Conceptual Repairs for EBR-II Containment Building

Materials & Fuels Complex
Idaho National Laboratory

18 July 2018

SGH Project 188109
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Mr. Stuart Jensen  
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Project 188109 – Repair Evaluation for EBR-II Containment

Re: BEA Contract No.00203691

Dear Mr. Jensen:

Please find enclosed our report entitled Conceptual Repairs for EBR-II Containment Building, which provides options and a proposed approach to repair the EBR-II Containment Building from the effects of limited water jet cutting. Drawings suitable for pricing are included as Appendix A to the report.

Sincerely yours,

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Idaho License No. 8453

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Senior Project Manager  
Idaho License No. 13241

Encl.
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EXECUTIVE SUMMARY

The EBR-II Containment Building is located in the Materials & Fuels Complex at the Idaho National Laboratory. During preparations for demolition of the building, a water jet process was used to cut portions of the exterior steel shell and interior reinforced concrete structure. Demolition efforts were suspended, and there is interest in restoring the structure to its original structural integrity in preparation for repurposing. Battelle Energy Alliance engaged Simpson Gumpertz & Heger Inc. to identify repair alternatives and evaluate their effectiveness in returning the Containment Building to use.

Repair of the EBR-II Containment Building includes realignment of the exterior steel shell, concrete removal and repair, and reinforcement repair. We considered options that included performing work from a combination of the interior space and from the exterior, and exclusively from the exterior of the Containment Building. Within these options, we considered repair variations and presented several of them.

Based on the information provided to us, assumptions made, considerations of code compliance, and level of effort, we believe performing the repairs utilizing interior access is the best approach. Our proposed repair procedure is presented in Section 11 and depicted in conceptual details suitable for pricing on drawings included in Appendix A.

Uncertainties exist in the proposed conceptual repair procedure that should be considered when preparing pricing; these are identified in Section 10. Additional field investigation, material testing, structural evaluation, and detailed code review should be performed to confirm the assumptions and approach, refine the cost estimate, and enable development of construction details.
1. INTRODUCTION

1.1 Background

The EBR-II Containment Building is located in the Materials & Fuels Complex (MFC) at the Idaho National Laboratory (INL). During preparations for demolition of the building, a water jet process was used to cut portions of the exterior steel shell and interior reinforced concrete structure. Demolition efforts were suspended, and there is interest in restoring the structure to its original structural integrity in preparation for repurposing. Battelle Energy Alliance, LLC (BEA) engaged Simpson Gumpertz & Heger Inc. (SGH) to identify repair alternatives and evaluate their effectiveness in returning the Containment Building to use (BEA Contract No. 00203691 [1]).

1.2 Objective

The objective of this project is to develop conceptual repair details to restore the EBR-II Containment Building to its original structural integrity. The details shall be suitable to enable cost estimation by BEA or an entity of their selection. Details should be developed consistent with modern codes and best practices.

1.3 Scope

The scope of work includes the following tasks:

- Review documentation provided by BEA.
- Prepare conceptual repair details suitable for cost estimation.
- Prepare a summary report.

We performed this work in accordance with the SGH Corporate Quality Manual [2].
2. DOCUMENT REVIEW

2.1 Information Provided by BEA

BEA provided SGH with the following relevant information, which we have reviewed to an extent appropriate for our work:

- Original drawings of the EBR-II Facility by the H.K. Ferguson Company [3]
- Exterior and interior photos of the EBR-II Containment Building

In addition, BEA provided other resources, such as INL seismic loading parameters and previous evaluations, which are not directly relevant to this assignment. We performed a limited review of these documents, only to identify the applicability to our work. We have not listed these references.

2.2 Other References

As part of our work, we have reviewed the following industry standards and references to the extent appropriate for our work:

- ACI 349-13 – Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary [5]
- ACI 318-08 – Building Code Requirements for Structural Concrete and Commentary [6]
- ACI 318-56 – Building Code Requirements for Reinforced Concrete [7]
- ASTM A15-54T – Tentative Specifications for Billet-Steel Bars for Concrete Reinforcement [10]
• Vintage Steel Reinforcement in Concrete Structures (CRSI) [14]
• Surface Preparation Standards (SSPC) No. 2 [15] and No. 3 [16]
• ASTM A305-47T – Tentative Specifications for Minimum Requirements for the Deformations of Deformed Steel Bars for Concrete Reinforcement [17]
3. DESCRIPTION OF STRUCTURE AND CUTS

3.1 Original Structure Construction

According to the original design drawings from the late 1950s with revisions into the mid-1960s [3], the EBR-II Containment Building is a cylindrical structure with a hemispherical dome and an ellipsoidal bottom surface. The cylindrical portion is 78 ft-9 in. tall with an inside shell diameter of 80 ft-0 in. (Figure 1). The structure projects 95 ft-3 in. above grade and 43 ft-6 in. below grade. The structure includes an operating floor at Elevation 129 ft-0 in. and several below-grade levels, along with a reactor cavity. Existing grade is approximately at Elevation 121 ft-0 in. The structure includes a number of openings near existing grade for access and penetrations.

The exterior surface of the structure below the hemispherical dome is a 1 in. thick steel shell made of ASTM A201 Grade B material, which has a minimum yield point of 32,000 psi and a tensile strength of 60,000 psi to 72,000 psi [12, 13]. The dome is made of 0.5 in. thick steel. Typically, inside the steel shell is a 12 in. thick reinforced concrete cylinder with a 4 in. thick shotcrete dome. The concrete structure is typically cast from nominal 2,500 psi concrete, and the dome is made from nominal 3,000 psi shotcrete. The above-grade portion of the concrete structure and dome is isolated from the steel shell with 0.5 in. thick premolded “joint filler” (as identified on the original drawings) material. Near the top of the cylinder is a reinforced concrete corbel that supports a crane rail and polar crane (Figure 2).

The typical 12 in. thick concrete cylinder is reinforced with No. 4 circumferential bars at 12 in. spacing at each face and No. 5 vertical bars at 7 in. spacing at each face (Figure 3). Additional bars are provided at the corbel (Figure 4). The outside vertical bars change to No. 8 bars within and above the corbel. The dome reinforcement is not legible on the provided drawings. Below the operating floor and above the ellipsoidal portion of the structure, the concrete wall thickness is 1 ft–11-1/2 in. and is reinforced with No. 6 circumferential bars at 12 in. spacing at each face and No. 6 vertical bars at 9 in. spacing at each face (Figure 5). The concrete cover and reinforcement material are not shown on the drawings.
Figure 1 – Cross Section through EBR-II Containment Building Shell (Drawing R-1 [3])
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EBR-II Dome Assessment Report R0
3.2 Relevant Modifications

EDF-10882 [4] identifies a number of planned and some completed modifications of the EBR-II Containment Building and adjacent facilities. The following paragraphs summarize those relevant to this assignment.
3.2.1 Water Jet Cuts

Page 12 of 23 of EDF-10882 [4] notes that a water jet cutting mockup was performed that resulted in the following three cuts into the EBR-II Containment Building:

- Vertical cut extending approximately 20 ft up the side of the cylinder wall
- A 4 ft vertical cut near the top of the cylinder wall
- Horizontal cut at the base of the cylinder wall (no cut dimensions provided)

Per discussions with Mr. Ben Coryell of BEA, the bottom of the longer vertical cut is approximately 14 in. above the top surface of concrete at the operating floor, and the horizontal cut is approximately 18 in. above the top surface of concrete at the operating floor. The elevation of the 4 ft vertical cut has not yet been determined. Per the supplied photograph (Figure 6), the water jet guide track or similar equipment is still attached to the exterior of the EBR-II.

EDF-10882 [4] states that these cuts have been temporarily sealed with a silicone-based sealant. EDF-10882 [4] identifies lessons learned, which include the following:

- The operators were able to “dial in” the equipment needed to penetrate the 1 in. thick steel shell and not penetrate the concrete more than 5 in.
- The 1 in. thick steel shell bowed and separated from the underlying concrete and isolation material by approximately 1 in. during the cutting. An evaluation concluded that this behavior was likely related to residual stresses created during fabrication and unrelated to buckling of the shell.

We have highlighted our understanding of these cuts on Figure 6 below.
3.2.2 Grout and Concrete Placement

Figure 3 on p. 9 of EDF-10882 [4] indicates the openings in the Containment Building below the operating floor were to be filled with grout. In addition, 6 in. of unreinforced concrete was to be placed on top of operating floor, and then up to an additional 24 in. of reinforced concrete sloped for drainage is to be placed on top of the unreinforced concrete. Page 14 of EDF-10882 [4] states that everything below the main floor has been filled with grout, and 6 in. of nominal
3,000 psi concrete has been placed on top of the main floor. Recent observations by Mr. Ben Coryell of BEA have confirmed that this concrete/grout layer has been placed, but the additional 24 in. of reinforced concrete has not been placed.
4. **KEY ASSUMPTIONS**

Our conceptual repair design options are based on the following key assumptions that should be resolved prior to preparation of final construction documents.

Steel reinforcement has a round cross section (vs. square or twisted), is deformed (vs. smooth, with deformation profile similar to modern bars), and is made from ASTM A15 Structural Grade having yield strength of 33,000 psi and ultimate strength of 55,000 psi to 75,000 psi.

a) Section 208(a) of ACI 318-56 [7] identifies that reinforcing bars shall conform to ASTM A15.

b) According to ASTM A15-54T [10] and A15-58T [11] and the Concrete Reinforcing Steel Institute (CRSI) publication *Vintage Steel Reinforcement in Concrete Structures* [14], three grades of reinforcement were manufactured during the time of the original design (Structural, Intermediate, and Hard); Structural Grade has the lowest properties.

c) Smooth bars were available at the time of original design but were phased out of use after ASTM A305-47T [17] was issued that set the standard for bar deformations. We do not expect that smooth bars were used.

d) Tension tests should be performed on a sample of bars extracted from the structure to understand their mechanical properties.

The reinforcement is weldable.

a) The chemical composition of the reinforcement steel is unknown to us. We expect that the carbon equivalent and allowable amounts of other elements, such as phosphorus and sulfur, of the structural grade steel is within a range to enable welding without extensive effort, but may require special pre- and post-heating procedures.

b) Chemical analysis should be performed on a sample of bars extracted from the structure to understand their chemical composition and enable development of appropriate weld procedures.

The minimum concrete cover is 3/4 in. to correspond to interior / non-exposed conditions.

a) We did not find a specified concrete cover on the provided drawings.

b) Section 507(b) of ACI 318-56 [7] requires a minimum concrete protective covering for reinforcement at wall and slab surfaces not exposed directly to the ground or weather of 3/4 in.

c) The use of smaller concrete cover increases the required lap splice length, so this is a conservative assumption.

d) The concrete cover will restrict the use of some splice details.

e) The concrete cover should be identified prior to selection of the rebar splice detail and joint type.
Reinforcement repair and concrete repair can be performed from the interior of the structure.

a) The location of the approximately 4 ft long vertical cut near the top of the cylinder is unknown, but it is likely very close to the corbel and rail supporting the polar crane. According to Drawing R-13 [3], there is 4 ft-11 in. vertical offset between the top of crane rail and the top of cylinder / bend line in the shell, so it is possible the cut is accessible from the interior of the structure. Interference from the corbel would likely mean that access to repair the cut reinforcement should be gained from the exterior of the structure.

b) Mr. Ben Coryell of BEA reported that the horizontal cut and the bottom of the long vertical cut are located above the top of concrete at the operating floor.

The shell cuts are narrow enough that they can be repaired without the need to splice additional plates at the joints.

a) The water jet cutting process created separations that can be enlarged, cleaned, and prepared for welding.

b) Backing can be installed through the exposed reinforcement bars and attached to the inside face of the shell to allow complete joint penetration welds that rejoin the plates across the cut line.
5. REPAIR CONFIGURATION

The overall configuration of the repairs will be controlled by (1) required access to the back side of the steel plate to install backing bars for the repair welding, (2) access to any reinforcing bars damaged by the cutting performed in the past, and (3) how the existing displaced position of the steel shell plates will be addressed.

If the repairs are accessed from the interior face of the structure, limited removal of the existing steel shell may be required, and the repair will use the least welding. If the repairs are accessed from the exterior of the structure, more existing plate will need to be removed and replaced, but it may make repair of the deflected plate easier. Access from the exterior will require less concrete removal than access from the interior and splicing the cut reinforcement will be easier from the exterior.

The interior surface of the existing shell must be accessed to install a backing bar for the repair welds. Backing could be inserted from the exterior of the shell and installed if a portion of the shell is first removed; however, this presents a potential code challenge. Access from the interior may be required to satisfy all code requirements. Removal of the backing requires access from the interior. Backing is discussed in further detail in Section 9.1 of this report. As noted in Sections 10 and 11 of this report, we recommend utilizing the interior space to repair the structure.

The actual depth to which the water jet penetrated the reinforced concrete cylinder and the internal damage that occurred at each cut location is not reported. EDF-10882 [4] notes that the operators were able to determine the appropriate pressures and speed to achieve a 5 in. penetration into the concrete, so deeper penetration depths could be possible. The width of the separation between cut segments of reinforcement is also unknown. Access to any cut reinforcement could be gained from the exterior or from the interior of the structure. At the 4 ft vertical cut at the top, the corbel may interfere with interior access; this should be confirmed prior to planning work at this location.

To gain access from the exterior, additional cuts in the shell plates will be required to allow a large segment to be removed. This would require significant additional work, including cutting a minimum steel shell opening of 1 ft-4 in. be created to provide sufficient access to remove and repair the reinforcement and concrete, rigging to remove the plate, installing backing from the exterior, repairing the shell using an inset plate, and all related work. Because of that, we have
proceeded on the basis that exterior access to repair the reinforcement and concrete will not be required.

Removal of the waterjet track may be required. If its anchorage adequately clamps the steel shell into its original geometry and does not interfere with shell repairs or concrete removal to access and repair the cut reinforcement, it can remain in place throughout the repairs and be removed if BEA so chooses.

We expect that the concrete structure has not displaced or otherwise deformed as a result of the waterjet cuts. Therefore, we believe the steel shell can be realigned by clamping to the concrete cylinder. Regardless of whether access is made through the exterior or interior, where the shell has deviated from its original geometry and prior to cutting the steel shell, we recommend installing threaded rods through the cross section or adhesive anchors into the concrete (or grout) to align the shell and prevent further peeling of the shell during any additional cutting operations. We anticipate that 1 in. diameter ASTM A449 threaded rods spaced at 2 ft on center along the cut will be sufficient. A channel, tube, or other continuous structural member should be placed between the rods and the nut / washer at the exterior surface of the shell parallel to the cut to provide near uniform clamping of the steel shell as the rods are tightened. The rods should be tightened by a hydraulic jack until the shell is realigned to the original geometry. The amount of force needed to tighten the rods depends on the point of separation of the steel shell from the joint filler material and the mechanical properties of the steel shell. We estimate a force of 20 kip, or 10 kip per foot should be sufficient to restore the shell to its original geometry. We expect that the concrete structure can resist this force without failing in punching shear or flexure. We recommend the use of a 4 in. by 4 in. steel bearing plate at the interior surface of the concrete to alleviate punching shear concerns; however, flexure must be addressed. This may require the use of steel members oriented parallel to the cut, similar to the configuration at the exterior face of the shell. If concrete removal approaches or encompasses the location of the bearing plate on the inside face of the concrete cylinder, then spreader members should be used to extend the bearing on the inside face of the concrete cylinder to at least 6 in. beyond the limits of the removed concrete. We recommend field inspection to identify the point of separation and follow-up analysis to obtain a more accurate estimate of the jacking force required to realign the shell and confirm that the concrete cylinder has sufficient capacity to resist the applied forces near the cut edge. Additionally, we recommend a trial be performed before purchasing all components to refine or otherwise modify the approach as necessary.
As an alternative to this approach, steel bucks or stiffeners formed to match the original geometry of the shell can be installed across the cut and pressed into the shell as the threaded rods are tightened to clamp the shell in place. This option may allow the through-bolts (threaded rods) to be installed farther from the cut to decrease the likelihood of interference with concrete removal, but we have not determined a layout or the associated forces required to perform this repair. The use of this option at the horizontal cut may make fabrication easier and less expensive than fabricating curved steel members oriented parallel to the cut, or steel shims can be used at multiple points along a straight member to provide relatively uniform contact on a curved surface. Use of this option will interfere with deposition of a continuous weld bead at the cut line. Workers would make the welds between the steel bucks, remove the bucks, and complete the weld.

Prior to drilling holes for the rods, we recommend scanning the concrete wall to identify reinforcement to avoid further damage. Small diameter pilot holes could also be used to locate the cut when looking from the interior surface. Any cut or damaged reinforcement should be repaired.

We considered other options to align the shell, such as wrapping the structure or a portion of the structure in prestressing tendons and tensioning them to restore the original geometry. This activity seems excessive, would require a specialized workforce, and would interfere with efforts to deposit a continuous weld. We also considered the use of heavy equipment to apply external forces to the shell to push it back into alignment. This approach is not very controlled, may only have local effects, and would likely interfere with the actual repair work. The installation of through-bolts / threaded rods and spreader channels to provide controlled and nearly uniform pressure on the shell, should allow unimpeded access to repair the shell.
6. REINFORCEMENT REPAIRS

To restore the integrity of the reinforced concrete structure, any reinforcement cut during the water jet cutting trials must be spliced. Three types of splices can be used, as follows:

- Lap splices
- Mechanical splices
- Welded splices

Multiple options are available for mechanical and welded splices.

Regardless of the type of splice chosen, samples of the reinforcement should be removed and analyzed in a laboratory to determine the bar material properties and chemistry since the results may eliminate some of the proposed options and will be required to determine appropriate welding procedures and processes.

6.1 Lap Splices

Lap splices involve placing a new bar against or near the existing cut reinforcement. The length of the new bar on both sides of the cut shall be sufficient to develop the strength of the reinforcement through bond with the surrounding concrete. Modern codes, such as ACI 349-13 [5], which references ACI 318-08 [6], require Class B lap splices to ensure ductility when splices are aligned. Per Section 12.15.1 of ACI 318-08 [6], Class B lap splices include a 1.3 multiplication factor on the development length of the reinforcement. Development length provisions are listed in ACI 318-08 Section 12.2 [6].

The use of lap splices is a reliable technology and will meet all code requirements. However, this method requires the largest amount of concrete removal (at least 1 ft-6 in. on either side of the cut) and will likely not be the least-expensive option.

6.2 Mechanical Splices

Mechanical splices are a code-recognized method to splice reinforcement that utilizes additional physical components to grip and restrain segments of reinforcement through mechanical means such as threads, friction, and bearing. Both ACI 318-08 [6] and ACI 349-13 [5] include requirements for the use of mechanical splices; ACI 349-13 [5] requirements are more stringent than ACI 318-08 [6].
Section 12.14.3.2 of ACI 318-08 [6] requires that mechanical splices develop in tension or compression, as required, at least 1.25 times the yield strength of the bar. This is referred to as a Type 1 splice. Section 12.14.3.2 of ACI 349-13 [5] requires that the mechanical splice develop the specified tensile strength of the bar in tension and 125% of the yield strength of the bar in compression. This is referred to as a Type 2 splice. Additionally, Section 12.14.3.7 of ACI 349-13 [5] requires staggering of mechanical splices by at least 30 in. if the strain measured over the full length of the splice exceeds by 50% or more the strain in a bar that is not mechanically spliced.

Since the reinforcement is expected to have a minimum yield strength less than 40,000 psi and a minimum ultimate tensile strength less than 75,000 psi [10, 11, 14], a mechanical coupler qualified as a Type 1 splice for a Grade 60 bar will meet both strength criteria. We have not reviewed mechanical splice stiffness data to determine which products meet the ACI 349-13 [5] criteria to prevent staggering but believe these components exist for the bar sizes applicable to this structure.

Two concerns about the use of mechanical splices to repair in-situ rebar are the ability to install the splice over in-place bars and the intrusion of the enlarged diameter of the component into the existing concrete cover. Offset splices can be used that includes the addition of another piece of reinforcement that alleviates fit-up concerns. As previously stated, we are unaware of the concrete cover and suspect it may be as small as 3/4 in. to represent interior / non-exposed conditions. A concrete cover this small will make it challenging to install the splice and maintain minimum required concrete cover.

Mechanical splicing is a viable solution; however, there are some risks given the uncertainty in the material strength and concrete cover.

6.3 Welded Splices

Welded splices are allowed by code. Section 12.14.3.4 of ACI 318-08 [6] requires welded splices to develop at least 1.25 times the yield strength of the bar. This requirement also applies to designs governed by ACI 349-13 [5]. Reinforcement welds are not prequalified. The typical approach requires development of a welding procedure and qualification of the process and welder(s) by creating a welded specimen using the actual material with those or similar dimensions, cutting it, and performing a macroetch examination for soundness. AWS D1.4 [9] provides requirements for this work.
As referenced by ACI 318-08 [6] and ACI 349-13 [5], AWS D1.4 governs welded reinforcement splices and provides criteria and pre-qualified joint types. Three types of joints are available, as follows:

- Direct butt joints
- Indirect butt joints
- Lap joints

Figure 7 shows examples of direct butt joints as presented in AWS D1.4. We prefer these joints from a technical perspective since they provide a clear, concentric load path. However, other than possibly Detail C for horizontal reinforcement, it is likely not feasible to use these types of joints to splice the existing reinforcement on the far face of the section. It is also possible that the contractor performing the work could qualify a full-penetration weld that does not require back-gouging or backing, but that is unknown at this time.

Figure 8 shows examples of indirect butt joints as presented in AWS D1.4. Several options are available, but welding to the far face of a bar will be difficult, and installing a piece of steel within the concrete cover may violate code cover requirements. An indirect butt joint that allows welding from one side will be preferred. Per Section 3.2.1 of AWS D1.4, transverse reinforcement is required at indirect butt joints to prevent splitting of concrete caused by eccentricity in the joint. We expect that three or four No. 3 seismic ties (135 deg hook on one end and 90 deg hook on the other end) will be sufficient to restrain the concrete at the splice.

Figure 9 shows examples of lap joints as presented in AWS D1.4; two options are presented. An additional steel plate or reinforcement bar is required. As is the case for indirect butt joints, Section 3.2.1 of AWS D1.4 requires transverse reinforcement at lap joints to prevent splitting of concrete caused by eccentricity in the joint. We expect the same transverse reinforcement details can be used as for indirect butt joints in this case.

The lap joint provides the greatest flexibility but requires the use of another bar or steel plate. Spliced bars should be comparable in chemistry and mechanical properties to the original steel. Assuming the original bars are made from ASTM A15 Structural Grade, ASTM A615 Grade 40 bars are likely the closest match. As previous stated in this report, rebar samples should be extracted and tested to determine their critical properties and support development of welding details.
All three welded splice options satisfy code requirements, but the direct butt joint will be the most difficult to create, particularly if welding through the entire cross section. The indirect butt and lap joints where the bars are welded at a visible face of the bar are the most practical. A steel plate or additional bar, plus No. 3 transverse reinforcement, are required at these welded splice joints.

![Direct Butt Joints per AWS D1.4](#)

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**Figure 7 – Direct Butt Joints per AWS D1.4 [9]**
Figure 8 – Indirect Butt Joints per AWS D1.4 [9]

Notes:
1. Gaps between bars and plate will vary depending on height of deformations but shall not exceed \( \frac{1}{4} D \text{ or } \frac{3}{16} \text{ in. (5 mm)} \), whichever is less.
2. Deformations shown on sectional views are for illustrative purposes only.
Figure 9 – Welded Lap Joints per AWS D1.4 [9]
7. CONCRETE REPAIRS

Concrete repairs include the following basic steps:

- Concrete removal
- Surface preparation of concrete and exposed reinforcement
- Installation of supplemental reinforcement
- Forming
- Pre-placement activities
- Placement
- Curing and protection

7.1 Concrete Removal

Chipping guns or hydrodemolition can be used to remove the concrete surrounding the cut reinforcement and to provide access to the interior face of the steel plate. We expect the concrete to be sound, which may require the use of relatively heavy 30 lb. chipping hammer to remove the majority of the concrete. Sufficient concrete must be removed to provide access to splice the reinforcement and allow new concrete or repair material to encapsulate the rebar and splice. Concrete should be removed around all exposed bars to provide a minimum 3/4 in. clearance. To the extent possible, a rectangular cavity should be made for concrete placement with the sides of the placement area perpendicular to the circumference. Edges should be saw-cut to a minimum depth of 3/4 in. (avoiding reinforcement) to allow for bonding and consolidation. Feathered edges must be avoided.

The specified nominal concrete strength is 2,500 psi; however, we expect the actual strength is higher. We expect that concrete removal performed from the exterior of the structure will require less effort than concrete removal performed from the interior with respect to required volume of concrete to be removed and replaced and the amount of reinforcement to clean prior to placement. With the potential code complication related to the backing as discussed in Section 9.1, both approaches are technically sound, and the selected repair approach should consider all aspects of the repair, including working environment, access, safety, reliability, cost, and schedule.
7.2 Surface Preparation

All concrete surfaces against which fresh concrete or cementitious repair material will be placed should be prepared by roughening to a minimum average 1/4 in. amplitude. This is often done with a bush hammer or other impact device. Excessive force that will bruise the near-surface concrete should be avoided.

The reinforcement should be cleaned to remove all loose mill scale, loose rust, loose paint, and other detrimental foreign matter. This may be accomplished by hand chipping, scraping, sanding, and wire brushing to meet SSPC-SP2 Hand Tool Cleaning [15] or by power wire brushing, power sanding, power grinding, power tool chipping, and power tool descaling to meet SSPC-SP3 Power Tool Cleaning [16].

Surfaces of concrete should be cleaned to remove dust and all deleterious substances that may interfere with bond. Pressure-washing the surface after it has been roughened is typically suitable to accomplish this.

We do not expect that the reinforcement is significantly corroded and in need of a protective coating or bonding agent. A protective coating such as Sika Armatec EpoCem 110 can be applied, if needed.

7.3 Installation of Supplemental Reinforcement

As noted in the previous section on splices, additional reinforcement may be required to prevent concrete splitting at splice repairs where eccentricity is introduced into the connection. Where sufficient room is available to develop the bars with hooks or bar end anchorages (e.g., Lenton Terminators), the reinforcement (likely No. 3 bars, ASTM A615 Grade 40) should installed by wire-tying it to the existing reinforcement. Where the cavity is too small to develop the new reinforcement, holes can be drilled into the existing concrete and the bars set in epoxy adhesive. Plastic or plastic-tipped chairs, if needed, should be used to ensure proper concrete cover for the new reinforcement.

7.4 Materials

The exact amount of concrete or repair material needed to restore the concrete shell is unknown and depends upon the length of the cuts and the amount of concrete removed at each cut. Assuming a total cut length of 50 ft and a full 1 ft thickness removal width of 1.5 ft, we estimate approximately 3 cu yds of material are required for placement. Additional material may be needed for testing, particularly if concrete produced from a batch plant is used.
Depending upon the volume of material desired to be placed at one time, either concrete produced from a batch plant or pre-bagged concrete repair material prepared onsite can be used. Depending upon the placement dimensions, pre-bagged repair mixes that do not already contain aggregate may require extension with 3/8 in. diameter aggregate to reduce heat of hydration. Follow the manufacturer’s requirements. Given the volume of concrete or repair material used, we anticipate that pre-bagged repair material would be used and extended with aggregate if it was not part of a purchased product.

The use of individually purchased materials, particularly aggregate, requires qualification. Many of the aggregate sources local to INL are known to contain potentially reactive aggregate. Materials must be carefully selected to restrict reactivity, or mitigation strategies must be incorporated into concrete mixes to manage the effects. Mix development including mitigation can be a lengthy process. We recommend using a prequalified mix with non-reactive aggregates or procuring pre-bagged repair mixes and non-reactive aggregate rather than developing a new concrete mix.

Pre-bagged repair mixes may be purchased with corrosion inhibitors and shrinkage-compensating properties. We do not expect that the reinforcement is corroded and therefore do not believe corrosion inhibitors are required in the mix, but given the dimensions of the repair areas (long and relatively narrow and thin) we recommend non-shrink mixes for this application if the entire volume will be placed at once. As an alternative, multiple placements and / or the addition of reinforcement or welded wire fabric may be warranted to control shrinkage in the long dimension.

Pumping the concrete or repair material presents special challenges; some mixes are more pumpable than others, meaning they will not segregate during pumping and will flow easily through the lines without requiring excessive pressures. Aggregate gradation and other mix proportions should be carefully considered if pumping is selected as the means to deliver the material to the repair areas.

### 7.5 Forming

The placement area should be formed by installing forms tight to the adjacent concrete, using gaskets and anchors as needed to make the forms watertight. Permanent anchors should be stainless steel; anchors removed after placement can be carbon steel. The forms should be designed and constructed assuming lateral fluid pressure of wet concrete (approximately 150 lbs per cubic foot) for the maximum placement height. The formwork should include
pluggable drains to remove the water and access and vent holes to enable consolidation, if needed, and prevent entrapping air. If concrete is placed from the interior, the forms should also contain access ports or bird’s mouths to allow concrete placement. Form release agent may be applied to the inside surface of the form, if necessary, being careful not to contaminate the concrete and reinforcement surfaces.

Any pre-molded joint filler that has been removed to provide access to the shell surface for installation of backing and welding must be replaced to maintain separation of the concrete from the steel shell. If the original material is no longer available, various rigid fiberboard and moldable foam products are available. Seams should be sealed with compatible products. Plastic sheeting can be used as a bond-breaker or to help contain moisture within the fresh concrete, if needed. We expect that plastic sheeting would only be used if the joint filler material was highly porous or if there was insufficient room to install the joint filler material.

7.6 Pre-placement Activities

To avoid excessive loss of moisture from the fresh concrete / repair material into the adjacent concrete, the placement area should be presoaked for 24 hrs prior to placement. The area should be drained approximately 4 hours prior to placement and all standing water removed.

7.7 Placement

Concrete or repair material will likely be placed using a form-and-pour or form-and-pump approach. As noted earlier, pumping presents challenges for the mix. It also requires equipment and a skilled operator. A pump truck is likely excessive for this activity but, if selected, requires access and venting if placed inside the Containment Building and concrete placement is from the interior. We are not aware if sufficient access is available for a pump truck to enter the facility. An in-line pump may be an option; we have not explored this.

A form-and-pour approach includes transporting the concrete or repair material to the repair areas and manually depositing it in the forms. Among other options, a crane and bucket can be used to transport and deposit the material, buckets of material may be hoisted to the placement area, or a limited amount of material may be transported via an aerial lift by a lift operator.

Concrete placement from the exterior will require openings in the steel shell that must be plugged after the placement.

Unless the concrete mix is self-consolidating, consolidation will be required to ensure uniformity of material placement and removal of voids. Mechanical vibration should be used for batched
concrete mixes and manufacturer’s recommendations should be followed for pre-bagged repair mixes.

7.8 Curing and Protection

The placement must be cured and protected from extreme temperatures and weather. We recommend a 7-day wet / moist cure with the forms in place; however, other means may be appropriate.
8. SHELL REPAIRS

The photographs do not clearly show the cut surfaces of the shell after the water jet cutting process; however, we expect that the edges are not appropriate for welding the shell back together without preparation. Two options to restore the capacity of the shell are presented below. A third option, which is likely easier and less costly, is also presented, but it does not restore the full capacity of the shell and is presented only as a potential option if an evaluation for calculated design demands is considered.

8.1 Backing

One of the primary challenges with the shell repairs is the installation and removal of backing. The following paragraphs identify code provisions related to backing.

According to Section 5.9.1.2 of AWS D1.1 [8], steel backing must be made continuous for the full length of the weld. All joints in steel backing shall be code-compliant complete joint penetration (CJP) groove welds. The code allows for exceptions in closed sections when approved by the Engineer. Additional code investigation and discussion with the code authors and/or welding specialists is required to determine if welding of the EBR-II Containment Building shell is a justified exception to this code requirement.

Because welds to backing bars can be highly susceptible to fatigue under cyclic loading, Section 5.9.1.4 of AWS D1.1 [8] typically requires that for cyclically loaded nontubular structures, steel backing of welds transverse to the computed stress shall be removed and the joints ground or finished smooth. Other conditions do not necessarily require removal of the backing, but when external welds are used to attach longitudinal steel backing that is to remain in place, the welds must be continuous fillet welds on both sides of the backing. Section 5.9.1.5 of AWS D1.1 [8] does not require backing to be welded full length or removed for welds in statically loaded members. In AWS D1.1 [8] terminology, cyclically loaded structures are those subjected to fatigue. Structural evaluation is required to determine if the stresses in the welds from cyclic loading, e.g. wind, are high enough to require compliance with these provisions.

Section 5.9.3 of AWS D1.1 [8] allows the use of non-steel backing. Copper, flux, glass tape, ceramic, iron powder, or similar materials that prevent melt-through are acceptable. Securing them in place may be challenging.

We present two options below that include the use of CJP welds. These require backing. For cost estimation, we recommend assuming that the backing may be tacked into place but must
be removed. A cost reduction will be realized if these conditions represent justified exceptions to the code; however, additional engineering effort, including calculation of demands, is likely required.

8.2 Weld Cut Joint

One option, which we have discussed with Mr. Raymond Clark, Fabrication Manager at MFC Fabrication Services at INL, is to perform arc air welding to gouge out the joint after realigning the shell. This process removes molten metal to enlarge the joint. Following the arc air welding process, the shell edges can be prepared with a grinder to create the desired profile. Steel backing would be installed from the inside of the structure and attached to the inside surface of the shell. Then, a CJP groove weld can be made to rejoin the shell pieces.

The arc air welding and joint preparation processes may create a root gap that is larger than any prequalified joint. If this occurs, a special detail can be prepared that must be tested to qualify the joint and welder. AWS D1.1 [8] includes provisions to perform this work.

One of the challenges to this approach is installing backing through both layers of reinforcement. Additionally, backing installed at the horizontal joint must be fabricated to match the curvature of the shell.

To help facilitate installation of the backing, the backing materials can be discontinuous plates that are butted and tacked together, but then they likely need to be removed after the shell is welded. Also, it is reasonable to expect that cutting of some reinforcement can be allowed as a temporary measure to provide better access. This approach should be confirmed by analysis but limiting the cut reinforcement to no more than two consecutive bars should be acceptable. All cut bars must be repaired.

8.3 Weld Inset Plate

Cutting the shell and installing an inset plate of the same or similar chemistry using CJP groove welds at all interfaces to the existing shell will restore the full capacity of shell. Similarly, if more than one plate is used, joints between plates should be made continuous through CJP groove welding. Depending upon the circumferential length of the plate, a planar plate may be sufficient if the horizontal edges align with the existing shell and allow for CJP welding within fit-up tolerances of the selected joint detail. To repair the horizontal cut in the shell, the use of a curved replacement plate (and backing plate) will be required.
This process is likely more work than the first option and will require more backing and welding, but it may allow reinforcement and concrete repair work to be performed from the exterior face of the structure. If work is performed from the exterior, the joint filler would be removed and concrete cast prior to making the shell repairs. Steel backing would be installed within the 1/2 in. gap previously occupied by the joint filler material. As noted above, installation and removal of the steel backing presents a challenge if work is performed from the exterior. A code clarification is required to determine the suitability of performing the work from the exterior.

8.4 Welded Cover Plate

Installing a cover plate over the cut in the shell and attached to the shell by fillet welding is easier and less expensive but does not fully restore the integrity of the shell. It is likely sufficient to resist all standard natural phenomena loading but does not provide the same capacity as an inset plate connection and technically does not meet the objective of this assignment.

8.5 Through-bolt Hole Repairs

To prevent potential degradation of the isolation material if not suitable for long-term exposure to weather, limit exposure of the concrete to weather, and restore the general appearance of the steel shell, through-bolt (threaded rod) holes in the shell should be repaired if the threaded rods are required to be removed. As a maintenance-free repair, we propose to repair the holes by placing steel plates over the holes and attaching the plates to the shell with fillet welds around the perimeter of the plates. These small holes in the shell will not significantly degrade the capacity of the shell and do not warrant special to attempt to try to install complete joint penetration welds without backing. In lieu of welded plates, the holes could be filled with sealant; however, maintenance may be required.
9. CONCLUSIONS

Based on the information provided to us by BEA and our work, including assumptions made, we conclude the following:

1. The EBR-II structure can be repaired to restore its capacity prior to the two vertical cuts and the one horizontal cut.

2. Assuming interior access is available at all cut locations, the complete repair may be performed from a combination of the interior and exterior of the structure.

3. If all work must be performed from the exterior at one of the locations, additional evaluation is required to compute stresses from cyclic loading and determine the applicability of specific code provisions related to installation and removal of backing.

4. Some of the construction details and material properties are unknown but can be determined through investigation and laboratory testing.

5. Development of appropriate reinforcement splice details requires sampling and laboratory testing. If welded splices are used, joint and welder qualification is required.

6. Based on considerations of code compliance and level of effort, performing the repairs utilizing interior access is the best approach. Our proposed repair procedure is presented in Section 11 and depicted in conceptual details suitable for pricing on drawings included in Appendix A. Additional effort is required to develop construction details and specifications.

7. Uncertainties exist in the proposed conceptual repair procedure that should be considered when preparing pricing, as follows:
   a. The availability of interior access at all three cut locations, particularly the joint near the top of the cylinder.
   b. The ability to realign the shell to its original geometry by applying force to it at a distance away from the cut edges.
   c. The magnitude of force required to realign the cut shell.
   d. The ability to gouge out material at the cut and prepare the joint for welding without requiring another plate.
   e. The ability and effort required to install and remove the steel backing to meet code requirements.
   f. The ability to make welded splices by working through the existing reinforcement cage.
PROPOSED REPAIR PROCEDURE

When interior access is available, we recommend performing repairs utilizing the interior space. Under the assumption that this is logistically possible, such as without interferences from the corbel that supports the polar crane rail, we have prepared conceptual details suitable to estimate the cost of the work. The drawings are provided as Appendix A to this report.

These conceptual details are based on the following logic, which represents one way to perform the work. Alternatives are available, and options are available within the general approach. Specific means and methods, such as the concrete transportation and placing technique, are not included in the logic below and should be selected by someone with knowledge of preferred practices, labor skill, cost, and availability of equipment and materials.

1. Scan the wall to identify reinforcement and other embedded items. Drill pilot holes if needed to help locate the cuts on the inside surface.

2. Install threaded rods and steel members on either side of the cuts where needed to realign the shell.
   a. This may not be needed at the horizontal cuts since the shell is unlikely to have displaced because of a circumferential cut.
   b. Remove the waterjet guide track if it interferes with the work.

3. Remove concrete full depth from the interior surface to provide access to the cut reinforcement and pre-molded joint filler. Saw-cut edges. Roughen the exposed surfaces to minimum average 1/4 in. magnitude.

4. Remove the pre-molded joint filler material. Leave neat, square edges to allow for installation of new material during repairs.

5. Prepare shell at cuts from the exterior surface. Use arc air welding, grinding, or other process to remove material at the cut edges. Grind edges smooth to prepare surfaces for welding.

6. Install steel backing from the interior. Tack weld to the inside surface of the shell.
   a. At the horizontal cut, fabricate the backing to match the curvature of the shell.
   b. Backing may be installed in multiple pieces but must provide a continuous surface for welding.
   c. Installation of backing may require cutting of reinforcement. Do not cut more than two consecutive bars per face without Engineering approval. All cut bars shall be repaired.

7. Repair the shell using CJP groove welds.
   a. If the root opening is too large to satisfy AWS D1.1 [8] criteria for prequalified welds for the selected process, prepare procedures to qualify the weld and welders.
b. Remove steel backing after completion of welding.
c. Inspect 100% of the length of all CJP welds using non-destructive volumetric methods.

8. Clean the exposed reinforcement to SSPC SP-2 [15] or SP-3 [16].

9. Repair the cut reinforcement by welding in accordance with AWS D1.4 [9], using one of the recommended welded splice details in that document.
   a. The reinforcement material and grade are unknown. Perform mechanical and chemical tests on specimens of the actual material to determine its properties and enable preparation of procedures and selection of filler material.
   b. Prepare procedures and qualify the weld and welders.
   c. If an indirect butt joint or lap joint is selected, transverse reinforcement is required at the splice.
   d. Inspect all welds visually and in accordance with project criteria.

10. Clean the concrete to remove any deleterious substance.

11. Install joint filler / expansion material to replace removed material. Seal joints to contain fresh concrete. Install plastic sheeting, if needed. Install transverse reinforcement as needed.

12. Install formwork against the interior surface of the structure. Provide watertight forms using gaskets and anchors as needed. Install access and vent holes to enable placement and prevent trapping air.

13. Presoak the repair area for 24 hrs prior to concrete placement. Remove water 4 hrs before placement.

14. Place batched concrete or pre-bagged repair material (extended with 3/8 in. aggregate if not pre-extended) mixed onsite using form-and-pump or form-and-pour methods. Unless self-consolidating concrete is used, mechanically vibrate batched concrete to ensure uniformity of the placed material and remove air voids. Follow manufacturer’s requirements for consolidation of pre-bagged repair material.

15. Cure and protect placed concrete / repair material. Wet/moist cure in forms for minimum 7 days.

16. Remove formwork and through-bolts and hardware.

17. Grout through-bolt holes and repair unsatisfactory defects within the repair area.

18. Repair bolt holes in the shell by fillet-welding steel cover plates over the holes.
11. REFERENCES


[5] American Concrete Institute Committee 349, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, ACI 349-13, American Concrete Institute, Farmington Hills, MI, June 2014.

[6] American Concrete Institute Committee 318, Building Code Requirements for Structural Concrete and Commentary, ACI 318-08, American Concrete Institute, Farmington Hills, MI, June 2008.

[7] American Concrete Institute Committee 318, Building Code Requirements for Reinforced Concrete, ACI 318-56, American Concrete Institute, Detroit, MI, July 1956.


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Appendix A
1. THESE DRAWINGS ARE INTENDED TO PROVIDE A CONCEPTUAL REPAIR PLAN FOR THE EXISTING WATERJET CHIMNEY AND GUIDE TRACK HOOD.

2. THESE DRAWINGS PROVIDE A CONCEPTUAL REPAIR PLAN FOR THE EXISTING WATERJET CHIMNEY AND GUIDE TRACK HOOD.

3. THESE DRAWINGS PROVIDE A CONCEPTUAL REPAIR PLAN FOR THE EXISTING WATERJET CHIMNEY AND GUIDE TRACK HOOD.

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5. THESE DRAWINGS PROVIDE A CONCEPTUAL REPAIR PLAN FOR THE EXISTING WATERJET CHIMNEY AND GUIDE TRACK HOOD.

6. CONCEPTUAL REPAIRS ARE BASED ON LIMITATIONS OF INFORMATION THAT REQUIRE CONFIRMATION AND EVALUATION PRIOR TO USE.

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50. CONCEPTUAL REPAIRS ARE BASED ON LIMITATIONS OF INFORMATION THAT REQUIRE CONFIRMATION AND EVALUATION PRIOR TO USE.
INSTALL STEEL BACKING FROM THE INTERIOR. TACK WELD TO THE INSIDE SURFACE OF THE SHELL.

PREPARE SHELL AT CUTS FROM THE EXTERIOR SURFACE. USE ARC AIR GOUGING, GRINDING, OR OTHER PROCESS TO DETERMINE ITS PROPERTIES AND ENABLE PREPARATION OF PROCEDURES AND SELECTION OF FILLER MATERIAL.

REPAIR THE SHELL USING COMPLETE JOINT PENETRATION (CJP) GROOVE WELDS.

A. AT THE HORIZONTAL CUT, FABRICATE THE BACKING TO MATCH THE CURVATURE OF THE SHELL.

C. INSTALLATION OF BACKING MAY REQUIRE CUTTING OF REINFORCEMENT. DO NOT CUT MORE THAN TWO INCHES OF REINFORCEMENT IF REQUIRED (NOT FOR CONSTRUCTION). BACKING MAY BE INSTALLED IN MULTIPLE PIECES.

B. PREPARE PROCEDURES AND QUALIFY THE WELD AND WELDERS.

A. IF THE ROOT OPENING IS TOO LARGE TO SATISFY AWS D1.1 CRITERIA FOR PREQUALIFIED WELDS FOR THE SELECTED PROCESS, PREPARE PROCEDURES TO QUALIFY THE WELD AND WELDERS.

STEP 6:
INSTALL JOINT FILLER/EXPANSION MATERIAL TO REPLACE REMOVED MATERIAL. SEAL JOINTS TO ENSURE UNIFORMITY OF THE PLACED MATERIAL AND REMOVE AIR VOIDS. FOLLOW MANUFACTURER'S INSTRUCTIONS.

UNLESS SELF-CONSOLIDATING CONCRETE IS USED, MECHANICALLY VIBRATE BATCHED CONCRETE TO HELP DETERMINE ITS PROPERTIES AND ENABLE PREPARATION OF PROCEDURES AND SELECTION OF FILLER MATERIAL.

PLACE BATCHED CONCRETE OR PREBAGGED REPAIR MATERIAL (EXTENDED WITH 3/8 IN. AGGREGATE IN N) CHANNELS FOR PRICING).

FORMS USING GASKETS AND ANCHORS AS NEEDED. INSTALL ACCESS AND VENT HOLES TO ENABLE REMOVAL EACH LINE OF CUT.

PLACE CONCRETE OR PREBAGGED REPAIR MATERIAL TO REPLACE REMOVED MATERIAL. SEAL JOINTS TO ENSURE UNIFORMITY OF THE PLACED MATERIAL AND REMOVE AIR VOIDS. FOLLOW MANUFACTURER'S INSTRUCTIONS.

STEP 7:
REMIove THE PREMOLDED JOINT FILLER MATERIAL. LEAVE NEAT, SQUARE EDGES TO ALLOW FOR INSTALLATION OF NEW REINFORCEMENT.

STEP 8:
INSTALL TRANSVERSE REINFORCEMENT AS NEEDED.

STEP 9:
CLEAN ALL EXPOSED REINFORCEMENT TO SSPC SP-2 OR SSPC SP-3.

STEP 10:
PREPARE PROCEDURES TO QUALIFY THE WELD AND WELDERS.

STEP 11:
INSTALL JOINT FILLER/EXPANSION MATERIAL TO REPLACE REMOVED MATERIAL. SEAL JOINTS TO ENSURE UNIFORMITY OF THE PLACED MATERIAL AND REMOVE AIR VOIDS.

STEP 12:
INSTALL TRANSVERSE REINFORCEMENT TO MEMBERS.

STEP 13:
INSTALL THE REPAIR SHELLS FOR 2 HOURS PRIOR TO CONCRETE PLACEMENT. REMOVAL OF WATER IS REQUIRED. PLACE CONCRETE OR PREBAGGED REPAIR MATERIAL TO REPLACE REMOVED MATERIAL. SEAL JOINTS TO ENSURE UNIFORMITY OF THE PLACED MATERIAL AND REMOVE AIR VOIDS. FOLLOW MANUFACTURER'S INSTRUCTIONS.

STEP 14:
INSTALL FORMWORK AGAINST THE INTERIOR SURFACE OF THE STRUCTURE. PROVIDE WATERTIGHT GASKETS AND ANCHORS AS NEEDED. INSTALL ACCESS AND VENT HOLES TO ENABLE REMOVAL EACH LINE OF CUT.

STEP 15:
REPLACE THE SHELLS USING COMPLETE JOINT PENETRATION (CJP) GROOVE WELDS.

STEP 16:
INSTALL JOINT FILLER/EXPANSION MATERIAL TO REPLACE REMOVED MATERIAL. SEAL JOINTS TO ENSURE UNIFORMITY OF THE PLACED MATERIAL AND REMOVE AIR VOIDS. FOLLOW MANUFACTURER'S INSTRUCTIONS.

STEP 17:
INSTALL REINFORCEMENT MATERIAL AND GRADE ARE UNKNOWN. PERFORM MECHANICAL AND CHEMICAL TESTS ON SPECIMENS OF THE ACTUAL MATERIAL AND JOINT FILLER MATERIAL.

STEP 18:
PREPARE PROCEDURES TO QUALIFY THE WELD AND WELDERS.

STEP 19:
INSTALL JOINT FILLER/EXPANSION MATERIAL TO REPLACE REMOVED MATERIAL. SEAL JOINTS TO ENSURE UNIFORMITY OF THE PLACED MATERIAL AND REMOVE AIR VOIDS. FOLLOW MANUFACTURER'S INSTRUCTIONS.
STEP 16: REMOVE FORMWORK, THREADED RODS, AND HARDWARE.

STEP 17: GROUT THREADED ROD HOLES AND REPAIR UNSATISFACTORY DEFECTS WITHIN THE REPAIR AREA.

STEP 18: REPAIR THREADED ROD HOLES IN THE SHELL BY FILLET-WELDING STEEL COVER PLATES OVER THE HOLES.