



VIBRACAST REFRACTORY LINING V-ANCHORS

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2. GENERAL
2.1 Scope

- a. This specification describes the refractory and anchorage materials to be used, and the methods of application, for internally insulating vessels, equipment, piping, and duct work with a 3" (75mm) to 6" (150mm) thick, vibracast monolithic refractory lining. Refractory lining in fired process heaters is not included.
- b. The refractory and all required hydrating water are blended in the mixer. The resulting mixture is transported to the installation site and placed where required. Forms are used to define the exposed surface of the lining. Consolidation and removal of air pockets is accomplished by vibration of the in place refractory.
- c. This specification is not applicable to materials that are conveyed or pumped to the installation site, nor is it applicable to self-leveling, pumpcast, or similar materials.
- d. Exceptions or variations shown in the UOP Project Specifications take precedence over requirements shown herein.
- e. When the Manufacturer's requirements for storage, mixing, placement, curing and heat drying, etc. are more stringent than those herein, the Manufacturer's requirements shall govern.

2.2 References

The edition in effect on the date of the contract award for the equipment shall be used, except as otherwise noted. When a referenced document incorporates another document, use the edition of that document required by the referenced document.

a. ASTM International (ASTM):

- (1) A479 "Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels"
- (2) A516 "Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate - and Lower-Temperature Service"
- (3) A820 "Standard Specification for Steel Fibers for Fiber-Reinforced Concrete"
- (4) C20 "Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water"
- (5) C71 "Terminology Relating to Refractories"
- (6) C113 "Standard Test Method for Reheat Change of Refractory Brick"


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- (7) C133 “Standard Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories”
- (8) C134 “Standard Test Methods for Size, Dimensional Measurements, and Bulk Density of Refractory Brick and Insulating Firebrick”
- (9) C201 “Standard Test Method for Thermal Conductivity of Refractories”
- (10) C309 “Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete”
- (11) C704 “Standard Test Method for Abrasion Resistance of Refractory Materials at Room Temperature”
- (12) C860 “Standard Practice for Determining the Consistency of Refractory Castable Using the Ball-In-Hand Test”
- (13) C862 “Standard Practice for Preparing Refractory Concrete Specimens by Casting”
- (14) C865 “Standard Practice for Firing Refractory Concrete Specimens”
- (15) D4285 “Standard Test Method for Indicating Oil or Water in Compressed Air”
- (16) E220 “Standard Test Method for Calibration of Thermocouples by Comparison Techniques”

- b. American Welding Society (AWS) A 5.4 / ASME SFA-5.4/SFA-5.4M, “Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding”.
- c. AWS A 5.9 / ASME SFA-5.9/SFA-5.9M, “Specification for Bare Stainless Steel Welding Electrodes and Rods”.
- d. AWS A 5.11 / ASME SFA-5.11/SFA-5.11M, “Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding”.
- e. American Petroleum Institute (API) Standard 936, “Refractory Installation Quality Control – Inspection and Testing Monolithic Refractory Linings and Materials”.
- f. The Society for Protective Coatings (SSPC), Specification SP-7, “Brush-Off Blast Cleaning”.
- g. National, state, and local governmental regulations and laws.

2.3 Governing Documents

- a. Refractory lining materials, testing, installation, and inspection shall comply with the requirements of API Standard 936, except where modified by either the UOP Standard Specifications or UOP Project Specifications and Drawings.


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- b. The refractory anchorage installer shall prepare a list of deviations (including sketches) from this UOP Standard Specification and the UOP Project Specifications and Drawings. The deviation list shall be submitted to the Owner and approved before the start of the refractory anchoring system installation.
- c. The refractory lining applicator shall prepare a detailed, written, procedure covering the entire lining process including materials, storage, qualification, installation, curing, heat drying, inspection and testing. The applicator shall prepare a list of deviations from this UOP Standard Specification and the UOP Project Specifications and Drawings. The procedure and deviation list shall be submitted to the Owner and approved before to the start of refractory installation.
- d. A pre-installation meeting between the owner, contractor, anchor and refractory installers, and heat drying contractor is recommended. The primary purpose is to ensure that the specification and job requirements are clear and understood by all parties. Additionally, any requested deviations may be discussed and resolved. Matters of responsibility and timing, as well as inspection issues, including hold points and notification requirements, may also be resolved.

2.4 Definitions

Terms related to refractory materials, installation, testing, inspection, etc. are defined in API Standard 936 and ASTM C71.

2.5 Extent of Refractory Lining

- a. Areas in which refractory lining is to be installed and the type, thickness, and extent of the lining in each area, are identified in the UOP Project Specifications and UOP Project Drawings.
- b. Refractory lining is not required in non-flowing (e.g., dead end) nozzles 6 inch NPS and smaller.
- c. Ceramic fiber shall be installed into nozzles, onto the shell, or in other locations only where specified in the UOP Project Specifications or UOP Project Drawings. Fiber packing in the annular space of nozzles shall extend to a point flush with the inside surface of the shell and then shall be covered with a metallic disc (see the UOP Project Specifications and Drawings) and the shell refractory.

3. ANCHORS, EDGING BARS, COLLARS, AND WELDING
3.1 Materials

- a. Anchors shall be 5/16 inch (8 mm) diameter, ASTM A479 Type 304, austenitic stainless steel rods, bent into the configuration illustrated on Figure 1. The anchors shall be solution annealed after forming.


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- b. Provide rubber or plastic caps 1/2 inch (13 mm) long and 30-50 mil (0.75 to 1.25mm) thick on the tip of each anchor leg. The caps shall be of a contrasting color for easy visual identification. The caps shall be shipped loose. Install the caps after anchor welding and postweld heat treatment, and immediately prior to the refractory installation.
- c. Collars and edging bars shall be 1/4 inch (6 mm) thick, fabricated from the same material as the shell to which they are welded. Collars and edging bars shall be a minimum of ASTM A516 Grade 55.
- d. Welding electrodes for anchor attachment to carbon, low alloy, or ferritic stainless steel shall be AWS A-5.4 / ASME SFA-5.4/SFA-5.4M, Class E-309-15, 16 or E-310-15, 16 or AWS A-5.9 / ASME SFA-5.9/SFA-5.9M Class ER 309 or ER 310. The welding electrode may also be AWS A-5.11 / ASME SFA-5.11/SFA-5.11M, Class ENiCrFe-2 or Class ENiCrFe-3.
- e. Anchors shall not be stud welded.

3.2 Installation of Anchors, Bars, and Collars

- a. Immediately prior to anchor installation, prepare the interior plate surface by grit blast cleaning to remove rust, loose mill scale, oil, dirt, or other foreign materials. The grit shall be compatible with the base metal (e.g. steel grit shall not be used on stainless steel base metal) and shall not damage or leave residue on the base metal. The grit and the blasting air supply shall be dry and clean. Testing of the air stream discharged from the hose shall be in accordance with ASTM D4285. Cleaning shall be brush-off blast clean in accordance with SSPC-SP-7.
- b. After grit blast cleaning, the surfaces to be lined shall be vacuum cleaned to remove all debris. Do NOT wash with water. Inspect the surfaces for cleanliness and repeat the above blast cleaning as necessary.
- c. Wax crayons, grease markers or other substances that will interfere with the quality of the attachment weld shall not be used to locate anchor, bar, and collar positions.
- d. Anchors, bars, and collars shall be welded to the shell as illustrated in Figures 1 through 5, 7, and 8. Welding shall be done after any radiographing or other nondestructive examination requirements are completed, but before postweld heat treatment. Do not weld to shell weld seams. When a row of anchors is to be placed at a shell weld seam, the anchors shall straddle the seam (i.e., anchors are placed on alternating sides of the seam). Grind all weld and weld slag that will interfere with placement of anchors, bars, and collars.
- e. Welding to equipment covered by a design or fabrication Code shall be performed by Code qualified welders.


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- f. Installed anchors, bars, and collars shall be inspected by the Owner or Owner's authorized representative. Each anchor shall be hammer tested by striking from several directions with an 8 to 16 ounce (225-455 gram) hammer. Loose or broken anchors or cracked welds shall be removed and replaced. Hammer test the replaced anchors.
- g. After installation of the anchors, after all post weld heat treatments, and just before refractory installation, place the anchor caps onto the end of each anchor leg.

4. LINING MATERIALS
4.1 Refractory

- a. Refractory materials shall be of a grade suitable for vibracast installation.
- b. Selection of the refractory product(s) to be installed shall be based upon positive experience with the product in the same or similar service to the anticipated service. Recommended suppliers and products are listed in Paragraphs 4.11.(2), 4.1m.(2), and 4.1n.(2).
- c. The category of refractory required (insulating, mid-weight, or insulating low iron) is specified in the UOP Project Specifications.
- d. Refractory shall be new. Reclaimed, recycled, reconditioned, rejected, or material beyond its shelf life shall not be used or blended into the new material at production or at installation.
- e. The as supplied refractory materials shall NOT include metal reinforcing fibers. Organic fibers, as recommended by the refractory manufacturer, are acceptable.
- f. Refractory material shall be provided in polyethylene lined bags, shipped on plastic shrink-wrapped pallets. Each pallet shall contain material from only one manufactured batch (i.e., lot or production/blending run). The polyethylene shrink-wrapping shall cover all sides of the shipment, including the underside, not including the pallet. The shrink-wrap shall not be removed until the refractory is to be used. If a bag is removed for testing, the shrink wrap shall be resealed immediately.
- g. Pallets shall be identified by order number and shall be numbered consecutively, beginning with one. The total number of pallets in the lot shall be included, i.e. 2 of 10. Material identification signs shall be prominently displayed on all sides of each pallet.
- h. Each bag and/or pallet of material shall include, as a minimum, the following information: manufacturers name; plant of manufacture; product brand name; batch identification; date of manufacture; an accurate bag weight (± 2 weight percent); mixing instructions (included hydrating water requirements); special cautions and/or requirements. If organic fibers are included, their presence shall be clearly indicated on each bag.


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- i. Refractory material shall be kept at a temperature between 50°F (10°C) and 80°F (27°C) for 24 hours prior to use. At all times the material shall be stored on an elevated ventilated platform, protected by a weatherproof covering above and on all sides, and so arranged that no water can come into contact with any of the material or bags. The platform shall be supported by a concrete slab or dry, durable surface, sloped to drain moisture away from the storage area. Care shall also be taken to avoid high humidity under the covering.
- j. Previously opened bags of refractory, materials that are older than the lesser of nine months or the manufacturer's shelf life from their date of manufacture, materials exhibiting agglomeration or lumps that are not easily broken by hand, and material that has gotten wet or is otherwise damaged shall not be used.
- k. The properties listed in Paragraphs 4.11.(3), 4.1m.(3) and 4.1n.(3) are the range of values from the product catalog data sheets for the recommended products. These values are often averages, rather than minimums. Guaranteed (or compliance) values shall be agreed upon with the chosen refractory vendor. The guaranteed values shall be the reference(s) used for all testing and material evaluations (see Section 8.1). Testing shall be in accordance with the listed specification(s).
- l. Lightweight Insulating Refractory
 - (1) These materials are used when excellent insulating ability is required but abrasion resistance and low iron content are not necessary.
 - (2) The following vibracast grade refractory products are recommended:

Manufacturer

Harbison-Walker Refractories
 AGC Plibrico Co., Ltd.
 Resco Products, Inc.
 Stellar Materials

Product Name

GREENLITE-45-L PLUS
 THERVEK C-LC3-22A
 RESCOCAST 9
 HEATBRAKE 508-B

Contact Information

www.anhrefractories.com
www.plibrico.co.jp
www.rescoproducts.com
www.thermbond.com

- (3) Following is the range of product catalog data sheet values for the recommended materials. The properties are based upon samples prepared by vibracasting and without metal reinforcing fibers. The listed ranges are for informational purposes and are not to be used for quality control or decision making regarding individual products.
 - (a) Setting time does not exceed 24 hours.
 - (b) Service temperature is at least 2400 °F (1315 °C).
 - (c) Density after heating to 1500°F (815°C) and cooling to ambient temperature is between 70 lb/ft³ (1120 kg/m³) and 90 lb/ft³ (1440 kg/m³) per ASTM C134.
 - (d) Cold crushing strength after heating to 1500°F (815°C) and cooling to ambient temperature is at least 600 psi (42 kg/cm²) per ASTM C133.


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- (e) Modulus of rupture after heating to 1500°F (815°C) and cooling to ambient temperature is at least 200 psi (14 kg/cm²) per ASTM C133.
- (f) Permanent linear change after heating to 1500°F (815°C) and cooling to ambient temperature is between 0.00 and -0.30% per ASTM C113.
- (g) Apparent porosity after heating to 1500°F (815°C) and cooling to ambient temperature is between 30 and 50 percent per ASTM C20.
- (h) Thermal conductivity at a mean temperature of 1000°F (540°C) is between 2.3 Btu-in/ft²-h-°F (0.35 W/m°C) and 3.0 Btu-in/ft²-h-°F (0.45 W/m°C) per ASTM C 201.
- (i) Iron oxides are less than 3.5 weight percent.
- (j) Aluminum oxides are greater than 33 weight percent.

m. Mid-weight Insulating and Abrasion Resistant Refractory

- (1) These materials are used when a material with good insulating and good abrasion resistant properties is required but low iron content is not a primary concern.
- (2) The following vibracast grade refractory products are recommended:

Manufacturer

Harbison-Walker Refractories
Morgan Thermal Ceramics
AGC Plibrico Co. Ltd.
Resco Products, Inc.
RHI Refractories

Product Name

GREENKLEEN 60 PLUS
KAO-TUFF CV
THERVEK V-3-24
RESCOCAST 17 EC
LEGRIT 135-1, 9COR,
including "Add-to-Cast"
FORMULA 6-AL
AR 153 VC

Contact Information

www.anhrefractories.com
www.morganthermalceramics.com
www.plibrico.co.jp
www.rescoproducts.com
www.RHI-ag.com
www.thermbond.com
www.vesuvius.com



- (3) Following is the range of product catalog data sheet values for the recommended materials. The properties are based upon samples prepared by vibracasting and without metal reinforcing fibers. The listed ranges are for informational purposes and are not to be used for quality control or decision making regarding individual products.
 - (a) Setting time does not exceed 24 hours.
 - (b) Service temperature is at least 2400 °F (1315 °C).
 - (c) Density after heating to 1500°F (815°C) and cooling to ambient temperature is between 100 lb/ft³ (1600 kg/m³) and 145 lb/ft³ (2320 kg/m³) per ASTM C134.


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- (d) Cold crushing strength after heating to 1500°F (815°C) and cooling to ambient temperature is at least 6000 psi (420 kg/cm²) per ASTM C133.
- (e) Modulus of rupture after heating to 1500°F (815°C) and cooling to ambient temperature is at least 900 psi (64 kg/cm²) per ASTM C133.
- (f) Permanent linear change after heating to 1500°F (815°C) and cooling to ambient temperature is between 0.00 and -0.30% per ASTM C113.
- (g) Apparent porosity after heating to 1500°F (815°C) and cooling to ambient temperature is between 20 and 40 percent per ASTM C20.
- (h) Thermal conductivity at a mean temperature of 1000°F (540°C) is between 5.3 Btu-in/ft²-h-°F (0.75 W/m°C) and 10.0 Btu-in/ft²-h-°F (1.45 W/m°C) per ASTM C201.
- (i) Erosion loss is less than 12cc per ASTM C704.
- (j) Iron oxides are less than 1.0 weight percent.
- (k) Aluminum oxides are greater than 35 weight percent.

n. Low Iron Insulating Refractory

- (1) These materials are used when an insulating material with a low iron content (below 1.0 weight percent) is required and abrasion resistance is not necessary.
- (2) The following vibracast grade refractory products are recommended:

<u>Manufacturer</u>	<u>Product Name</u>	<u>Contact Information</u>
Harbison-Walker Refractories	CAST-O-LITE 30 LI PLUS	www.anhrefractories.com
AGC Plibrico Co. Ltd.	THERVEK C-LC3-23	www.plibrico.co.jp
Resco Products, Inc.	RESCOCAST 4 LI	www.rescoproducts.com
Stellar Materials	HEATBRAKE 508-B	www.thermbond.com

- (3) Following is the range of product catalog data sheet values for the recommended materials. The properties are based upon samples prepared by vibracasting and without metal reinforcing fibers. The listed ranges are for informational purposes and are not to be used for quality control or decision making regarding individual products.
 - (a) Setting time does not exceed 24 hours.
 - (b) Service temperature is at least 2500°F (1370C).
 - (c) Density after heating to 1500°F (815°C) and cooling to ambient temperature is between 65 lb/ft³ (1040 kg/m³) and 100 lb/ft³ (1600 kg/m³) per ASTM C134.


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- (d) Cold crushing strength after heating to 1500°F (815°C) and cooling to ambient temperature is at least 500 psi (35 kg/cm²) per ASTM C133.
- (e) Modulus of rupture after heating to 1500°F (815°C) and cooling to ambient temperature is at least 200 psi (14 kg/cm²) per ASTM C133.
- (f) Permanent linear change after heating to 1500°F (815°C) and cooling to ambient temperature is between 0.00 and -0.30% per ASTM C113.
- (g) Apparent porosity after heating to 1500°F (815°C) and cooling to ambient temperature is between 30 and 50 percent per ASTM C20.
- (h) Thermal conductivity at a mean temperature of 1000°F (540°C) is between 2.5 Btu-in/ft²-h-°F (0.37 W/m°C) and 4.0 Btu-in/ft²-h-°F (0.58 W/m°C) per ASTM C201.
- (i) Iron oxides are less than 1.0 weight percent.
- (j) Aluminum oxides are greater than 45 weight percent.

4.2 Water

Mixing water shall be potable (suitable for drinking) with a pH between 6 and 8. Water from the firefighting system shall not be used. Water shall contain less than 50 ppm chlorides, and be free from deleterious impurities. Equipment used for storing and handling of the water shall be clean, so that no contaminating material is introduced. Water temperature shall be between 40°F (5°C) and 80°F (27°C) {see paragraphs 5.4a.(2), 5.4a.(3) and 5.4b.(8)}.

4.3 Metal Reinforcing Fibers

Reinforcing fibers shall comply with ASTM A820. Fibers shall be 20 mil (0.5mm) Type 304 austenitic stainless steel, with a length of 1 inch (25 mm). The material tensile strength shall comply with the requirements of the specified metallurgy. Fibers shall be of a uniform size and shape and shall not clump together. Fibers that become magnetic shall not be used. Fibers manufactured by the melt extract process (ASTM A820 Type III) are preferred, alternatively, corrugated fibers may be manufactured from slit sheets (ASTM A820 Type II). Corrugated fibers shall be twisted about their longitudinal axis. The corrugations shall be a smooth and gentle curvature, without any sharp bends. The corrugation range shall not exceed 1/16 inch (1.5 mm).

5. REFRACTORY INSTALLATION

5.1 Equipment and Tools

- a. Equipment and tools used for refractory mixing, handling, and installation shall be clean and in good operating condition.


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- b. Backup or spare equipment and tools shall be provided at the jobsite for all items that would halt refractory placement in the event of their failure.
- c. The capacity and number of pieces of equipment and tools in use during refractory installation shall be sufficient to ensure that application will proceed uninterrupted.

5.2 Preparation

- a. Refractory installation shall not begin until after completion of welding, postweld heat treatment, and pressure testing. If the refractory installation must take place prior to pressure testing, all pressure retaining weld seams shall be left unlined, i.e., exposed to the testing medium, and the testing medium shall not damage or degrade the refractory.
- b. The mixing area and the installation site shall be kept clean, dry, and isolated from the surrounding area by use of heavy plastic or other means. The protective means shall prevent the entry of dust, rain or other deleterious material and shall protect against excessive wind, heat, and exposure to the sun (i.e., shaded).
- c. The area to be lined shall be well lit and ventilated to provide good visibility and a cool breathable atmosphere during refractory installation.
- d. Provide a reliable means of communication between the mixing and installation sites that is effective while both sites are in operation. Test the system under actual conditions and locations.
- e. The surface to which the refractory lining is to be installed shall be dry and clean. Grit blast cleaning immediately prior to installation of the refractory is required if:
 - (1) Anchors have been installed over 30 days
 - (2) Rust, weld slag or spatter, oil or grease, dirt, loose scale, debris, or other foreign materials are present on the surface to be lined
 - (3) The surface does not comply with the requirements of SSPC SP-7.
 - (4) Hydrotest was performed after the grit blast cleaning for anchor installation.
- f. When grit blast cleaning is required, remove the anchor caps prior to grit blast cleaning. Per paragraph 5.2l, the removed caps shall be discarded; new caps will be reinstalled. The grit shall be compatible with the base metal (e.g. steel grit shall not be used on stainless steel base metal) and shall not damage or leave residue on the base metal. The grit blasting air supply shall be clean and dry. Testing for contamination of the air stream discharged from the hose shall be in accordance with ASTM D4285. Grit blast cleaning shall be brush-off blast clean in accordance with SSPC-SP-7.
- g. After grit blast cleaning, the surfaces to be lined shall be vacuum cleaned to remove all debris. Do NOT wash with water. Inspect the surfaces for cleanliness and repeat the above grit blast cleaning as necessary.


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- h. Structural members, nozzle extensions, and other items within the limits of the lining shall be wrapped with 1/8 inch (3 mm) thickness of non-absorbent paper (not cardboard) or coated with bitumen to prevent moisture absorption from or bonding to the refractory lining. Paper shall be taped into place. Additional paper or bitumen may be required for large nozzles, elevated temperatures, or other conditions in order to accommodate radial thermal growth or movement of the item.
- i. Openings shall be closed by means of sealed wood or metal jacketed plugs, slightly tapered (smaller towards the shell), and of such dimensions that they fit snugly into the openings. The surfaces of the plug(s) shall be lightly coated with a release agent approved by the refractory manufacturer to prevent binding. The plugs shall not be removed from the openings or disturbed until the refractory lining has developed its final set.
- j. Obstructions that will interfere with the satisfactory and continuous application of the refractory lining (e.g., ladders, scaffolding, etc.) shall be avoided.
- k. Nozzle necks and other areas that cannot be vibracast with the shell shall be cast or hand packed prior to beginning installation of the shell lining. Cast or hand packed nozzle lining shall extend to one inch (25 millimeters) from the inside shell surface. The full thickness nozzle lining shall be trimmed perpendicular to the nozzle inside diameter. The remaining refractory is installed with the shell lining.
- l. Immediately prior to refractory placement, place anchor caps onto the ends of any anchor legs not already covered by a cap. Caps that are loose or are removed for any reason shall be replaced with new caps prior to refractory placement.”
- m. When welded joints or seams in the backing material will be completed after the refractory has been installed, the refractory shall be installed as shown in Figure 7. After welding, examination, and heat treatment have been completed, the remaining lining shall be installed. This interruption of application shall follow the procedures described in Paragraph 5.4e. When the seam is located in an inaccessible location of a small (less than or equal to 24 inch ID of lining) item, and neither heat treatment or radiography is performed, the detail shown in Figure 8 may be used.

5.3 Forms

- a. The free surface of the refractory shall be defined by watertight, carbon steel, forms.
- b. The formwork shall be solid and stable with bracing as required. It shall not deform, shift, or deflect under the load (weight), buoyancy, and head of fluid refractory at any time during the refractory installation process. The formwork shall withstand an unbalanced refractory head of at least three feet (one meter). The forms shall be designed to withstand vibration of the refractory including the possible attachment of vibrators to the formwork.
- c. The formwork shall be designed for easy, rapid disassembly after the refractory has hydrated and cured. Disassembly shall not damage the refractory, e.g., cutting with heat (arc gouging) or water jets is not acceptable. Bolted forms are preferred.


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- d. Form components shall fit tightly together and shall align with one another to avoid creation of steps or ledges in the lining. Joints in the forms shall be sealed to prevent leakage of refractory and water.
- e. Forms shall be coated with a parting agent approved by the refractory vendor to prevent adherence between the refractory and the form.
- f. When the forms are in place the area into which refractory will be cast shall be clear and unobstructed.
- g. The forms shall be provided with casting (pouring) ports or openings as described in paragraph 5.4c.(10). Provide a means of closing and sealing the opening when the refractory level approaches the opening. The closure means shall be adequate for any applied loads and head of refractory.
- h. All forms shall be in place prior to the start of casting to eliminate unnecessary interruptions in the placement of refractory. Interruptions contribute to the formation of cold joints.
- i. The forms shall be installed concentrically within the lined item or as otherwise specified by the project documents to result in the required lining thickness and configuration.
- j. The formwork shall result in an inner lining surface within $\pm 1/4$ inch (6 mm) of the specified dimensions. The lining thickness shall be within $\pm 1/2$ inch (13 mm) of the specified value.
- k. Joints between adjacent forms shall not be located at nozzles or critical areas.

5.4 Application

- a. Precautions
 - (1) When mixing and handling refractory, personnel shall wear appropriate personnel protective equipment (PPE), shall comply with all appropriate safety measures as defined by the refractory manufacturer's Material Safety Data Sheet (MSDS) for the subject material, and shall comply with other measures required at the site and by the applicable licensing and governing bodies.
 - (2) During cold weather, the refractory lining and the surface to which it is applied shall be continuously kept at a temperature above 50°F (10°C) during application, curing, and before heat drying. If required, suitable means for heating and/or exterior insulation shall be provided; however, live steam shall not be used for this purpose.


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- (3) During hot weather, the refractory lining and the surface to which it is applied shall not exceed a temperature of 95°F (35°C) during application. If required, the exterior surface of the vessel shall be cooled by shading, spraying with cold water, air conditioning, or other means before and while the refractory lining is being applied. Installation at night, when it's cooler and there is no radiant heat from the sun, may be considered. After refractory application, cooling of shell is no longer required.
- (4) The interior shell temperature shall be registered by temperature recorders with a minimum of 3 thermocouples around the shell for each recorder. The thermocouples shall be calibrated in accordance with ASTM E 220. The number of recorders and thermocouples and their location shall be approved by the Owner or the Owner's authorized representative. The shell temperature where refractory is being applied shall be monitored. Certified copies of the shell temperature control log shall be provided to the Owner or the Owner's authorized representative.

b. Mixing and Quality Control

- (1) Mixing shall be performed in a horizontal, paddle type mixer. Concrete mixers shall not be used.
- (2) The mixer shall be stabilized, grounded and fixed into place on level ground or a solid platform near the installation site. Provide large, clear, access areas at the mixer. Cover the mixer with a coarse metal grid, or other system, to prevent entry of bags, tools, or other foreign objects.
- (3) Mix only as much refractory as will be placed within 20 minutes or the working time of the refractory, whichever is less.
- (4) The full contents of each bag of premixed refractory material shall be used. Do not use bags that have been wet or that have been previously opened.
- (5) No cement, lime, or other admixtures of any kind shall be added to the premixed refractory materials as received from the manufacturer. The only permitted addition is metal reinforcing fibers.
- (6) Refractory lining materials from one manufacturer shall not be mixed with those from other manufacturers.
- (7) Metal reinforcing fibers shall be screened into the dry refractory lining material in the mixer at the job site. Fibers shall be added at a rate of 3% by weight (i.e., weight of fibers divided by weight of refractory) for each batch of refractory material.
- (8) The mix temperature shall be maintained between 60°F (15°C) and 80°F (27°C).
- (9) Prior to mixing the first batch of the day, or after a lengthy pause, moisten all interior surfaces of the mixer, including the blades.


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- (10) Weigh 10 bags randomly selected from throughout the pallet of refractory (e.g., not all from the top). If each bag is within ± 2 percent of the weight marked on the bag, the water to be added to the mixer for bags from that pallet may be based upon the average weight of the sampled bags. If any bags are outside of ± 2 percent of the weight marked, each bag from that pallet must be weighed before it is discharged into the mixer. The mixer water addition is then based upon the actual weight of the refractory in the mixer. Each pallet of material shall be evaluated separately.
- (11) The refractory material shall be thoroughly dry mixed with the reinforcing fibers. The refractory shall be introduced into the mixer first and dry mixing begun. The reinforcing fibers shall be introduced into the refractory materials in the operating mixer as a rain of individual fibers through a shaken or vibrating screen to prevent clumping of the fibers.
- (12) The amount of water required for proper hydration, the mixing procedure and time, and the mix consistency shall be in accordance with manufacturer's recommendation and the results of the prequalification testing (see Section 8.4).
- (a) Ninety to ninety-five percent of this water is initially added to the mixer and blended. If necessary, additional water is then added and blended until a mix of the proper consistency is obtained.
 - (b) Do not add excess water. The mix should have a slightly moist sheen and should be stiff, i.e., retaining its shape when placed on a flat surface. ASTM C860, the "ball in hand" method is one way to evaluate the mix consistency.
 - (c) The final water addition shall be within the water range provided by the refractory manufacturer.
 - (d) The water shall be added to the refractory/fiber mixture as a rain while the refractory dry mixes.
- (13) The mixer shall be discharged into a clean dry metal, plastic, or sealed/lined wooden container. Material that misses the container, is discharged onto the ground, etc. shall not be used. Discharged refractory shall not be placed back into the mixer or remixed.
- (14) The refractory shall be transported to the installation site in clean, dry, metal or plastic buckets, trays, or other similar impervious container. The means of transportation shall prevent the separation of the refractory components or the entry of foreign material.


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(15) All equipment (mixer, discharge and transport containers, etc.) shall be thoroughly washed and dried before use, at the end of each workday, and at the end of the refractory installation. The mixer and paddles shall be thoroughly cleaned after each batch (i.e., mixer charge) to prevent build-up of refractory lining materials. The discharge and transport containers and all tools used in mixing and applying the refractory lining shall be cleaned after each batch and kept free of all deleterious materials.

(16) The supply of refractory to the installation site shall be continuous, uninterrupted, and provided to the site at approximately the rate of refractory placement throughout the refractory installation.

(17) For each batch of refractory mix, the total weight of water, refractory, and reinforcing fibers added to the mixer, and the resulting weight percent of water, shall be reported and recorded. The refractory manufacturer and product name, type of reinforcing fibers, installation location, atmospheric conditions, mixing temperatures, installation procedures, and job site conditions shall also be recorded. Provide the Owner or the Owner's authorized representative with certified copies of the quality control log.

c. Placement

(1) Application shall be made by vibracasting. The size and style of the equipment, and the installation procedure, shall be as required for the specific refractory lining application.

(2) Refractory shall be placed at its final location. Movement of the refractory within the forms shall be minimized.

(3) Application by hand packing of the refractory is permitted only in limited areas where contouring is required or where space limitations do not permit formwork and vibracasting. Approval by the Owner is required before hand packing is used. The refractory shall be suitable for hand-packing and shall be installed in accordance with the manufacturer's instructions. The refractory shall be placed in a manner that ensures complete filling of the area to be lined, e.g., "knifing" or puddling. Prior to installation, a mock-up shall be prepared to demonstrate that the hand packed material is properly consolidated and flaw free. Samples shall be taken for property testing in accordance with Paragraphs 8.3b. and 8.3c. Troweling of the surface is not permitted.

(4) Only qualified personnel thoroughly familiar and experienced with vibracast installation of refractory lining shall be employed for this work.

(5) The shell, form, and anchors shall be inspected to confirm that they are clean and that all anchor caps are in place before the lining is installed. Refractory that adhered to the shell, form, or anchors during earlier refractory installation shall be removed before refractory is installed. Replace any missing caps. The lining installation procedure shall not dislodge any of the anchor caps.


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- (6) Do not use refractory that has begun to setup or that is more than 20 minutes or the manufacturers' recommended working time old (whichever is less).
- (7) The lining installation procedure, including vibration, shall not dislodge any anchor tip caps. If any caps come loose, they shall be removed from the refractory mix and a new cap placed on the anchor tip.
- (8) Refractory installation shall be downhand.
- (9) During refractory installation the item to be lined shall be placed in a position that provides good access for refractory placement, permits downhand refractory installation, eliminates all enclosed or unvented areas, and permits the escape of air during refractory vibration. If necessary, venting or installation (casting) nozzles in the forms or shell may be considered to allow complete filling and a high quality refractory installation. Venting or installation (casting) nozzles in the shell shall be filled with refractory and blanked-off. Venting or installation (casting) nozzles in the forms shall be filled with refractory to a point beyond the lining surface. After removal of the forms, the excess refractory shall be trimmed flush with the lining surface.
- (10) The refractory shall not fall more than 6 feet (1800 mm) between the shell and the form. When a drop of more than 6 feet (1800 mm) is required, installation shall utilize a chute and observation/casting ports in accordance with Figure 9.
 - a. At least two casting ports shall be provided at each elevation. The casting ports shall be no more than 180° or 6 feet (1800 mm) apart in circumference nor separated by more than 6 feet in elevation. Casting ports at each elevation shall be located midway between the ports at the previous elevation.
 - b. When the refractory level approaches an observation/casting port, the port shall be closed and sealed. Installation of the closure means shall not delay or interfere with the continuous refractory installation. Refractory shall continue from the next highest installation opening.
 - c. Where possible, the means of closure shall result in a refractory surface flush with the surrounding refractory. Otherwise, the excess refractory shall be removed after the forms are removed.
 - d. The installation chute or hose length shall be vertical and as short and straight as possible. Bends shall not interfere with the smooth, continuous flow of refractory. The hose or chute shall completely discharge under the influence of gravity.
- (11) Refractory installation shall be continuous and uninterrupted to avoid the creation of joints within the refractory. Refractory shall be installed around the circumference or perimeter in a manner to raise the refractory level behind the forms at an approximately even rate; i.e., the refractory head shall not be significantly greater on any portion of the formwork than on any other portion.


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- (12) Lined items shall remain in the same position throughout lining installation and curing unless this results in an area of inferior refractory placement. In that case the refractory may be installed in two (or more) placements with the lined item orientation optimized for each placement. The joint(s) between placements shall be located in sheltered areas and shall comply with the requirements of Section 5.4.e. Reorientation shall not detrimentally affect the previously placed refractory.
- (13) The full refractory thickness shall be placed at each location in a single application. The direction of placement shall be perpendicular to the thickness, i.e., parallel to the surface being lined.
- (14) If the forms shift or deflect resulting in an out-of-tolerance lining, or a ledge in the refractory (e.g., where form sections join) the affected refractory shall be completely removed and replaced in accordance with Section 9.
- (15) Refractory shall not be placed in longitudinal strips, or in any manner that results in continuous joints in the direction of process fluid flow.

d. **Vibration**

- (1) Refractory shall be consolidated (eliminating voids and removing air) by vibration applied through the base material. When necessary, vibration may be applied through the forms. The forms shall not be damaged, moved, or distorted by the vibration, nor shall any of the seams leak.
- (2) The means and duration of vibration shall be based upon the methods and procedures demonstrated during the crew prequalification (see paragraph 8.4c). This is particularly critical for lightweight refractories, which are especially susceptible to separation or other damage if incorrectly vibrated.
- (3) Vibration shall not be used to move the refractory. Refractory shall be deposited at its intended, final position.
- (4) Inserted vibrators shall not be used.
- (5) Vibrators shall be attached to the lined item by circumferential straps, chains or a similar means. The straps shall be tightened to transmit the vibration around the circumference. Do not attach the vibrator to welded lugs or attachments.
- (6) The vibrators shall input a force greater than the weight being vibrated, including the refractory, form, and shell. Vibrators shall be located so that all portions of the refractory receive sufficient vibration energy for effective consolidation. Each vibrator shall be independently controlled.
- (7) Provide vibrators at multiple elevations as required. Locate the vibrator(s) at each level midway between those of the previous level.


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- (8) Vibration shall begin before placement of refractory and, at each point, continue until the refractory has been placed, has fully consolidated, and air bubbles are no longer being released. The surface may begin to develop a slight sheen due to water. Do not over vibrate. Lightweight refractories are especially susceptible to over-vibration.

e. Interruption of Application

- (1) When application is interrupted before completion of the lining, sections of the forms that are not completely filled shall be removed and the refractory lining shall immediately be cut back to the shell between anchors with a steel trowel. The cutback shall be made at a right angle to the shell and at a location where the full refractory thickness has already been applied. Material beyond the cut and material left in the chute, hose, and mixer over 20 minutes shall be discarded.
- (2) Anchors and plate surfaces shall be completely cleaned of all refractory lining materials. Replace any dislodged anchor caps.
- (3) During the period of interruption in application, curing of the refractory lining already applied shall be in accordance with Section 6.1.
- (4) Immediately prior to resuming refractory application, the exposed surface of the refractory lining to which a bond must be made shall be cleaned of all loose refractory material and debris, roughened, and thoroughly wetted with lining mixing water.
- (5) The lining shall not be permitted to stand before heat drying when the ambient temperature is expected to fall below 50°F (10°C), unless provisions are taken to keep the lining above 50°F (10°C).
- (6) When installation is halted for the day, all exposed surfaces of the refractory shall be covered, and/or sealed. All openings in the item being lined shall be covered, closed, and/or sealed.

6. CURING AND HEAT DRYING

6.1 Curing

- a. The curing period shall begin immediately after installation of each section of lining and shall last until a minimum of 24 hours after curing of the last segment of the lining has begun. Refractory shall be cured for at least 24 hours.
 - (1) The lined item shall not be moved until at least 24 hours after the completion of the refractory lining installation.
 - (2) During the curing period, the temperature of the vessel shell and refractory lining shall be kept above 50°F (10°C).
 - (3) Forms shall remain in place throughout the curing period.


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- b. During the curing period, exposed refractory lining shall be protected from moisture loss by a spray applied owner and refractory manufacturer approved membrane curing compound. Refractory surfaces covered by forms do not require additional measures (e.g., curing compound) to prevent moisture loss. The curing compound shall be a non-flammable, non-reactive, non-toxic, membrane forming solution of resin and hydrocarbon base in conformance with ASTM C309, with a low permeability, compatibility with aluminous cements, ease of application, short drying time, and long storage life. It shall contain a factory added contrasting color to allow identification of the areas to which the compound has been applied and shall burn off of the surface to which it was applied at a temperature between 150°F (65°C) and 200°F (95°C).
- c. Spray application of the membrane curing compound shall begin immediately after application of the lining, as soon as the surface is dry to the touch. A one coat application of membrane curing compound of sufficient thickness to completely cover the exposed surfaces of the lining shall be used. The membrane curing compound shall be allowed to dry tack free before lining is installed in an adjoining area. Adequate ventilation shall be provided during the membrane curing compound application and curing period.
- d. After curing and removal of the forms, the refractory lining shall be tested by striking with the ball of a 16 ounce (455 gram) ball peen hammer at about one foot (300 mm) intervals over the entire surface. Any voids or dry filled spaces will emit a dull sound; the full lining depth in these areas shall be removed and replaced.
- e. Refractory shall not be exposed to steam until heat drying has been completed.

6.2 Heat Drying

- a. All refractory lining shall be heat dried after removal of the forms and prior to being placed into service. If the lining is to be subjected to hydrostatic testing, it shall be cured and fully heat dried before and fully heat dried again after testing.
- b. Heat drying shall be performed by personnel experienced in, and with the equipment required for, heat drying of refractory lined equipment.
- c. The heat drying contractor shall prepare a detailed plan for review and approval prior to the start of heat drying (see paragraph 2.3b.). The plan shall include the heating and cooling rates, hold points and durations, heat source(s) and location(s), the means of monitoring refractory and shell temperatures, and the means of ensuring all of the refractory is exposed to the dryout medium and adequately dried.
- d. Heat drying of the refractory shall begin as soon after completion of the refractory installation, the 24 hour curing period, and the removal of forms as is practical. Items that were lined in the shop shall be heat dried in the shop. Between the end of curing and the performance of heat drying, the refractory shall be kept above 50°F (10°C) and shall not be exposed to moisture (e.g., rain, snow, steam, etc.) or contaminants. If heat drying does not occur within 30 days of completion of the refractory curing period, the equipment shall be sealed and kept above 50°F (10°C) until heat drying is performed.


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- e. Lining shall be completely heat dried and inspected prior to (and independent of) startup of the equipment, vessels, piping, and duct work.
- f. Sections that do not have the full required thickness of insulating refractory lining or are otherwise not adequate for the maximum heat drying temperature (e.g., inadequate metallurgy or thickness, or cannot accommodate the thermal expansion) shall be sealed or otherwise protected from the drying temperatures. Temperature of these areas, and of the metal beneath the refractory lining, shall be monitored to ensure that they do not exceed their allowable temperature values. Heat drying of refractory in these areas shall be performed separately.
- g. Provide the heat necessary for dryout by use of gas fired heaters only. The gas supply shall be clean, reliable, and adequate to reach and maintain the required temperatures.
- h. Heat shall be applied to the exposed surface of the refractory lining only. Heaters shall not be located inside of equipment being dried nor shall the lining be exposed to radiant heat or flame impingement. Heat drying shall not be performed in a furnace or as a part of postweld heat treatment. Do not insulate the outer metal surface.
- i. Multiple heaters may be used to maintain the required temperatures over the entire lining surface. If multiple heaters are used, their operation shall be coordinated so that all hold periods and temperature changes occur at the same time and rate.
- j. The flow of heated air shall be controlled so that the entire surface of the refractory is subjected to the movement of air and the full heat drying cycle. Dead or low flow areas are not permitted. Back pressure, throttling of the air flow, or other means may be necessary. During heat drying the lined equipment shall be oriented to allow even heating of the refractory (i.e., a more uniform temperature profile) and permit the escape of moisture (steam)(i.e., eliminate trapped or enclosed areas). Vertical positioning of the item to be dried is generally preferred. During the drying period, adequate ventilation shall be provided for the escape of moisture. Special consideration shall be given to areas that are difficult to dry or vent, such as refractory lined nozzles with an interior metallic liner.
- k. Interior temperatures during heat drying shall be monitored and controlled with thermocouples placed a maximum of 1/2 inch (13mm) from the lining surface.
 - (1) The thermocouples shall be arranged to measure the air, not the refractory, temperature.
 - (2) Calibrate the thermocouples in accordance with ASTM E 220.
 - (3) Thermocouples shall be placed in circumferential rings around the refractory surface, with at least 4 thermocouples equally spaced in each ring. In small diameter items, the number of thermocouples may be reduced to maintain a minimum of approximately 5 feet (1500 mm) between thermocouples in a ring. Rings shall be placed to fully monitor the heating profile of the refractory surface, including the bottom, top, and midpoint of cylindrical sections, to ensure that all of the refractory is properly heated and dried. Stagger the thermocouples in adjacent rings so they are not above or below each other.


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- (4) Thermocouples shall also be placed near the hot air inlets, the exhaust air vents, and in the rear of any enclosed areas.
- (5) Include thermowells where the refractory surface temperature is expected to be the greatest and least.
- (6) The thermocouple's output shall be continuously monitored throughout heat drying, and all of the thermocouples shall be connected to recorders to provide a record of the heat dry.
- (7) The final arrangement of thermocouples and recorders shall be approved by the Owner or their authorized representative before the start of heat drying.
- l. Heating rates shall be controlled by the refractory thermocouple exposed to the greatest temperature and rate of temperature change, typically the thermocouple nearest the heat source.
- m. Hold temperatures and durations shall be achieved by the coolest thermocouple, typically the one nearest the exit.
- n. Provide exterior skin thermocouples to monitor the exterior metal temperature during dryout. Frequent infrared scans may be substituted for external skin thermocouples. At a minimum, monitor the temperature in areas expected to see the greatest metal temperature (e.g., at the hot air inlet or where the exterior of the metal is in an enclosed or heated area). Monitor and record these temperatures in the same manner as used for the interior temperatures.
- o. Heat drying shall proceed as follows (except where the refractory manufacturer's recommended heat drying procedure is more stringent):
 - (1) Raise the temperature of the air in contact with the refractory lining at a continuous rate not to exceed 50°F (28°C)/hour to approximately 300°F (150°C).
 - (2) Hold for a minimum of 1.5 hours per inch (25 mm) of lining thickness. All thermocouples shall reach and maintain a steady temperature for a minimum of 30 minutes prior to completing the hold and proceeding with the dryout.
 - (3) Raise the internal temperature of the air in contact with the refractory at a continuous rate not to exceed 50°F (28°C)/hour to approximately 700°F (370°C).
 - (4) Hold for a minimum of 1.5 hours per inch (25 mm) of lining thickness. All thermocouples shall reach and maintain a steady temperature for a minimum of 30 minutes prior to completing the hold and proceeding with the dryout.
 - (5) Raise the internal temperature of the air in contact with the refractory at a continuous rate not to exceed 50°F (28°C)/hour to the internal process operating temperature.
 - (6) The shell temperature shall reach at least 220°F (105°C) during the final hold.


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- (7) Hold for a minimum of 1.5 hours per inch (25 mm) of lining thickness. All thermocouples shall reach and maintain a steady temperature for a minimum of 30 minutes prior to completing the hold and proceeding with the dryout.
- (8) After the final hold period, cool down shall be at a continuous rate not to exceed 100°F (56°C) /hour with no holds to approximately 300°F (150°C). After reaching approximately 300°F (150°C) the remaining cool down may be without heating.
- (9) If steaming is observed during any hold period, the hold period shall be maintained until steaming ceases.
- (10) Length of the hold periods, and the overall duration of the heat dry, shall be determined by the thickest portion of lining being dried.
- (11) Additional hold points are permissible.
- (12) The shell temperature shall not exceed the design temperature of the shell.
- (13) The air temperature differential between any two thermocouples within the item being heat dried shall not exceed 100°F (56°C).
- (14) If heat is lost, resume the dryout procedure using the heating rate specified at the temperature at which the ability to heat is regained.
- p. As an alternative to the method described in paragraph 6.2o.(2) through (5), the refractory temperature may be raised without any holds at a continuous rate not to exceed 25°F (14°C) per hour between the hold at 300°F (150°C) and the final hold temperature.
- q. When heat drying is completed the lining shall be inspected and any area with full depth cracks 1/16 inch (1.6 mm) wide and larger, non-full depth cracks 1/8 inch (3.2 mm) wide and larger, depressions exceeding 1/4 inch (6 mm) in depth or two inches (50 mm) in any other direction, and spalling or unbonded material shall be removed and replaced in accordance with Section 9.
- r. When lining that has been in hydrocarbon operation is exposed to the heat drying of new lining, precautions shall be taken to prevent ignition of the coke.
- s. Field seams and repairs shall receive the same curing and heat drying as the remainder of the lining.
- t. Provide the Owner or the Owner's authorized representative with certified copies of the heat drying procedure, internal heater, recorder, and thermocouple locations, and temperature control log.


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7. INSPECTION

The Owner or the Owner's authorized representative reserves the right to inspect the refractory lining during all phases of preparation, application, repair, curing, heat dry, and clean-up. The following operations shall be included in those witnessed:

- a. Pre-installation meeting with the refractory installer to discuss the installation procedure and any deviations from this Standard Specification or the UOP Project Specifications and Drawings.
- b. Preparation of the vessel by grit blast cleaning; welding of anchors, bars, and collars; wrapping of paper; placing of insulation; and covering of openings.
- c. Installation of the forms including materials, location, bracing, alignment of neighboring sections, provisions for removal, vibrators (including energy output, placement, and attachment), refractory installation ports, and venting of the refractory filled space.
- d. Pre-installation testing of the refractory materials (if required) and pre-qualification of the installation crew.
- e. Mixing of refractory materials with reinforcing fibers and water to ensure that correct materials and procedures are used, that containers and water are clean, and that the entire contents of each bag is poured into the mixing machine.
- f. Application of vibration to ensure that vibration is present for the proper time period, proper vibration methods are used, the vibration is effective, the refractory is neither over or under-vibrated, and separation or other undesirable effects do not occur.
- g. Vibracasting of refractory materials to ensure that proper placement technique is used, no previously opened or wet bags of refractory are used and that specified procedures are followed when the application is interrupted.
- h. Curing and heat drying of the refractory lining to ensure that the proper curing technique and heat drying temperatures, ramps, and holds are used.
- i. Removal of the forms after curing and inspection of the lining for voids or other damage.
- j. Inspection of lining after curing and after heat drying to ensure no unacceptable voids, cracks, spalling, or unbonded material is present.
- k. Removal and replacement of unacceptable refractory lining to ensure that the rework is compatible with the original lining application.
- l. Copies of all logs, record of areas of refractory repair, and test reports.
- m. Removal from plant site of refractory lining applicator's equipment, materials, and debris. Job site to be left broom clean.


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The approval or acceptance of the above operations by the Owner or the Owner's authorized representative does not relieve the refractory manufacturer and/or refractory lining applicator of any responsibility, warranty, or guarantee.

8. TESTING

8.1 Compliance Values for Physical Property Testing

- a. The Owner, refractory manufacturer, and contractor (as applicable) shall agree upon vibration cast installation based guaranteed or compliance values for all physical properties to be tested. If guaranteed or compliance values are not specified, then the manufacturer's data sheet values shall be used. The results of physical property testing shall be compared against the guaranteed or compliance values.
- b. The refractory manufacturer shall provide a recommended weight percent of mixing or hydration water to be added at the mixer. The refractory manufacturer shall also provide water curves indicating the effect upon refractory properties (e.g., cold crushing strength, permanent linear change, abrasion resistance, etc.) of a ± 10 percent variation (or alternate range as specified by the manufacturer) in the amount of mixing water.

8.2 Testing at the Manufacturers Plant

- a. The manufacturer of the refractory materials shall provide material data sheets and test certificates of vibration cast samples of the supplied refractory (i.e., the material to be shipped). Sample preparation shall be in accordance with ASTM C862. Tests may be performed by the manufacturer or a mutually agreed upon independent laboratory. Specimen requirements (e.g., preparation, number, and shape) and testing shall be in accordance with the ASTM Standards and modifications listed below. Except for mid-weight insulating and erosion resistant materials, each lot or batch and every third pallet (beginning with the first pallet) or fraction thereof of materials within each batch or lot shall be tested. For mid-weight insulating and abrasion resistant materials, each lot or batch and each pallet within each lot or batch shall be tested. Samples shall be prepared from a bag of refractory randomly selected from the pallet. The entire bag shall be used to prepare the refractory from which the samples are prepared. Testing shall be without metal reinforcing fibers. The test certificates shall include the following information:
 - (1) Name of manufacturer
 - (2) Name of refractory material
 - (3) Dates of manufacture and testing
 - (4) Batch and serial number
 - (5) Order number
 - (6) Bulk density (minimum of 3 specimens per sample, tested per ASTM C134 as modified per API Standard 936), undried (green) and fired.


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- (7) Cold crushing strength (minimum of 3 specimens per sample, tested per ASTM C133 as modified per API Standard 936) using 2 inch cubes.
- (8) Permanent linear change (minimum of 2 specimens per sample, tested per ASTM C113 as modified per API Standard 936)
- (9) Apparent porosity (per ASTM C 20 using one-half of the permanent linear change specimen.)
- (10) Abrasion Resistance (minimum of 2 specimens per sample, tested per ASTM C704 as modified per API Standard 936) – Mid-weight insulating and abrasion resistant refractory materials only
- b. Tests shall be performed on samples that have been heated to 1500°F (815°C) and cooled to ambient temperature. Heating shall be in accordance with ASTM C865.
- c. Refractory properties shall meet or exceed the guaranteed or compliance values. If guaranteed values have not been specified, the manufacturer's data sheet values shall be met.
- d. No specimen result shall be more than 5 percent of the limiting value beyond the minimum or maximum limiting value. All of the specimen results shall be within ± 20 percent of the average value of the sample. No more than one specimen of the sample shall be beyond the limiting value(s).

8.3 Pre-installation Testing at the Job Site

- a. Material that is more than three months old, shows evidence of minor damage or minor moisture exposure (including any pallet from which a wet bag has been discarded, and any other pallets stored with it.), or has been exposed to temperatures beyond the storage limits of this specification, shall be retested approximately two weeks before the start of the refractory installation. Material that is nine or more months old or beyond its shelf life, if it is less than nine months, shall not be used. With the exception of mid-weight insulating and abrasion resistant materials, prepare vibration cast samples for testing from each lot or batch and every third pallet (beginning with the first pallet) or fraction thereof, of refractory material within each batch. For mid-weight insulating and abrasion resistant materials, each lot or batch and each pallet within each lot or batch shall be tested. The samples shall be prepared from a bag of refractory randomly selected from the pallet and shall be in accordance with ASTM C862. The entire bag shall be used to prepare the refractory from which the samples are made. Samples shall not include metal reinforcing fibers.
- b. The samples shall be tested for bulk density (per ASTM C134), cold crushing strength (per ASTM C133) and permanent linear change (per ASTM C113) after heating to 1500°F (815°C) in accordance with ASTM C865, and cooling to ambient temperature. Mid-weight insulating and abrasion resistant refractories shall also be tested for abrasion resistance (per ASTM C704). All tests shall be modified as noted in Paragraph 8.2a.


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- c. Tests shall be conducted by a qualified independent laboratory before installation of the refractory material. Test results shall meet or exceed the guaranteed or compliance values. If guaranteed values have not been specified then the manufacturer's data sheet values shall be met. Specimen results shall comply with the limits specified in Paragraph 8.2d. In addition, the test results shall not differ from the results reported by the manufacturer (see Section 8.2) by more than 20 percent. If the tests do not meet these criteria, the refractory material shall not be used.
- d. Provide the Owner or the Owner's Authorized Representative with certified copies of the test results.

8.4 Pre-qualification of the Installation Crew

- a. Each refractory installer and other members of the installation crew shall be pre-qualified with each vibration cast refractory material before refractory installation to ensure that proper procedures are used. Pre-qualification shall be performed at the job site using the same equipment, materials, utilities, crew members, and installation procedures (including vibration method (vibrator type, force, arrangement, and attachment) and time) that will be used for the refractory lining application. A minimum of one mock-up (see paragraph 8.4b.) shall be cast for each material to be installed by vibration casting. Certification from a previous job or site is not acceptable.
- b. Installer prequalification shall consist of casting and inspecting a mock-up for each material to be vibracast.
 - (1) The mock-up shall simulate the most difficult area to be vibracast, e.g., complex geometry (elbows, nozzles, protrusions through the lining, tees, etc.) or poor access (remote and confined areas, beneath horizontal forms, etc.). At a minimum the mock-up assembly shall be a cylinder 24 inches (600 mm) OD and 36 inches (900 mm) long.
 - (2) The refractory thickness shall equal the lining thickness to be installed and shall utilize the same tolerances.
 - (3) The mock-up shell and the forms shall be steel. Both shall be designed for removal without damaging the contained refractory and shall be coated with a refractory vendor approved parting agent to prevent adherence to the refractory. The form system shall simulate the forms and form system to be used for the lining installation.
 - (4) The mock-up assembly and the forms shall withstand the fluid head of freshly placed refractory and the applied vibration without deformation or displacement.
 - (5) Provide anchors of the same style and spacing as will be used for the refractory lining. Anchors shall be bolted to the mock-up assembly in a manner that permits removal of the mock-up plates.


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- (6) The refractory shall be vibracast (with steel fibers if steel fibers will be used for the installed lining) using the same installation and vibration procedures to be used for the installed lining.

c. During crew prequalification:

- (1) Determine the optimum weight percentage of mixing water.
- (2) Determine the optimum mixing time.
- (3) Determine the refractory working time.
- (4) Demonstrate the suitability of the method of vibration application and vibration duration.

- d. After curing for 24 hours (see Section 6.1), remove the forms and the mock-up backing plates to observe the installation. Weigh the mock-up and determine the undried (green) density. The undried (green) density shall be within ± 5 percent of the manufacturer's value for vibration cast samples. The intact mock-up shall be inspected, then broken and re-inspected. Voids, spalling, laminations, honeycombing, over compaction, uneven fiber distribution, shadowing at anchors, or other indications of poor installation are not acceptable. Samples of the refractory shall be tested as indicated in Section 8.3b. and 8.3c. Only if inspection of the pre-qualification mock-up and the results of any testing are acceptable will the crew be allowed to install the refractory lining.

8.5 Sampling During Installation

- a. The refractory lining installer shall prepare as-installed refractory samples on the job site as a part of the installation process. Samples shall be prepared once per crew per shift, for each lined item, for each continuously cast portion of the lining, for each refractory material, and for each mixing station. The number of test boxes required on the job site shall be agreed upon with the Owner or the Owner's authorized representative.
- b. The samples (with reinforcing fibers) shall be representative of the installed refractory, including casting procedures, vibration, and curing in the same manner (but not heat drying). Use a suitably marked 4 1/2" by 9" (115 x 225 mm) box of a depth equal to the lining thickness. A standard "shoebox" {4 1/2" x 4 1/2" x 12" (115 x 115 x 300 mm)} is also acceptable. Test specimens shall be cut from the refractory block. Cast enough boxes to provide all of the required test specimens. Alternatively, the test specimens may be directly formed and cast per ASTM C862.
- c. Boxes shall be coated with a refractory manufacturer approved parting agent to prevent adherence of the refractory. The sample shall be cured in accordance with Section 6.1 for 24 hours. The box may be placed on the scaffolding after vibracasting but otherwise shall remain undisturbed and protected at the installation site until curing has been completed.


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- d. Marking of the refractory samples shall make it possible to identify each sample by number; date, time, and method of application; product name and batch number of the refractory material; location of application (e.g., sample map); steel fiber percentage; weight percent of water added; weather; shell surface, water, material, and mix temperatures; and name of the installer. Markings shall also indicate the front, back, top, bottom, left, and right sides of the sample.
- e. The lining installer shall keep the cured samples on site available to the Owner or the Owner's authorized representative, who will indicate the extent of testing to be performed in accordance with ASTM Standards. Testing shall be in accordance with the procedures and requirements of Section 8.3.
- f. In case of disagreement on the test results, or failure to comply with the acceptance criteria, the refractory lining applicator may remove additional samples from the installed lining. Testing (at his own expense) shall be in accordance with the specified ASTM Standards by a mutually agreed upon qualified independent laboratory. Any remedial measures required as the result of testing shall be agreed upon with the Owner or the Owner's authorized representative.

9. SEAMS AND REPAIRS

9.1 Preparation

- a. Unacceptable refractory lining shall be saw cut at a right angle to the shell the full depth of the lining, laterally to acceptable lining, and removed. The shell shall not be damaged. Unacceptable lining includes thin areas, severely spalled, fractured, poor quality (e.g., soft, porous), eroded and missing lining, refractory at hot spots, and refractory not performing its intended function. With the exception of core samples, the minimum area removed shall be sufficient to expose at least three noncontinuous anchors as indicated on Figure 6. Cuts shall be made midway between anchors. Corners shall be rounded to a smooth, generous contour throughout the depth of the refractory.
- b. Small (e.g., hairline), random, cracks are not a concern nor a cause for repair. These cracks are frequently a positive feature, indicating the lining is held tightly to the shell. They also act as expansion joints and close as the refractory heats and expands. Cracks larger than the limits given in paragraph 6.2q., or cracks exhibiting signs of coking, catalyst entry or other indications they are open and allowing flow during operation require repair.
- c. Core samples shall be round, taken at a right angle to the shell, and shall extend to the shell. The shell shall not be damaged. The shell shall be cleaned and a new anchor installed. Caps shall be placed on the anchor tips.


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- d. The anchors and shell shall be cleaned of refractory, debris, loose material, or contaminants and new caps installed on the anchor tips. If the anchors or their attachment weld are damaged, the anchor shall be replaced.
 - (1) Cut the legs from the old anchor but leave the weld undisturbed.
 - (2) If the base metal was not postweld heat treated (PWHT), weld the new anchor to the base metal.
 - (3) If the base metal was PWHT and PWHT will be required if the new anchor is welded to the base metal, consider welding the new anchor to the remnants of the old anchor.

9.2 Lining Installation

- a. Immediately before placement of the new refractory, the joining surface of the sound lining adjacent to the seam or repair area shall be cleaned of debris, roughened, and completely wetted with lining mixing water prior to application of the replacement lining.
- b. Refractory lining at seams and repairs shall be performed in the same manner as the original lining application, including curing and heat drying. The seam or repaired area shall be fully vented to permit complete filling by the refractory and venting of the steam produced during heat drying. If necessary, venting or installation (casting) nozzles in the forms or shell are permissible (see paragraph 5.4c.(9)). Proposed methods of repair shall be approved by the Owner or the Owner's authorized representative before repairs are started.
- c. Provide the Owner or Owners Authorized Representative with certified copies of records indicating the location, size, damage discovered, and extent and means if repair at each repair site. Include the refractory used, anchor material, style and location, the method of anchor and refractory installation, curing and dryout procedures, conditions during the repair, etc.

10. SHIPPING
10.1 Preparation

Shop installed refractory lining shall be prepared for shipment in a manner that ensures delivery to the destination in the original cast, cured, and heat dried condition.

10.2 Bracing and Support

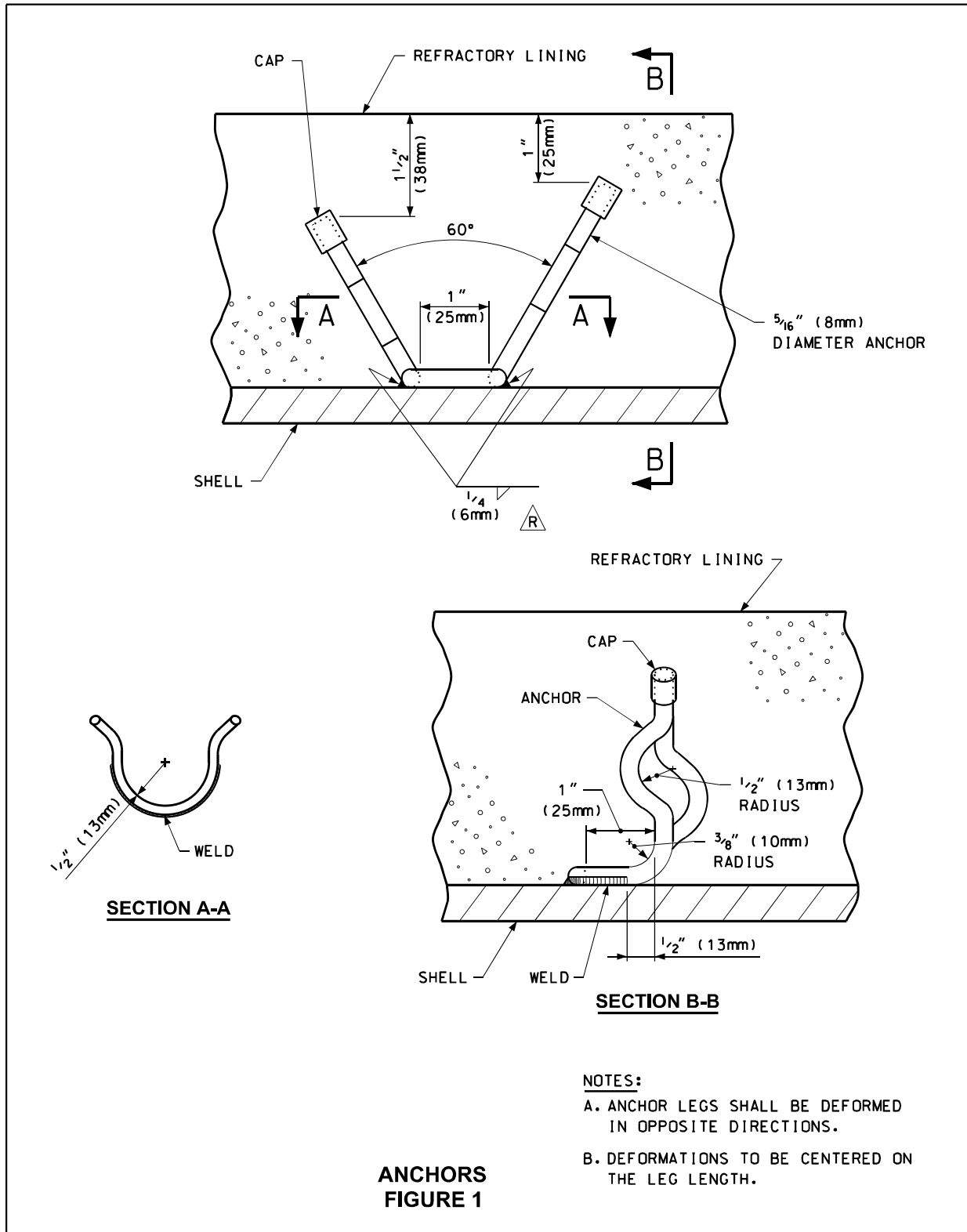
Distortion or deflection of the lined item may damage the refractory lining. Prevent distortion or deflection by means of braces, truing rings, support location, proper lifting and rigging techniques, and /or other means.

10.3 Sealing

Seal the equipment from atmospheric conditions (e.g., apply a curing compound to the refractory surface, close and seal all openings) during shipment and storage.

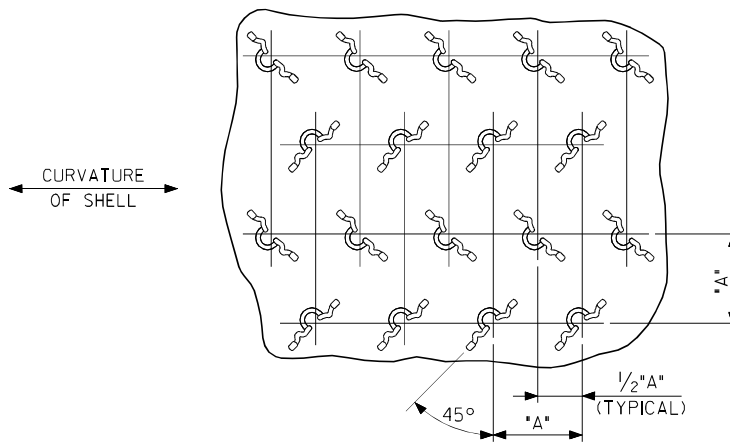

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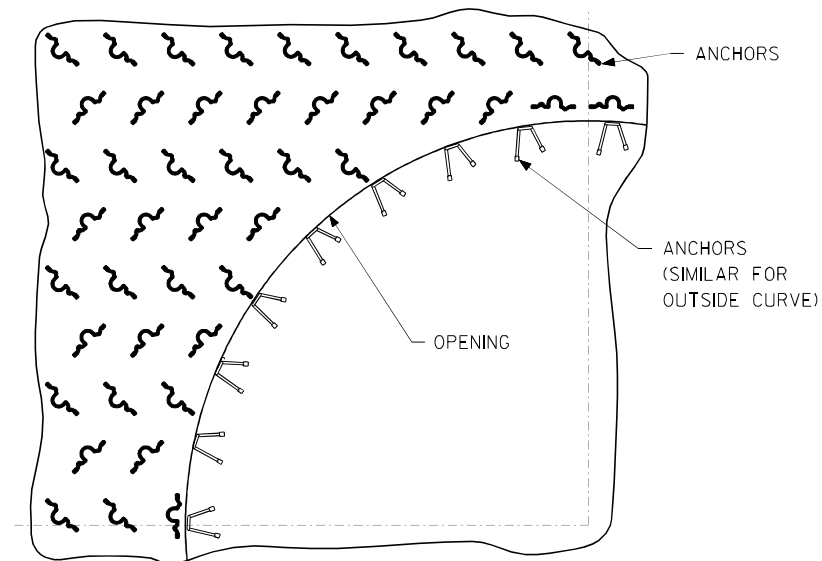
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**ANCHOR PATTERN**

ORIENTATION DURING REFRACTORY INSTALLATION	ANCHOR SPACING (DIMENSION "A")
CONVEX KNUCKLES, CONVEX OVERHEAD AREAS, AND FLAT OVERHEAD AREAS	1.0 × T
CONCAVE KNUCKLES AND CONCAVE OVERHEAD AREAS	1.5 × T
HORIZONTAL CYLINDRICAL SHELLS	1.5 × T
VERTICAL WALLS AND CYLINDRICAL SHELLS	2.0 × T

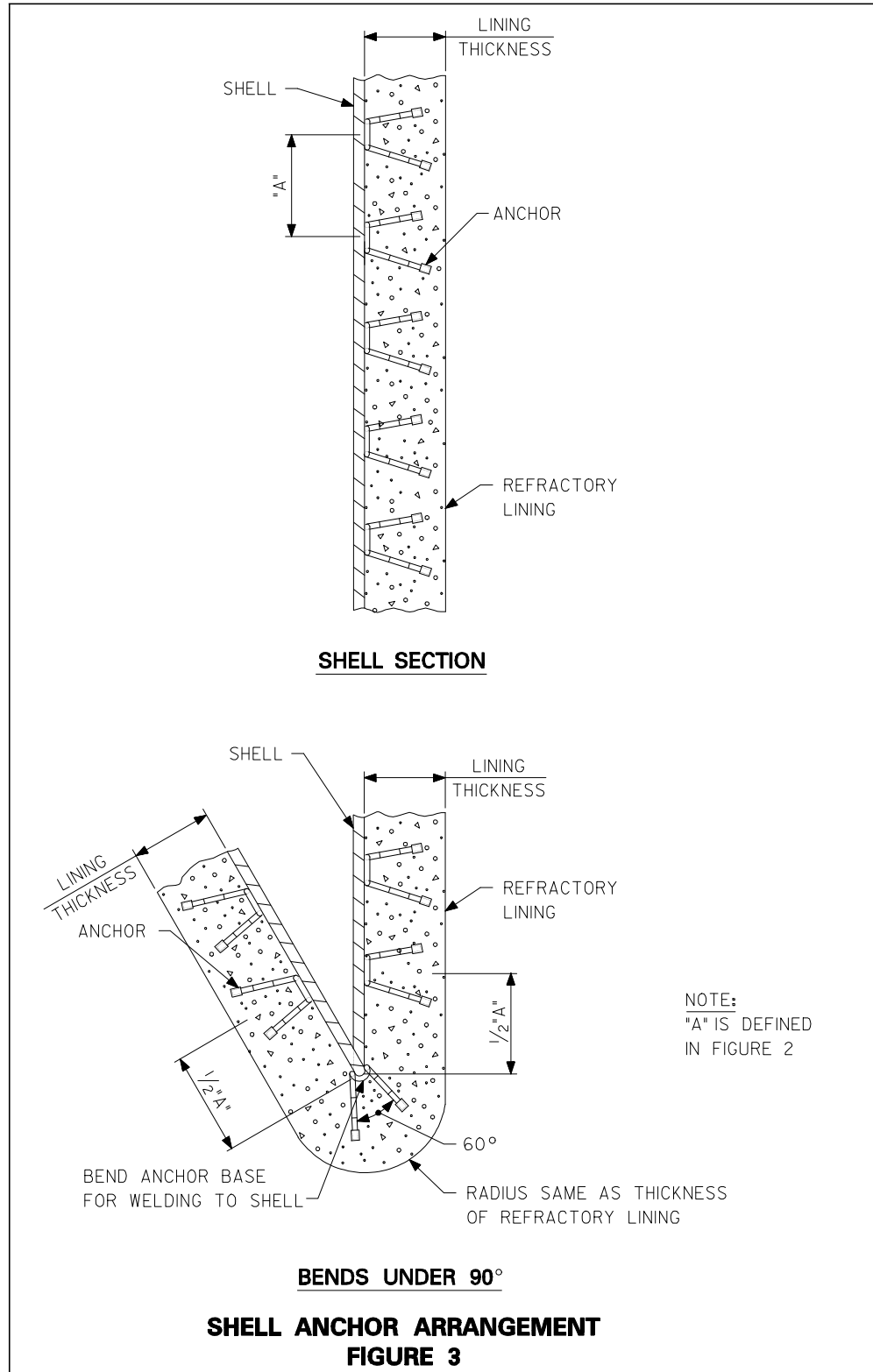
ANCHOR ATTACHMENT POINT SPACING**NOTES:**

- A. T=THICKNESS OF REFRACTORY LINING
- B. MAXIMUM ANCHOR SPACING SHALL BE 12 INCHES (300MM)
- C. ANCHOR SPACING IS MEASURED AT THE ANCHOR TIPS, NEAR THE LINING HOT FACE 

**MANWAY AND NOZZLES**
**ANCHOR ARRANGEMENT
FIGURE 2**


**VIBRACAST REFRACTORY LINING
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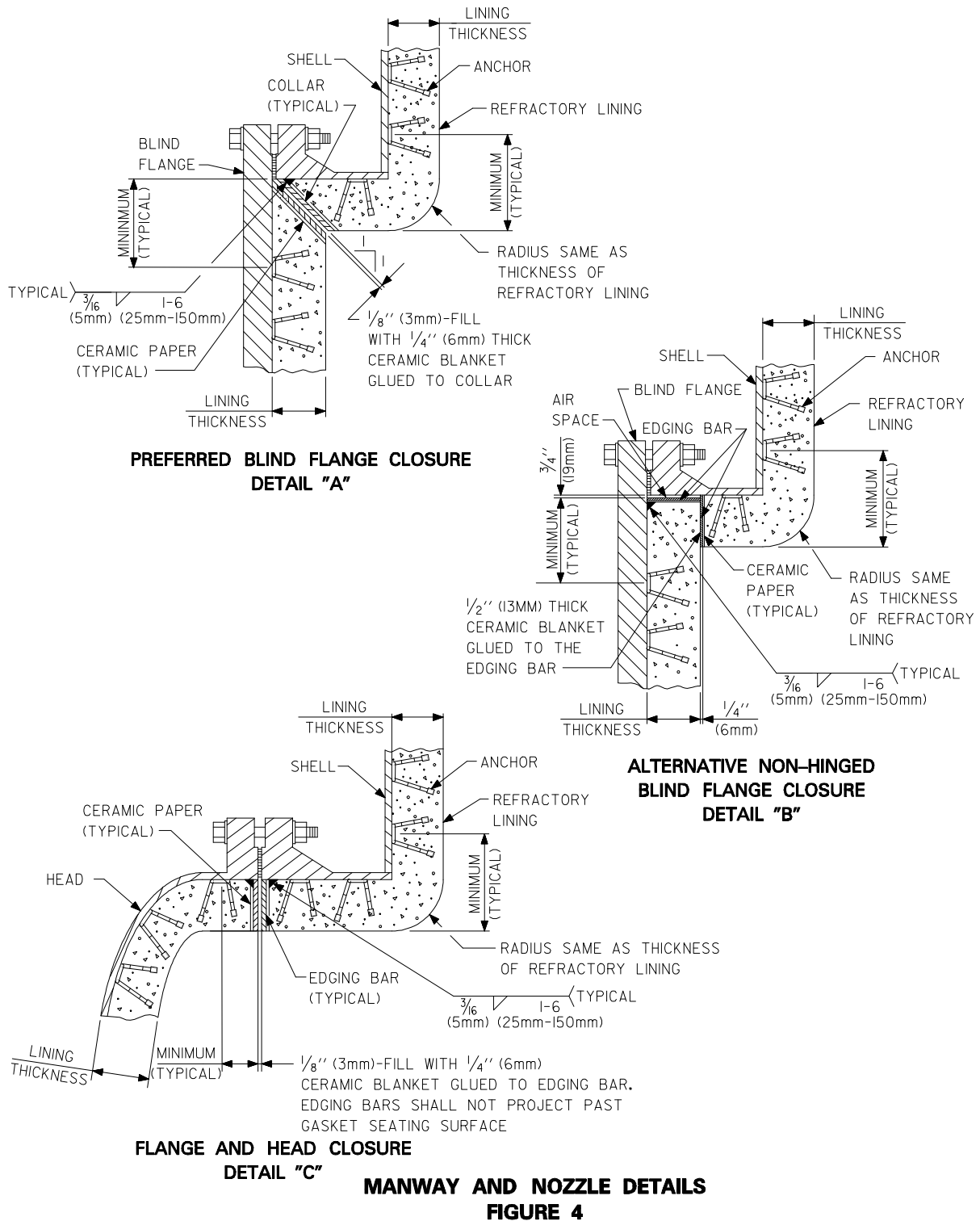


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VIBRACAST REFRACTORY LINING V-ANCHORS

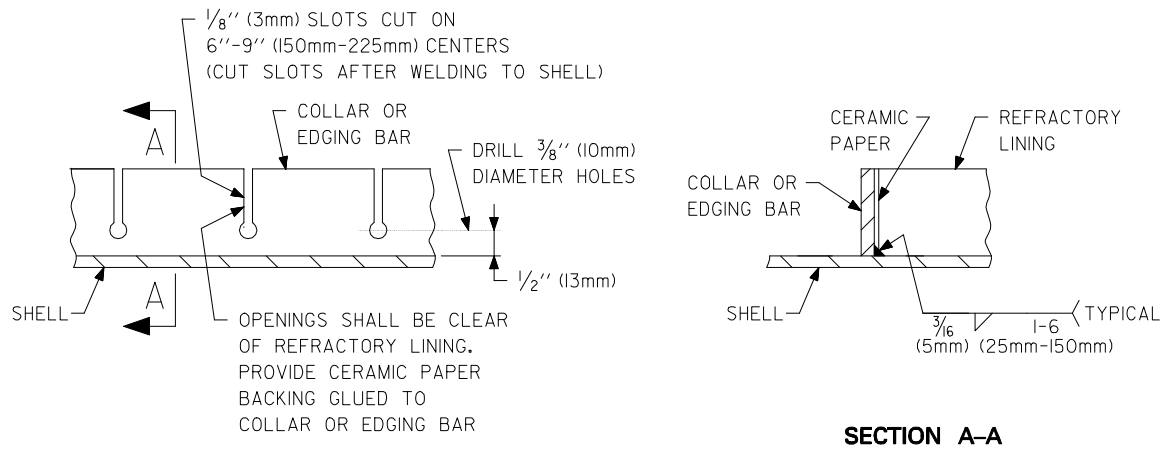
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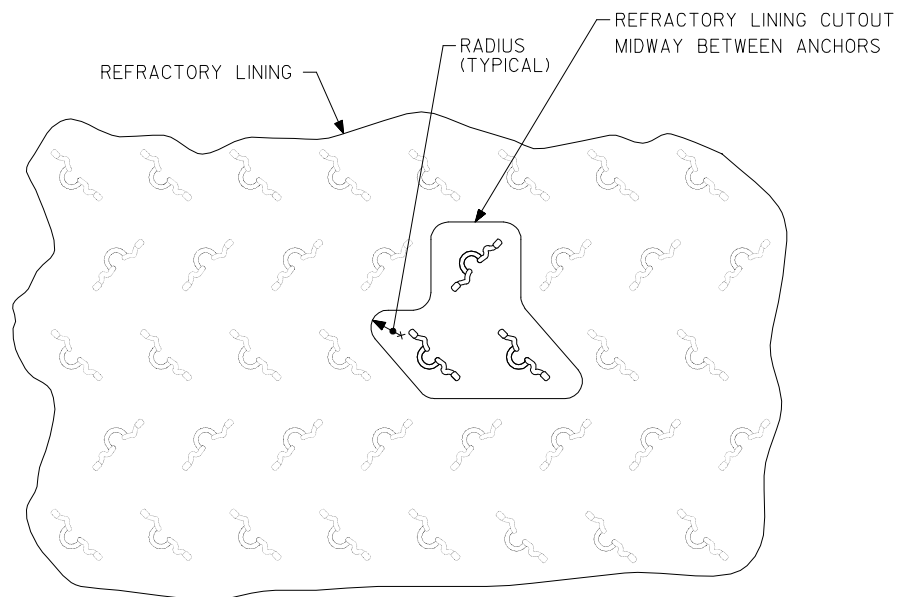
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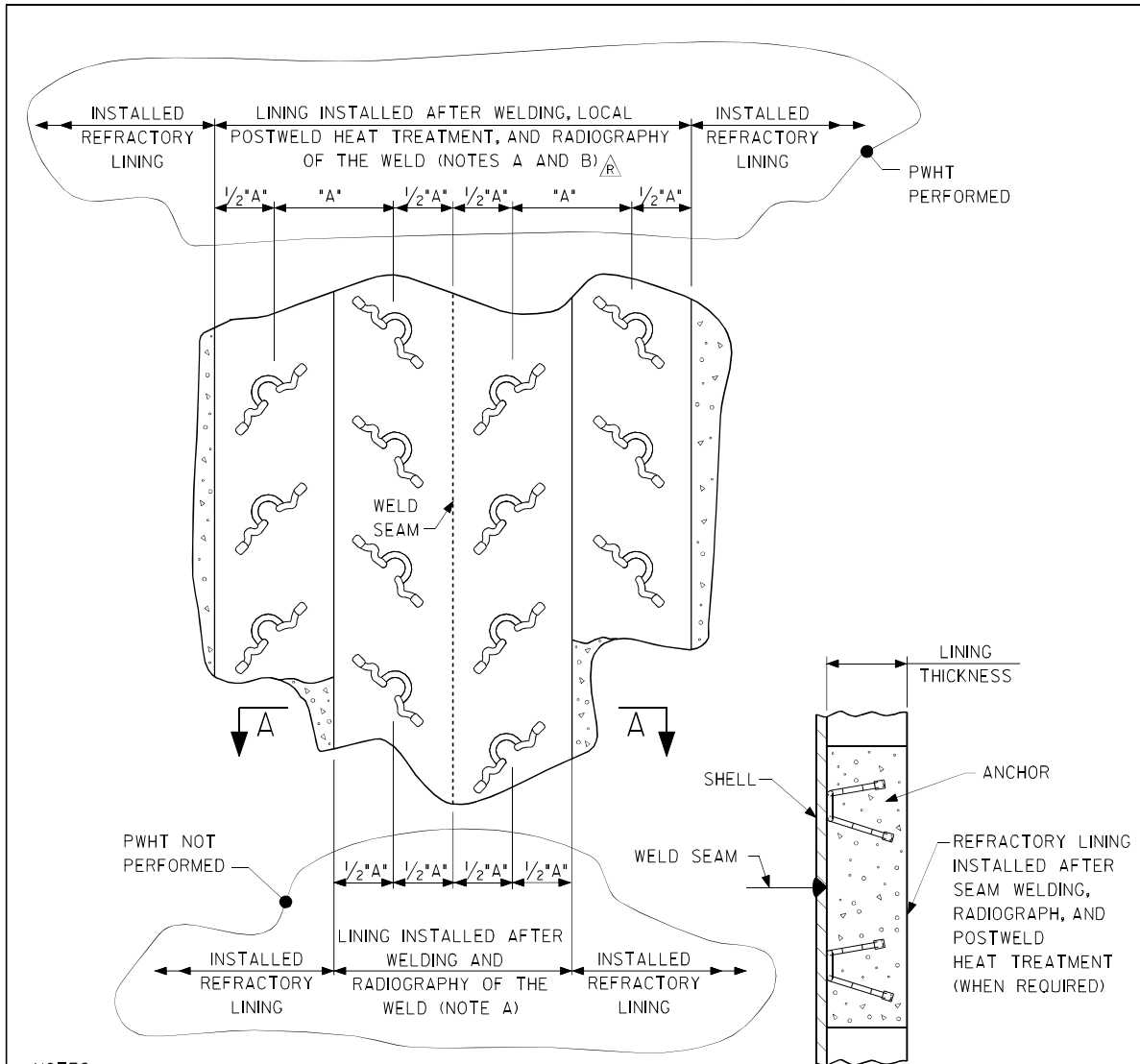
**COLLAR OR EDGING BAR
FIGURE 5**



**LINING CUTOUT FOR REPAIR
FIGURE 6**


**VIBRACAST REFRACTORY LINING
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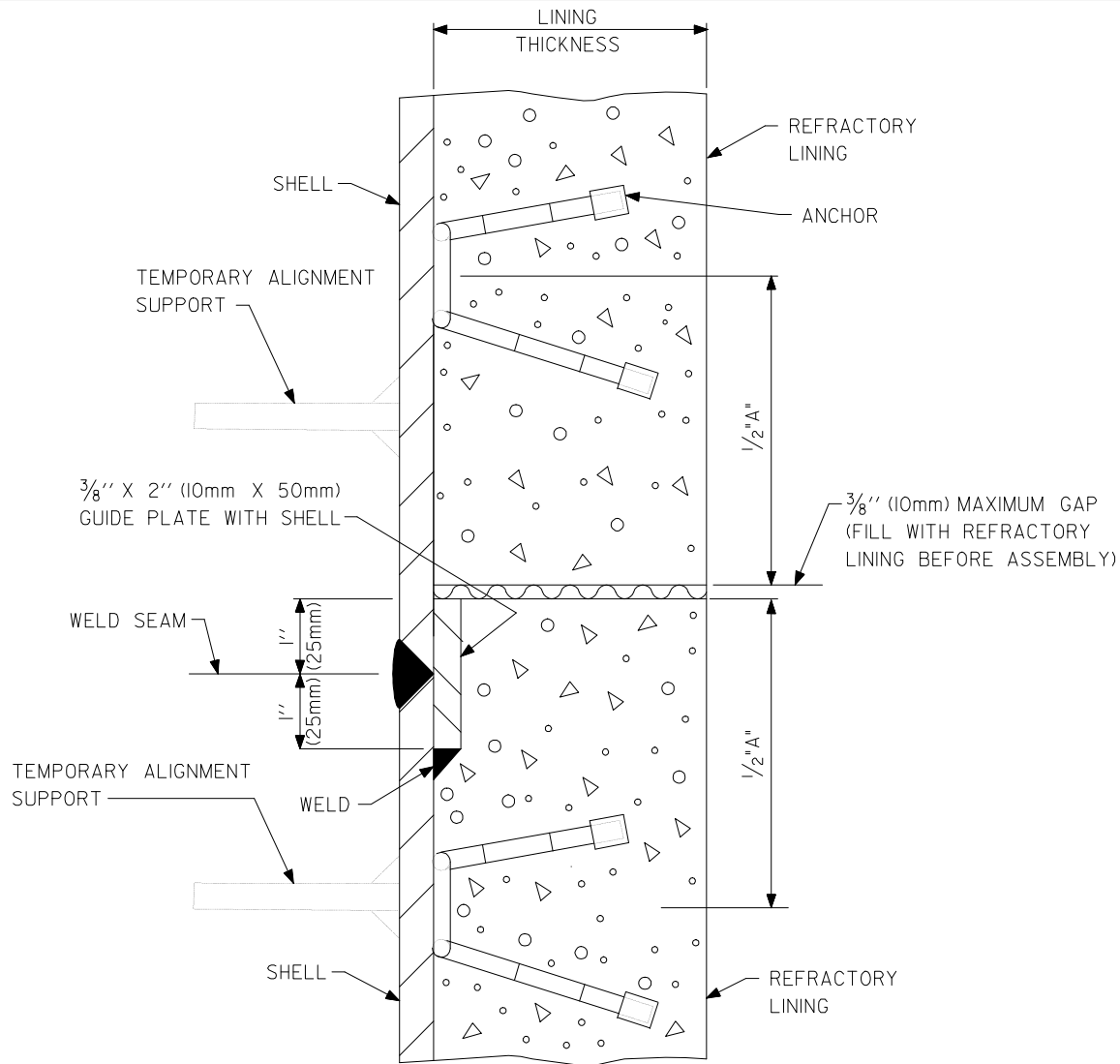
**NOTES:**

- INCREASE REFRACTORY GAP WIDTH IF REQUIRED FOR HIGH QUALITY INSTALLATION OF REFRACTORY AND TO PERMIT RADIOGRAPHY AND HEAT TREATMENT WITHOUT REFRACTORY DAMAGE. SEAM(S) TO BE CENTERED BETWEEN ROWS OF ANCHORS
- ALL ANCHORS SHALL BE WELDED TO THE BASE METAL BEFORE \triangle_R POSTWELD HEAT TREATMENT
- REFRACTORY FIELD JOINTS SHALL BE APPLIED BY VIBRACASTING WITH APPROPRIATE GRADE REFRACTORY MATERIALS
- $''A''$ IS DEFINED IN FIGURE 2

**SEAM DETAILS
FIGURE 7**


**VIBRACAST REFRACTORY LINING
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**NOTES:**

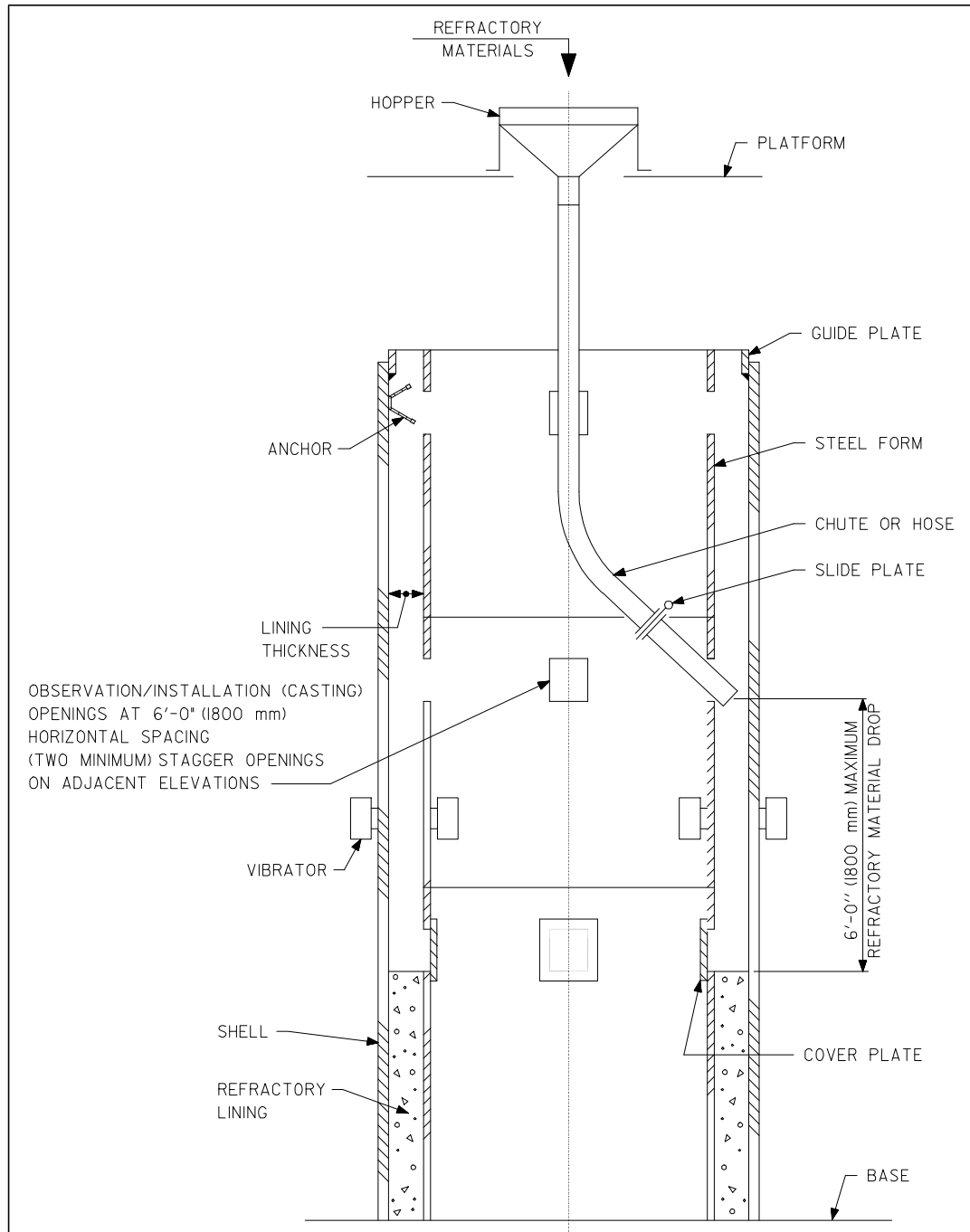
A. USE ONLY FOR INACCESSIBLE JOINTS IN SMALL ITEMS (LESS THAN OR EQUAL TO 24 INCH (600MM) ID OF LINING) WHERE RADIOGRAPHY AND POSTWELD HEAT TREATMENT ARE NOT PERFORMED.

B. "A" IS DEFINED IN FIGURE 2.

**CLOSED SEAM DETAILS (SEE NOTE A)
FIGURE 8**


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**REFRACTORY INSTALLATION PROCEDURE
FIGURE 9**