5.3 Containment

5.3.1 Summary of Containment

Baseline information for the Containment is provided in Section 2.0, Site History, Description, and Baseline Condition.

The Containment is surrounded by the Auxiliary Building on the north, east, and west sides, and on a portion of the south side. The Containment basement top-of-slab elevation is 976.5 ft below the reactor and 991 ft along the perimeter. A tunnel is located around the perimeter below the slab to access the post-tension cables (stressing gallery). The floor elevation of the stressing gallery is about 969 ft. The basement floor elevation of the Auxiliary Building where the Containment adjoins it ranges from el. 971 to 1004 ft. The outside grade is approximately at el. 1004 ft.

The Containment is supported on 20-in.-diameter open-ended steel pilings with 1.031-in.-thick walls extending into sound bedrock. Where solution cavities were located below the piles, they were underreamed and extended past the cavities. The piles are filled with sand up to 1 ft from grade, and the remainder is filled with concrete. To provide a solid bearing surface, the piles are capped with a 2-in.-thick ASTM A36 steel cap plate that is 22 in. by 22 in. The number of piles in each circle is constant, with each pile circle 5 ft closer to the center. Therefore, the piling density increases toward the center of the building. The stressing gallery tunnel is not supported by piles.

The mat foundation is a 10- to 12-ft-thick concrete slab reinforced with two layers of mild reinforcing. The exterior walls are approximately 3.9-ft-thick post-tensioned reinforced concrete. A steel liner is located on the interior of the wall. The roof is a 55-ft-radius concrete dome monolithically integrated into the exterior walls. Interior floors and walls are cast-in-place reinforced concrete. Thicknesses vary per room use and floor span.

5.3.2 Inputs/References Supporting the Analysis

Table 5.3-1 lists references provided by OPPD and other documents used to support HDR's analysis.

Table 5.3-1 - References for Containment

Document Title	OPPD Document Number (if applicable)	Date	Page Number(s)
Condition Report	CR 2011-5761	6/23/2011	All
Condition Report	CR 2011-5763	6/23/2011	All
Condition Report	CR 2011-5792	6/24/2011	All
Condition Report	CR 2011-7265	9/9/2011	All
System Design Basis Document	SDBD-CONT-501, Rev 32	9/30/2010	
Piling Plan Containment & Auxiliary Building	11405-S-1 (#16380)	5/6/1968	
Structure Inspection	SE-PM-AE-1004	7/16/2009	All
Naval Facilities Engineering Command, Design Manual 7.01, Soil Mechanics		9/1986	All

Detailed site observations—field reports, field notes, and inspection checklists—for the Containment are provided in Attachment 8.

Observed performance and pertinent background data are as follows:

- A sand boil/piping feature was observed (originally reported in CR 2011-7265) near the southwest corner of the Missile Shield Room. This room is located on the outside of the south wall of the Auxiliary Building (common wall to both spaces) and has an unfinished, pea gravel floor surface. Ingress/egress can be gained only from Door 45, located outside the Auxiliary Building (there is no connecting doorway between the Missile Shield Room and the adjacent Auxiliary Building). This feature was measured using a hand tape measure and vertically probed using a fiberglass T-probe. Field measurements indicated that the feature is about 3.5 ft in diameter and 1 ft deep. A high-water line was observed on the interior walls about 0.8 ft above the floor. Various utility conduits extend vertically into the ground along the outside wall at the southwest corner (a few feet west of the alignment of the boil/piping feature). The Main Underground Cable Bank, MH-1 to the Auxiliary Building, runs through the subsurface, extending east to west below the location of the boil/piping feature.
- As early as 1993, excessive flow into a sump in the Turbine Building basement was observed. Subsequently, this flow was attributed to unfiltered groundwater entering breaks in drainage pipes under the Turbine Building basement floor slab. The Turbine Building is adjacent to and east of the Auxiliary Building.
- In 1997 a void, estimated to be approximately 10 x 8 x 1 ft, was documented below the basement floor slab in the Turbine Building. For further information see Section 5.8. A more detailed discussion of this KDI is presented in Section 4.1.
- The stressing gallery is a tunnel located below the mat floor slab of the Containment. The gallery has one entrance in and out from Room 22 of the Auxiliary Building. The gallery provides access to the Containment wall post-tensioning strands and runs the entire perimeter of the Containment. The stressing gallery was found to contain a large amount of water in low level areas of the floor near the two sump pits. Water covered approximately half of the floor area at the time of HDR's inspection. Water was approximately 4 in. deep at the sump pit locations and decreased in depth away from the pits due to floor slab slope. The source of the water was not apparent from the inspection. Previous testing of the water by OPPD discovered that the water contained Cesium-134. Very little sediment was seen in the water.
- Pumps had been removed from the sumps in the stressing gallery prior to HDR's inspection.
- The Containment was protected from floodwater by an Aqua Dam for the majority of the 2011 flood; however, the Aqua Dam failed for a short period of time because it was damaged, which allowed floodwater to enter the area inside the perimeter of the Aqua Dam.

5.3.3 Assessment Methods and Procedures

5.3.3.1 Assessment Procedures Accomplished

Assessments of the Containment included the following:

- Visual inspection of the interior of the Containment's lowest levels (perimeter rooms only). Visual inspection of other interior rooms is not necessary to provide report results.
- Visual inspection of the exposed, above-grade exterior of the structure.

- Visual inspection of sumps in the stressing gallery for the presence of water, the water level, and the presence of sediment in the water.
- An assessment of collected survey data to date for indications of trends in the movement of the structure.
- A review of previously documented condition reports, as-built building plans, and geotechnical reports to determine possible weak points in the Containment's construction that could be affected by the 2011 flood.

Additional investigations were performed. These included the following non-invasive geophysical and invasive geotechnical investigations:

- Seismic surveys (seismic refraction and refraction micro-tremor) in the PA. (Test reports were not available at the time of Revision 0.)
- Geotechnical test borings in the PA. Note that OPPD required vacuum excavation for the first 10 ft of proposed test holes to avoid utility conflicts. Therefore, test reports will not show soil conditions in the upper 10 ft of test boring logs. (Test reports were not available at the time of Revision 0.)

5.3.3.2 Assessment Procedures Not Completed

No additional assessment procedures have been identified for this structure.

5.3.4 Analysis

Identified PFMs were initially reviewed as discussed in Section 3.0. The review considered the preliminary information available from OPPD data files and from initial walk-down observations. Eleven PFMs associated with five different Triggering Mechanisms were determined to be "non-credible" for all Priority 1 Structures, as discussed in Section 3.6. The remaining PFMs were carried forward as "credible." After the design review for each structure, the structure observations, and the results of available geotechnical, geophysical, and survey data were analyzed, a number of CPFMs were ruled out as discussed in Section 5.3.4.1. The CPFMs carried forward for detailed assessment are discussed in Section 5.3.4.2.

5.3.4.1 Potential Failure Modes Ruled Out Prior to the Completion of the Detailed Assessment

The ruled-out CPFMs reside in the Not Significant/High Confidence category and for clarity will not be shown in the Potential for Failure/Confidence matrix.

Triggering Mechanism 2 – Surface Erosion
CPFM 2b – Loss of lateral support for pile foundation

Reason for ruling out:

- It was evident from the site inspection that no surface erosion occurred in the vicinity of the Containment.

Triggering Mechanism 3 – Subsurface Erosion/Piping
CPFM 3e – Loss of lateral support for pile foundation (due to river drawdown)

Reason for ruling out:

- The structure is a sufficient distance from the river to be outside the zone of influence of the CPFM.

Triggering Mechanism 4 – Hydrostatic Lateral Loading (water loading on structures)
CPFM 4c – Wall failure in flexure
CPFM 4d – Wall failure in shear
CPFM 4e – Excess deflection

Reasons for ruling out:

- The Containment is designed to withstand an external water load due to flooding of the Missouri River to el. 1014 ft (see SDBD-CONT-501, Rev 32). The peak flood elevation in 2011 was approximately 1006.9 ft, which is less than the structural design basis.
- Visual observations did not identify distress to the Containment that can be attributed to this CPFM.

Triggering Mechanism 5 – Hydrodynamic Loading
CPFM 5a – Overturning
CPFM 5b – Sliding
CPFM 5c – Wall failure in flexure
CPFM 5d – Wall failure in shear
CPFM 5e – Damage by debris
CPFM 5f – Excess deflection

Reasons for ruling out:

- The Containment was protected from floodwater by an Aqua Dam for the majority of the 2011 flood; however, the Aqua Dam failed for a short period of time because it was damaged, which allowed floodwater to enter the area inside the perimeter of the Aqua Dam.
- The Containment is designed to withstand an external water load due to flooding of the Missouri River to el. 1014 ft (see SDBD-CONT-501, Rev 32). The peak flood elevation in 2011 was approximately 1006.9 ft, which is less than the structural design basis.
- Visual observations did not identify distress to the structure that can be attributed to this CPFM.

Triggering Mechanism 6 – Buoyancy, Uplift Forces on Structures

CPFM 6a – Fail tension piles
CPFM 6b – Cracked slab, loss of structural support
CPFM 6c – Displaced structure/broken connections

Reasons for ruling out:

- The Containment is designed to withstand an external water load due to flooding of the Missouri River to el. 1014 ft (see SDBD-CONT-501, Rev 32). The peak flood elevation in 2011 was approximately 1006.9 ft, which is less than the structural design basis.
- Visual observations and survey measurements indicate no structure movement. Therefore, it is unlikely that the tension piles failed (CPFM 6a) or that the structure was displaced or damaged (CPFM 6c) due to buoyancy effects.

Triggering Mechanism 7 – Soil Collapse (first time wetting)

CPFM 7b – Displaced structure/broken connections
CPFM 7c – General site settlement
CPFM 7d – Piles buckling from down drag

Reasons for ruling out:

- The pile foundations are located below el. 979.0 ft, while the normal river level is at approximate el. 992.0 ft. Therefore it is logical to assume that the soils below the mat foundation have been previously wetted.
- The peak flood elevation prior to 2011 was documented as 1003.3 ft, which would indicate the soils below and surrounding the Containment had been saturated at this time.

Triggering Mechanism 10 – Machine/Vibration-Induced Liquefaction

CPFM 10b – Displaced structure/broken connections
CPFM 10c – Additional lateral force on below-grade walls
CPFM 10d – Pile/pile group instability

Reasons for ruling out:

- The underlying soils were improved with vibroflotation to reduce the risk of liquefaction.
- Machine/vibration-induced liquefaction was not observed at the site.
- This is not a changed condition due to the flood. The Containment has been in service for 38 years under similar saturated soils and machine vibration.
- Temporary pumping equipment located on the ground inside the perimeter of the Aqua Dam produced minimal localized vibrations and was offset from the structure and therefore is deemed to have inconsequential effects.

Triggering Mechanism 11 – Loss of Soil Strength due to Static Liquefaction or Upward Seepage

CPFM 11b – Displaced structure/broken connections
CPFM 11c – Additional lateral force on below-grade walls
CPFM 11d – Pile/pile group instability

Reasons for ruling out:

- The underlying soils were improved with vibroflotation to reduce the risk of liquefaction.
- The sandboil/piping feature observed in the missile room of the Auxiliary Building was determined to be too shallow to be significant.
- Visual observations and survey measurements indicate no structure movement. Therefore, degradation that can be attributed to this PFM did not occur.

Triggering Mechanism 12 – Rapid Drawdown

CPFM 12a – River bank slope failure and undermining surrounding structures
CPFM 12b – Lateral spreading

Reason for ruling out:

- The Containment is located a sufficient distance away from the riverbank and therefore is outside the zone of influence of a bank slope failure.

Triggering Mechanism 13 – Submergence

CPFM 13b – Corrosion of structural elements

Reasons for ruling out:

- The Containment has not been subjected to corrosive circumstances that would be considered beyond the normal conditions. The Containment was protected from floodwater by an Aqua Dam for the majority of the 2011 flood; however, the Aqua Dam failed for a short period of time because it was damaged, which allowed floodwater to enter the area inside the perimeter of the Aqua Dam. Therefore, any structural elements being wetted by the 2011 flood was considered in the original design of the facility.
- This is not a changed condition due to the flood. The Containment has been in service for 38 years under similar saturated soils. Reviewed condition survey reports have not indicated signs of distress that would be attributed to corrosion due to submergence.

Triggering Mechanism 14 – Frost Effects

CPFM 14a – Heaving, crushing, or displacement

Reason for ruling out:

- The Containment foundation is a minimum of 25 ft below grade and is therefore not susceptible to frost. In addition, frost-susceptible connecting utilities are also below frost level.

5.3.4.2 Detailed Assessment of Credible Potential Failure Modes

The following CPFMs are the only CPFMs carried forward for detailed assessment for the Containment as a result of the 2011 flood. This detailed assessment is provided below.

Triggering Mechanism 3 – Subsurface Erosion/Piping
CPFM 3b – Loss of lateral support for pile foundation (due to pumping)

The Turbine Building, which is adjacent to the Auxiliary Building, has a documented history of a void below the foundation slab dating back to 1997. This void was confirmed via cored holes in the foundation slabs and camera recordings of broken drain piping that lies under the floor slab. Conversations with OPPD personnel indicate that groundwater has been flowing at varying rates through these broken pipes into the sump from 1993 to the present day. The rate of flow into the sump is directly related to the hydraulic head of the groundwater. As the floodwater increased in elevation across the facility, observed flow rates increased. The flow of groundwater into this drain piping system through the breaks in the pipes is one of the KDIs discussed in Section 4. This drain pipe system was designed as a closed system; therefore, the pipes are not surrounded by appropriate filter systems to preclude the transportation of soils from the surrounding area under the slab. It is possible to assume that because the groundwater moves below the foundation and into the broken piping, some movement of the soil has occurred. If these voids were to continue under the Containment, they could become large enough to create a loss of lateral support for the piling.

The Triggering Mechanism and CPFM could then occur as follows: multiple potentially connected seepage paths could exist in the soil backfill at the site, including soil backfill in utility trenches, granular trench bedding, and building floor drains with open/broken joints. The paths could be exposed at some locations to the river floodwater and high groundwater. This network of seepage paths could be connected to the sump pit in the Turbine Building. The breaks in the piping have been documented for an extended period (dating back to at least 1993), thus creating a continuous head differential on the potential seepage path networks. Gradient was potentially sufficient to begin erosion of surrounding soil. The gradient during the 2011 flood was increased, which could have led to higher flows through the seepage path networks. The unfiltered seepage condition will remain until the breaks in the piping system are repaired, which means the potential for further erosion remains. Erosion could extend out, creating large voids under the Turbine Building base slab and potentially under the Containment. The potential damage includes loss of soil support around piles leading to pile buckling, decreased pile capacity, and foundation failure.

The following table describes observed distress indicators and other data that would increase or decrease the potential for degradation associated with this CPFM for the Containment.

Adverse (Degradation/Direct Floodwater Impact More Likely)	Favorable (Degradation/Direct Floodwater Impact Less Likely)
A documented void exists under the foundation slab of the Turbine Building with a known hydraulic connection between groundwater elevation and flows into the building sump.	The in situ and fill material around the piling was compacted to the requirements under the Class I structures (vibroflotation). This higher density granular material is less susceptible to erosion.
	There have been no observed signs of structural distress in the floor slab under the current loading conditions.
	Surveyed elevations for the foundations show no significant signs of movement.
	The bottom of the mat foundation is about 10 ft lower in elevation than the bottom of the Turbine Building mat foundation, making it unlikely that voids migrated below the Containment foundation.
Data Gaps: • The presence, size, and location of the voids below the foundation slab	

Conclusion

Significance

Potential for Degradation/Direct Floodwater Impact

Indicators for this CPFM have been observed in the Turbine Building, which is near the Containment. The voids below the base slab in the Turbine Building are known to exist with heavy flows of water being pumped from the sump. Because the 2011 flood caused increased flow through the broken drain pipes, the potential that the 2011 flood caused further and more rapid degradation due to this CPFM is high. It is possible, but not likely, that these voids extend under the Auxiliary Building and to the Containment mat foundation. The potential for degradation is low due to the distance between the Turbine Building and the Containment and the presence of vibrocompacted soils under both the Auxiliary Building and Containment.

Implication

The occurrence of this CPFM on a large scale could negatively impact the capacity of the piling supporting the building. This could lead to excessive foundation movement and negatively impact the integrity or intended function of the Containment. Because the pile system is robust, and voids of this size are not likely, the implication of the potential degradation for this CPFM is low.

Confidence

The extent of subsurface erosion and its potential impact on the building is not known due to the lack of data gathered on subsurface conditions. Because there is not enough information on the subsurface conditions at this time, and the pumping in the Turbine Building could have caused subsurface erosion, the confidence for this CPFM is low.

Summary

For CPFM 3b, as discussed above, the potential for degradation is low because the pumping in the Turbine Building is unlikely to have caused enough erosion to impact the integrity or intended function of the structure. Although large amounts of erosion are not likely, large depths of erosion and degradation could impact the integrity or intended function of the structure. The combined consideration of the potential for degradation and the implications of that degradation to a structure of this type puts it in the "not significant" category. The data currently collected are not sufficient to rule out this CPFM. Therefore, the confidence in the above assessment is low, which means more data and/or continued monitoring and inspections are necessary to draw a conclusion.

5.3.5 Results and Conclusions

The CPFM evaluated for the Containment is presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation.

	Low Confidence (Insufficient Data)	High Confidence (Sufficient Data)
Potential for Failure **Significant**		
Potential for Failure **Not Significant**	CPFM 3b	

5.3.6 Recommended Actions

Further forensic investigations and physical modifications are recommended to address CPFM 3b for the Containment. CPFM 3b is associated with unfiltered flow of groundwater into the Turbine Building basement drain piping system (KDI #1). These recommendations are described in detail in Section 4.1.

Water observed in the pre-stressing gallery cannot be attributed to a specific source at this time. To determine the water's source, it is suggested that the water be removed and a procedure developed and implemented to determine the source of the water. Once a source is determined, the proper personnel should be notified and the area inspected to determine whether further analysis or corrections are necessary.

Continued monitoring is recommended to include a continuation of the elevation surveys of the previously identified targets on this structure and surrounding site. The purpose is to monitor for signs of structure distress and movement or changes in soil conditions around the structure. The results of this monitoring increase the confidence in the assessment results. Elevation surveys should be performed weekly for 4 weeks and biweekly until December 31, 2011. At the time of Revision 0, groundwater levels had not yet stabilized to nominal normal levels. Therefore, it is possible that new distress indicators could still develop. If any new distress indicators are observed before December 31, 2011, appropriate HDR personnel should be notified immediately to determine whether an immediate inspection or assessment should be conducted. Observation of any new distress indicators might result in a modification of the recommendations for this structure.

5.3.7 Updates Since Revision 0

Revision 0 of this Assessment Report was submitted to OPPD on October 14, 2011. Revision 0 presented the results of preliminary assessments for each Priority 1 Structure. These assessments were incomplete in Revision 0 because the forensic investigation and/or monitoring for most of the Priority 1 Structures was not completed by the submittal date. This revision of this Assessment Report includes the results of additional forensic investigation and monitoring to date for this structure as described below.

5.3.7.1 Additional Data Available

The following additional data were available for the Containment for Revisions 1 and 2 of this Assessment Report:

- Results of KDI #1 forensic investigation (see Section 4.1 and 8.3)
- Results of geophysical investigation by Geotechnology (see Attachment 6C).
- Results of geotechnical investigation by Thiele Geotech (see Attachment 6A).
- Data obtained from inclinometers by Thiele Geotech (see Attachment 6A).
- Results of continued survey by LRA (see Attachment 6E).

5.3.7.2 Additional Analysis

The following analysis of additional data was conducted for the Containment:

- Results of geophysical investigation report by Geotechnology

  Seismic Refraction and Seismic ReMi tests performed around the outside perimeter of the power block identified deep anomalies that could be gravel, soft clay, loose sand, or possibly voids.

- Results of geotechnical investigation by Thiele Geotech

Six test borings were drilled, with continuous sampling of the soil encountered, to ground truth the Geotechnology seismic investigation results as part of the KDI #2 forensic investigation. Test bore holes were located to penetrate the deep anomalies identified in the seismic investigation. The test boring data did not show any piping voids or very soft/very loose conditions that might be indicative of subsurface erosion/piping or related material loss or movement.

All of the SPT and CPT test results conducted for this Assessment Report were compared to similar data from numerous other geotechnical investigations that have been conducted on the FCS site in previous years. This comparison did not identify substantial changes to the soil strength and stiffness over that time period. SPT and CPT test results were not performed in the top 10 ft to protect existing utilities.

Data from inclinometers to date, compared to the original baseline measurements, have not exceeded the accuracy range of the inclinometers. Therefore, deformation at the monitored locations since the installation of the instrumentation has not occurred.

- Results of continued survey by LRA

  Survey data to date compared to the original baseline surveys have not exceeded the accuracy range of the surveying equipment. Therefore, deformation at the monitored locations, since the survey baseline was shot, has not occurred.

The CPFMs that could not be ruled out in Revision 0 are analyzed below based on the additional data available for Revisions 1 and 2 of this Assessment Report.

Triggering Mechanism 3 – Subsurface Erosion/Piping

CPFM 3b – Loss of lateral support for pile foundation (due to pumping)

CPFM 3b for the Containment is associated with KDI #1. Section 4.1 and 8.3 presents the results of additional forensic investigation that was conducted to ascertain whether this CPFM could be ruled out. The results of these additional forensic investigations show that soils in the vicinity of the Containment Building have been negatively affected by this triggering mechanism, and that the possibility exists that the soil under the Containment Building has also been negatively affected. It was not possible to test the soils under the Containment Building for this Assessment. Therefore, no conclusions can be reached regarding the potential for failure for this CPFM. HDR recommends that OPPD employ the services of an Appendix B consultant to evaluate the potential for loss of lateral pile support under the Containment Building from Subsurface Erosion/Piping (due to Pumping). Assuming that this analysis shows that there is no issue with the loss of lateral support for the pile foundation under the Containment Building, this CPFM is moved to the quadrant of the matrix representing "No Further Action Recommended Related to the 2011 Flood."

5.3.7.3 Revised Results

The CPFM evaluated for the Containment is presented in the following matrix, which shows the rating for the estimated significance and the level of confidence in the evaluation.

	Low Confidence (Insufficient Data)	High Confidence (Sufficient Data)
Potential for Failure **Significant**		
Potential for Failure **Not Significant**		CPFM 3b

5.3.7.4 Conclusions

In the assessment of the FCS Structures, the first step was to develop a list of all Triggering Mechanisms and PFMs that could have occurred due to the prolonged inundation of the FCS site during the 2011 Missouri River flood and could have negatively impacted these structures. The next step was to use data from various investigations, including systematic observation of the structures over time, either to eliminate the Triggering Mechanisms and PFMs from the list or to recommend further investigation and/or physical modifications to remove them from the list for any particular structure. All CPFMs for the Containment other than CPFM 3b had been ruled out prior to Revision 1. CPFM 3b was further investigated in KDI #1 as described in Sections 4.1 and 8.3. These forensic investigations have not provided enough information to rule out CPFM 3b for the Containment Building. It is recommended that the physical modifications described in KDI #1 (Section 4.1 and Section 8.3) be implemented to stop the triggering mechanism, and that OPPD employ the services of an Appendix B consultant to evaluate the potential for loss of lateral pile support under the Containment Building from Subsurface Erosion/Piping (due to Pumping). Assuming that this analysis shows that there is no issue with the loss of lateral support for the pile foundation under the Containment Building, this CPFM is moved to the quadrant of the matrix representing "No Further Action

Recommended Related to the 2011 Flood." OPPD has informed HDR that they are utilizing the services of an Appendix B structural engineering firm to evaluate this structure.