Phase 2 – Guidance for Field Segmentation and Welding of Induction Bends and Elbows

INGAA Foundation Workshop on Welding of Field Segmented Induction Bends and Elbows for Pipeline Construction

Bill Bruce – Det Norske Veritas (U.S.A.), Inc.
October 20, 2011
Background

- Cold field bends are not practical for all pipeline construction applications
  - Bends with a tighter radius than can be accomplished by cold field bending are often required to accommodate abrupt directional changes; either points of inflection, changes in topography

- Some tight-radius points of inflection or changes in topography can be accommodated by ordering induction bends with specific bend angles
  - Generally true for points of inflection which can be surveyed in detail prior to construction
  - Required bend angles are not always known prior to construction, particularly for changes in topography in hilly terrain

- Segmenting long radius elbows and induction bends is a necessary part of normal construction practice
  - May also be required during pipeline repair where purchasing a precise bend angle is logistically impossible due to time constraints
Scope of Work for Phase 2

- Phase 1 – Guidance for specification and purchase

- Phase 2 – Guidance for field construction practices
  - Optimal methods for mapping, cutting, beveling and transitioning
  - Optimization of joint designs for unequal wall thickness transitions
  - Limits for high-low misalignment during field fit-up
  - Methods for measuring high-low and methods for addressing excessive misalignment
  - Backwelding methods and practices
  - General guidance for avoiding hydrogen cracking
  - Radiographic issues for welds with internal transitions
  - Guidance for revision of construction specifications

- Phase 3 – Guidance for existing pipelines
Optimal Methods for Mapping, Cutting, Beveling and Transitioning

- Use of segmented induction bends and elbows often involves:
  - Transition welds between dissimilar wall thickness materials
  - The need to cope with high-low misalignment due to:
    - Out-of-roundness
    - Diameter shrinkage of the segmented fitting
    - Particularly segmented induction bends

- Segmented end should always be welded to a short transition pup first
  - Allows access for backwelding (if necessary) and for inspection after welding
  - Allows a pipe-to-pipe weld to be made in the field

- Practical information was collected during a series of field exercises
  - Document current practices
  - Optimize methods based on observations
  - Develop generic procedure for segmenting
Field Exercise at C.J. Hughes in Nitro, West Virginia

- Involved segmenting a 36-inch diameter by 0.750 inch thick 90-degree 6D-radius segmentable induction bend
  - Determined dimensional characteristics both before and after cutting
  - Documented various methods for beveling and transitioning
  - Segmented sections were welded to pipe pup sections
    - Partial welds in some cases

- Example plan for Weld #1:

1) Weld #1:
   - Use the 20-45 degree segment to weld onto a 0.500” wt pup.
   - Internally transition 45-degree end of the bend to 0.500” wt using conventional torch and grind methods.
   - Rotate pup to get “best” bevel alignment with transitioned end of bend.
   - Measure and record bevel offsets at each “o’clock” position.
   - Deposit a stringer bead, hot pass and backweld in the areas around the weld where the internal offset exceeds 3/32”.
   - Verify that a single backweld can transition the internal offset back toward the pup.
   - Try multiple weld passes on the backweld and/or a different welding rod diameter at different points around the bend, if needed, to determine the optimum backweld method.
   - Check alignment offset measurements from before and after welding to determine if the heating and welding caused any changes.
Steps in Segmenting Procedure

- Mapping
  - Determining the location of cut points so that the desired bend angle is produced
- Rough cutting
- Beveling
- Transitioning
- Welding
Two methods of locating cut points were investigated
- Determine and measure arc lengths along intrados and extrados
- Determine and measure chord lengths along neutral axis (top or bottom)

Both involve the use of geometry/trigonometry
- Tables can be developed that minimize the need for manual calculations

Both require that the bend or elbow is situated so that it is flat and level

Both require use of center finder for locating neutral axis
Mapping – 2 of 3

- Induction bends are typically provided with tangent ends
  - To locate cut points, tangent point (i.e., point of first deviation from straight on tangent end) must first be determined using a straight edge

- Cut points are then established by measuring either arc length along intrados and extrados or measuring chord length along neutral axis
  - Measuring chord length was determined to be more accurate and simpler than measurement along the intrados and extrados
Mapping – 3 of 3

- Flexible steel band is used to establish the cut point around circumference
  - Punch marks are made through coating, coating is removed, and cut point is re-established using flexible steel band

- Out-of-roundness at proposed cut point should be measured prior to making rough cuts
  - Can be performed using calipers and linear scale or micrometer
  - If out-of-roundness is excessive, cut point can be re-established from other end to determine if out-of-roundness is more favorable
Rough Cutting

- Performed manually using an oxy-fuel torch
- Made without bevel
  - Beveling will be performed later
- Out-of-roundness should be measured again after rough cutting
  - From inside using either calipers and a linear scale or a micrometer
Beveling

- Oxy-fuel cutting equipment typically used to bevel line pipe material is not suitable for induction bends and elbows
  - When mounted on bend or elbow, curvature prevents a square end from being produced

- Technique to bevel a segmented bend or elbow involves tack welding bend or elbow to a straight section of pipe
  - Alignment to straight section of pipe is accomplished using Dearman style clamp

- Beveling equipment is mounted to the straight section of pipe and the cutting head is positioning the so that cut is made back towards straight section of pipe
Transitioning – 1 of 4

- Bends and elbows typically have greater wall thickness than pipe pup sections
  - Requires that wall thickness of bend or elbow be transitioned at weld bevel or that backwelding is used

- Transitioning involves aligning pipe pup section to the bend or elbow using Dearman style clamp

- Inside diameter of pipe pup section is scribed onto beveled end of segmented bend or elbow using soapstone
Transitioning – 2 of 4

- Transition is produced by grinding or a combination of oxy-fuel cutting and grinding
  - Resulting weld bevel/transition must meet requirements of Figure I-5 from ASME B31.8 or §434.8.6 of ASME B31.4
Transitioning – 3 of 4

- Rounding (convexity) of the ground surface of transition should be avoided when producing transitions
  - Purpose of transition is to avoid stress concentration where ground surface intersects with toe of the root pass

![Diagram showing incorrect rounding](image1)

![Diagram showing correct rounding](image2)
Transitioning – 4 of 4

- Measure wall thickness at weld bevel using calipers after the transition is complete
  - Ensure compliance with minimum requirements
    - ≥ 92% nominal wall thickness of pup
    - ≥ 83% nominal pup thickness for:
      - 0.6 design factor in a Class 1 area
      - 0.5 design factor in a Class 2 area
      - 0.4 design factor in a Class 3 area

- Measure taper angle
  - 14° minimum
  - 30° maximum
  - No excessive convexity of concavity of ground surface
Welding – 1 of 2

- Dearman style clamp is used to establish fit-up for welding pipe pup sections to segmented bends and elbows

- Internal misalignment should be distributed evenly around circumference using adjustment capabilities of Dearman style clamp

Mathey Dearman Double Chain Clamp - D251 Series
Welding – 2 of 2

- Internal misalignment should be measured prior to welding using a purpose-built measuring device.

- Root pass welding is carried out in a conventional manner following a qualified welding procedure once optimal alignment is achieved.

- Backwelding can be used as a remedial measure if excessive internal misalignment prevents an acceptable root pass from being made or if minimum wall thickness requirement at weld bevel has been violated.
Cutting and Beveling Machines

- Field exercises focused on conventional methods for segmenting induction bends and elbows (i.e., oxy-fuel cutting and hand grinding)

- Aggressive Equipment Corporation’s Steel Split Frame® equipment was identified for machine cutting, beveling, and transitioning
  - Design is such that it can easily be attached to curved surfaces
    - Clamping feet that swivel
  - Profile is very narrow
  - Cutting, beveling, and tapering can be accomplished with a single setup
Steel Split Frame® Demonstration – 1 of 2

- Demonstration conducted at manufacturer’s facility
  - 36 inch OD by 1.000 inch thick X70 90-degree 3R elbow
  - 36 inch OD by 0.500 inch thick X52 induction bend
- Basic components are two half rings that make up frame and either a pneumatic or hydraulic motor
- Cutting and beveling can take place simultaneously
- Internal tapering takes place separately
Steel Split Frame® Demonstration – 2 of 2

- Capable of producing a perfect circle or an out-of-roundness attachment can be used to follow the OD
- Has some advantages over conventional methods
  - Bevel is much more uniform than manually-produced bevel
  - Rounding of internal taper surface avoided
- Equipment is versatile and useful
  - Certainly a viable option for use in segmenting induction bends and elbows
  - Available in diameter sizes from 4 to 80 inch OD
  - Available for rent or for purchase
Joint Designs for Unequal Wall Thickness Transitions

- Guidance pertaining to joint designs for unequal wall thickness transitions and/or unequal strength materials is provided in Appendix I of ASME B31.8 and in §434.8.6 of ASME B31.4
  - Requirements for transition joints in these two codes are essentially identical
  - Allow transitions to be accomplished by tapering and/or by backwelding

- Appendix I refers to the joint designs shown in Figure I-5

- Joint designs in Figure I-5 are based on work by George and Rodabaugh in 1950s
  - Developed considering only pressure loading

- When joining higher-strength thinner-wall material to lower-strength thicker-wall material, transition taper in lower-strength material benefit from “bridging effect”
  - Thin end of the taper is supported by adjacent thicker material

- A minimum taper of 1:4 (14 degrees) was recommended

- While the joint designs shown in Appendix I have served the industry well, they do not explicitly take axial loading into account
  - Axial loads can occur during lifting and lowering-in and due to soil settlement
Figure I-5 in ASME B31.8

- Includes acceptable joint designs for:
  - Internal offset
    - When the outside diameters match but the wall thicknesses are unequal
  - External offset
    - When the inside diameters match but the wall thicknesses are unequal
  - Combination offset
    - When the wall thicknesses are unequal and one side of the joint has both a smaller inside diameter and a larger outside diameter

- Does not cover all situations that may arise in the field
  - Situation not addressed by Figure I-5 is internal and external offset in the same direction
    - When one side of the joint has both a smaller inside diameter and a smaller outside diameter
  - Often occurs when welding segmented induction bends due to diameter shrinkage during the induction bending process
    - Not all induction bends have diameter shrinkage and elbows are less likely to have diameter shrinkage than induction bends
Figure I-5 and Joint With Diameter Shrinkage
Unequal Wall Thickness Transitions

- Particularly problematic when component on one side has diameter shrinkage

- Internal tapering alone applied to component with diameter shrinkage can lead to a reduction in wall thickness that can reduce axial load carrying capacity of joint
  - If inside diameter of a component with diameter shrinkage is tapered so that weld bevel lands match, resulting material on low side of joint may be insufficiently thick

- For axial loading of joints with high-low misalignment caused by diameter shrinkage of thicker side, it is clearly advantageous to use joint designs that involve backwelding such as those shown in Figures I-5 (c) and (d) as opposed to those shown in Figures I-5 (a) and (b)
  - Joint designs with backwelds tend to maintain wall thickness throughout the joint
  - Size and position of backweld can simply be adjusted to account for high-low misalignment

- The same is true for equal wall thickness joints with diameter shrinkage on one side of the joint
  - Even though Appendix I does not address equal wall thickness joints, features of the joint designs shown in Figure I-5 may occasionally be applied when excessive misalignment is present
Option (b) → (b) – Unequal Wall Thickness Joint

Example of unequal wall thickness joint with no misalignment joined using option (b) in Appendix I, Figure I-5

Example of unequal wall thickness joint with 3mm misalignment joined using option (b) in Figure I-5

Same as above with 6mm misalignment showing area of potential weakness

3.0 mm (20%) misalignment

6.0 mm (40%) misalignment
Option (b) → (d) – Unequal Wall Thickness Joint

Example of unequal wall thickness joint with no misalignment joined using option (b) in Appendix I, Figure I-5

Example of unequal wall thickness joint with 3mm misalignment joined using option (d) in Figure I-5

Same as above with 6mm misalignment

3.0 mm (20%) misalignment

6.0 mm (40%) misalignment
Option (b) – Equal Wall Thickness Joint

Example of equal wall thickness joint with no misalignment

Example of equal wall thickness joint with 3mm misalignment joined using option (b) in Figure 1-5

Same as above with 6mm misalignment showing area of potential weakness

3.0 mm (20%) misalignment

6.0 mm (40%) misalignment
Option (c) – Equal Wall Thickness Joint

Example of equal wall thickness joint with no misalignment

Example of equal wall thickness joint with 3mm misalignment joined using option (d) in Figure I-5

Same as above with 6mm misalignment

3.0 mm (20%) misalignment

6.0 mm (40%) misalignment
Double-Vee Butt Weld Option

- Potentially attractive option for joints with high-low misalignment caused by diameter shrinkage of the thicker side

- Similar to option shown in Figure I-5 (d), except that weld preparation is provided on both sides (ID and OD) of the joint

- Potential advantages include:
  - Reduced overall volume of weld metal
  - Root pass defects that are located mid-thickness where their severity is decreased

- While applicable in principal, it is not known how often this practice is used in this application
Double-Vee Butt Weld Option

Example of unequal wall thickness joint with no misalignment joined using double-Vee butt weld option

3.0 mm (20%) misalignment

Same as above with 3mm misalignment

6.0 mm (40%) misalignment

Same as above with 6mm misalignment
Weld Metal Build-Up Option

- Apply weld metal build-up (weld metal buttering) to the inside of the side without diameter shrinkage prior to beveling
- Similar to backwelding except that the “backweld” is deposited prior to beveling
- After the weld metal buildup is complete, a weld bevel that matches at the weld root can be produced on both sides of the joint
- While applicable in principal, it is not known how often this practice is used
Joint Design Guidance for Unequal Wall Thickness Transitions

- Guidance pertaining to which joint design option in Figure I-5 to use for which applications:
  - If outside diameters are equal, any of the joint designs shown in Figures I-5 (a) through (d) are appropriate
    - Outside diameters should be considered equal if they differ by no more than 3/16 inch (4.7 mm)
  - If inside diameters are equal, either of the joint designs shown in Figures I-5 (e) and (f) are appropriate
    - Inside diameters should be considered equal if they differ by no more than 3/16 inch (4.7 mm)
  - When there is diameter shrinkage on one side of the joint (i.e., when one side of the joint has both a smaller inside diameter and a smaller outside diameter), joint designs that involve backwelds, such as those shown in Figures I-5 (c) and (d) should be used
    - Diameters should be considered unequal if they differ by more than 3/16 inch (4.7 mm)
  - For components that are sufficiently thick (e.g., one side of the joint has both a smaller inside diameter and a larger outside diameter), the joint design shown in Figure I-5 (g) is appropriate
Other Guidance for Application of Figure I-5 – 1 of 3

- Many users of Appendix I tend to focus on Figure I-5 without paying sufficient attention to the text in Appendix I

- Guidance that should be followed when using joint designs Figures I-5:
  - While not specifically required in the text of Appendix I, Figures I-5 (c) and (d) specify a 30 degree maximum angle for the backweld
  - Welders tend to under-weld backwelds because of confined space conditions
  - May result in angles greater than 30 degree and associated stress concentrations
  - While not specifically required by Figures I-5 (c) and (d), the text of Appendix I indicates that “…sharp notches or grooves at the edge of the weld…. … shall be avoided”
  - Weld toes should blend smoothly into the base metal so that stress concentrations are avoided
    - Particularly those at the thin-wall side of backwelds
Other Guidance for Application of Figure I-5 – 2 of 3

- Care should be taken when attempting to combine features from the various sub-figures in Figure I-5
  - It may not be appropriate to combine Figures I-5 (c) and (e) (internal and external offset, respectively) and apply the maximum allowable internal and external offset to an equal wall thickness joint with diameter shrinkage on one side
    - The resulting 0.5t offset may be excessive for an equal wall thickness joint
    - It is not appropriate to apply the taper requirements in Figures I-5 (b) and (f) to an equal wall thickness joint with diameter shrinkage on one side
- When using joint designs that involve backwelds, the guidance provided pertaining to backwelding should be followed
  - Joint design guidance indicates a strong preference for backwelding unless conditions are ideal
  - When backwelding is used, it is very important that it be carried out properly
Other Guidance for Application of Figure I-5 – 3 of 3

- When drawn in cross section, it is simple to see what combinations of joint design and diameter shrinkage lead to a reduction in wall thickness or stress concentrations that can reduce the axial load carrying capacity of the joint.

- In practice however, this is much more difficult to determine, as the internal and external features of the weld can only be viewed separately without relative position to one another.

- Advance planning is required to ensure that areas of reduced wall thickness and stress concentrations are not produced.
Field Welding of Segmented Fittings

- Welding aspects that are unique to the use of segmented induction bends and elbows:
  - By definition, segmented induction bends and elbows are located at points of inflection, or at changes in topography, which tend to be more susceptible to high stresses from bending loads caused by pipeline movement due to soil settlement
  - The use of segmented induction bends and elbows often involves transition welds between dissimilar wall thickness materials, which tend to concentrate stresses due to bending
  - The use of segmented induction bends and elbows often involves the need to cope with high-low misalignment because of out-of-roundness and/or diameter shrinkage of the segmented fitting, which also tend to concentrate stresses due to bending

- Transition pups should always be welded to the end of a segmented fitting so that a pipe-to-pipe weld can be made in the field

- Transition pups can be relatively short
  - Welds to transition pups are simpler to make than welds to full or longer lengths of pipe
  - Short transition pups alleviate difficulty with alignment and provide access for backwelding (if necessary) and for inspection
Transition Pup Length

- Should be long enough to distribute stresses away from transition welds but short enough to allow access for visual inspection and backwelding if necessary
- Access for visual inspection and backwelding is also dependent on pipe diameter
  - Larger diameter pipe allows better access than smaller diameter pipe
- For larger diameter pipe where access is not restricted by pipe diameter (e.g., 20 inch diameter and above), transition pup length should generally be at least 24 inch or one pipe diameter, whichever is smaller
- For smaller diameter pipe, transition pups can be shorter but should not be less than one-half pipe diameter in length
Transition Pup Wall Thickness

- Segmented induction bends and elbows are generally thicker than the line pipe material to which they will eventually be joined.

- It is preferable for the wall thickness of transition pups to be in between the wall thickness of the fitting and the wall thickness of the line pipe material.

- For typical pipeline designs, it is preferable for the transition pup to be at least 1/8 inch (3.2 mm) less than the nominal wall thickness of the fitting but no more than 1/4 inch (6.4 mm) less.

- In cases where diameter shrinkage is high, it may be necessary to use a transition pup of the same nominal wall thickness as the bend to ensure sufficient wall thickness at the transition bevel.

- When determining wall thickness for transition pups, design pressure requirements must always be met.
Double Transition Pups

- It has been suggested that segmenting induction bends and elbows should be joined using two pups on each end
  - A transition pup with a wall thickness between the wall thickness of the fitting and the line pipe material
  - A second pup with a wall thickness equal to that of the line pipe material

- Allows not only a pipe-to-pipe weld to be made in the field, but the pipe-to-pipe weld is between materials of equal wall thickness

- While there may some benefit to this practice, the additional cost may outweigh the potential benefits
Avoiding Stress Concentrations

- Even with the dimensions of the pipe pup optimized, it is important that the toe of the root pass or backweld transition smoothly from the ground surface to minimize stress concentrations.

- The angle between the weld toe and the ground surface should not create a sharp notch, and undercut should be avoided.

- Remedial action for less than ideal geometry at the toe of a completed root pass or backweld include:
  - Light weld toe grinding
  - Depositing additional backweld passes
Limits for High-Low Misalignment – 1 of 2

- Difficulty associated with high-low misalignment in pipeline girth welds is two-fold
  - It makes root pass welding difficult
  - It results in stress concentrations in completed welds

- There are currently no absolute limits for misalignment in API 1104 provided that the misalignment is distributed evenly around the circumference
  - The word ‘should’ is used to describe the 1/8 inch (3 mm) maximum offset specified

- The detrimental effects of misalignment in completed welds are related to the magnitude of the misalignment relative to the pipe wall thickness
  - High-low of 1/8 inch represents only 25% for 0.500 inch thick pipe but 50% of the pipe wall thickness for 0.250 inch thick pipe
It may be possible for the most talented of welders to make an acceptable root pass with high-low misalignment approaching 1/8 inch.

- Root passes with high-low approaching 1/8 inch that achieve full penetration often have poor root pass profiles that can result in stress concentrations.

- Beyond 1/8 inch misalignment, the probability of producing root pass discontinuities, such as incomplete penetration, burnthrough, etc., increases significantly.
Axial Load Carrying Capacity of Unequal Wall Thickness Joints with Various Amounts of Misalignment

- Center for Reliable Engineering Systems (CRES) used finite element analysis to predict the reduction in axial load carrying capacity of unequal wall thickness joints with various amounts of misalignment and for different weld profiles

- Yong-Yi Wang will present the results
Load Capacity of Transition Joints

- **Objective - basic question**
  - What is the load capacity of a transition joint with varying amount of high-low misalignment?

- **Load capacity**
  - The maximum load that a weld can carry in the pipe longitudinal direction.

- **Load capacity reduction factor**
  - Load capacity of a joint with misalignment divided by the load capacity of a joint without misalignment

- **Approach**
  - Finite element analysis at CRES
  - Key variables
    - Level of high-low misalignment
    - Weld profile
Various Weld Profiles

- Pup
- Weld Metal
- Bend
Joints of Option (d) of I-5, Smooth Internal Transition

- **Misalignment = 0.0 mm**
- **Load capacity reduction = 0%**

- **Misalignment = 3.0 mm**
- **Load capacity reduction = 0.2%**

- **Misalignment = 6.0 mm**
- **Load capacity reduction = 0.4%**

- **Misalignment = 9.0 mm**
- **Load capacity reduction = 0.6%**
Joints with Sharp Reentrant Angle on Thinner Side

- Red dashed line:
  Likely plastic flaw path, i.e., failure location

- Misalignment = 3.0 mm
- Load capacity reduction = 1.2%

- Misalignment = 6.0 mm
- Load capacity reduction = 4.1%

- Misalignment = 9.0 mm
- Load capacity reduction = 4.8%
Joints with 45-Deg. Internal Transition to Thinner Side

- **Red dashed line:**
  Likely plastic flaw path, i.e., failure location

- Misalignment = 6.0 mm
- Load capacity reduction = 3.8%

- Misalignment = 9.0 mm
- Load capacity reduction = 4.6%
Significant misalignment can be tolerated with only a slight reduction in load carrying capacity when there is a smooth internal transition from the thicker side to the thinner side.

- Misalignment of 3, 6, and 9 mm represents 19.7, 39.4, and 59.1% of the thinner (0.6 inch thick) side of the joint, respectively.

A more significant reduction occurs when the internal transition to the thinner side is not smooth and when the internal transition is steeper than allowed by Figure I-5.
General Observation on Load Capacity

- The maximum misalignment should generally be limited to no more than 1/3 (33.3%) of the wall thickness of the thinner material
  - Larger misalignment can be tolerated with only a slight reduction in load carrying capacity when the weld profile is properly transitioned.
  - The general limit chosen is intended to account for less than perfectly smooth transitions to the thinner side of the joint
  - When the thickness of the thinner side of the joint is less than 3/8 inch, the maximum high-low misalignment is less than the 1/8 inch limit recommended in API 1104
Are We Home Yet?

- Premises of the analysis
  - No cracks. Generally sound welds
  - Weld strength matches the strength of the base material (pipe and bend)
    - With the benefits of weld reinforcement and weld bevel, one might tolerate 10% undermatching
  - No fatigue loading
  - Stress on the welds is less than SMYS.

- Factors of further considerations
  - Weld strength relative to the actual strength of the pup and bend
  - HAZ softening of low hardenability materials welded with high heat input processes
  - Ground movement hazards / lack of support that produce bending moment

- Newer materials (microalloyed TMCP steels) have lower strain hardening capacity
  - Reduced tolerance to property and dimensional variations
Failure of Fitting in the Intrados

- Pipeline design has been focused on the control of hoop stress.
- Longitudinal stress is not adequately considered.
- The interaction of hoop and longitudinal stresses is even less though about.
Methods for Measuring High-Low

- Both devices work equally well for equal wall thickness joints
- Device with wire feelers is best for measuring internal misalignment for joints with an internal taper on one side
  - One feeler can be bent to match the taper angle
Methods for Addressing Excessive Misalignment

- Internal line-up clamps can alleviate some high-low misalignment problems due to out-of-roundness during production welding of thinner-wall line pipe materials
  - Hydraulic cylinders re-round thinner-wall line pipe materials during root pass welding

- Internal line-up clamps cannot be used for welds that join segmented bends and elbows to transition pups

- Hot or cold re-rounding (plastic deformation) of segmented induction bends and elbows in the field should be prohibited

- Backwelding is only option for addressing excessive misalignment for welds that join segmented bends and elbows to transition pups
Backwelding
- Depositing one or more weld pass from inside the pipe
- Relatively common technique for repairing or otherwise making the root region of what is intended to be a single-sided, open root butt weld acceptable

Potential problems/difficulty with backwelds
- Normally deposited last and do not benefit from tempering associated with the thermal cycle from subsequent passes
- Typically consist of relatively small beads that are deposited at relatively low heat input levels
- Crack-susceptible weld microstructures may result from backwelds that are deposited last
- Location of backwelds makes them difficult to make
- Confined space, difficult to see (poor lighting, smoke), potential for arc burns, etc.
- Location of backwelds makes them difficult to inspect
- Often inspected by no one other than the welder
- Achieving adequate preheat temperature is problematic with the welder inside the pipe

Because of potential problems, backwelding is normally thought of as an undesirable practice
- Last-ditch effort
Backwelding Methods and Practices – 2 of 2

- Backwelding is an attractive and perfectly acceptable solution to misalignment problems when carried out properly
  - Perfectly acceptable *when carried out properly*

- Potential problems are minimized when attaching transition pups to segmented induction bends and elbows because the pup can be relatively short
  - Allows access for the welder
  - Allows visual inspection without having to crawl inside a long length of pipe

- Overcoming potential problems related to the formation of crack-susceptible weld microstructures
  - Develop suitable welding parameters for backwelds that are deposited last
    - Cap passes are deposited last...
  - Deposit backweld first (i.e., deposit the root pass from the inside)
    - Or deposit backweld prior to completing the weld from the outside
Procedure Qualification for Backwelding

- Current 20th Edition of API 1104 does not require a specific welding procedure specification for backwelding
  - Bead sequence is not an essential variable for procedure qualification
  - It is good practice to weld and test joints with and without backwelds if backwelding is to be permitted
    - It is good practice to consider the addition of a backweld to be an essential variable for procedure qualification

- Proposed 21st Edition of API 1104 will have specific provisions for qualifying welding procedures with backwelds
Electrode Selection for Backwelds

- Backwelds made using cellulosic-coated electrodes are acceptable provided that a welding procedure specification has been developed and qualified using cellulosic-coated electrodes.

- Backwelds made using low-hydrogen electrodes are more desirable since the risk of hydrogen cracking is significantly reduced.

- Consideration should be given to specifying and using low-hydrogen electrodes for the backwelds.
  - Electrode grouping and direction of welding are essential variables for procedure qualification in API 1104.
  - Also essential variables for welder qualification.

- Preheating requirements for welds made using low-hydrogen electrodes are typically less than for welds made using cellulosic-coated electrodes.
  - Alleviates concerns for achieving adequate preheat temperatures with the welder inside the pipe.
Single or Multi-Pass Backwelds

- Depends on extent of misalignment

- Single-pass backwelds are acceptable provided that a WPS has been developed and qualified using a single pass backweld

- Multi-pass backwelds are more desirable
  - Previous passes benefit from tempering associated with the thermal cycle from subsequent passes
  - If extent of misalignment is small, there may not be sufficient space for a multi-pass backweld
    - Unless a second pass is used primarily for tempering and is subsequently ground off

- For multi-pass backwelds, the beads should be deposited to maximize tempering in more crack-susceptible area
  - Beads should be stacked away from thinner side of the joint
Partial Circumference Backwelds

- If a weld requires backwelding at a particular location, a full circumferential backweld is not required.

- Backwelding is only required where the extent of misalignment makes it necessary.

- Backwelds should be long enough so that steady-state heat flow conditions are established.
  - Backwelds should be a minimum of 2 inches in length, but are only required at areas of excessive high-low misalignment.
Backweld Profile

- Completed backwelds should transition smoothly into the pipe material
- The profile of completed backwelds should follow requirements in Figures 1-5
  - 30 degree maximum angle for backweld
- Weld toes should blend smoothly into the base metal so that stress concentrations are avoided
  - Particularly at thin-wall side of backwelds
- Geometric details of a completed backweld should be the subject of careful visual inspection by the welding inspector
- Remedial measures for completed backwelds that are found to have unacceptable geometry include grinding and depositing additional backweld passes
Backwelding Summary

- When carried out properly, backwelding is a perfectly acceptable solution to misalignment problems

- Particularly well-suited for attaching transition pups to segmented induction bends and elbows
  - Potential problems associated with confined space, preheating, and visual inspection are minimized because the pup can be relatively short

- While not necessarily required by the current edition of API 1104 (20th Edition), it is good practice to weld and test joints with and without backwelds
  - i.e., it is good practice to consider the addition of a backweld to be an essential variable for procedure qualification

- When qualifying a procedure for backwelding, consideration should be given to specifying and using low-hydrogen electrodes for the backwelds
General Guidance for Avoiding Hydrogen Cracking

- The rate of pipeline incidents (leaks and ruptures) attributed to defective girth welds has traditionally been low
  - Axial stresses (i.e., those perpendicular to girth welds) from pressure loading are significantly lower in a completed pipeline than those in the circumferential direction

- Some recent hydrostatic test failures have been attributed to hydrogen-induced cracking in repair and tie-in welds

- Hydrogen cracking requires that three primary independent conditions be satisfied simultaneously;
  - Hydrogen must be present in the weld
  - There must be a susceptible weld microstructure
  - Tensile stresses must be acting on the weld
Hydrogen in the Weld – The Primary Culprit

- Cellulosic-coated (AWS EXX10-type) electrodes
  - Well suited for depositing one-sided welds
  - Capable of high deposition rates when welding downhill

- Cellulosic-coated electrodes result in the introduction of a considerable amount of hydrogen in the weld
  - Atomic hydrogen in the arc atmosphere is readily absorbed by the molten weld metal
  - A significant reduction in solubility occurs when the weld solidifies
  - Hydrogen becomes trapped in the solid steel as the weld cools to ambient temperature
  - Typically 40 to 60 ml/100 g of deposited weld metal

- Hydrogen that remains in the weld following completion must be managed
Weld Microstructures

- Heat-affected zone HAZ microstructures have traditionally been considered to be the most susceptible to hydrogen cracking
  - Crack-susceptible HAZ microstructures tend to be characterized by high hardness
  - Promoted by steels that have a high carbon content and/or a high carbon equivalent (CE) value and by fast weld cooling rates

- Most modern line pipe steels have a very low carbon content and a very low CE compared to older line pipe steels
  - This combined with relatively slow weld cooling rates result in low HAZ hardness levels in modern line pipe steels

- Weld metal microstructures deposited using higher strength welding consumables can also be susceptible to cracking

- When the magnitudes of two of the three conditions necessary for hydrogen cracking are extreme, levels of the third that are not normally associated with cracking can become problematic
  - When hydrogen level and tensile stresses are extreme, weld microstructures that are not normally considered to be susceptible can lead to cracking
Tensile Stresses Acting on the Weld

- **Residual stresses**
  - Unavoidable in welds
  - Result from restraint and thermal contraction upon cooling
  - Tie-in and repair welds are more highly restrained mainline production welds

- **Applied stresses – partially-completed production girth welds**
  - Following completion of the root pass when the line-up clamp is removed and the pipe string is re-set by lifting and lowering

- **Applied stresses – completed girth welds**
  - During lifting and lowering-in
  - Following backfilling if pipeline profile does not fit the ditch or when differential soil settlement occurs

- **Stresses can be magnified by stress concentrations**
  - At weld defects
  - At areas of misalignment (high-low)
Prevention of Hydrogen Cracking

- To prevent hydrogen cracking, at least one of the three conditions necessary for its occurrence must be eliminated or reduced to below a threshold value
  - Hydrogen in the weld
  - Susceptible weld microstructure
  - Tensile stresses acting on the weld
- Of these three requirements, the most misunderstood seems to be hydrogen in the weld
- When pipeline girth welds are made using cellulosic-coated electrodes, the amount of hydrogen that remains in the weld following completion must be managed
- This is most effectively accomplished by proper application of preheating (when required) and the use of properly-developed welding parameters
Preheating/Slow Cooling – The Primary Defense

- Preheating is carried out for one of two reasons:
  - Control or limit the formation of crack susceptible microstructures
  - To allow diffusion of hydrogen

- The primary benefit of preheating modern pipeline girth welds is diffusion of hydrogen

- The diffusion rate of hydrogen in steel is strongly dependent on temperature
  - Diffusion rate increases by two orders of magnitude (i.e., 100 times) when temperature in increased from ambient (20°C) to 100°C
  - Greater portion of the hydrogen in the weld can diffuse away if a weld remains warm for a longer period of time after completion

![Graph showing the diffusion rate of hydrogen in steel vs. temperature]
Preheating Guidance

- Common preheating methods include gas torches (radiation methods), electric resistance heaters (conduction methods), and induction heaters (induction methods)
  - Common temperature measurement methods include contact thermometers, non-contact infrared pyrometers, and temperature indicating crayons

- Preheating should be applied so that the full volume of material surrounding the joint is thoroughly heated to above the specified-minimum temperature

- Preheating crew should not be allowed to get too far ahead of the root pass welding crew
  - If this occurs, preheat should be reapplied prior to depositing the root pass

- For large diameter pipe, the preheat temperature should not be allowed to fall to below the minimum-required temperature before any individual weld pass is completed
  - If this occurs, welding should be interrupted and preheat should be reapplied
Time Between Passes

- Welding without interruption can have the same beneficial effect of preheating
  - Heat from the welding operation is sufficient to maintain interpass temperature without the continuous external application of heat

- API 1104 uses “time between passes” instead of “minimum-required interpass temperature”
  - Maximum time between completion of the root pass and the start of the second pass – essential variable for procedure qualification
  - Maximum time between the completion of the second pass and the start of other passes – non-essential variable

- Intent is to avoid entrapment of hydrogen and to limit amount of time for cracking to occur

- Can be ineffective if time limits are not followed in the field or if ambient conditions are unfavorable
  - High winds and/or low temperatures
Adherence to Qualified Welding Procedures

- The purpose of qualifying a welding procedure is to demonstrate that the parameters specified in that procedure are capable of producing sound welds under production conditions

- Current regulations in the US require that qualified welding procedures are followed in the field
  - Level of oversight practiced to ensure that this happens varies widely
  - More important for large diameter, thick-wall, high strength pipelines than for smaller-diameter, thinner-wall, lower-strength pipelines
  - Little guidance exists for the level of oversight required for a particular application

- Guidance for welding inspection personnel should include how to monitor:
  - Fit-up (e.g., measurement of and limits for high-low misalignment)
  - Welding parameters (e.g., current, arc voltage, and travel speed)
  - Preheat and interpass temperature (or time between passes), etc.

- General descriptions of why monitoring of each of these parameters is important (e.g., the importance of preheating and what it does) should also be provided
Control of Weld Microstructures

- **Heat-Affected Zone** – Use of preheating (when necessary) and properly-developed welding parameters tends to result in relatively low hardness levels in the HAZ of girth welds in most modern line pipe steels
  - Several recent failures occurred in spite of very low measured hardness levels in the HAZ (e.g., 200 to 260 HV)
  - Controlling weld hydrogen levels and stresses acting on the weld is a more appropriate strategy for controlling the risk of hydrogen cracking in the HAZ of girth welds in modern line pipe steels

- **Weld Metal** – Careful selection of higher strength cellulosic-coated consumables should be practiced to control the risk of hydrogen cracking in the weld metal
  - e.g., avoid the use of AWS E9010 electrodes
  - Consider the use of low-hydrogen electrodes or processes for repair and tie-in welds
Control of Stresses Acting on Weld – Secondary Defense

- Avoid applied stresses during construction
  - Avoid early release of line-up clamp and use care when re-setting the pipe string
  - Make sure the pipeline profile fits the ditch
  - Use care when lifting and lowering-in

- Avoid longitudinal stresses from differential ground settlements and ground movements
  - Use care at road crossing, different soil conditions (settled vs. new soil), anchor points (e.g., adjacent to points of inflection), spans, landslide, etc.

- Little quantitative guidance exists

- Minimize stress concentrations by avoiding excessive high-low misalignment
  - No absolute limits for misalignment in API 1104 provided that the misalignment is distributed evenly around the circumference
  - Properly maintain line-up clamps, etc.
Hydrogen Cracking Summary

- None of the factors related to the occurrence of hydrogen cracking in pipeline girth welds (or guidance pertaining to minimizing the risk of cracking) presented here are new
  - Of these however, the factor that appears to be most misunderstood is control of weld hydrogen levels
  - When pipeline girth welds are made using cellulosic-coated electrodes, the amount of hydrogen that remains in the weld following completion must be managed
  - This is most effectively accomplished by proper application of preheating (when required) and the use of properly-developed welding parameters (including time between passes)
    - Resulting slow cooling allows hydrogen diffusion

- Hydrogen diffusion demonstration video
  - Shows the diffusion of hydrogen from welds made using different types of electrodes
  - Shows the beneficial effect of preheating and slow cooling and the importance of proper care of low-hydrogen electrodes
    - [http://www.youtube.com/watch?v=Wjz8eh3uxkU](http://www.youtube.com/watch?v=Wjz8eh3uxkU)
Inspection Issues for Welds with Internal Transitions

- Hydrogen cracks are planar discontinuities with sharp ends
- Radiographic inspection is not particularly well-suited to detecting planar discontinuities unless they happen to align with the radiation source
- Radiographic inspection of unequal wall thickness joints even more difficult due to the grossly different radiographic density on one side of the joint compared to the other
- Parameters for radiographic inspection should be optimized when inspecting critical pipeline girth welds (e.g., repair and tie-in welds) for cracks using RT
  - X-ray source is more effective at detecting cracks than gamma ray source
  - Class 1 film is more sensitive than Class 2 film
Special Radiographic Techniques for Unequal Wall Thickness Transitions

- Two techniques are available to accomplish effective RT examination of transition welds to accommodate the large variation in penetrated thickness
  - Use film cassettes that are double loaded with one fast-speed film and one slow-speed film
    - Slower speed film should be the first film (closer to the radiation source) in the film cassette
    - Faster-speed film should be the second film (further away from radiation source) in the film cassette
  - Make two radiographic exposures utilizing the same speed film for both exposures but different exposure times
    - Radiograph the thin wall portion of the weld using an exposure time appropriate for that portion
    - Radiograph the thicker portion of the weld using an exposure time appropriate for that portion
  - Results in two radiographs that can be used for complete evaluation of the weld

- For inspection of critical pipeline girth welds, consideration should be given to the use of alternative or complementary inspection techniques such as ultrasonic testing
Time Delay Prior to Inspection

- Hydrogen cracking often requires time to occur
  - Also referred to as delayed cracking

- A sufficient delay time should be allowed to elapse prior to inspection for hydrogen cracking

- When determining appropriate delay times prior to inspection:
  - Time-dependent nature of hydrogen cracking should be considered
  - Expected susceptibility of the weld to cracking should also be considered

- Longer delay times decrease the chance that cracking can occur after inspection has been completed

- The probability of cracking, and thus the importance of determining an appropriate delay time, can be minimized by using more conservative welding procedures
  - If hydrogen in the weld is allowed to diffuse away after welding by careful application of preheating and slow cooling (or post-heating), or if low-hydrogen electrodes are used, the probability of cracking is significantly reduced, and immediate inspection may be justified
Proposed Guidance for Revision of Construction Specifications

- Results of field exercises were used to develop a generic procedure for segmenting induction bends and elbows using conventional methods
  - Can be incorporated into company construction specifications

- Generic procedure includes the following topics:
  - Identifying Bends to be Cut
  - Required Equipment
  - Selecting the Transition Pup
  - Bend Layout
  - Checking Angle, Ovality and Squareness
  - Cutting the Bend
  - Aligning the Weld Bevel
  - Grinding the Internal Transition
  - Final Bevel and Alignment Checks
  - Welding the Pup to the Bend

- Requirements are for a hypothetical pipeline company
  - Users may want to alter these requirements and/or add additional requirements
Generic Procedure for Segmenting

1. SCOPE

1A A segmentable bend is one that was purchased and manufactured to meet 1% ovality throughout the bend arc. Some bends are not purchased as segmentable, and thus must not be cut.

1B Where it becomes necessary to segment an induction bend or 3R bend fitting (i.e., cut a smaller bend angle out of a larger bend), the requirements of this procedure must be met in addition to following all other Company welding and construction specifications.

1C On a project where induction (hot) bends or 3R bend fittings have been furnished to enhance construction, any bends with exact angles that were purchased for use at specific station numbers must be marked to identify their designated locations and installed at those locations.

1D Cold field bends should be used on piggable pipelines, where practical, for all bend angles that can be made with a field bending machine.

1E Special care shall be used to ensure that all cutting, alignment and welding parameters have been met. Dimensions and measurements should all be double-checked.

2. IDENTIFYING BENDS TO BE CUT

2A Prior to cutting a bend segment, the following information must be confirmed with the purchase order and/or material test report (MTR): bend is segmentable, bend radius, and bend number. The bend radius and bend number shall be recorded on a "Bend Segmenting Report".

2B The description of bend radius can be referred to as either D or R, such as 6D or 6R. This description 6D or 6R means the radius of the bend is 6 times the nominal pipe diameter (OD).

2C Bends which are ordered as “segmentable” shall be marked “SEGMENTABLE” and the material documentation for segmentable bends shall specifically state the bend is segmentable. Non-segmentable bends may also be marked as “Do Not Cut” or “Do Not Segment”.

2D A bend shall NOT be cut if it is marked with a specific station number (e.g., 237+22) which indicates that the bend is intended to be installed at a specific location without being cut.

3. REQUIRED EQUIPMENT

3A The following Measurement Equipment is needed to use this inspection procedure:

3A1 OD Calipers and rule with 1/64" or less graduations or OD Micrometers

3A2 Slide Calipers

3A3 Tape Measure

3A4 Squares

3A5 Hi/Lo Gage
Generic Procedure for Segmenting

<table>
<thead>
<tr>
<th>Merchandise</th>
<th>Segmenting Induction Bends and 3R Elbow Fittings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3A6</strong></td>
<td>Protractor</td>
</tr>
<tr>
<td><strong>3B</strong></td>
<td>The following Fabrication Equipment is needed to follow this procedure</td>
</tr>
<tr>
<td><strong>3B1</strong></td>
<td>Dearnor Style Clamp – required for diameters greater than 18”</td>
</tr>
<tr>
<td><strong>3B2</strong></td>
<td>Center Punch</td>
</tr>
<tr>
<td><strong>3B3</strong></td>
<td>Level – various lengths</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>SELECTING THE TRANSITION PUP</td>
</tr>
<tr>
<td><strong>4A</strong></td>
<td>Transition pipes are required on the segmented end of induction bends to provide for pipe-to-pipe welds at all tie-ins and to facilitate back-welding, if required. The bend bevel. Restrictions are placed on the length of the transition pup based on pipe diameter to facilitate access to the interior of the pipe-to-bend weld for visual inspection and potential backwelding.</td>
</tr>
<tr>
<td><strong>4A1</strong></td>
<td>For pipe diameters 20” and greater, the transition pup installed on the segmented end of the bend is required to be a minimum of 14 feet.</td>
</tr>
<tr>
<td><strong>4A2</strong></td>
<td>For pipe diameters 18” and smaller, the transition pup installed on the segmented end of the bend is required to be a minimum of 6 inches long and a maximum of 8 inches long.</td>
</tr>
<tr>
<td><strong>4B</strong></td>
<td>The wall thickness of the transition pup shall typically be less than the wall thickness of the bend. This may not always be the case because the manufacturing process for an induction bend will reduce the average diameter within the bend arc by about 1/8” to 1/4”.</td>
</tr>
<tr>
<td><strong>4C</strong></td>
<td>The nominal wall thickness of the transition pup shall be:</td>
</tr>
<tr>
<td><strong>4C1</strong></td>
<td>No more than 1/4” (0.250”) less than the nominal wall thickness of the bend</td>
</tr>
<tr>
<td><strong>4C2</strong></td>
<td>Preferably at least 1/8” (0.125”) less than the nominal wall thickness of the bend (if pipe is available), provided the design pressure is met</td>
</tr>
<tr>
<td><strong>4C3</strong></td>
<td>No greater than the nominal wall thickness of the bend (if thinner pipe is not available)</td>
</tr>
<tr>
<td><strong>4D</strong></td>
<td>In cases where the bend diameter shrinkage is high, it may be necessary to use a transition pup of the same nominal wall thickness as the bend to ensure sufficient wall thickness at the bend transition bevel (subject to the limitations of §8F1.2). The pop pipe may require external transition to ensure the weld cap angle does not exceed 30 degrees.</td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>BEND LAYOUT</td>
</tr>
<tr>
<td><strong>5A</strong></td>
<td>For marking, cutting, and beveling, the bend should be situated so it sits in a flat and level position. The cut point for the desired angle shall be precisely measured and marked at top and bottom using the arc chord length from Tables 1 – 6, as shown in Figure 1, being sure to use the table with the appropriate pipe diameter (e.g., 16” or 42”) and the column for the bend radius (3D, 6D or 9D). It is important that the true top and true bottom (neutral axis) are determined for correct marking location using a center finder tool similar to the one shown in Figure 2. For arc chord lengths for pipe diameters other than those listed in the table, the chord equation is provided in the Table.</td>
</tr>
<tr>
<td><strong>5B</strong></td>
<td>The following steps should be followed to lay out the bend angle:</td>
</tr>
<tr>
<td><strong>5B1</strong></td>
<td>Check the end for vertical squareness and re-bevel the end if it is out of square by more than the following tolerances:</td>
</tr>
<tr>
<td><strong>5B1.1</strong></td>
<td>1/2 inch for pipe 24” to 42” diameter</td>
</tr>
<tr>
<td><strong>5B1.2</strong></td>
<td>3/8 inch for pipe 12” to 22” diameter</td>
</tr>
<tr>
<td><strong>5B1.3</strong></td>
<td>1/4 inch for pipe smaller than 12” diameter</td>
</tr>
<tr>
<td><strong>5B2</strong></td>
<td>For induction bends with straight tangents, find the true tangent length on both the intrados and extrados (the inside radius and outside radius of the bend, i.e., ± 0.00 degrees from the neutral axis) as shown in Figure 1. The neutral axis is located in the 12:00 and 6:00 clock positions when the bend is in a flat and level position per §5A. This can be done using a straitedge to check when the pipe deviates from straight or starts to bend.</td>
</tr>
</tbody>
</table>

Guidance for Field Segmentation and Welding of Induction Bends and Elbows
October 20, 2011
© Det Norske Veritas AS. All rights reserved.
Generic Procedure for Segmenting

6 CHECKING ANGLE, OVALITY AND SQUARENESS

6A Using calipers (see Figure 3) and a ruler with at least 1.64' increments or large diameter micrometers, measure the outside diameter of the bend at the proposed cut location across the following 4 clock positions: 12.00-6.00, 1.30-7.30, 3.00-9.00, and 4.30-10.30 (i.e., every 45 degrees). Company Welding Inspector shall record the “prior to cut” diameter measurements on a “Bend Segmenting Report”. The ovality must be calculated using the following:

\[ \% \text{Ovality} = 100 \times \left( \frac{\text{Minimum Diameter} - \text{Minimum Diameter}}{\text{Nominal Pipe Diameter}} \right) \]

6B If ovality at the desired cut location is > 1.0%, then the bend angle shall be measured from the opposite tangent or bend end, repeating the steps in Section 3, to determine if the ovality is within 1.0%. If ovality is > 1.0% in both cases, then the bend must be set aside for a different location that needs a different bend angle. The Technical Champion of this procedure designer and Company Field Engineer responsible for the project shall be advised that the ovality is > 1.0%. Another segmentable induction bend, unless approved by the Technical Champion, must be selected for this angle and the above steps must be repeated. In other words, do not cut a segmentable bend at a location where the ovality is > 1.0%.

6C After the cut-line has been marked, the bend angle must be checked to confirm it is accurate and the cut-line is square using a reliable method, such as the ones shown in Figures 4 and 5 with squares and string-lin'es, or possibly using a laser system. Dimension should be re-checked and the bend cut-line adjusted, if necessary.

6D A punch should be used to mark the cut-line locations on the cut-line previously marked with a soap stone (§5D) through the coating and onto the pipe surface so that the location marks are visible after the coating has been removed.

6E Remove the coating where the cut is to be made. Mark the cut-line around the circumference aligning the bend with the punch marks.

6F Make sure the punch marks to the punch with a soap stone or marker on both sides of the cut-line to ensure the measurement locations for use after cutting. No punch marks shall remain in the surface after welding is complete.

6G A bend angle may be cut out a bend section with tuyeres by using the same methods outlined in this procedure using chord lengths, angle and squareness checks, and a transition pop on both ends of the bend.

7 CUTTING THE BEND

7A Cut the bend and then check for squareness. Several possible methods for checking end squareness are shown in Figures 4, 5 and 6. The ends should be square to the tolerances provided in §6B, top to bottom and side to side.

7B A temporary pop must be tack-welded to the cut end of the bend to mount the beveling machine bend squarely, and the back-bevel technique shall be used to cut a standard external 30° bevel (-6°, +6°) on the cut end of the bend. A Deamann style chain clamp (see Figure 10) shall be used for line-up to achieve the best possible alignment of the

8 ALIGNING THE WELD BEVEL

8A Ovality of pop pipe shall be checked at both ends to ensure it does not exceed 1% maximum. Using calipers (see Figure 3) and a ruler with 1.64' increments or large diameter micrometers, measure the outside diameter of the pop across the following 4 clock positions: 12.00-6.00, 1.30-7.30, 3.00-9.00, and 4.30-10.30 (i.e., every 45 degrees). Company Welding Inspector shall record diameter measurements on a “Bend Segmenting Report”. The ovality must be calculated using the following formula:

\[ \% \text{Ovality} = 100 \times \left( \frac{\text{Minimum Diameter} - \text{Minimum Diameter}}{\text{Nominal Pipe Diameter}} \right) \]

8B The specific transition pop that will be welded to the bend cut end shall have a standard 30° weld bevel, shall be lined-up with the bend positioned in a Deamann style clamp for large diameter pipe, and shall be rotated to achieve the best possible alignment that minimizes the effects of ovality, thus achieving the least amount of average high/low around the entire weld bevel. The weld seams of the pop may be rotated to any 0° clock position necessary to ensure that the weld bevel meets the alignment requirements of this procedure, as long as the 3° minimum offset between seams of the pop and bend is maintained.

8C The internal alignment shall be inspected, and the areas with the greatest amount of high/low shall be measured. The high/low should be evenly distributed as best as possible and the pop shall be locked into position. The alignment location of the pop weld seams shall be marked on the bend to ensure alignment during subsequent fit-ups.

8D The external offset between the pop and bend shall not exceed 1.3 the nominal wall thickness of the pop pipe (see Figure 8) at any location. A straight-edge and vernier caliper may be used to make these measurements.

8E Once the optimum bevel alignment has been determined, a sharpened soap stone or marker shall be laid flat on the inside of the pop to scribe a line on the bend bevel that represents the extent of material to removed to create the internal transition on the inside of the bend, shown as the “First Mark” in Figure 7.

8F Remove the pop pipe from the clamp. Measure on the bend bevel the minimum wall thickness from the mark on the bend end to the material on the side of the pipe, at a minimum of the following 8 clock positions: 12.00, 1.50, 3.00, 4.50, 6.00, 7.50, 9.00, 10.30 (i.e., every 45 degrees), and in addition also measure the location where visual inspection indicates the remaining thickness appears to be the least.

8F1 The measured thickness of the bend must meet one of the following:

8F1.1 No less than the nominal wall thickness of the pop pipe, or

8F1.2 No less than 0.83 times the nominal wall thickness, where the remaining bend end thickness after grinding is confirmed by the Engineer to meet x

0.6 design factor in a Class 1 area
Generic Procedure for Segmenting

0.5 design factor in a Class 2 area
0.4 design factor in a Class 3 area

Note: This second case is typically used where the transition pop thickness is near to or the same as the bend wall thickness.

SF2 If the thickness is less than the above limit, the pop shall be realigned and adjusted to achieve a better fit-up. Repeat Steps 8A through 8F.

SF3 If a better alignment cannot be obtained, then a second line shall be marked on the bend bevel at a distance of one transition pop wall thickness from the outside surface of the bend, shown as the "Second Mark" in Figure 7 (or mark at a minimum of 0.8 times nominal wall thickness of pop, if allowed per [SF1.2]).

SF4 If the difference between the two lines on the bend bevel is ≤ 3/8" (0.375"), then the second line will be the start point for the internal transition on the bend (see "Second Mark" in Figure 7). The offset between the lines is ≥ 1/16" (0.062"), then a backwall will be required. Backwall shall be a minimum of 3\(^2\) in length, but are only required at these offset locations. Full circumferential backwalls are not required.

SF5 If the difference between the two lines on the bend bevel is > 3/8" (0.375"), then a different pop pipe shall be used, and Steps 8A through 8F must be repeated.

GRINDING THE INTERNAL TRANSITION

9A Once the above requirements are met, the inside surface of the bend shall be ground to the appropriate mark to form the internal transition bevel. The angle of the transition bevel must be 14° to 30°. The use of a hand-held tool or any other thermal cutting method to cut any portion of the internal bend is not acceptable.

9B After grinding of the bevel (including the land face) and internal transition is complete, Company Welding Inspector shall measure the bevel thickness and internal transition bevel angle at the following 8 clock positions: 12:00, 1:30, 3:00, 4:30, 6:00, 7:30, 9:00, and 10:30 (i.e., every 45 degrees).

10 FINAL BEVEL AND ALIGNMENT CHECKS

10A The following limits must be met for the bend weld bevel and internal transition bevel (as shown in Figure 8):

10A.1 Minimum actual measured bevel thickness on the bend after transitioning:

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10A.1.1</td>
<td>≥ 92% nominal wall thickness of pop (i.e., an under-tolerance of up to 8% of the nominal pop wall thickness is allowed)</td>
</tr>
<tr>
<td>10A.1.2</td>
<td>≥ 83% nominal pop thickness, if allowed in [SF1] (i.e., this absolute minimum bevel thickness is subject to the requirements of [SF1], and no under-tolerance is allowed)</td>
</tr>
</tbody>
</table>

10A.2 Internal transition bevel angle:

10A.2.1 Minimum 14°
Generic Procedure for Segmenting

11B4 Where multiple backweld beads are required, the weld bead sequence must be from the transition pop up to the bend as shown in the “Backweld Bead Detail” in Figure 8.

11C Company Welding Inspector shall also visually inspect the weld for inadequate penetration (IP), cracks, pinholes, internal and external undercut.

11D The results of the visual inspection shall be reported on a “Bend Segmenting Report”.

Figure 1: Bend Layout Using Chord “c” to Determine Segment Angle \( \alpha \)

Look-up values of “c” in Tables 1 to 6

Figure 2: Center Finder Marking Tool
Generic Procedure for Segmenting

Figure 3: Top – Calipers; Bottom – Large Diameter Micrometer

Figure 4: Confirm Bend Angle $\alpha$ With Two Squares

Figure 5: Confirm Angle and Squareness With Two String Lines

(Angles and squareness should be checked after initial marking and after cutting)

Figure 6: Two Optional Methods for Checking End Squareness
Generic Procedure for Segmenting

Figure 7: Mark Bend for Transition

Figure 8: Weld Alignment Limits and Details

Figure 9: Correction of Improper Backward Technique

Figure 10: Dearman Style Chain Clamp
### Generic Procedure for Segmenting

#### Table 1

<table>
<thead>
<tr>
<th>Angle (deg)</th>
<th>Chord Length c (inches) for Radius of 16 inches</th>
<th>Chord Length c (inches) for Radius of 20 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>D1</td>
<td>D2</td>
</tr>
<tr>
<td>9</td>
<td>7.5</td>
<td>9.4</td>
</tr>
<tr>
<td>10</td>
<td>6.4</td>
<td>8.5</td>
</tr>
<tr>
<td>11</td>
<td>5.2</td>
<td>7.8</td>
</tr>
<tr>
<td>12</td>
<td>4.1</td>
<td>6.9</td>
</tr>
<tr>
<td>13</td>
<td>3.1</td>
<td>5.7</td>
</tr>
<tr>
<td>14</td>
<td>2.2</td>
<td>4.9</td>
</tr>
<tr>
<td>15</td>
<td>1.3</td>
<td>4.0</td>
</tr>
<tr>
<td>16</td>
<td>1.0</td>
<td>3.3</td>
</tr>
<tr>
<td>17</td>
<td>0.8</td>
<td>2.8</td>
</tr>
<tr>
<td>18</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>19</td>
<td>0.5</td>
<td>2.1</td>
</tr>
</tbody>
</table>

#### Table 2

<table>
<thead>
<tr>
<th>Angle (deg)</th>
<th>Chord Length c (inches) for Radius of 24 inches</th>
<th>Chord Length c (inches) for Radius of 30 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>D1</td>
<td>D2</td>
</tr>
<tr>
<td>9</td>
<td>7.5</td>
<td>9.4</td>
</tr>
<tr>
<td>10</td>
<td>6.4</td>
<td>8.5</td>
</tr>
<tr>
<td>11</td>
<td>5.2</td>
<td>7.8</td>
</tr>
<tr>
<td>12</td>
<td>4.1</td>
<td>6.9</td>
</tr>
<tr>
<td>13</td>
<td>3.1</td>
<td>5.7</td>
</tr>
<tr>
<td>14</td>
<td>2.2</td>
<td>4.9</td>
</tr>
<tr>
<td>15</td>
<td>1.3</td>
<td>4.0</td>
</tr>
<tr>
<td>16</td>
<td>1.0</td>
<td>3.3</td>
</tr>
<tr>
<td>17</td>
<td>0.8</td>
<td>2.8</td>
</tr>
<tr>
<td>18</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>19</td>
<td>0.5</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Plus additional tables for 24 through 42 inch OD
Summary for Phase 2

- Phase 2 of this project involved development of guidance for field construction practices

- Optimal methods for mapping, cutting, beveling and transitioning induction bends and elbows were developed

- Recommended practices for welding in the field and for a variety of related issues were also developed
  - Optimization of joint designs for unequal wall thickness transitions
    - Joint design guidance indicates a strong preference for backwelding unless fit-up conditions are ideal
  - Limits for high-low misalignment
  - Backwelding methods and practices
  - General guidance for avoiding hydrogen cracking
  - Inspection issues for welds with internal transitions
  - Time delay prior to inspection

- Information was summarized and used to develop a generic specification for segmenting and welding of induction bends and elbows
  - Generic procedure will be made public (e.g., a DNV Recommended Practice)
Safeguarding life, property and the environment

www.dnv.com