Case N-561-3
Alternative Requirements for Wall Thickness Restoration of Class 2 and High Energy Class 3 Carbon Steel Piping
Section XI, Division 1

Inquiry: As an alternative to replacement or internal weld repair, what requirements may be applied for wall thickness restoration of Class 2 and high-energy Class 3 carbon steel piping systems that have experienced internal wall thinning from localized erosion, corrosion, and cavitation or pitting?

Reply: It is the opinion of the Committee that areas of Class 2 and high-energy (i.e., greater than 200°F or 275 psig maximum operating conditions) Class 3 carbon steel piping experiencing internal wall thinning from localized erosion, corrosion, and cavitation or pitting may have the wall thickness restored externally by means of a weld-deposited carbon or low-alloy steel overlay on the outside surface of the piping in accordance with the following requirements. Excluded from these provisions are conditions involving corrosion-assisted cracking or any other form of cracking.

1 GENERAL REQUIREMENTS

(a) The overlay shall be performed in accordance with a Repair/Replacement Plan satisfying the requirements of IWA-4150.1

(b) The overlay shall meet the requirements of Article IWA-4000, except as stated in this Case.

(c) If the minimum required thickness of deposited weld metal necessary to satisfy the requirements of 3 is greater than the nominal thickness for the size and schedule of the piping, the provisions of this Case shall not apply.

(d) Weld overlay shall not be performed more than once in a single location.

2 INITIAL EVALUATION

The material beneath the surface to which the weld overlay is to be applied shall be ultrasonically examined in accordance with IWA-2232 to verify no crack-like defects exist. The existing average wall thickness and the rate, extent, and configuration of degradation to be reinforced by the weld overlay shall be determined. The adjacent area shall be examined to verify that the overlay will encompass the entire unacceptable area. Consideration shall be given to the cause of degradation. The extent of degradation in the piping shall be evaluated to ensure that there are no other unacceptable locations within the surrounding area that could affect the integrity of the overlaid piping. The dimensions of the surrounding area to be evaluated shall be determined by the Owner, considering the type of degradation present. The effect of the overlay on the piping and any remaining degradation shall be evaluated in accordance with IWA-4160.

3 DESIGN

3.1 GENERAL DESIGN REQUIREMENTS

(a) Unless otherwise established by theoretical or experimental analysis, or by proof testing as provided for in 3.3 or 3.4, the full thickness of the weld overlay shall extend a distance of at least \( s \) in each direction beyond the area predicted, over the design life of the overlay to infringe upon the required thickness, \( t_{nom} \).

where

\[
R = \text{outer radius of the component}
\]

\[
s \geq \frac{3}{4} \sqrt{\frac{R}{t_{nom}}}
\]

\( t_{nom} = \text{nominal wall thickness of the component} \)

When applicable to satisfy the minimum \( s \) dimension, the overlay may be extended over adjacent compatible low-alloy steel weld and base metal that is not experiencing wall thinning.

1 The references to Section XI in this Case refer to the 2017 Edition. For use of this Case with other Editions and Addenda, refer to Table 1 from the Guideline for Cross-Referencing Section XI Cases.

2 Design thickness as prescribed by the Construction Code.
Edges of the weld overlay shall be tapered to the existing piping surface at a maximum angle (“α” in Figure 1) of 45 deg. Final configuration of the overlay shall permit the examinations and evaluations required herein, including any required preservice or inservice examinations of encompassed or adjacent welds.

(b) The thickness shall be sufficient to maintain required thickness for the predicted life of the overlay, and, except for the tapered edges, the overlay shall have a uniform thickness.

(c) The tensile strength of the weld filler metal used for the overlay shall be at least that specified for the base metal to which it is applied.

(d) The predicted maximum degradation of the overlaid piping and the overlay over the design life of the overlay shall be considered in the design. The predicted degradation of the piping shall be based on in-situ inspection and established data for similar base metals. If the weld overlay is predicted to become exposed to the corroding medium, the predicted degradation of the overlay shall be based upon established data for base metals or weld metals with similar chemical composition to that of the filler metal used for the weld overlay.

3.2 DESIGN

The design of weld overlays not prequalified by 3.3, 3.4, or 3.5 shall be in accordance with the applicable requirements of the Construction Code or NC-3100, ND-3100 and NC-3600, ND-3600 (including Appendix II), and shall consider the weld overlay as an integral portion of the piping or component upon which it is applied (not as a weld). The allowable stress values of the base metal shall apply to the design of the deposited weld metal. The following factors shall be considered in the design and application of the overlay:

(a) The shrinkage effects, if any, on the piping.

(b) Stress concentrations caused by application of the overlay or resulting from existing and predicted piping internal surface configuration.

(c) Flexibility analysis was required by the original construction code, the effect of the weld overlay shall be reconciled with the original analysis. For rectangular-shaped overlays on piping designed to NC-3650 or ND-3650 and aligned parallel or perpendicular to the axis of the piping, the following stress intensification factors (SIFs) shall be applied in the load transition area extending outward from the overlay weld toe a distance $2.5 \sqrt{R_{t_{\text{nom}}}}$:

(1) for straight pipe, use $SIF = 2.1$.

(2) for tees and branch connections when the toe of the overlay is not less than $2.5 \sqrt{R_{t_{\text{nom}}}}$ from any branch reinforcement in Figure 1, use $SIF = 2.1$.

(3) for standard elbows and pipe bends, apply a multiplier of 1.7 to the calculated SIF from Table NC-3673.2(b)-1 or Table ND-3673.2(b)-1, to obtain the SIF to be used.

(4) for circumferential butt welds between two piping components described in (1) through (3), use $SIF = 2.1$.
(5) for configurations other than described in (1) through (4), the SIF may be determined in accordance with Section III, Appendix II.

(6) As an alternative to using the SIFs of (1) through (4), lower SIFs may be determined in accordance with Section III, Appendix II.

(d) The effects of different coefficients of thermal expansion between the weld overlay filler metal and the base metal.

### 3.3 PROOF TEST QUALIFICATION AS A PIPING PRODUCT

As an alternative to design, the configuration of weld overlays may be qualified by performance of proof testing of a mockup in accordance with the following requirements:

(a) A satisfactory mockup burst test shall qualify the design or configuration for application in the same orientation on the same type of item, and the same location on fittings, when the following conditions are satisfied (see Figure 1):

1. The base metal is of the same P-No. and Group Number when impact properties are applicable, as the base metal tested.
2. The specified minimum tensile strength of the item does not exceed that specified for the base metal tested.
3. The average thickness of the overlay areas is at least the thickness of the mockup plug, \( u \).
4. The overlap on the full thickness of base metal, \( s \), is at least that of the mockup.
5. The transition angle at the outer edges of the overlay, \( \alpha \), is not greater than that of the mockup.
6. The overlay surface finish is similar to or smoother than that tested.
7. The maximum proportionate axial dimension, \( L/D \), is not more than that tested.
8. The maximum proportionate circumferential dimension, \( C/D \), is not more than that tested.
9. The nominal diameter is not less than one-half nor more than two times the diameter tested.
10. The nominal thickness/diameter ratio, \( t/D \), is not less than one-half nor more than three times the \( t/D \), ratio tested.

(b) The mockup base shall consist of new base material of similar configuration, or type of item, as the item to be overlaid. A rounded-corner segment of the base material shall be removed to represent the maximum proportionate size (axial dimension of \( L \) and circumferential dimension of \( C \)) and location of thinning or pitting to be compensated for by the weld overlay. A plug of the same base metal and of uniform thickness \( u \), which shall not exceed the smallest average thickness on which the overlays will be permanently applied, shall be full-penetration welded around the opening and flush with the outside surface of the piping. Alternatively, an equivalent volume of base metal may be removed from the inside surface of the mockup by machining or grinding, without need for welding in a closure plug.

(c) The mockup weld overlay shall be applied in accordance with the design or specified configuration using the specified weld filler metal. Maximum section thickness at the overlaid opening (weld metal plus base metal plug, \( u + w \)) shall not exceed \( 87\frac{1}{2}\% \) of the nominal thickness of the piping.

(d) Straight pipe equivalent to a minimum of one pipe diameter, or one-half diameter for piping over NPS 14, shall be provided (butt-welded to the mockup, if necessary) beyond both ends of the overlay. The piping shall be capped and the completed mockup assembly shall be thoroughly vented and hydrostatically pressure tested to bursting. To qualify the design for general application within the limits of (a), burst pressure shall not be less than

\[
p = \frac{2tS_{acc}}{D_0}
\]

where

- \( D_0 \) = outside diameter of the pipe, in.
- \( P \) = minimum acceptable burst pressure, psi
- \( S_{acc} \) = reported actual tensile strength of the base metal being tested, psi
- \( t \) = minimum specified thickness (excluding manufacturing tolerances) of the base metal being tested, in

(e) If flexibility analysis was required by the original Construction Code, the effect of the weld overlay shall be reconciled in accordance with 3.2(c).

### 3.4 PROOF TEST QUALIFICATION FOR SPECIFIC APPLICATIONS

As an alternative to design by analysis or proof test qualification as a piping product, the design or configuration of weld overlays may be qualified for limited service conditions using the provisions of NC-6900 and ND-6900. “Proof Tests to Establish Design Pressure,” except that component hydrostatic testing is not required (other than as required by Article IWA-4000). The mockups shall be fabricated and tested in accordance with the provisions of 3.3(b), 3.3(c), and 3.3(d), and shall be applied in accordance with the provisions and conditions of 3.3(a). The provisions of 3.3(e) shall be met.

### 3.5 PREQUALIFIED DESIGN

Application of weld overlays on straight pipe, portions of tees not less than \( \frac{1}{2} \sqrt{\frac{R_{nom}}{2}} \) from any branch reinforcement in Figure 1, standard elbows, and associated welds to correct limited degradation shall be exempt from the requirements of 3.2 through 3.4 provided all of the following conditions are satisfied in Figure 1:
(a) The requirements of 3.1 apply.

(b) The finished overlay shall be circular, oval, full-circumferential or rectangular in shape.

(c) The distance between toes of adjacent overlays shall not be less than \( \frac{3}{4} \sqrt[4]{R_{\text{nom}}} \) on pipe or tees, nor less than \( 2 \sqrt{R_{\text{nom}}} \) on elbows.

(d) The maximum dimension compensated by a circular or oval overlay shall not exceed the lesser of \( \frac{1}{2} \) the nominal outside diameter of the piping or 8 in.

(e) For rectangular overlays on piping with nominal thickness not less than standard wall nor more than 0.112 \( D_o \), the following shall apply:
   (1) The overlays shall be aligned parallel with or perpendicular to the axis of the piping;
   (2) Corners shall be rounded with radii not less than the overlay thickness;
   (3) The base metal shall be P-No. 1 material, with impact properties not applicable;
   (4) The specified minimum tensile strength of the overlaid item shall not exceed 60,000 psi;
   (5) The average thickness of the overlay area \( u \) shall be at least \( \frac{3}{8} \) in.;
   (6) The full thickness of the overlay shall extend a distance \( s \) beyond the area predicted to infringe upon the base metal required thickness, where \( s = \frac{1}{4} \sqrt[4]{R_{\text{nom}}} \);
   (7) The overlay surface finish may be as-welded or smoother;
   (8) For NPS 4 through NPS 16 the maximum axial and circumferential dimensions compensated by the overlay shall not exceed one-half the nominal outside diameter.
   (9) For rectangular overlays on piping greater than NPS 16, the maximum angle of taper, \( \alpha \), shall not exceed 30 deg, and the maximum axial dimension and area of base metal predicted to be below the required thickness shall not exceed that defined by
      \[
      L_{\text{max}}(\text{in.}) = 0.11D_o + 1.84
      \]
      \[
      A_{\text{max}}(\text{in.}^2) = 0.455D_o - 0.8
      \]
      where
      \( A_{\text{max}} = \) maximum area of base metal predicted to degrade below the required thickness over the remaining life of the overlay, \( \text{in.}^2 \)
      \( L_{\text{max}} = \) maximum axial dimension of base metal predicted to degrade below the required thickness over the remaining life of the overlay, \( \text{in.} \)
   (f) If flexibility analysis was required by the original Construction Code, the effect of the weld overlay shall be reconciled in accordance with 3.2(c).

4 STEAM- OR WATER-BACKED APPLICATIONS

(a) For overlays applied with water backing, the qualification, application, examination and repair requirements of the temper bead welding technique described in IWA-4610 and either IWA-4670\(^3\) or IWA-4680\(^4\) shall apply.

(b) Steam systems, regardless of wall thickness, or water-backed piping with wall thickness less than the diameter of the electrode, shall be depressurized before welding.

5 INSTALLATION

(a) The entire surface area to which the weld overlay is to be applied shall be examined using the liquid penetrant or magnetic particle method, with acceptance criteria in accordance with NC-2500 or ND-2500, and NC-5300 or ND-5300 for the product form (base metal or weld) involved.

(b) If through-wall repairs are necessary to satisfy the acceptance criteria, or result from weld overlay, they shall be accomplished by sealing with weld metal using a qualified weld procedure suitable for open-root welding. This weld shall be examined in accordance with (a). In addition, the first layer of overlay over the repaired area shall be examined in accordance with (a). If such repair is performed on a wet surface, the permitted life of the overlay shall be until the end of the next refueling outage.

(c) Overlay weld metal shall be deposited using a groove-welding procedure qualified in accordance with Section IX and the Construction Code, Section IX and Section III, or IWA-4610 and either IWA-4620, IWA-4670,\(^3\) or IWA-4680.\(^4\) The qualified minimum thickness specified in the weld procedure does not apply to the weld overlay or associated base metal repairs.

(d) The surface of the weld overlay shall be prepared by machining or grinding, as necessary, to permit performance of surface and volumetric examinations required by 6 and any subsequent preservice or inservice examinations. For ultrasonic examination, a surface finish of 250 RMS or better is required.

6 EXAMINATION

(a) The completed weld overlay shall be examined using the liquid penetrant or magnetic particle method and shall satisfy the surface examination acceptance criteria for welds of the Construction Code or NC-5300 and ND-5300.

(b) The weld overlay, including the existing piping upon which it is applied, shall be examined to verify acceptable wall thickness.

Weld overlays shall be volumetrically examined as base metal repairs when required by the Construction Code, except as follows:

1. Class 3 weld overlays are exempt from volumetric examination when the Construction Code does not require that full-penetration butt welds in the same location be volumetrically examined.

2. Class 3 weld overlays not exceeding 10 in.² surface area are exempt from volumetric examination.

3. Other weld overlays shall be exempt from volumetric examination when the finished applied thickness \( w \) in Figure 1 does not exceed:
   - (a) \( \frac{1}{3} t \) for \( t \leq \frac{3}{4} \) in.
   - (b) \( \frac{1}{4} \) in. for \( \frac{3}{4} \) in. < \( t \leq 2\frac{1}{2} \) in.
   - (c) the lesser of \( \frac{3}{8} \) in. or 10% of \( t \) for \( t > 2\frac{1}{2} \) in.

where \( t \) is the finished full-section thickness of compensated area (e.g., \( w + u \) in Figure 1).

4. When volumetric examination is required, the full volume of the finished overlay, excluding the tapered edges, but including the volume of base metal required for the service life of the overlay, shall be examined in accordance with the Construction Code or Section III using either the ultrasonic or radiographic method, and shall, to the depth at the surface of the existing piping, satisfy the acceptance criteria for welds of the Construction Code or NC-5300 and ND-5300. Any volume of the existing piping, beneath the weld overlay that is taken credit for in the design, shall satisfy the volumetric acceptance criteria of NC-2500 and ND-2500 or NC-5300 and ND-5300 as applicable.

7 IN-SERVICE EXAMINATION

(a) Examinations shall be performed to characterize the thinning of the underlying pipe wall as a benchmark for subsequent examinations of the overlay.

(b) The Owner shall prepare a plan for additional examinations to verify that minimum wall thickness is not violated over the life of the overlay. The frequency and method of examination shall be determined based on an evaluation of the degradation mechanism.

(c) Except as required by 5(b), the maximum service life of the overlay shall be two fuel cycles unless wall thickness examinations during each of the two fuel cycles are performed to establish the life of the overlay. If the cause of the degradation is not determined, the maximum permitted life of the overlay shall be until the end of the next refueling outage.