, Figure 4 is a tabular presentation of the graph in Figure 3.

Figure 2

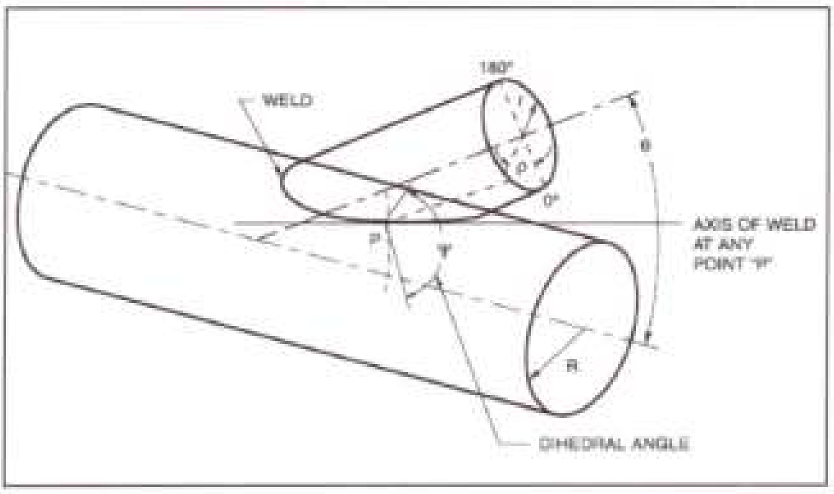


Figure 3

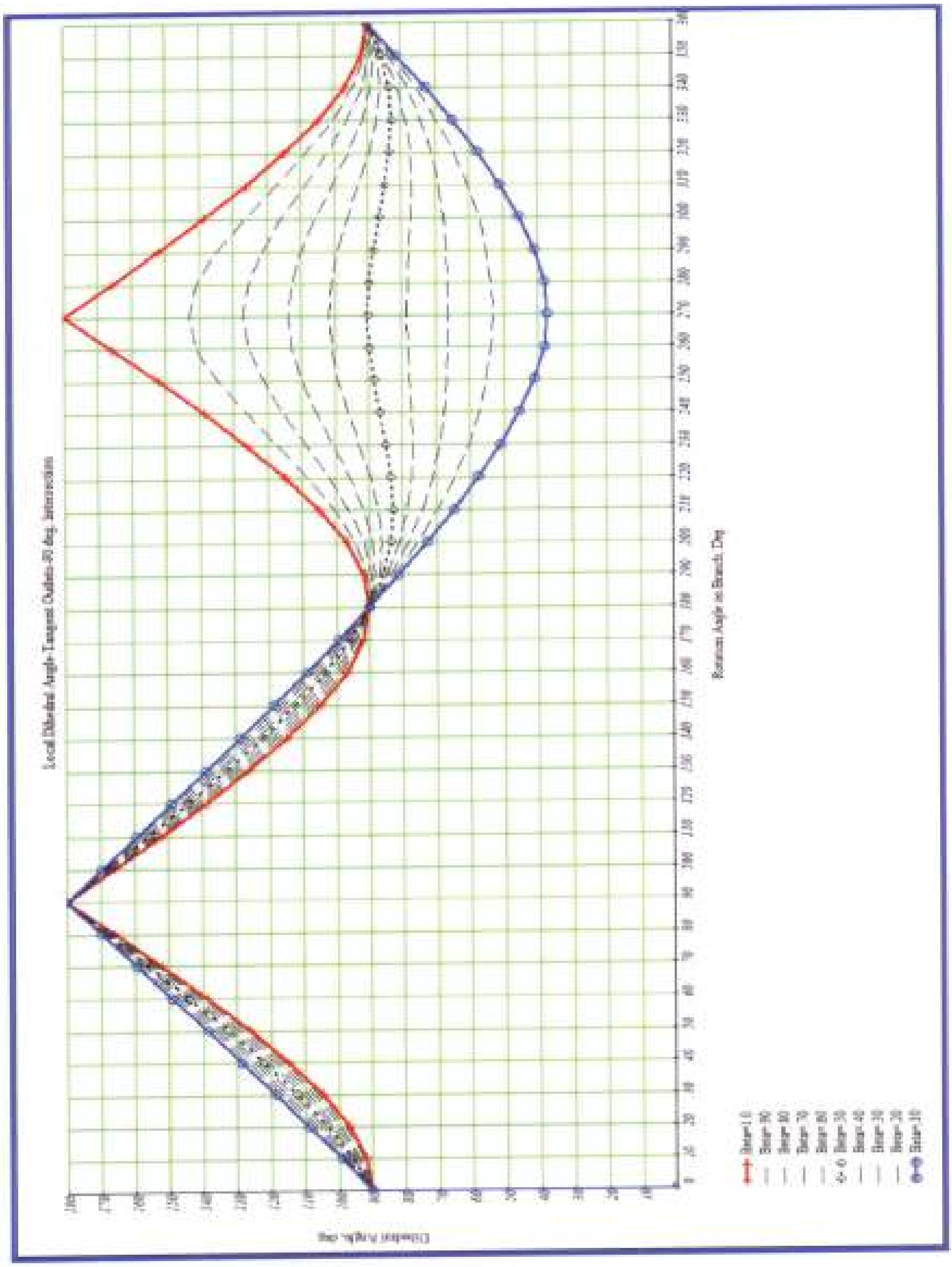


Figure 4

Rotation Angle on Branch, deg	Local Dihedral Angle, deg									
	Beta									
0	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
0	90	90	90	90	90	90	90	90	90	90
10	92	93	93	94	95	96	97	98	98	99
20	97	98	99	101	102	103	105	106	107	109
30	104	106	107	109	110	112	114	115	117	118
40	114	116	117	119	120	122	123	125	127	128
50	126	127	129	130	131	133	134	135	137	138
60	139	140	141	142	143	144	145	146	147	149
70	152	153	153	154	155	156	156	157	158	159
80	166	166	167	167	167	168	168	169	169	170
90	180	180	180	180	180	180	180	180	180	180
100	166	166	167	167	167	168	168	169	169	170
110	152	153	153	154	155	156	156	157	158	159
120	139	140	141	142	143	144	145	146	147	149
130	126	127	129	130	131	133	134	135	137	138
140	114	116	117	119	120	122	123	125	127	128
150	104	106	107	109	110	112	114	115	117	118
160	97	98	99	101	102	103	105	106	107	109
170	92	93	93	94	95	96	97	98	98	99
180	90	90	90	90	90	90	90	90	90	90
190	92	91	89	88	87	86	85	84	82	81
200	97	94	91	89	86	84	81	78	76	73
210	104	100	96	91	87	83	78	74	70	65
220	114	108	102	96	89	83	77	71	64	58
230	126	117	108	100	93	85	77	69	60	51
240	139	126	115	105	96	87	77	68	57	45
250	152	134	121	110	99	88	78	67	55	41
260	166	141	125	113	101	90	78	67	54	38
270	180	143	127	114	102	90	78	66	53	37
280	166	141	125	113	101	90	78	67	54	38
290	152	134	121	110	99	88	78	67	55	41
300	139	126	115	105	96	87	77	68	57	45
310	126	117	108	100	93	85	77	69	60	51
320	114	108	102	96	89	83	77	71	64	58
330	104	100	96	91	87	83	78	74	70	65
340	97	94	91	89	86	84	81	78	76	73
350	92	91	89	88	87	86	85	84	82	81
360	90	90	90	90	90	90	90	90	90	90

Code Rules

The ASME BPV Code provides the following guidance for tangent outlets per paragraph UG-36(b)(1),

(1) Properly reinforced openings in cylindrical and conical shells are not limited as to size except with the following provisions for design. The rules in UG-36 through UG-43 apply to openings not exceeding the following: for vessels 60 in. (1 500 mm) inside diameter and less, one-half the vessel diameter, but not to exceed 20 in. (500 mm);
for vessels over 60 in. (1 500 mm) inside diameter, one-third the vessel diameter, but not to exceed 40 in. (1 000 mm). (For conical shells, the inside shell diameter as used above is the cone diameter at the center of the opening.)
For openings exceeding these limits, supplemental rules of 1-7 shall be satisfied in addition to the rules of this paragraph. Alternatively, openings in cylindrical or conical shells exceeding these limits may be designed for internal pressure using the rules of 1-10. [See UG- 36(c)(2)(d).]

For most water works applications, simple calculations for tangent outlets can be performed according to ASME rules in paragraphs UG-36 through UG-43 as illustrated in the example problem to follow.

Welding Details

Welding design is critical to the success of tangential outlets. Welds for tangent outlets must provide adequate strength to meet the design loads, yet permit easy welder access to achieve complete joint penetration and promote good weld quality. Suggested weld design is reflected in the welding details shown in Figure 5.

Constructability is best if pipe shells are groove welded as indicated in Figure 5. The pipe shells that are in tension under internal pressure, apply a through-thickness loading. This loading places added emphasis on the z-axis steel properties that become an important design consideration for thick steels. Collar reinforcement on tangent outlets is difficult to install because of unfavorable geometry, however, for most water works applications, the author believes that adequate reinforcement of the main and outlet pipes is possible without need for extra reinforcement by a collar. The example problem to follow illustrates tangent outlet reinforcement without a collar.

Welding procedure specifications (WPSs) should be qualified per ASME BPV Code Section IX for notch tough welding and Supplementary Essential Variables. Procedure qualification records should document heat input limits and Charpy tests should be conducted in both heat affected zone (HAZ) and weld metal. Charpy acceptance should be the same as base metal; for full-sized 10 millimeter (mm) coupons, acceptance is often 25 ft-lbs energy at a test temperature of 30°F as recommended in AWWA C200, *Steel Water Pipe-6 In. (150 mm) and Larger*.

For main pipe diameters larger than 30", welder access is assumed to be primarily from inside the main pipe for application of single bevel groove welds. Exterior fillet welds are applied to balance weld metal shrinkage and control distortion. However fillet welds are limited by tangent outlet geometry where the local dihedral angle is less than approximately 120 degrees as indicate in Figure 5. The local dihedral angle is constantly changing around the welded joint, however the groove angle should remain constant to avoid welding difficulties. For example, a groove angle that becomes too narrow may result in inability of the welder to adequately clean weld passes, thus trapping slag. Too wide a groove angle results in excessive weld metal, greater weld shrinkage and distortion. Geometry requires that weld bevels must vary if groove angles are constant and local dihedral angle varies. Welding symbols alone are not sufficient to describe welding details indicated in Figure 5. The author believes that a typical tangent outlet design should include several full scale joint welding details similar to that shown in addition to beveling diagrams (not shown) to convey detailed design information to the shop fabricators and welders.

Figure 6 and 7 illustrate the developed views of the branch and main pipes that are components of a tangent outlet.

Figure 5

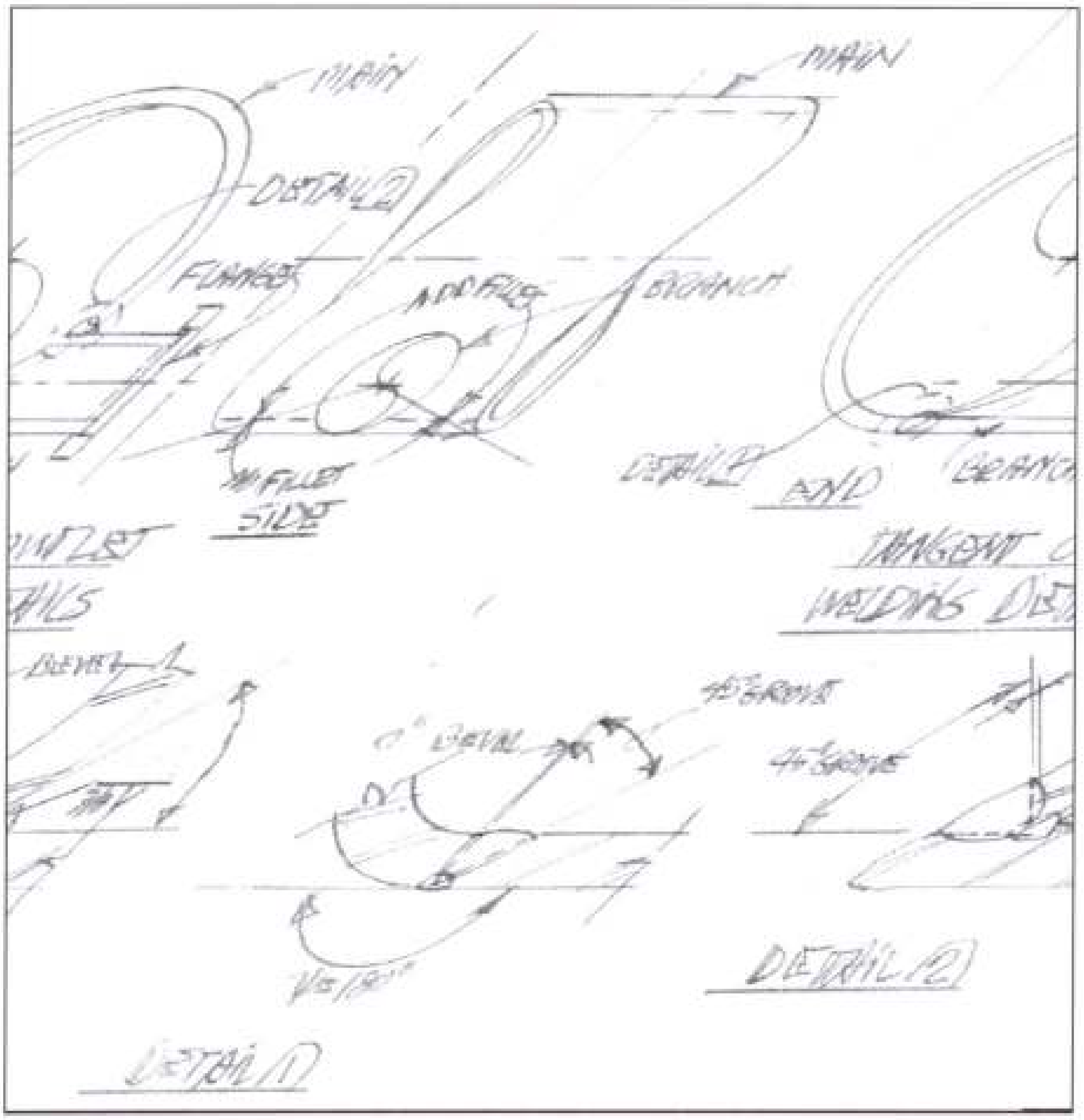


Figure 6

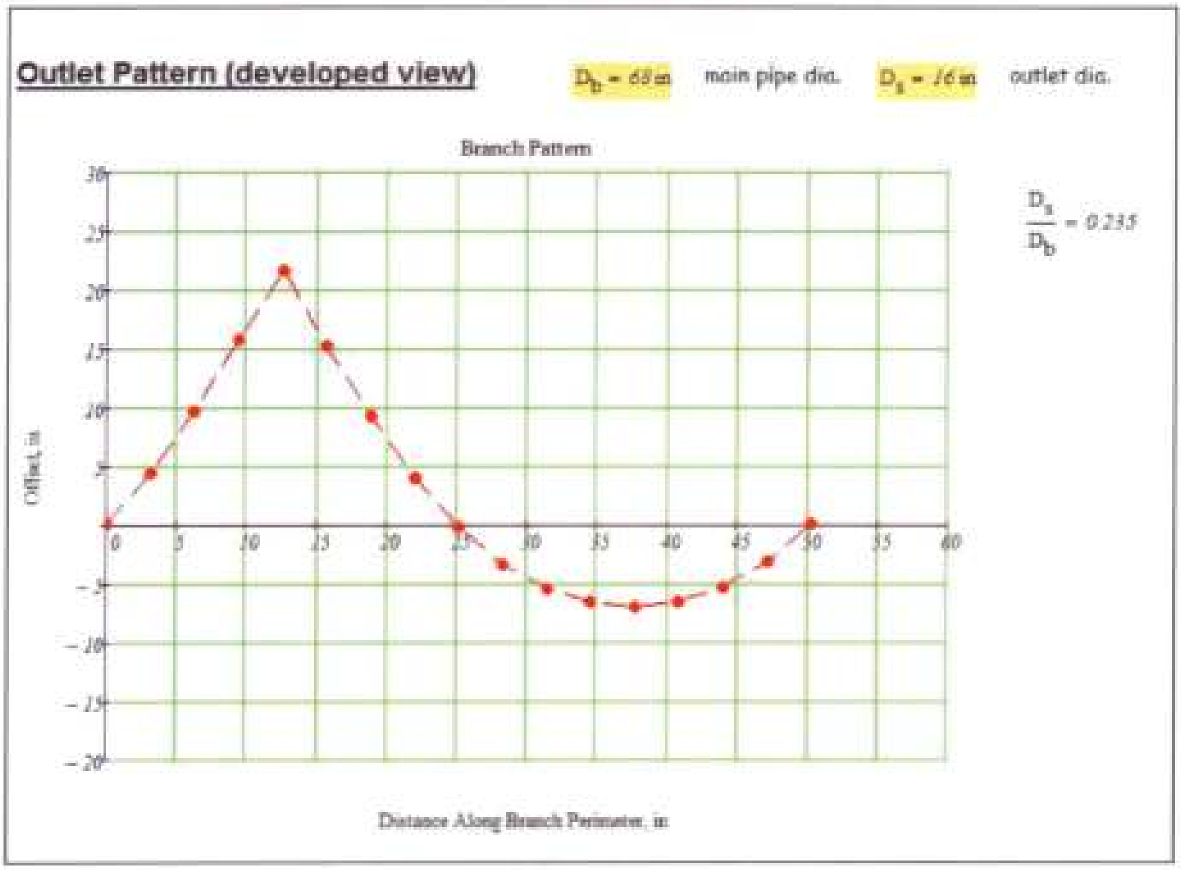
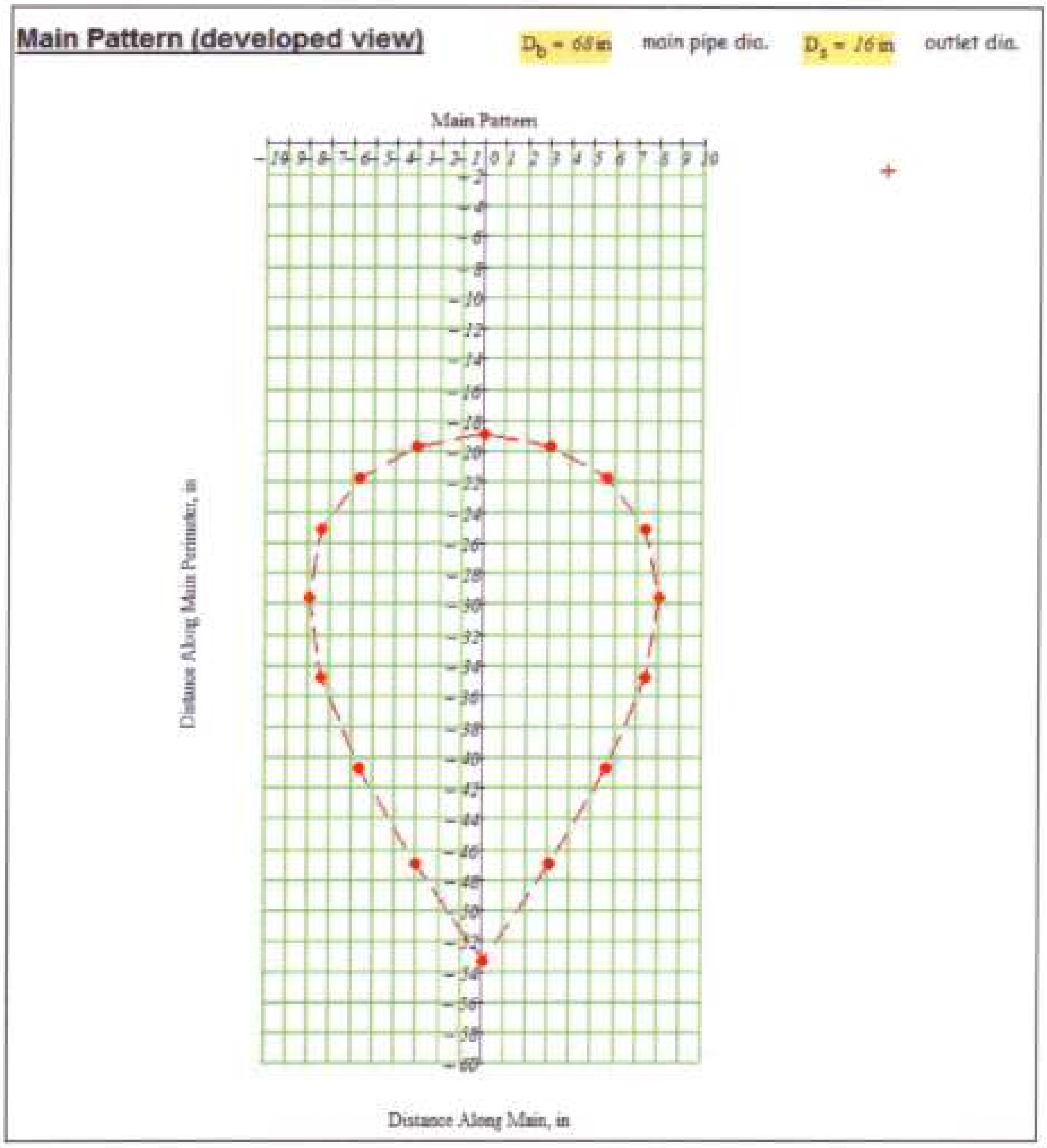

Outlet Pattern (developed view)
Db = 68 in
main pipe dia.
Ds = 16 in
outlet dia.
Branch Pattern
Ds/Db = 0.235
Offset, in
Distance Along Branch Perimeter, in

Figure 7



Summary

Design and fabrication of a tangent outlet requires a high degree of skill to make it function reliably as a safe, integral part of a conveyance system as intended by the designer. Competent tangent outlet design can only occur by employing skills that require understanding of engineering and fabrication. The tools presented in this paper are intended to make both the designer and fabricator's job easier for proper tangent outlet component sizing, geometry, welding, and testing.

References

American Society of Mechanical Engineers (ASME). (2011). *Boiler and Pressure Vessels Code, Section VIII, Rules for Construction of Pressure Vessels, Division 1.*

American Water Works Association (AWWA). (2004). *Steel Water Pipe: A Guide for Design and Installation (M11), Fourth Edition.*

American Welding Society (AWS). (2010). *Structural Welding Code – Steel D1.1/D1.1M-2010.*

Example Problem

Input $D_b = 68\cdot in$ main pipe dia. $D_s = 16\cdot in$ outlet dia. $\theta := 90\cdot deg$ Intersection angle of outlet

ASME BPV Code Section VIII, Div. 1, UG-37 rules; follow example L-7.7

$S_v := 20\cdot ksi$ ASTM A516, Grade 70, allowable stress for main pipe per ASME SEC II, Part D

$S_n := 17.1\cdot ksi$ ASTM A53, Grade B, Type E or S or ASTM A106, Grade B, gr. 70, allowable stress for outlet per ASME SEC II, Part D

area of req'd reinforcement. Strength reduction factors; $f_{r1} := \frac{S_n}{S_v}$ and $f_{r2} := f_{r1}$ $f_{r1} = 0.855$ $f_{r2} = 0.855$

$P := 325\cdot psi$ internal pressure $R := \frac{D_b}{2}$ $R = 34\cdot in$

$E := 1.0$ assumed joint efficiency; no welds intersect tee connection

$R_n := \frac{D_s}{2}$ $R_n = 8\cdot in$ $t = 1.00\cdot in$ thickness of main $t_n = 1.031\cdot in$ thickness of nozzle, 16" X SCH 100

Calculations

$t_r := \frac{P\cdot R}{S_v\cdot E - .6\cdot P}$ $t_r = 0.558\cdot in$ req'd shell thickness $t_e := 0\cdot in$ collar or wrapper thickness

$t_{rn} := \frac{P\cdot R_n}{S_n\cdot E - .6\cdot P}$ $t_{rn} = 0.154\cdot in$ req'd nozzle thickness

ignore weld size as reinforcement because it does not contribute much

a.) check limits of reinforcement parallel to vessel wall (in PA direction) $F := 30$; larger of chord length thru nozzle circumferentially or nozzle diameter longitudinally $\Delta := \phi$ $\boxed{\Delta = 90\cdot deg}$

$\alpha := \frac{\pi}{2} - \operatorname{asin}\left(\frac{R - D_s}{R}\right) = 58.034\cdot deg$ $d_c := 2\cdot R\cdot\sqrt{1 - \cos\left(\frac{\alpha}{2}\right)^2}$ $d_c = 32.985\cdot in$ chord length thru opening circumferentially

$L_2 := R\cdot\alpha = 34.438\cdot in$ arc length thru opening circumferentially

$d_l := \frac{D_s}{\sin(\Delta)}$ $d_l = 16\cdot in$ nozzle diameter longitudinally

Set $d := d_c$ for PA direction.. $\boxed{d = 32.985 \cdot in}$

limit of reinforcement normal to vessel wall; smaller of $2.5 \cdot t = 2.5 \cdot in$ or $2.5 \cdot t_n + t_e = 2.577 \cdot in$

$A := d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1})$ $\quad A = 9.285 \cdot in^2$

area available from shell is larger of:

$A_{11} := d \cdot (E \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$ $\quad A_{11} = 23.567 \cdot in^2$ or

$A_{12} := 2 \cdot [(t + t_n) \cdot (E \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E \cdot t - F \cdot t_r) \cdot (1 - f_{r1})]$ $\quad A_{12} = 2.498 \cdot in^2$

$A_1 := \left| \begin{array}{l} A_{11} \text{ if } A_{11} > A_{12} \\ A_{12} \text{ otherwise} \end{array} \right.$ $\quad A_1 = 23.567 \cdot in^2$ picks greater

area available from nozzle is smaller of:

$A_{21} := 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$ $\quad A_{21} = 3.75 \cdot in^2$ or

$A_{22} := 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n$ $\quad A_{22} = 3.866 \cdot in^2$

$A_2 := \left| \begin{array}{l} A_{21} \text{ if } A_{21} < A_{22} \\ A_{22} \text{ otherwise} \end{array} \right.$ $\quad A_2 = 3.75 \cdot in^2$ picks lesser

$\boxed{A_1 + A_2 = 27.318 \cdot in^2}$ this area available is greater than that req'd $\boxed{A = 9.285 \cdot in^2}$
thus opening is adequately reinforced in PA direction

b.)Check hoop direction $F := 1.0$ and $d := d_l$ $\quad d = 16 \cdot in$

$A := d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1})$ $\quad A = 9.094 \cdot in^2$

area available from shell is larger of:

$A_{11} := d \cdot (E \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$ $\quad A_{11} = 6.941 \cdot in^2$ or

$A_{12} := 2 \cdot [(t + t_n) \cdot (E \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E \cdot t - F \cdot t_r) \cdot (1 - f_{r1})]$ $\quad A_{12} = 1.551 \cdot in^2$

$$A_1 := \begin{cases} A_{11} & \text{if } A_{11} > A_{12} \\ A_{12} & \text{otherwise} \end{cases} \qquad A_1 = 6.941 \cdot in^2$$ picks greater

area available from nozzle is smaller of:

$$A_{21} := 5 \cdot (t_n - t_m) \cdot f_{r2} \cdot t \qquad A_{21} = 3.75 \cdot in^2$$ or

$$A_{22} := 5 \cdot (t_n - t_m) \cdot f_{r2} \cdot t_n \qquad A_{22} = 3.866 \cdot in^2$$

$$A_2 := \begin{cases} A_{21} & \text{if } A_{21} < A_{22} \\ A_{22} & \text{otherwise} \end{cases} \qquad A_2 = 3.75 \cdot in^2$$ picks lesser

$\boxed{A_1 + A_2 = 10.691 \cdot in^2}$ this area available is greater than that req'd $\boxed{A = 9.094 \cdot in^2}$ thus opening is adequately reinforced in hoop direction

$A_1 + A_2 > A = 1$

Conclusion Make main & nozzle 1" thickness (16"× SCH 100) $\boxed{t = 1 \cdot in}$ $\boxed{t_n = 1.031 \cdot in}$ $P = 325 psi$