

Assessment Process, Procedures, and Methods

3.0 **ASSESSMENT PROCESS, PROCEDURES, AND METHODS**

The purpose of the assessment process is to qualitatively determine the significance of the potential for failure of each FCS structure due to the effects of the 2011 Missouri River flood. This section of the Assessment Report presents detail on the steps in the assessment process, a description of the methods used during the field observations, a list of all of the Triggering Mechanisms and their associated PFMs that were identified, a list of the PFMs determined to be “non-credible” in the initial screening (prior to the detailed assessments), and the reasons for their elimination. This section also presents information on the assessment methods used to determine the significance of the potential for failure due to the 2011 Missouri River flood.

3.1 Assessment Process

As discussed in Section 1.1, this Assessment Report presents the findings of HDR’s assessment of changes to the soil or rock that supports the structures at FCS due to the 2011 Missouri River flood and/or any direct impacts of floodwater that may have negatively impacted those structures. Structures to be assessed were selected and prioritized by OPPD (see Table 1-1) and include buildings, process structures, equipment foundations, tank foundations, and electrical towers, all of which are referred to as structures in this Assessment Report.

The post-flooding assessment of FCS structures was completed by first conducting a systematic and thorough visual observation of each structure to identify any outward signs of distress caused by the flood. After the visual observations, data on the 2011 flood, including the areal extent, water depths, water velocities, and the effect on groundwater at the FCS site, were compiled. Baseline data for the geology, geomorphology, geotechnical, and design conditions prior to the 2011 flood were also compiled. A list of flood-induced Triggering Mechanisms that could have caused degradation to the soil and/or rock that supports the FCS structures and/or could have caused direct impacts on structures due to the force of the floodwater was then developed. Examples of Triggering Mechanisms include settlement, erosion, stability, hydraulic actions, and frost actions. Using the list of potential Triggering Mechanisms, a comprehensive list of PFMs was developed. PFMs are the ways in which a structure might fail. Failures are any errors or defects, and can be potential or actual. Examples of PFMs include undermining and settlement of shallow foundation/slab, undermined buried utilities, and loss of lateral support for pile foundations. Using the knowledge compiled for the baseline on each structure’s design standard (for example, shallow or deep founded building or buried utility), a list of corresponding PFMs was compiled for each structure from the comprehensive list of PFMs. A detailed list of Triggering Mechanisms and PFMs is presented in Section 3.4.

Once the list of PFMs was compiled for each structure, these PFMs were screened to determine if they were “credible” (CPFMs), which means a particular PFM could have occurred or could be in progress due to the changes caused by the 2011 flood. This included a determination of whether the Triggering Mechanisms for the CPFMs could have been or were actually initiated by the flood (potential for degradation/direct floodwater impact). As a result, some PFMs were determined to be non-credible. For example, PFMs arising from river bank erosion were eliminated because no evidence of bank erosion was observed. A detailed list of PFMs eliminated from detailed study is presented in Section 3.6.

Assessment Process, Procedures, and Methods

During detailed assessment, when additional data were available including the results of the systematic visual observations, a secondary screening took place to rule out additional CPFMs. This might have resulted in the elimination of all of the CPFMs initially identified for a particular structure, or there could be remaining CPFMs, which are discussed in detail in this Assessment Report. Also, the PFMs screened out as non-credible in the initial screening described above were reviewed again in light of the additional available data to determine if they should be added back to the list of CPFMs. The remaining CPFMs were evaluated to determine first the potential for degradation to the soil or rock that supports the structure and/or the direct floodwater impacts due to the 2011 flood and then the implications of that degradation to a structure of that particular design type. The combination of the potential for degradation/direct floodwater impact and of the implications of that degradation/impact is termed the “potential for failure” and is then categorized as “significant” or “not significant.” The final step in the analysis was to evaluate the “confidence” in the potential-for-failure determination as either “low” or “high.”

3.2 Assessment Process Steps

The purpose of the assessment process is to qualitatively determine the significance of the potential for failure of each FCS structure due to the effects of the 2011 flood. The assessment process involved eight steps, as shown in Figure 3-1. In addition, the assessment process has several feedback loops to allow for incorporation of new information as it becomes available and revision of the subsequent steps as appropriate.

- Step 1. Site Description and Baseline Condition/History** – Review construction documents, as-built drawings, previous reports, and plant performance history to determine the pre-flood conditions at the site. This step is necessary to allow a comparison of the pre-flood and post-flood conditions. Baseline information for the FCS site and structures was compiled to include data on the geology, geomorphology, geotechnical, and design conditions prior to the 2011 flood. In addition, data on the 2011 flood itself, including the areal extent, water depths, water velocities, and the effect on groundwater at the FCS site were compiled. The baseline condition and history as it pertains to the various structures at the site is provided in Section 2.0 of this Assessment Report.
- Step 2. Potential Failure Modes** – Using the compiled data on the 2011 flood in Step 1, develop a list of Triggering Mechanisms. Using the list of potential Triggering Mechanisms, develop a comprehensive list of PFMs. Using the knowledge compiled for the baseline on each structure’s design standard, select the corresponding PFMs for each structure from the comprehensive list. The list of identified PFMs is presented in Section 3.4.

Assessment Process, Procedures, and Methods

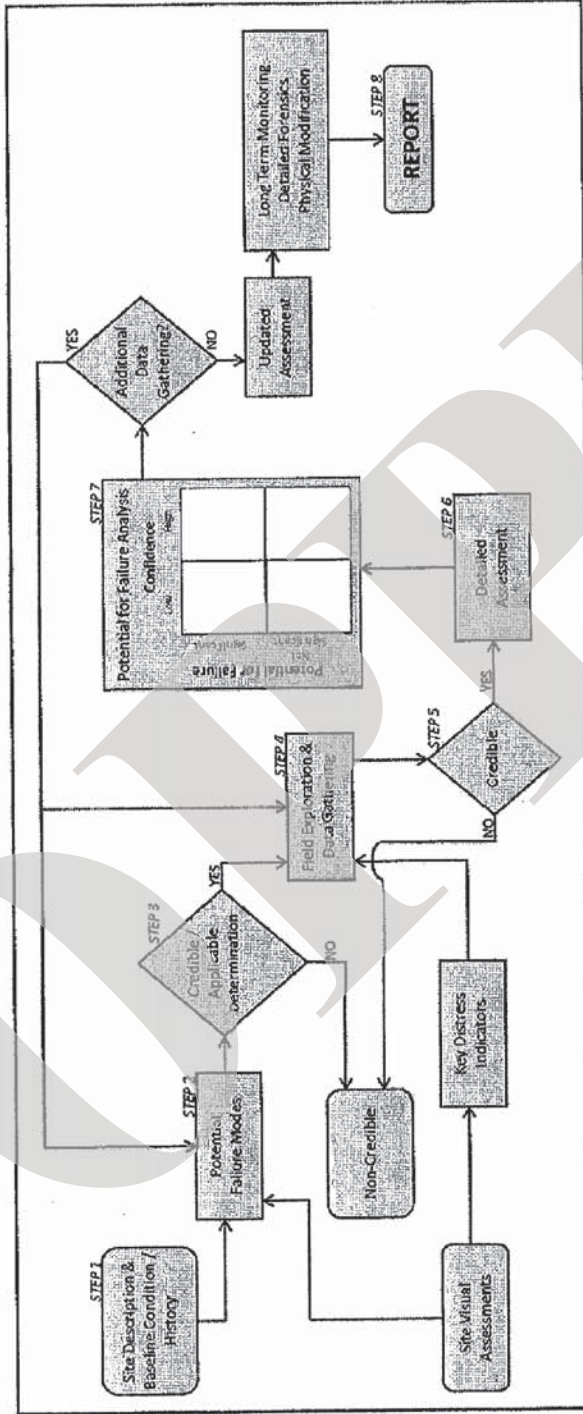


Figure 3-1 – Plant and Facility Geotechnical and Structural Assessment Process

Assessment Process, Procedures, and Methods

- Step 3. Credible/Applicable Determination** – Conduct initial screening of Triggering Mechanisms and PFMs to determine if a specific PFM is applicable, credible, or non-credible for a particular structure. The initial screening is based on general review of background information, prior knowledge of the site, and observations from the initial site inspection(s). In this step, PFMs are categorized as one of following:
- Not Applicable – PFMs that are not applicable to that type of structure (For example, “loss of lateral support for pile foundation” would not apply to a structure that does not have a pile foundation.)
 - Credible – PFMs that are 1) physically possible, and 2) significant enough to be further evaluated
 - Non-credible – PFMs (or their associated Triggering Mechanisms) for which the chance of their existence is judged to be so small, based on the available information, that they are considered negligible contributors to the potential for failure
- Develop methods and procedures for evaluating CPFMs, including the scope and objectives for various field exploration activities, distress indicators to look for in the field, and a list of baseline data required for the evaluation of a particular CPFM.
- Step 4. Field Exploration and Data Gathering** – Conduct field visits, geophysical and geotechnical testing, laboratory testing, structural condition assessment, civil inspections, field survey, and other field data gathering. This step also includes additional research of existing OPPD documents to identify basis of design, construction details, and performance history of a structure or system in question.
- Step 5. Credible** – Reassess each CPFM identified in Step 3 using the additional data and analysis to determine if any of the CPFMs should be “ruled out” prior to detailed assessment. In addition, review the PFMs screened out as non-credible in the initial screening described above in light of the additional available data to determine if they should be added back to the list of CPFMs. This could result in the elimination of all of the CPFMs initially identified for a particular structure, or there might be remaining CPFMs that will be carried forward for detailed assessment.
- Step 6. Detailed Assessment** – Conduct a detailed assessment of each remaining CPFM for each structure to identify changes from the baseline conditions. Determine whether the Triggering Mechanisms for the CPFMs were actually initiated by the flood (potential for degradation/direct floodwater impact).
- Step 7. Potential for Failure Analysis** – Given the potential for degradation/direct floodwater impact as identified in Step 6, determine the significance of the potential for failure. The significance of the potential for failure is determined by the combined consideration of two elements: the first element is the potential for degradation/direct floodwater impact, and the second is the implications of that degradation/direct floodwater impact to a structure built to its specific design standard.

Assessment Process, Procedures, and Methods

The rationale for the potential-for-failure significance determination, including a description of the role each element played in that determination, is provided in Sections 5.0 and 6.0 of this Assessment Report for Priority 1 and Priority 2 Structures, respectively:

- **Not Significant/High Confidence** – “Not Significant” indicates that the potential for failure (the combined consideration of the potential for degradation/direct floodwater impact and the implications of that degradation/direct floodwater impact to a structure built to its specific design standard) has been qualitatively evaluated as “low.” “High Confidence” indicates that additional information and studies are not likely to increase the confidence in the findings or change the conclusions. By definition, all of the non-credible PFMs (see Tables 3-3 and 3-4) and “ruled out” CPFMs fall into this category. There are no recommended actions identified for any CPFMs listed in this category.
- **Not Significant/Low Confidence** – “Not Significant” indicates that the potential for failure (the combined consideration of the potential for degradation/direct floodwater impact and the implications of that degradation/direct floodwater impact to a structure built to its specific design standard) has been qualitatively evaluated as “low.” “Low Confidence” indicates that additional information and studies are required to increase confidence in the findings. The CPFMs included in this category are those for which additional data are required to confirm that there are “no further recommended actions.”
- **Significant/Low Confidence** – “Significant” indicates that the potential for failure (the combined consideration of the potential for degradation/direct floodwater impact and the implications of that degradation/direct floodwater impact to a structure built to its specific design standard) has been qualitatively evaluated as “high.” “Low Confidence” indicates that additional information and studies are required to increase the confidence in the findings. The CPFMs included in this category are those for which additional data are required to determine whether physical modification will be recommended.
- **Significant/High Confidence** – “Significant” indicates that the potential for failure (the combined consideration of the potential for degradation/direct floodwater impact and the implications of that degradation/direct floodwater impact to a structure built to its specific design standard) has been qualitatively evaluated as “high.” “High Confidence” indicates that additional information and studies are not likely to increase the confidence in the findings or change the conclusions. The CPFMs included in this category are those for which physical modifications are recommended. Any additional data are required only to facilitate the implementation of those physical modifications.

Document the reasons why a CPFM for any particular structure was placed in one of these categories, including a description of the role each element played in the significance determination (see Sections 5.0 and 6.0 of this Assessment Report for Priority 1 and Priority 2 Structures, respectively).

Summarize the results for each structure using a four-quadrant matrix. This matrix, provided as Table 3-1, shows the rating for the estimated total potential for failure along the vertical axis and the level of confidence along the horizontal axis.

Assessment Process, Procedures, and Methods

Table 3-1 – Potential for Failure/Confidence Matrix and Associated Recommended Actions

| | Low Confidence (Insufficient Data) | High Confidence (Sufficient Data) |
|---|---|--|
| Potential for Failure Significant | Recommend additional detailed forensic investigations and/or monitoring leading to a decision on physical modification to a structure | Recommend detailed forensic investigations leading to physical modification to a structure |
| Potential for Failure Not Significant | Recommend continued monitoring to confirm no further recommended actions | No further recommended actions related to the 2011 flood |

Step 8. Report – Following the potential-for-failure assessment, determine whether additional data are needed. Summarize the results of the assessment, and document specific recommended actions.

3.3 Field Observations

The 2011 flood event covered nearly 80 percent of the FCS site. Some of the FCS structures were protected by engineering measures (such as sandbags, temporary berms, and other flood-proofing measures), but many of the FCS structures, including a number of buried infrastructure systems, were not. As floodwater receded, visual observations of each structure were conducted to identify any obvious signs of distress or to identify Triggering Mechanisms that could lead to distress. The inspections were completed by three-person teams consisting of HDR professionals experienced in structural, civil, and geotechnical engineering. The overall FCS site was also visited by a variety of other HDR professionals for purposes of generally assessing the flood damages and site conditions.

Prior to conducting the site inspections, each discipline lead developed a checklist of specific structural and utility system concerns or issues that might have resulted from prolonged exposure to the floodwater. Copies of each checklist (structural, civil, and geotechnical) are included in Attachment 3 of this Assessment Report. Examples of the concerns and issues include the following:

- Is there evidence of distress from flood forces on the structure caused by foundation uplift, foundation undermining, or other actions?
- Is there evidence of surface erosion or observable scour?
- Is the existing revetment protection undamaged?
- Is there evidence of moisture damage to concrete or metallic surfaces?
- Are there any signs of tilting or cracking of concrete slabs?

Assessment Process, Procedures, and Methods

- Is there observable ground subsidence?
- Is there observable pavement subsidence?
- Is there observable soil piping (sand boils, sinkholes)?

3.4 Identified Potential Failure Modes

The assessment teams identified 15 potential Triggering Mechanisms relative to the 2011 flood and FCS site inundation that could have materially and negatively impacted FCS structures. Once the Triggering Mechanisms were identified, PFMs that could develop as a result of those mechanisms were identified. A list of identified Triggering Mechanisms and associated PFMs is provided in Table 3-2.

| Triggering Mechanism No. | Triggering Mechanism | PFM No. | Potential Failure Mode |
|---------------------------------|---|----------------|---|
| 1 | River Bank Erosion/Scour | 1a | Undermining shallow foundation/slab |
| | | 1b | Loss of lateral support for pile foundation |
| | | 1c | Undermined buried utilities pipes/cables |
| | | 1d | Additional lateral force on piles |
| 2 | Surface Erosion | 2a | Undermining shallow foundation/slab |
| | | 2b | Loss of lateral support for pile foundation |
| | | 2c | Undermined buried utilities |
| 3 | Subsurface Erosion/Piping | 3a | Undermining and settlement of shallow foundation/slab (due to pumping) |
| | | 3b | Loss of lateral support for pile foundation (due to pumping) |
| | | 3c | Undermined buried utilities (due to pumping) |
| | | 3d | Undermining and settlement of shallow foundation/slab (due to river drawdown) |
| | | 3e | Loss of lateral support for pile foundation (due to river drawdown) |
| | | 3f | Undermined buried utilities (due to river drawdown) |
| | | 3g | Sinkhole development due to piping into karst voids |
| 4 | Hydrostatic Lateral Loading (water loading on structures) | 4a | Overturning |
| | | 4b | Sliding |
| | | 4c | Wall failure in flexure |
| | | 4d | Wall failure in shear |
| | | 4e | Excess deflection |
| 5 | Hydrodynamic Loading | 5a | Overturning |
| | | 5b | Sliding |
| | | 5c | Wall failure in flexure |
| | | 5d | Wall failure in shear |
| | | 5e | Damage by debris |
| | | 5f | Excess deflection |
| 6 | Buoyancy, Uplift | 6a | Fail tension piles |

Assessment Process, Procedures, and Methods

Table 3-2 – Triggering Mechanisms and Potential Failure Modes

| Triggering Mechanism No. | Triggering Mechanism | PFM No. | Potential Failure Mode |
|--------------------------|--|---------|---|
| | Forces on Structures | 6b | Cracked slab, loss of structural support |
| | | 6c | Displaced structure/broken connections |
| 7 | Soil Collapse (first time wetting) | 7a | Cracked slab, differential settlement of shallow foundation, loss of structural support |
| | | 7b | Displaced structure/broken connections |
| | | 7c | General site settlement |
| | | 7d | Piles buckling from down drag |
| 8 | Soil Solutioning | 8a | Not applicable |
| 9 | Swelling of Expansive Soils | 9a | Cracked slab, differential heave of shallow foundation, loss of structural support |
| | | 9b | Displaced structure/broken connections |
| | | 9c | Fail tension piles |
| | | 9d | Additional lateral force on below-grade walls |
| 10 | Machine/Vibration-Induced Liquefaction | 10a | Cracked slab, differential settlement of shallow foundation, loss of structural support |
| | | 10b | Displaced structure/broken connections |
| | | 10c | Additional lateral force on below-grade walls |
| | | 10d | Pile/pile group instability |
| 11 | Loss of Soil Strength due to Static Liquefaction or Upward Seepage | 11a | Cracked slab, differential settlement of shallow foundation, loss of structural support |
| | | 11b | Displaced structure/broken connections |
| | | 11c | Additional lateral force on below-grade walls |
| | | 11d | Pile/pile group instability |
| 12 | Rapid Drawdown | 12a | River bank slope failure and undermining surrounding structures |
| | | 12b | Lateral spreading |
| 13 | Submergence | 13a | Corrosion of underground utilities |
| | | 13b | Corrosion of structural elements |
| 14 | Frost Effects | 14a | Heaving, crushing, or displacement |
| 15 | Karst Foundation Collapse | 15a | Piles punching through karst voids due to additional loading |

3.5 Initial Screening of Potential Failure Modes

A summary of Triggering Mechanisms and associated PFMs by structure is presented in Attachment 4. Structures to be assessed were selected and prioritized by OPPD and included buildings, process structures, equipment foundations, tank foundations, and electrical towers (structures). In Attachment 4, the structures are grouped into three categories:

Assessment Process, Procedures, and Methods

- Class I structures
- Non-class I structures inside the PA
- Non-class I structures outside the PA

PFMs judged by the assessment teams to be credible based on initial screening are labeled “C” in Attachment 4. Failure modes deemed non-credible are labeled NC in Attachment 4, and failure modes that do not apply to a particular structure are labeled NA in Attachment 4.

Attachment 4 presents the results of initial screening. As more information becomes available, each PFM will be reevaluated and rerated as appropriate. The results of the PFM analysis for each structure and system are presented in Sections 5.0 and 6.0 of this Assessment Report.

3.6 Potential Failure Modes Deemed Non-Credible for All Structures

The results of the field observations combined with review of FCS design documents indicated that some of the potential Triggering Mechanisms and/or their associated PFMs listed in Table 3-2 did not occur or were not deemed credible as a result of the 2011 flood. For example, site investigations revealed no evidence of bank scour along the east boundary of the site. Therefore, all the PFMs associated with the Triggering Mechanism of river scour/bank erosion were determined to be non-credible because the Triggering Mechanism did not occur. The PFMs described in Table 3-3 were judged to be non-credible for all FCS structures evaluated with the exception of the PFMs associated with Triggering Mechanism 9, which was judged to be non-credible for only Priority 1 Structures. Table 3-3 shows Triggering Mechanisms 10, 12, 13 and 14 as non-credible, note that these Triggering Mechanisms were deemed non-credible after the completion of the assessments for Priority 1 Structures and before the assessment of Priority 2 Structures. The rationale for their elimination from the list of CPFMs is also presented.

| Table 3-3 – Potential Failure Modes Determined to be Non-Credible | | |
|---|---|--|
| Identifier | Potential Failure Mode | Rationale for Elimination |
| Triggering Mechanism 1 – River Bank Erosion/Scour | | |
| PFM 1a | Undermining shallow foundation/slab | Triggering Mechanism 1 did not occur: <ul style="list-style-type: none"> • Bathymetric survey of the river channel and banks indicated no observable sloughing, scouring, or other signs of bank erosion. • Visual observations of the river bank indicated no sloughing, scouring, or other signs of bank erosion. • Bank stabilization features installed by USACE are robust, and there is no known major bank failure as a result of 2011 flooding. • The river is back to nominal normal levels, and the Triggering Mechanism was not observed. |
| PFM 1b | Loss of lateral support for pile foundation | |
| PFM 1c | Undermined buried utilities pipes/cables | |
| PFM 1d | Additional lateral force on piles | |
| Triggering Mechanism 3 – Subsurface Erosion/Piping | | |
| PFM 3d | Undermining and settlement of shallow foundation/slab (due to river drawdown) | The river is back to nominal normal levels, and the PFMs were not observed. |
| PFM 3e | Loss of lateral support for pile foundation (due to river drawdown) | |
| PFM 3f | Undermined buried utilities (due to river drawdown) | |

Assessment Process, Procedures, and Methods

| Table 3-3 – Potential Failure Modes Determined to be Non-Credible | | |
|---|---|--|
| Identifier | Potential Failure Mode | Rationale for Elimination |
| PFM 3g | Sinkhole development (due to piping into karst voids) | Karst voids are filled with water. There is no head differential (gradient) to initiate this type of soil erosion. |
| Triggering Mechanism 8 – Soil Solutioning | | |
| PFM 8a | Various | Triggering Mechanism 8 did not occur: <ul style="list-style-type: none"> Mineralogy of local soils is not susceptible to solutioning. |
| Triggering Mechanism 9 – Swelling of Expansive Soils | | |
| PFM 9a | Cracked slab, differential heave of shallow foundation, loss of structural support | Triggering Mechanism 9 did not occur for Priority 1 Structures: <ul style="list-style-type: none"> Highly expansive soils are not present under the Priority 1 Structures. Structures are founded either on non-expansive select fill or on non-expansive native granular soils (pile-supported structures). Note: These PFMs were analyzed further for Priority 2 Structures where, in some cases, expansive soils are present. |
| PFM 9b | Displaced structure/broken connections | |
| PFM 9c | Fail tension piles | |
| PFM 9d | Additional lateral force on below-grade walls | |
| Triggering Mechanism 10 – Machine/Vibration Induced Liquefaction | | |
| PFM 10a | Cracked slab, differential settlement of shallow foundation, loss of structural support | Triggering Mechanism 10 did not occur: <ul style="list-style-type: none"> Groundwater is back to nominal normal levels, and the PFMs were not observed. |
| PFM 10b | Displaced structure/broken connections | |
| PFM 10c | Additional lateral force on below-grade walls | |
| PFM 10d | Pile/pile group instability | |
| Triggering Mechanism 12 – Rapid Drawdown | | |
| PFM 12a | River bank slope failure and undermining surrounding structures | Triggering Mechanism 12 did not occur: <ul style="list-style-type: none"> Groundwater is back to nominal normal levels, and the PFMs were not observed. |
| PFM 12b | Lateral spreading | |
| Triggering Mechanism 13 – Submergence | | |
| PFM 13a | Corrosion of underground utilities | Triggering Mechanism 13 did not occur: <ul style="list-style-type: none"> The structures were not subjected to a corrosive environment that would be considered beyond normal conditions. |
| PFM 13b | Corrosion of structural elements | |
| Triggering Mechanism 14 – Frost Effects | | |
| PFM 14a | Heaving, crushing, or displacement | Triggering Mechanism 14 did not occur: <ul style="list-style-type: none"> Prior to ground freezing, the groundwater returned to nominal normal levels. |
| Triggering Mechanism 15 – Karst Foundation Collapse | | |
| PFM 15a | Piles punching through karst voids due to additional loading | Triggering Mechanism 15 did not occur: <ul style="list-style-type: none"> Piles were driven or drilled to an elevation below the deepest karst/erosional feature. Explorations for the design/construction extended into bedrock. No voids exist below the pile tips. Additional vertical load due to soil down drag is minimal compared to the “baseline” vertical load. |

Assessment Process, Procedures, and Methods

3.7 Assessment Methods

Table 3-4 lists the various methods that might be used to determine the significance of the potential of failure for any of the structures. The methods included visual observations of the structures and civil works, field surveys, and geophysical and geotechnical investigations. Field teams composed of structural, civil, and geotechnical engineering professionals examined the structures as floodwater receded. These investigations were based on detailed checklists, as noted in Section 3.3. The results of the visual observations were supplemented with elevation surveys and geophysical and geotechnical investigations. Note also that Table 3-4 lists methods for Triggering Mechanisms 10, 12, 13, and 14; however, these Triggering Mechanisms were deemed non-credible after the completion of the assessments for Priority 1 Structures and before the assessment of Priority 2 Structures.

OPPD

Assessment Process, Procedures, and Methods

| Potential Failure Mode (PFM) | | Investigation Method | | | |
|------------------------------|--|--|--|---|---------------------------|
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 1. River Bank Erosion/Scour | a. Undermining shallow foundation/slab | These PFMs were determined to be non-credible. | | | |
| | b. Loss of lateral support for pile foundation | | | | |
| | c. Undermined buried utilities pipes/cables | | | | |
| | d. Additional lateral force on piles | | | | |
| 2. Surface Erosion | a. Undermining shallow foundation/slab | [Note: these actions were taken for each PFM.] Interview OPPD staff. Review plans and specifications to identify pertinent design and construction details needed to define pre-flood conditions. Review OPPD Condition Reports to determine changes and modifications since construction. Review flood data including observed flow conditions, depths, and velocities. | Observe surface condition for erosion, broken pavement, depressions, gullies, and other signs of distress, and hand probe area adjacent to structures. | Look for settlement of slab, cracks in foundation and walls, tilt, or settlement of foundation. | |
| | b. Loss of lateral support for pile foundation | | Observe soil conditions around structure for settlement. | Observe pile-supported slab for cracking or excessive deflection. | |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Potential Failure Mode (PFM) | | Investigation Method | | | |
|--------------------------------|---|---|---|---|--|
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 2. Surface Erosion (continued) | c. Undermined buried utilities | | Observe surface condition for erosion, broken pavement, depressions, gullies, and other signs of distress, and hand probe area adjacent to structures. Conduct video inspection of open conduits and pipe in soil if accessible or as possible. | | |
| | 3. Subsurface Erosion/Piping | a. Undermining and settlement of shallow foundation/slab (due to pumping) | Observe surface condition around buildings for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations or slabs. | Observe settlement of slabs, cracks in foundation, or settlement of foundation. | Test for voids using ground penetrating radar (GPR). Hydro-excavate suspect areas where feasible. |
| | b. Loss of lateral support for pile foundation (due to pumping) | | Observe soil conditions around structure for settlement. | | Sample areas adjacent to structures using standard penetration test (SPT) or cone penetration test (CPT) methods as appropriate. |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Investigation Method | | | | | |
|--|--|--------------------------|--|---|--|
| Potential Failure Mode (PFM) | | | | | |
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 3. Subsurface Erosion/Piping (continued) | c. Undermined buried utilities (due to pumping) | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Conduct video inspection of open conduits and pipe in soil if accessible or as possible. Inspect utility manholes (MHs) if possible. Identify MH penetrations that leak; look for sediment in MH bottom and in pumped water. | Observe soil conditions at utilities for settlement or lost soil material. | Test for voids using GPR. Hydro-excavate suspect areas where feasible. Open test pit where feasible. |
| | d. Undermining and settlement of shallow foundation/slab (due to river drawdown) | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe soil conditions around structure for settlement of slab, cracks in foundation, or settlement of foundation. | Test for voids using GPR. Hydro-excavate suspect areas where feasible. |
| | e. Loss of lateral support for pile foundation (due to river drawdown) | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. | Observe soil conditions around structure for settlement. | Sample areas adjacent to structures using SPT or CPT methods as appropriate. |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Potential Failure Mode (PFM) | | Investigation Method | | | |
|--|--|---|---|--|--|
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 3. Subsurface Erosion/Piping (continued) | f. Undetermined buried utilities (due to river drawdown) | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Conduct video inspection of open conduits and pipe in soil if accessible or as possible. Inspect utility MHs if possible. Identify MH penetrations that leak; look for sediment in MH bottom and in pumped water. | Observe soil conditions at utilities for settlement or lost soil material. | Test for voids using GPR. Hydro-excavate suspect areas where feasible. Open test pit where feasible. |
| | g. Sinkhole development (due to piping into karst voids) | This PFM was determined to be non-credible. | | | |
| 4. Hydrostatic Lateral Loading (water loading on structures) | a. Overturning | | Survey/monitor elevation of designated points on foundations. | Observe structures for signs of movement. | |
| | b. Sliding | | Survey/monitor elevation of designated points on foundations. | Observe structures for signs of movement. | |
| | c. Wall failure in flexure | | Survey/monitor elevation of designated points on foundations. | Observe perimeter walls and below-grade walls for signs of cracking, water leakage, or excessive (visible) deflection. | |
| | d. Wall failure in shear | | Survey/monitor elevation of designated points on foundations. | Observe perimeter walls and below-grade walls for signs of cracking, water leakage, or excessive (visible) deflection. | |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Potential Failure Mode (PFM) | | Investigation Method | | | |
|--|-----------------------|--------------------------|---|---|---------------------------|
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 4. Hydrostatic Lateral Loading (water loading on structures) (continued) | e. Excess deflection | | Survey/monitor elevation of designated points on foundations. | Observe perimeter walls and below-grade walls for signs of cracking, water leakage, or excessive (visible) deflection. | |
| | a. Overturning | | Survey/monitor elevation of designated points on foundations. | Observe structures for signs of high water exposure or structure movement. | |
| 5. Hydrodynamic Loading | b. Sliding | | Survey/monitor elevation of designated points on foundations. | Observe structures for signs of high water exposure or structure movement. | |
| | c. Failure in flexure | | | Observe exposed structure for signs of high water. Observe exposed structural elements for signs of cracking, water leakage, or excessive (visible) deflection. | |
| | d. Failure in shear | | | Observe exposed structure for signs of high water. Observe exposed structural elements for signs of cracking, water leakage, or excessive (visible) deflection. | |
| | e. Damage by debris | | | Observe exposed structure for signs of high water or impact abrasions/damage from debris. | |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Potential Failure Mode (PFM) | | Investigation Method | | | |
|--|--|--------------------------|---|---|---|
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 5. Hydrodynamic Loading (continued) | f. Excess deflection | | | Observe exposed structure for signs of high water. Observe exposed structural elements for signs of cracking, water leakage, or excessive (visible) deflection. | |
| | a. Failed tension piles | | | Observe pile-supported slabs for cracking, upward deflection. | |
| 6. Buoyancy, Uplift Forces on Structures | b. Cracked slab, loss of structural support | | Observe perimeter grade condition for anomalies, and hand probe alignment or area adjacent to structures. | Observe pile supported slabs for cracking or upward deflection. | Hydro-excavate suspect areas. |
| | c. Displaced structure/broken connections | | Observe perimeter grade condition for anomalies, and hand probe alignment or area adjacent to structures. | Observe structures for cracking, broken members, or other signs of structural distress. | |
| | a. Cracked slab, differential settlement of shallow foundation, loss of structural support | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe soil conditions around structure for settlement of slab, cracks in foundation, or settlement of foundation. | Hydro-excavate suspect areas. Obtain undisturbed samples, and test density and water content. |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Potential Failure Mode (PFM) | | Investigation Method | | | |
|---|---|---|---|---|---|
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 7. Soil Collapse (first time wetting) (continued) | b. Displaced structure/broken connections | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe structures for cracking, broken members, or other signs of structural distress. | Hydro-excavate suspect areas. Obtain undisturbed samples, and test density and water content. |
| | c. General site settlement | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | | Hydro-excavate suspect areas. Obtain undisturbed samples, and test density and water content. |
| | d. Piles buckling from down drag | | | Observe pile-supported slabs for cracking or downward deflection. | Hydro-excavate suspect areas. Obtain undisturbed samples, and test density and water content. |
| 8. Soil Solutioning | a. Not applicable | This PFM was determined to be non-credible. | | | |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Investigation Method | | | | | |
|--|--|--------------------------|---|--|--|
| Potential Failure Mode (PFM) | | | | | |
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 9. Swelling of Expansive Soils | a. Cracked slab, differential heave of shallow foundation, loss of structural support | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe foundations for cracking and/or deflection from swelling. | Sample areas adjacent to structures using Shelby Tube sampling and laboratory analysis as appropriate. |
| | b. Displaced structure/broken connections | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe structures for cracking, broken members, or other signs of structural distress. | Sample areas adjacent to structures using Shelby Tube sampling and laboratory analysis as appropriate. |
| | c. Fail tension piles | | | Observe pile-supported slabs for distress. | |
| | d. Additional lateral force on below-grade walls | | | Observe perimeter walls and below-grade walls for signs of cracking, water leakage, or excessive (visible) deflection. | Sample areas adjacent to structures using Shelby Tube sampling and laboratory analysis as appropriate. |
| 10. Machine/Vibration-Induced Liquefaction | a. Cracked slab, differential settlement of shallow foundation, loss of structural support | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe foundations for cracking and/or deflection from swelling. | Sample areas adjacent to structures using SPT or CPT methods as appropriate. Hydro-excavate suspect areas. Conduct seismic refraction surveys. |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Potential Failure Mode (PFM) | | Investigation Method | | | |
|--|---|--------------------------|---|---|--|
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 10. Machine/Vibration-Induced Liquefaction (continued) | b. Displaced structure/broken connections | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe structures for cracking, broken members, or other signs of structural distress. | Sample areas adjacent to structures using SPT or CPT methods as appropriate. Hydro-excavate suspect areas. Conduct seismic refraction surveys. |
| | c. Additional lateral force on below-grade walls | | | Observe perimeter walls and below-grade walls for signs of cracking, water leakage, or excessive (visible) deflection. | Sample areas adjacent to structures using SPT or CPT methods as appropriate. Hydro-excavate suspect areas. Conduct seismic refraction surveys. |
| | d. Pile/pile group instability | | | Observe pile-supported slabs for cracking, downward deflection. Test for voids using GPR. | Sample areas adjacent to structures using SPT or CPT methods as appropriate. Hydro-excavate suspect areas. Conduct seismic refraction surveys. |
| 11. Loss of Soil Strength due to Static Liquefaction or Upward Seepage | a. Cracked slab/differential settlement/shallow foundation/loss of structural support | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe foundations for cracking and/or deflection from swelling. Survey/monitor elevation of designated points on foundations. | Sample areas adjacent to structures using SPT or CPT methods as appropriate. Hydro-excavate suspect areas. Conduct seismic refraction surveys. |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Potential Failure Mode (PFM) | | Investigation Method | | | |
|--|--|--------------------------|--|--|--|
| Triggering Mechanism | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| II. Loss of Soil Strength due to Static Liquefaction or Upward Seepage (continued) | b. Displaced structure/broken connections | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe structures for cracking, broken members, or other signs of structural distress. | Sample areas adjacent to structures using SPT or CPT methods as appropriate. Hydro-excavate suspect areas. Conduct seismic refraction surveys. |
| | c. Additional lateral force on below-grade walls | | | Observe perimeter walls and below-grade walls for signs of cracking, water leakage, or excessive (visible) deflection. | Sample areas adjacent to structures using SPT or CPT methods as appropriate. Hydro-excavate suspect areas. Conduct seismic refraction surveys. |
| | d. Pile/pile group instability | | | Observe pile-supported slabs for cracking, downward deflection. | Sample areas adjacent to structures using SPT or CPT methods as appropriate. Hydro-excavate suspect areas. Conduct seismic refraction surveys. |

Assessment Process, Procedures, and Methods

Table 3-4 – Potential Methods and Procedures for Addressing Identified Potential Failure Modes

| Investigation Method | | | | | |
|-------------------------------|--|---|---|--|--|
| Potential Failure Mode (PFM) | PFM Description | Background Data Research | Field Observations | Structure Assessment | Subsurface Investigations |
| 12. Rapid Drawdown | a. River bank slope failure and undermining surrounding structures | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. Survey/monitor elevation of designated points on foundations. | Observe soil conditions around structure for eroded or lost material, settlement of slab, cracks in foundation, or settlement of foundation. | Install and monitor inclinometers. Hydro-excavate suspect areas. |
| | b. Lateral spreading | | Observe surface condition for anomalies, and hand probe alignment or area adjacent to structures. | Observe site soils conditions for signs of soil movements or spreading. | Install and monitor inclinometers. |
| 13. Submergence | a. Corrosion of underground utilities | Review cathodic protection records. | Conduct video inspection of open conduits and pipe if accessible or as possible. | | |
| | b. Corrosion of structural elements | | | Observe exposed structural elements for signs of rust, degraded material, or other signs of corrosion. | |
| 14. Frost Effects | a. Heaving, crushing, or displacement | | | | Test soil properties. |
| 15. Karst Foundation Collapse | a. Piles punching through karst voids due to additional loading | This PFM was determined to be non-credible. | | | |