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SEISMIC EVALUATION AND UPGRADE OF TEST REACTOR HEAT EXCHANGER SUPPORTS

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ABSTRACT

Existing nuclear structures, systems and components (SSC) may require evaluation as seismic criteria is revised over time. SSCs or their attachments may need to be upgraded to meet code requirements for the revised seismic criteria. Therefore, a comprehensive effort from a qualified design team will be beneficial to the success of the project. In this paper, we discuss a case study of seismic evaluation and upgrade of a test reactor's heat exchanger supports for Performance Category (PC)-4 criteria according to DOE-STD-1020-2002. The scope of the structural evaluation included evaluation of tie rod assemblies, reinforced concrete column and wall supports and the respective attached anchorage. We found that the tie rod assemblies at top, and reinforced concrete column supports and wall supports at the bottom required upgrade to meet code and project requirements. Per the owner's request, we designed new anchorage at the tie rod assemblies. We also designed steel jacket assemblies at the concrete columns to resist bi-axial bending and to transfer column top anchorage demands to the foundation. Per ACI 349-06, ductile failure modes for anchorage to concrete are encouraged or significant capacity reduction factors must be used. At tie rod anchorage to walls and column upgrade anchorage at the floor, we developed a design using reduced section dog-bone connection plates to ensure a ductile failure mode at the connections, which helped reduce the overall anchorage design details. We worked through many design changes during upgrade construction due to unexpected interferences and fit-up issues. This paper discusses our seismic evaluation, upgrade design and construction support for the heat exchanger supports.

INTRODUCTION

The pressurized water reactor began operation in 1969. A seismic assessment of the seismic category I components performed prior to our involvement identified the supports of the five primary heat exchangers as components needing to be addressed. The operator requested our independent assessment, and we determined the methodology to perform seismic upgrade design for the supports of the five primary heat exchangers.

EXISTING CONDITIONS

The primary heat exchangers are located in a reinforced concrete structure. The primary heat exchangers are identical and aligned in the east-west direction. Four of the heat exchangers are located in a common pit. The fifth heat exchanger is located in a separate pit to the east (Figure 1).

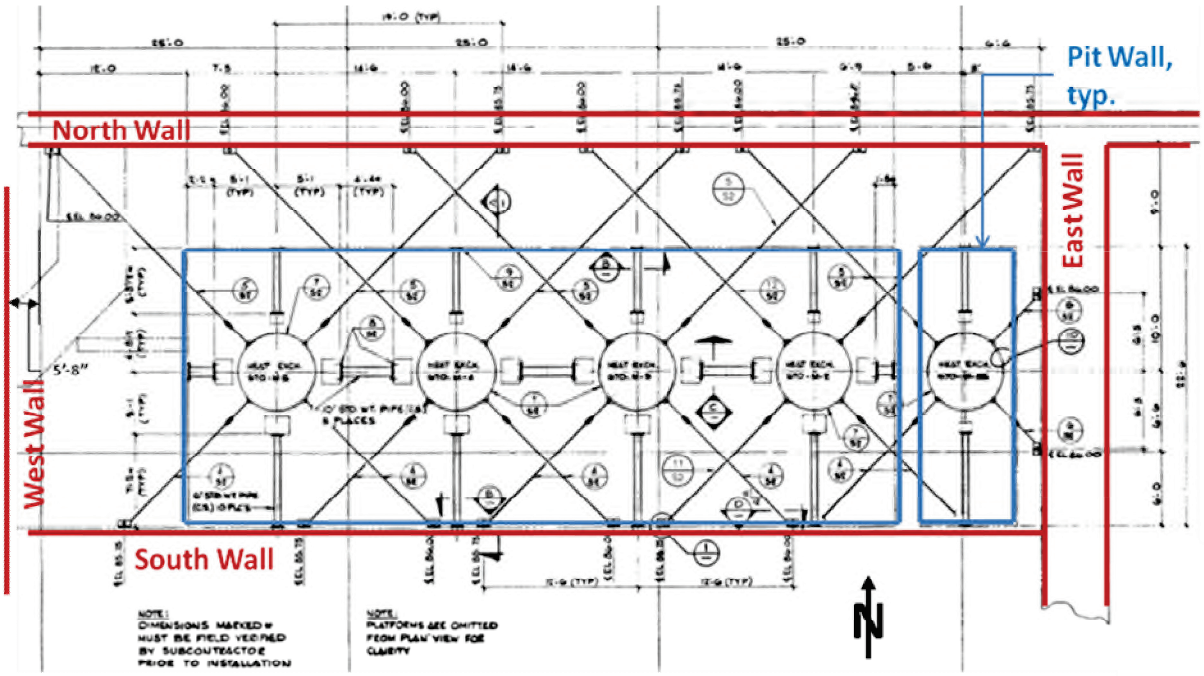

Figure 1. Annotated plan view of the primary heat exchangers and supports, Ebasco (1964)

Each of the five heat exchangers is a vertical U-tube and shell unit, approximately 38 ft tall from head to head (top to bottom) with an outside diameter of 5 ft – 9 in. and has a filled weight of approximately 113,000 lb.

The four western heat exchangers are supported near the base vertically by structural steel arms that attach to 24 in. x 18 in. x 6 ft – 7 in. tall reinforced concrete columns on the east, west and south and to a W12x45 column to the north. Attachment to the concrete columns is through four cast-in L-shaped anchor bolts. Attachment to the steel columns is through bolted and welded connections, and the steel columns are attached to the concrete floor through expansion (cinch) anchors. The north and south columns are braced laterally in the north-south direction to the pit walls with structural steel pipe sections, and the east and west columns are braced laterally to the pit walls or adjacent columns by structural steel pipe sections. The pipe braces are welded to end plates that are welded to the steel columns and attached to the pit walls by four expansion anchors.

The eastern heat exchanger is supported near the base vertically by W12x45 columns to the north and south and by pockets in the pit walls to the east and west. Structural steel pipe sections brace the steel columns in the north-south direction as discussed above. Attachment to the west concrete wall is through four cast-in L-shaped anchor bolts; attachment to the east concrete wall is through four cast-in straight anchor bolts with plate washers at the embedded end. Access to the wall pocket connections is limited.

The heat exchangers are each braced laterally near the top by a set of four tie rods attached to a belly band that surrounds the heat exchangers. The tie rods are oriented diagonally in plan and attach to the reinforced concrete walls through anchor plates, each secured with four expansion anchors. Interference from existing piping and conduit runs prevents some of the tie rods from maintaining a horizontal plane. Figure 2 shows a view of the heat exchangers looking to the west.

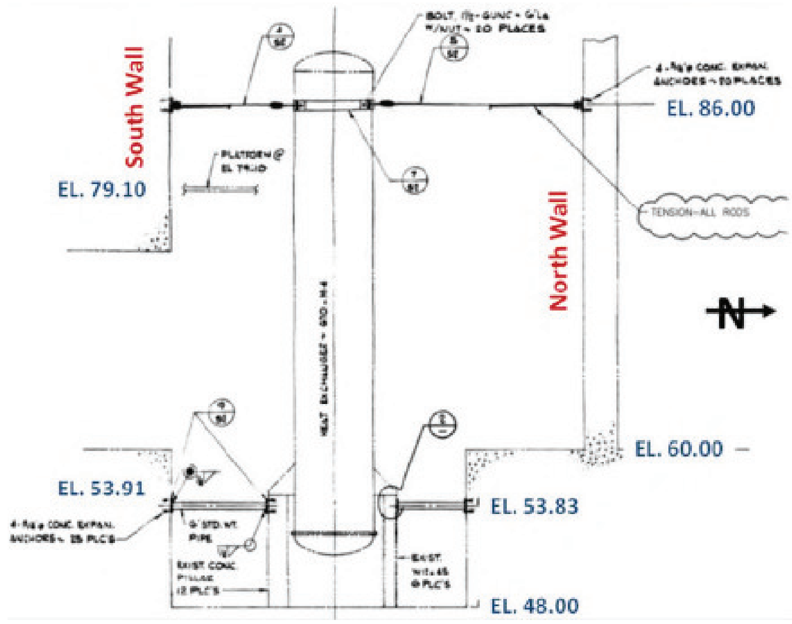

Figure 2. Elevation view of primary heat exchanger looking west, Ebasco (1964)

We reviewed the following components to determine if they met the governing standards:

- Tie rod assemblies, including anchorage, belly band, and attachments
- Reinforced concrete column supports and top and bottom anchorage
- Anchorage to reinforced concrete walls

EVALUATION AND UPGRADE CRITERIA

Evaluation Criteria

The governing standards include:

- *Natural Phenomena Hazard Design and Evaluation Criteria for DOE Facilities*, DOE-STD-1020-2002,
- *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*, ASCE/SEI 43-05, and

For application of ASCE/SEI 43-05 criteria, the primary heat exchangers fall under Seismic Design Category (SDC) 5. Limit state C is appropriate. This work is considered Safety-Related and operates under ASME NQA-1 requirements.

Upgrade Criteria

The structural analysis and upgrade design related to reinforced concrete and attachments conforms to *Code Requirements for Nuclear Safety-Related Concrete Structures (ACI 349-06) and Commentary*.

The analysis and design of anchorage to concrete was performed in accordance with the following criteria:

- Concrete is assumed to be cracked under service load conditions unless justified by non-destructive field evaluation.
- Specified post-installed anchors are undercut-type anchors and have been previously tested or tested before final design and deemed suitable for dynamic loading by the International Code Council (ICC). Section 6.3 of ASCE 43-05 requires undercut anchors for SDC-5.

- The design drawings specify the testing requirements for anchorage.

The structural evaluation and upgrade design related to structural steel components conforms to *Specification for Structural Steel Buildings*, ANSI/AISC 360-05, and *Specification for Safety-Related Steel Structures for Nuclear Facilities*, ANSI/AISC N690-06.

LOADING

Seismic loads are typically calculated based on combining co-directional responses by the Square Root of the Sum of the Squares (SRSS) or by the 100-40-40 combination per ASCE 4-98. The SRSS approach causes the signs of the seismic terms to be lost, so they are typically added to and subtracted from the nonsiesmic loads to ensure the maximum effects are captured. The facility operator provided design loads at the tie rods at top and reactions at bottom that were based on the 80% nonexcedence probability demands from a probabilistic seismic analysis. The column loads were provided as vertical, tangential, and radial loads as absolute values, and they were not separated into dead, live, and seismic components. Figure 3 shows the orientation of the loading.

Initially, we conservatively considered the full magnitudes of the provided loads to act simultaneously in orientations selected to create the worst case effects on the evaluated element. However, it soon became apparent that this approach produced design demands on certain elements that were unrealistic, so with the facility operator's approval, we performed additional limited finite element analyses to develop more reasonable design demands and determine an appropriate sign convention for each load system.

In addition to the loads noted above, we considered environmental effects such as temperature and humidity ranges and also accident conditions such as flooding of the pit. Since the pipe struts were below the accident flood level, we considered the effects of buoyancy on these elements and their connections.

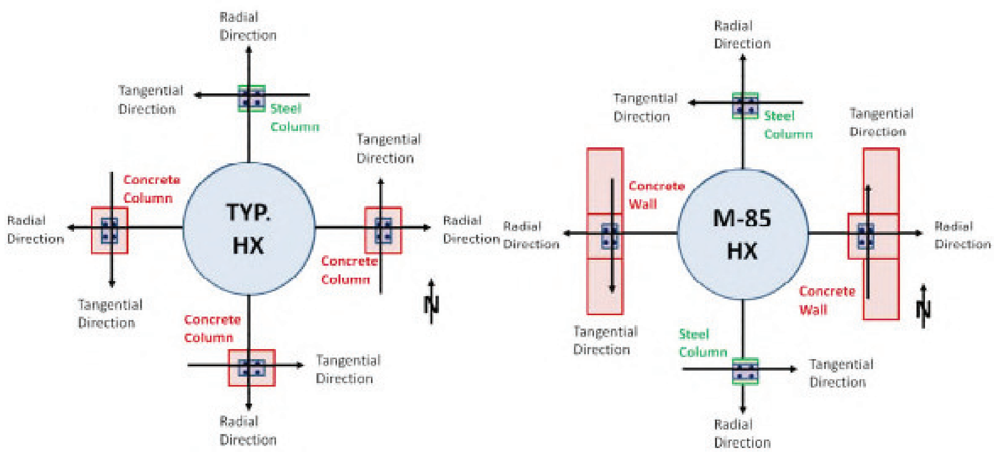

Figure 3. Layout of Heat Exchanger Supports Showing Load Directions at Four West Heat Exchangers (Left) and East Heat Exchanger (Right)

SEISMIC UPGRADE DESIGN AND CONSTRUCTION

Establish Qualified Team

One of the key steps to a successful project is establishing a qualified team. We established our team with engineers and draftsmen that individually or collectively had experience in design, evaluation, and construction of nuclear facilities. It is important to have personnel on the team that understand the special challenges of construction inside a nuclear facility and the commitment that may be needed to maintain the project schedule that is often built around outages. Likewise, the facility operator used a qualified team with experienced personnel, and they hired contractors and suppliers with appropriate experience and skills to execute the project.

Upgrade Methodology

Based on the loading and methodology described above, our analysis showed the tie rod anchorage and assemblies, reinforced concrete column supports and anchorage, and anchorage at walls in the east pit area required upgrade to meet code and project requirements.

Besides the technical upgrade criteria identified previously, the upgrade design needed to comply with additional requirements:

- Maintain the approximate stiffness of the existing load path assumptions from the previous analysis model or verify that the new and existing equipment and components are adequate for the new load path and support reactions.
- Place high priority on feasibility of construction in a radiological and contaminated area with limited access for equipment and machinery.
- Preserve personnel access throughout the facility, including ability to inspect, maintain, and replace heat exchanger components.

Jobsite Walkdown

Prior to beginning our upgrade design, the project manager performed a walkdown of the general area surrounding the heat exchangers. The walkdown provided the opportunity to observe the condition of the existing structure, locations of existing structures such as catwalks, layout of existing equipment, piping, and other utilities, access limitations, and areas of higher radiation that should avoided whenever possible. The walkdown provides perspective to the designer that may not be readily achieved by reviewing photos.

Anchorage and Attachments

One of the most challenging aspects of the upgrade was the design of the anchorage. The demands were high, the locations of the anchorage were already established or restricted, adhesive anchors were not allowed and no supplementary or anchor reinforcement existed at the anchorage locations. We needed to find a way to utilize ductile detailing to produce a proper and feasible design to avoid use of the strength reduction factors required by ACI 349-06 Section D.3.6 for nonductile anchorage conditions.

Given the existing construction and limitations, we could not produce a ductile failure in the anchors prior to failure of the concrete. Therefore, we sought to limit the demands on the anchors by designing the attachments to yield at a load level corresponding to anchor group forces not greater than 75% of the anchor design strength to satisfy Par. D.3.6.2. We designed and inserted dog-bone sections in the load path and used data from tension tests on the same plate material from which the dog-bones were fabricated to create ductile elements that had sufficient strength to meet the code-required demands. This approach allowed us to limit the size and number of anchors.

Based on experience with retrofitting existing concrete anchorage, it is inevitable that some of the specified anchor locations will coincide with existing reinforcement or embedded items. Therefore, we provided tolerances on our drawings to allow limited relocation of anchors. More importantly, we allowed margin in our design calculations to accommodate a number of relocation scenarios, including some beyond the limits allowed on our drawings.

In addition to the anchorage design, we developed an anchor testing program and identified acceptance and monitoring criteria. Our specifications required anchor installation by qualified personnel, so a representative from HILTI trained the installers on a mock-up outside of the facility to properly follow the manufacturer's instructions. The representative explained how to identify when the anchors are correctly installed. As part of the quality assurance requirements, we specified proof testing prior to initial installation inside the facility and also verification pull testing on a sample of anchors once they were installed. We defined the acceptance criteria and inspection and monitoring criteria in our specifications.

Figure 4 shows a photo of a completed upper tie rod assembly and anchorage. We designed new anchorage plates and specified HILTI HDA-T undercut anchors. We specified new tie rods and turnbuckles (same size as previous) and designed dog-bone sections to ensure a ductile failure and limit demands on the anchor bolts. We specified pretensioning requirements for the tie rod bracing to maintain effectiveness after temperature increases during operation.

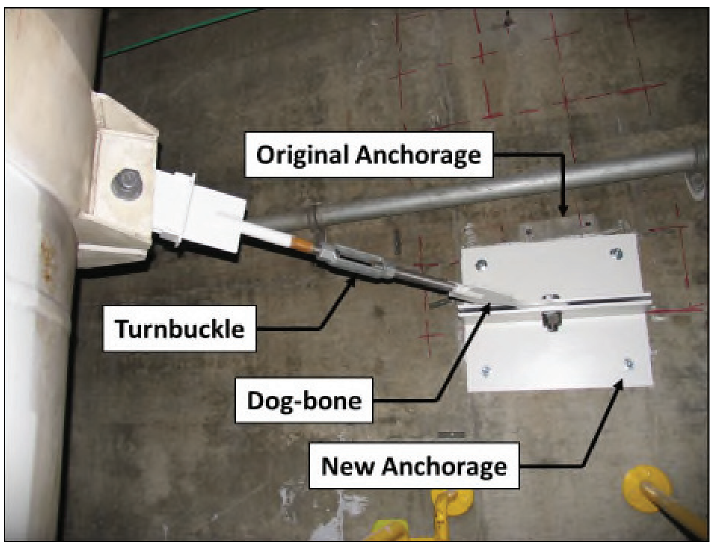

Figure 4. Completed Tie Rod Assembly and Anchorage (Photo Courtesy of facility operator)

Concrete Columns

Figures 5 shows the seismic upgrade design at the concrete support columns and connecting anchorage, and Figure 6 shows an image of a completed column upgrade. The design consists of a steel jacket assembly at the upper portion of the columns to confine anchorage shear breakout and transfer overturning demands to new steel attachments, which provide a load path to the base anchorage to resist overturning. The steel attachments include HSS sections for compression, tie rods and turnbuckles for tension and reduced dog-bone sections to achieve ductile behavior and limit anchor demands. Steel plates on top of the column welded to the existing heat exchanger anchor plates and new jacket assembly provide an alternate load path for shear transfer to the column. Anchorage plates at the column base are connected to the slab with HILTI HDA-P undercut anchors. The columns are supported laterally through compression only pipe bracing.

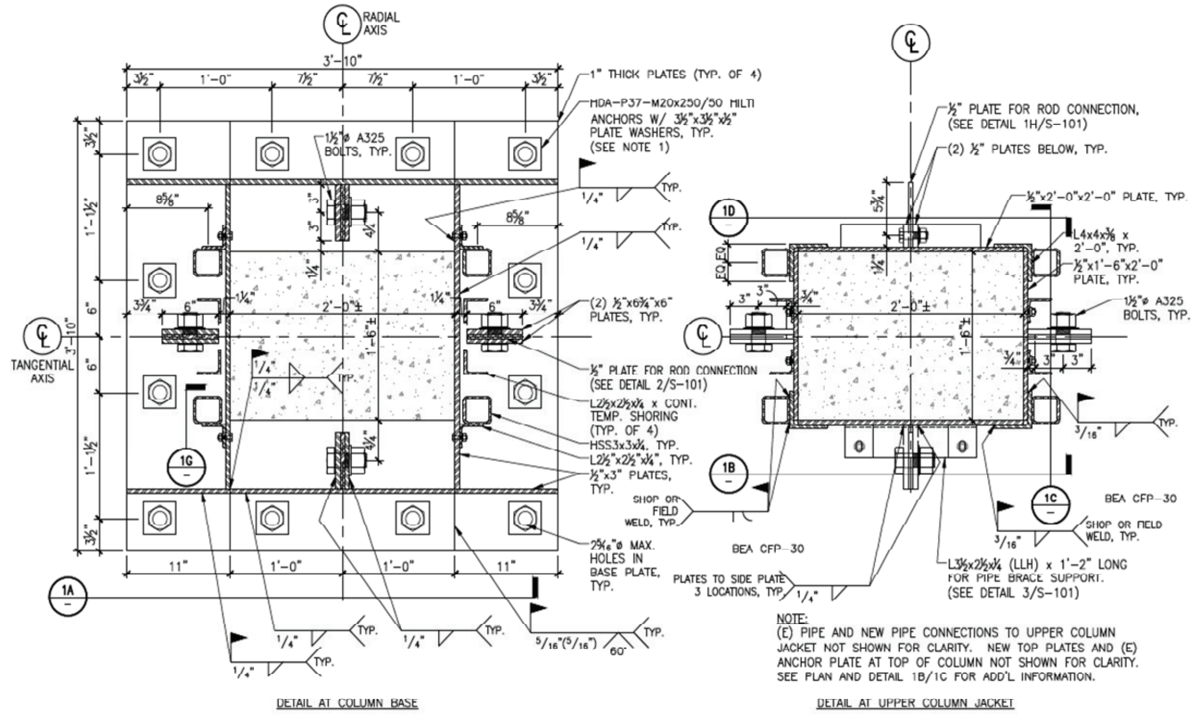

Figure 5. Upgrade Design – Concrete Columns and Anchorage, Plan View at Base (Left) and Mid-Height of Column (Right)

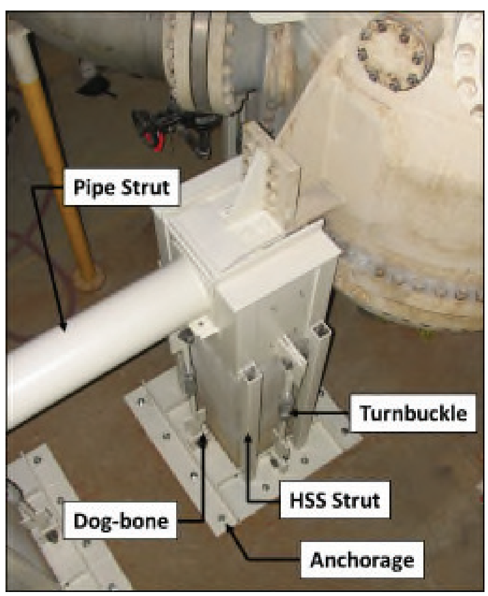

Figure 6. Completed Concrete Columns and Anchorage Upgrade (Photo courtesy of facility operator)

East Pit Area

Figures 7 and 8 show the seismic upgrade of the east wall of the east pit. A similar upgrade exists at the west wall of the east pit. The upgrade consists of steel plates welded adjacent to the existing anchor plate and a vertical confinement plate anchored to the wall with HILTI HDA-T undercut anchors to resist shear breakout at the heat exchanger connection. The upgrade also provides a load path for north-south demands parallel to the wall.

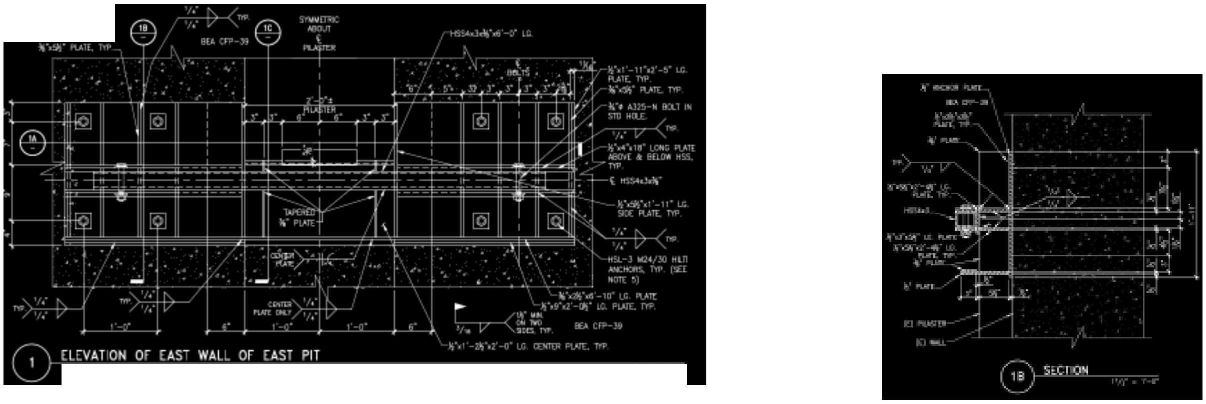

Figure 7. Upgrade Design – East Pit East Wall Elevation and Side View

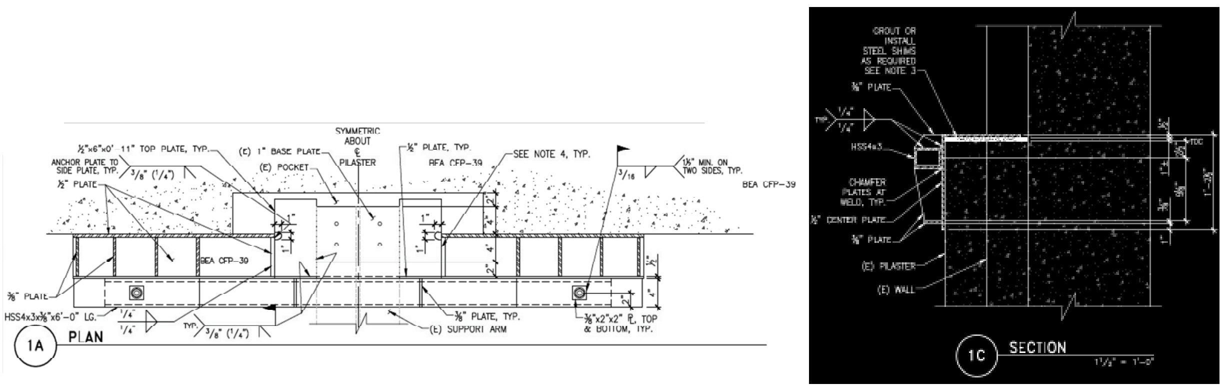

Figure 8. Upgrade Design – East Pit East Wall Plan and Side View

3D Modeling

In addition to design calculations, design drawings, and specifications, we produced fabrication and assembly drawings for the upgrade. Due to the complexity of the installation, we prepared a 3D model of the upgrade design using SolidWorks and created step-by-step progress images with instructions to describe our recommended (not required) procedure to install each of the upgrades. These drawings proved valuable during construction.

Construction Support

Upon the facility operator’s request, we continued our involvement in the project during construction by providing remote engineering support to the facility's project manager and field engineer. Despite the project team’s efforts to identify all interferences through a predesign walkdown and preconstruction subsurface investigation, the project encountered several unforeseen circumstances during construction that required design changes or drawing modifications.

Interferences with reinforcement required relocation of many post-installed anchors. However, as noted above, the built-in design margin was sufficient to permit the anchor relocations. Interference with a sump in the base slab required a new design to avoid the floor opening. Limited access between the east heat exchanger and the pit walls prevented installation of the specified anchors and required modification of the anchor layout and selection of new post-installed anchors. Through determination, creative thinking, and close communication between the project team members, the project was able to overcome each of these challenges and arrive at a successful completion.

CONCLUSIONS

This paper presented a case study of seismic evaluation and upgrade of test reactor heat exchanger supports for Performance Category 4 criteria according to DOE-STD-1020-2002. The scope of the structural evaluation included evaluation of tie rod assemblies, reinforced concrete column and wall supports and the respective attached anchorage. We found that the tie rod assemblies, reinforced concrete column supports and walls of the east pit area required upgrade to meet code and project requirements. We designed new anchorage at the tie rod assemblies. We also designed steel jacket assemblies at the concrete columns to resist bi-axial bending and to transfer column top anchorage demands to the foundation. Per ACI 349-06, ductile failure modes for anchorage to concrete are encouraged or significant capacity reduction factors must be used. At tie rod anchorage to walls and column upgrade anchorage at the floor, we developed a design using reduced section dog-bone connection plates to ensure a ductile failure mode at the connections, which helped reduce the overall anchorage demands. We worked through many field requests during upgrade installation to address unexpected interferences and fit-up issues, and the margin that we included in our original anchorage design enabled us to accommodate most anchor relocation needs.

This paper discussed seismic evaluation, upgrade design, and construction support for the heat exchanger supports. We followed a systematic approach to perform this work that included the steps listed below. While every project is different, implementation of the following steps, as appropriate, should help ensure a successful project at a nuclear facility:

- Establish a qualified team with the necessary skills, commitment, and experience to properly perform the work.
- Perform a walkdown of the jobsite to determine actual conditions that may differ from design drawings and gain a broader or deeper understanding than may be achieved by reviewing documents and photos.
- Develop appropriate design criteria and loading based on appropriate codes such as ASCE 4, ASCE 43 and DOE-STD-1020.
- Allow tolerances in the design to assist with unforeseen fit-up issues and interferences of anchorage with concrete reinforcing during construction.
- Provide 3D modelling when appropriate to show the construction sequence and design for complex upgrades.
- Develop an anchor installation and testing program, including use of mock-ups and manufacturer assistance to train installers and establish quality assurance criteria and expectations.
- Where concrete anchorage is required, consider use of reduced section dog-bone steel attachment elements to limit demands on anchorage in order to avoid use of strength reduction factors required by ACI 349-06 Section D.3.6 for nonductile anchorage conditions.
- Provide monitoring requirements for operations and maintenance personnel to follow and understand when action is necessary.

REFERENCES

American Concrete Institute, *Code Requirements for Nuclear Safety-Related Concrete Structures (ACI 349-06) and Commentary*, Farmington Hills, MI, 2007.

American Institute of Steel Construction, *Steel Construction Manual*, 13th edition, 2005.

American National Standards Institute and American Institute of Steel Construction, *Specification for Safety-Related Steel Structures for Nuclear Facilities*, ANSI/AISC N690-06, Chicago, IL, 2007.

American Society of Civil Engineers, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*, ASCE/SEI 43-05, Reston, VA, 2005.

American Society of Civil Engineers, *Seismic Analysis of Safety-Related Nuclear Structures and Commentary*, ASCE/SEI 4-98, Reston, VA, 1998.

ICC Evaluation Service, Inc., "Hilti HDA Carbon Steel and Stainless Steel Undercut Anchors for Cracked and Uncracked Concrete", ESR-1546, March 2008.

U.S. Department of Energy, *Natural Phenomena Hazard Design and Evaluation Criteria for DOE Facilities*, DOE-STD-1020-2002, Washington, D.C., 2002.