Appendix H
Conceptual Lower Level Outlet (LLO) Gate Design Report

Chehalis River Basin Flood Damage Reduction Project

Lewis County, Washington

April 24, 2024

Chehalis River Basin
Flood Control Zone District

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Executive Summary

To provide higher levels of flood protection for the upper Chehalis River Basin and maintain river habitat, it has been proposed to build a flood retention-only (dry dam) facility with a non-permanent reservoir. The outlet works of such a system must allow unimpeded flow in the Chehalis River, while also providing impoundment and regulated water release during periods of flooding. The design of the outlet valves and gates address two potential conditions including the dry dam, Flood Retention Expandable (FRE) structure loading and a potential expansion to a permanent pool, Flood Retention Expandable- Future Condition (FRE-FC) option. The outlet works will be located at the base of the dam. For the FRE-FC condition, high water levels will load the outlet conduits. Any flow regulation structures, such as gates or valves, will have to be able to withstand significant pressures when activated to stop the water flow. The complexity of the design of these gates or valves is the driving factor to perform modeling at this design phase. To ensure the design of the gates and valves is feasible and operable, finite element modeling and analysis was conducted at this design stage, and detailed hereafter within this report.

Task Order 26 is presented herein and includes the design of the hydromechanical aspects of the outlet works for the revised FRE and FRE-FC conditions. Recommended steel gate types for the five fish passage outlets and conceptual opening sizes for the water-quality ports are provided. The conduit structure consists of eleven total conduits. These are: five water quality ports, a reservoir evacuation conduit, and five conduits contain hydraulic steel structure (HSS) gates. Hereafter, the five HSS gate conduits comprise what shall be referred to as the Lower Level Outlet (LLO) structure. Four of the five conduits within the LLO will contain a 10-foot wide by 16-foot-high bonneted slide gates, while one conduit that contains a 12-foot wide by 20-foot high Tainter valve. The main goal of these five LLO gates is to allow for fish and sediment passage through the dam, and allow the existing river to achieve as close to natural flow conditions as possible. The five LLO gates will run through the base of the dam from the upstream inlet tower to into a downstream stilling basin. In the event of a flood, the HSS gates at the LLO will be utilized to close off the flow of fish passage outlets to control the flow of water.

A Tainter valve will be utilized at the FRE flood condition and will be sealed permanently if the FRE-FC condition is required in the future. All four adjacent high-head bonneted slide gates will be utilized at the FRE condition, yet only two will be designed to be operated at the FRE-FC condition, while the other two will be sealed permanently in the event of a future FRE-FC expansion. However, to allocate for possible operational flexibility as the design progresses, the Tainter valve, in addition to the four bonneted slide gates, were evaluated in this report to withstand high-head applications as required for the FRE-FC condition. For reference, a “hydraulic head” is hereafter defined as water pressure created by the difference in elevation between the upstream and downstream water surface elevations (WSEs) of a gate.

In addition, five water quality ports at variable elevations will be blind-flanged, as these will not be needed for the FRE condition. The purpose of these water quality ports will be to achieve ideal temperatures and discharge conditions if an FRE-FC structure were to be implemented in the future. The remaining single conduit is a 9-foot diameter evacuation conduit that is intended to provide floodwater evacuation and reservoir drawdown for both the FRE or FRE-FC conditions.

Conceptual gate sizes and configurations are reflected in the 10% Conceptual Design Drawing Set that accompanies this report. The design parameters may change as the design phases progress; thus, the gate sizes and configurations are strictly conceptual. At this stage in design, the FRE-FC

seismic load case (LC5B.3) controlled the 12-foot by 20-foot Tainter valve conceptual design and dimensions. The 12-foot width was selected because as the width of the Tainter valve increased, general overstressing of the structure occurred, particularly with regards to plate girder elements. To mitigate this overstressing, other structural elements, such as stiffeners and hangers would have to be added to the design. The width of the Tainter valve may be increased to a 14-foot or 16-foot width configuration, which incurs further custom fabrication that may increase manufacturing costs. If the Tainter valve is to be decommissioned for the FRE-FC condition or the FRE-FC condition is never built, then a wider gate could be possible, and may be studied in forthcoming analyses as the design progresses.

1 Background

The Chehalis River Basin Flood Damage Reduction project objective is to develop recommendations for a series of measures aimed at reducing damage to the communities of the Chehalis River Basin from Pe Ell to Centralia during major flood events. Among these measures is a proposed Flood Retention Expandable (FRE) structure on the Chehalis River, south of the town of Pe Ell.

The Chehalis River Basin Flood Damage Reduction, Revised Project Description Report (RPDR) is a supplemental report documenting the relocation of and changes to the FRE facility (Proposed Project) as originally documented within the Combined Dam and Fish Passage Conceptual Design Report (HDR Engineering, Inc. [HDR] 2017) and FRE Dam Alternative Report (HDR 2018).

The RPDR describes, supports, contrasts, and illustrates the changes to the Proposed Project in a single comprehensive document.

After the 2007 flood of the Chehalis River Basin, which incurred an estimated $900 million in economic damages, the Chehalis River Basin Flood Authority (CRBFA) was founded to research flood hazard mitigation strategies. Initial site investigations and site characterizations for potential dam sites were conducted in 2015 and 2016 by HDR and Shannon & Wilson (CBWG, 2017).

A U.S. Army Corps of Engineer's (USACE) Section 404 permit and subsequent draft Environmental Impact Statement (DEIS) was published in 2020, wherein two alternatives were investigated. Alternative 1 proposed the FRE condition, and Alternative 2, a Flood Retention Only (FRO) facility (USACE, 2020). The difference between the FRE and FRO proposals is the latter would utilize a smaller foundation and would have no design allotment for future flood storage capacity expansion, noted hereafter as Flood Retention Expandable- Future Condition (FRE-FC).

Alternative 1 is the topic of this report, wherein the conceptual design of the conduit structure, for the FRE and FRE-FC conditions, is investigated. An additional DEIS was authorized by Washington's State Environmental Policy Act (SEPA), with an emphasis on native aquatic species restoration and climate resilience (WDE, 2020). A draft Biological Assessment and Essential Fish Habitat (EFH) assessment was conducted (USACE, 2021) with an emphasis on improving native salmonoid species' transport and habitation for the FRE structure (USACE, 2021).

As a result of these multifaceted concerns, an advanced understanding of the FRE and FRE-FC operations was warranted to address USACE and SEPA commentary. A reevaluation of the LLO structures and fish passage requirements was conducted, and the Roller Compacted Concrete (RCC) configuration has been moved upstream and changed from a straight to an arched RCC dam, to minimize impacts to the original site's Traditional Cultural Property (TCP) designation, as determined in late 2021 (HDR, 2023). Since 2014, the Chehalis River Basin Flood Control Zone District (CRBFCZ) has contracted HDR for engineering design services, under contract No. 10264664. This contract has supported multiple Supplemental Agreements that have worked to address the evolved nature of the Proposed Project.

2 Introduction

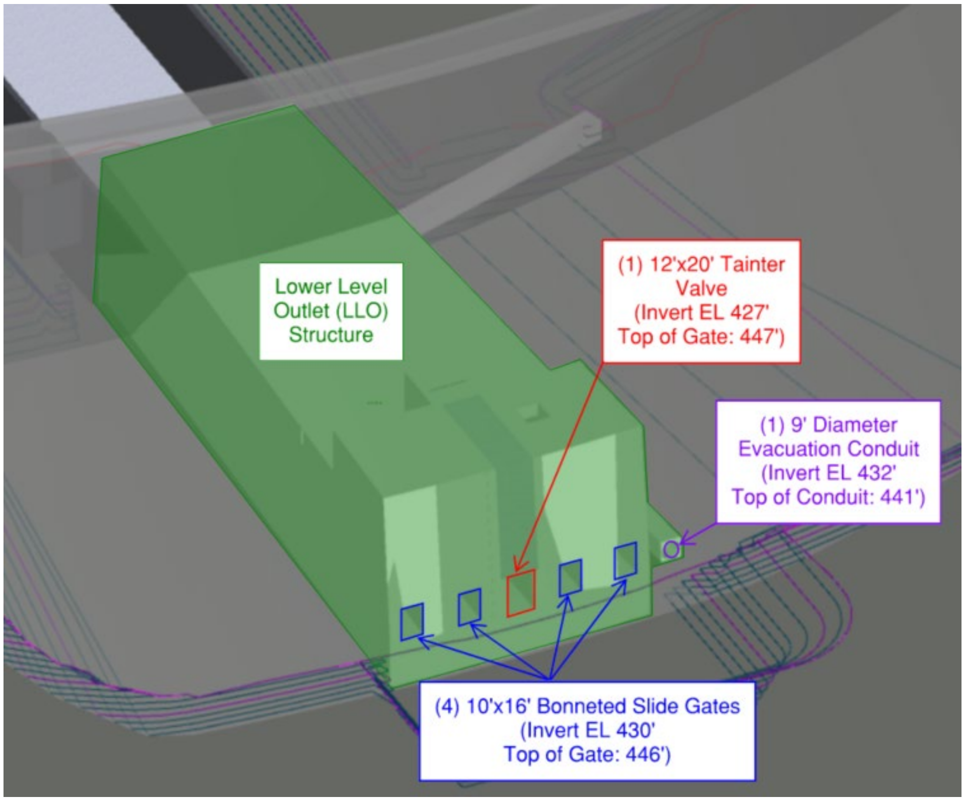
On April 20, 2023, Supplemental Agreement (SA) 07 was signed and enacted to continue conceptual design aspects of the Chehalis Dam design, such as advanced hydraulics and hydrology modeling and open-channel volitional fish passage design (for National Marine Fisheries Service [NMFS] compliance). As Appendix H to the RPDR, this report documents the scope of work produced under SA 07, Task 26: Hydro-Mechanical Gate Design. This assesses the conduit structure, which includes the following:

- Qualitative Gate Type Study
- Conceptual Quantitative Gate Size and Arrangement
- Conceptual Quantitative Sizing of Upstream Closure
- Qualitative Valve Type Study
- Conceptual Valve Conduits Assessment

The basis of this report discusses the conceptual LLO design that is present for the FRE and FRE-FC conditions, in addition to water quality inlets and evacuation conduit parameters. The LLO consists of five total conduits, which all constitute hydraulic steel structure (HSS) gates- these are four 10-foot wide by 16-foot high bonneted slide gates, and one 12-foot wide by 20-foot high Tainter valve. Outside of the LLO, there are five conduits are water quality ports that are blind flanged until the FRE-FC condition is constructed. The eleventh and final conduit is a 9-foot diameter emergency discharge conduit regulated with an isolation valve. All LLO conduits run from the upstream face of the FRE Structure and through the outlet section of the dam and release into the stilling basin downstream, as shown in Figure 1 and Figure 2. The arrangement and spacing of gates and conduits are to serve three unique purposes:

- Fish Passage
- Water Quality
- Floodwater Evacuation
- Emergency Drawdown

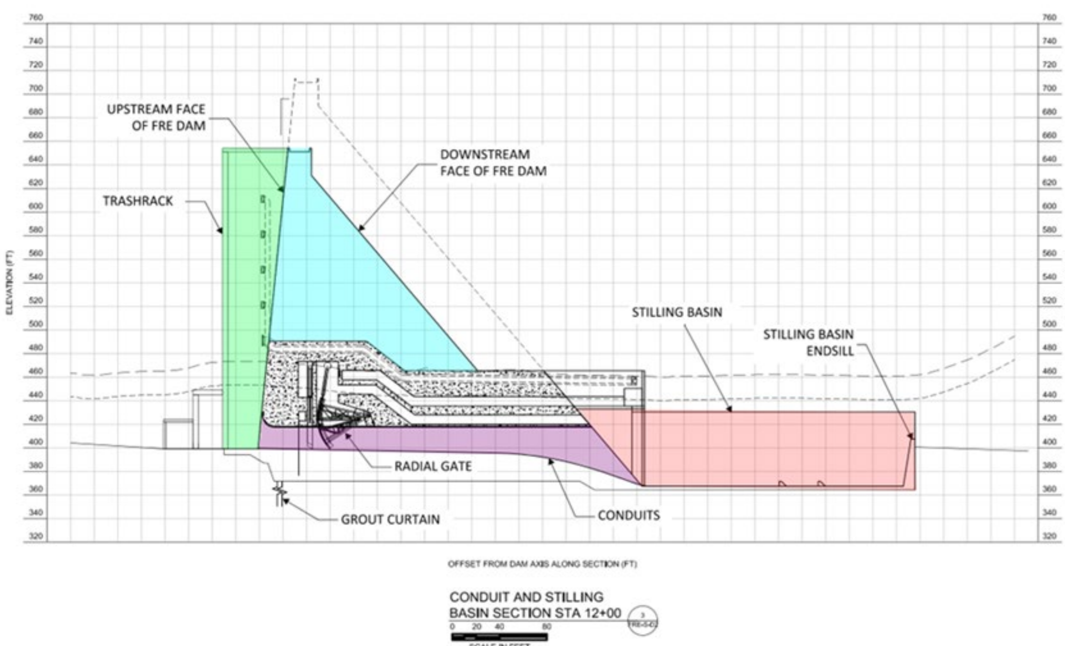
Figure 1. Conceptual Layout Upstream Face of Conduit Structure



Note: Water Intake Outlets Not Shown. HDR (2023)

For further information regarding LLOs see Table 1 in Section 2.3.

Figure 2. Conceptual Layout Upstream Face of Outlet Works Tower



Source: HDR (2023)

The progression of conceptual design for both gate types within Task Order 26 followed the following order: First, an initial gate analysis model was completed and recorded for both the Tainter valve and the Bonneted slide gate. A conceptual gate design was implemented for both gate types.

2.1 Initial Gate Analysis Modeling

An evaluation of multiple HSS gate types, and the evaluation criteria used to select the designated gates within this report, are expanded upon in Section 4.1.

For the initial gate model analysis, the intent was to evaluate the existing design prior to 2023. The design prior to 2023 included multiple large Tainter valves at the base of the dam, indented to operate under high-head applications. With the environmental benefit of having a wider gate for fish passage and sediment sluicing, feasibility studies were requested to determine reasonable gate size possibilities. The intent for this initial analysis was to serve as a basis for further design iterations.

A Tainter valve was evaluated with two configurations: one in which the gate end frames contain two strut arms, and another wherein the valve end frames contained three strut arms. As the conceptual design progressed, it was decided to abandon the three-strut arm configuration. This was due to likely constructability issues due to member congestion and weldability constraints at the valve trunnion supports. Therefore, the two-arm 12-foot wide x 20-foot high valve approach was selected for initial analysis.

The ideal width of the conduit for the Tainter valve was of high importance in the conceptual design discussions. For the initial analysis, the goal was to have the LLO gates and fish passage conduit able to pass 5,000 cubic feet per second (cfs) of flow. Though a wider valve would beget higher discharge capacity through the LLO, the initial analysis resulted in a gate width of 12 feet as the most structurally tenable. At 12 feet wide, the initial analysis showed that conventional, readily commercially available steel sizes could be used for gate fabrication. Wider valve widths, up to 16 feet wide, were evaluated, but abandoned at this phase of design due to significant two-sided and one-sided lift demand that would arise as the design progresses. Furthermore, Tainter valves wider than 12 feet would require significant use of non-standard, custom steel sections, thereby increasing the cost of valve fabrication.

2.2 Conceptual Gate Design

Following the initial gate analysis modeling, a conceptual design for the LLO gates, and additional conduits and valves, was performed to determine whether the design needs were met to give future design recommendations as the design progresses.

It was decided that the one Tainter valve would be sufficient to serve as the main fish passage outlet through the LLO. Additionally, the Tainter valve would allow for sediment sluicing and replicating the in-situ streambed flow. The design methodology of the conceptual design of the Tainter valve is detailed in Section 4.2. The conceptual design allows for a two-arm strut configuration utilizing conventional steel sizes, as noted above.

The four bonneted slide gates, two on each side of the Tainter valve, will be used in conjunction with the Tainter valve for fish passage. The bonneted slide gate configuration was chosen for the sealing capabilities of the gate type, as well as the strength of the gate for the extreme loading required of the gates. The design methodology, as well as the design principles of the bonneted slide gates, is detailed in Section 4.3 of this report. The Tainter valve, in addition to two of the four bonneted slide gates, is intended for use for the FRE condition only. Two of the four bonneted slide gates, one on each side of the Tainter valve, are intended to resist high-head applications and serve as backup for the 9-foot diameter evacuation conduit for both the FRE and FRE-FC conditions. The two bonneted slide gates and the Tainter valves designed for lower-head operation would be decommissioned in the FRE-FC condition, as denoted in Table 1. However, to allocate for possible operational flexibility as the design progresses, the Tainter valve, in addition to the four bonneted slide gates, were evaluated in this report to withstand high-head applications as required for the FRE-FC condition, with the WSEs as denoted in Table 2. For this stage in design, the bonnet and other aspects of the bonneted slide gates were not explicitly designed as these characteristics will be developed as the design progresses.

The emergency evacuation conduit is also an integral part of the conceptual design of the outlet structure. The emergency evacuation conduit is detailed in Section 6. The purpose of the evacuation conduit is to provide reservoir evacuation post-flood event or for emergency drawdown. The evacuation conduit for FRE conditions is made up of a bell mouth intake, a trashrack, a bulkhead slot, a steel-lined and concrete-encased pipe, and an isolation valve with a vent. The purpose of each of these members is to provide a smooth flow profile into the conduit and filter debris from entering the conduit.

The water quality ports were also included in the conceptual design. The purpose of the water quality ports is to achieve the desired temperature discharge conditions downstream of the dam for the FRE-FC condition. This is achieved through a system of conduits that convey water from varying elevations of the forebay pool. The inlets of the water quality ports are positioned at various elevations at the upstream face of the outlet structure to adjust the downstream water temperature and turbidity. Section 5 of this report displays further visuals of the water quality ports.

Depending on the water elevations of the reservoir, some LLO gates may be in use, or decommissioned, depending on the FRE or FRE-FC condition. Section 2.3 details these water level conditions for the LLO structures.

2.3 LLO Objectives: FRE and FRE-FC Conditions

Provisions to incorporate the proposed FRE-FC condition, should this phase be constructed in the future, are necessary at this design phase to successfully and efficiently design the FRE condition. By consequence, careful selection of the operating criteria and objectives of both the FRE and FRE-FC conditions, are required for constructability, serviceability, and functionality. This section discusses the conceptual uses of conduit structures for both conditions, shown in and summarized in Table 1.

The LLO is intended to replicate the in-stream flow and velocity of the in-situ channel, through which adult salmon, steelhead, resident fish, and lamprey currently navigate. The Chehalis River, which the proposed FRE and FRE-FC will impound, discharges approximately 4,000 cubic feet per second (cfs) of usual flow. During higher flow events, above the anticipated fish migration flows, and during flood retention scenarios, captured sediment is anticipated to be flushed out of the conduits. The material will naturally begin to mobilize out of the conduits as discharges rise above 4,000 cfs or by higher flow velocity occurring under the Tainter valves as the valves are closed (CRBFCZ, 2017).

The Tainter valve is intended to serve as the main fish passage outlet through the conduit structure. Additionally, the Tainter valve will allow for sediment sluicing and is intended to replicate the in-situ streambed discharge flow. The four bonneted slide gates, two on each side of the Tainter valve, will be used in a similar capacity for fish passage. The Tainter valve, in addition to the other two bonneted slide gates, is intended for use for the FRE condition only.

The five water quality ports in place for the potential FRE-FC condition are intended to be used as temperature control orifices, to selectively withdraw water at various elevations (from mid-crest height to below the spillway crest), to address both warmer and cooler water discharge needs downstream. These water quality ports are intended to be utilized in the FRE-FC condition only. By consequence, these outlets will be sealed with blind flanges for the FRE condition. A detailed explanation of the utility of these water quality ports is in Section 5.

The 9-foot diameter flood evacuation conduit, adjacent to the bonneted slide gates (Figure 1 and Figure 2) will serve as an evacuation orifice, for emergency evacuation of the reservoir in an extreme event, and meet the evacuation criteria of 5,000 cfs of surplus discharge capacity. This is assuming that none of the other conduits are in use.

Table 1 summarizes the operational objectives of all five LLO gates.

Table 1. Designation of LLO Structures for FRE and FRE-FC Conditions

Gate Type and # of instances	Size	FRE (Purpose)	FRE-FC (Purpose)
Tainter valve (1)	12’-0” Wide x 20’-0” High	Full operation and utilized for flow regulation	Not in use (decommissioned)
Bonneted Slide Gates (4)	10’-0” Wide x 16’-0” High	All four gates are in full operation and utilized for flow regulation	Two of four gates are in full operation and utilized for flow regulation Two of four gates are not in use (decommissioned)
Water Quality Ports (5)	7’-0” Diameter (1) 1’-0” Diameter (4)	Not in use (blind-flanged)	Full operation
Flood Evacuation Conduit (1)	9’-0” Diameter	Not in use (blind-flanged)	Full operation

3 Existing Documentation

Existing documentation that is referenced in this report includes:

- **Contractual Reports:**
  - Supplemental Agreement 07- Upstream FRE Structure Revised Project Description, dated April 20, 2023, by HDR Engineering (HDR).

- **Analysis Reports:**
  - Preliminary Design Earthquake Time Histories, Chehalis Basin Flood Mitigation, Pe Ell, Washington, by Shannon & Wilson Inc, dated September 30, 2015 (S&W).
  - Chehalis Basin Strategy, Combined Dam and Fish Passage Conceptual Design Report dated June 2017 by Chehalis Basin Work Group (CRBFCZ).
- **Environmental Impact Statements:**
  - Chehalis River Basin Flood Damage Reduction Project, NEPA EIS, dated September 18, 2020 by the U.S. Army Corps of Engineers (USACE), Seattle District.
  - State Environmental Policy Act Draft Environmental Impact Statement, Proposed Chehalis River Basin Flood Damage Reduction Project, dated February 27, 2020, by the State of Washington Department of Ecology (WDOE).
  - Chehalis River Basin Flood Damage Reduction Project: Flood Retention Facility, Airport Levee Improvements, and Mitigation Actions, dated September 2021, USACE, Seattle District.
- **Design Standards:**
  - Design of Hydraulic Gates, dated 2004, Erbisti, Paulo C.F.
  - Guidelines for Evaluation of Water Control Gates, dated June 2010, American Society of Civil Engineers (ASCE), Foltz.
  - Engineering Manual (EM) 1110-2-2107, Design of Hydraulic Steel Structures, dated August 1, 2022, USACE.
  - EM 1110-2-6053, Earthquake Design and Evaluation of Concrete Hydraulic Structures, dated May 1, 2007, USACE.
  - EM 1110-2-2400, Structural Design and Evaluation of Outlet Works, dated June 2, 2003, USACE.
  - EM 1110-2-1602, Hydraulic Design of Reservoir Outlet Works, dated October 15, 1980, USACE.
  - Engineering Regulation (ER) 1110-2-1806, Earthquake Design and Evaluation for Civil Works Projects, dated May 31, 2016, USACE.
  - Steel Construction Manual, AISC 360, 15th Edition, dated May 2017, American Institute of Steel Construction (AISC).

4 Gates at the Outlet Works

4.1 Outlet Works Gate Type Study

Per the Task Order 26 contract, the hydromechanical team has explored the practicality of multiple gate types, including existing ones used for similar applications as are anticipated for Chehalis FRE and FRE-FC. The design methodology will be referencing USACE EM 1110-2-2107 (USACE, 2022), with further reference from other sources as noted. This section details the typical advantages and disadvantages of the several HSS gate types that were evaluated for the conceptual conduit structure. USACE criteria are utilized hereafter, as the dam is largely intended is for flood control measures. Furthermore, the load cases denoted in EM 1110-2-2107 are more closely aligned to the operations criteria, than HSS evaluation criteria from alternate agencies such as United States Bureau of Reclamation (USBR) or Federal Energy Regulatory Commission (FERC).

Several different HSS gate types can be utilized to meet the LLO performance objectives. Of the multiple HSS gate types, the following were evaluated in this study: Tainter valves (Section 4.1.1), vertical lift gates (Section 4.1.2), wheel-mounted gates (Section 4.1.2.1), slide gates (Section 4.1.2.2), and bulkhead gates (Section 4.1.2.3). For each gate type, an investigation of existing gates at similar dams was evaluated for their applicability and utility for the FRE, and FRE-FC conditions. Of interest were each gate type’s characteristics and expected performance parameters for the following criteria:

- Operational reliability
- Gate self-weight
- Functional simplicity
- Maintainability
- Extraneous structural requirements (slots, piers, chambers, guides, etc.)
- Magnitude and direction of forces transmitted into the main concrete structure of dam
- Gate hoist system and appurtenance design requirements
- Ease of transportation and erection
- Sluicing sediment capacity
- Hydrodynamic loading capacity

Importantly, the FRE-FC conditions will require high-head loading across all gates within the LLO. A hydraulic head is defined as water pressure created by the difference in elevation between the upstream and downstream WSEs across a gate. As noted in Figure 1, the invert elevation of the Tainter valve is 3 feet lower than the invert elevation of the four bonneted slide gates. By consequence, the two gate types are hydrostatically loaded slightly differently. However, the headwater elevations shown in Table 2 remain applicable across all five gates within the LLO.

Table 2. Headwater Surface Elevations for all HSS Gates

Water Surface Elevation Condition	Return Interval (Years)	Headwater Elevation (feet-NAVD88)
FRE-FC Usual Pool	0 to 10	628.0
FRE-FC Unusual Pool	10 to 750	687.0
FRE-FC Extreme Pool	750+	709.0

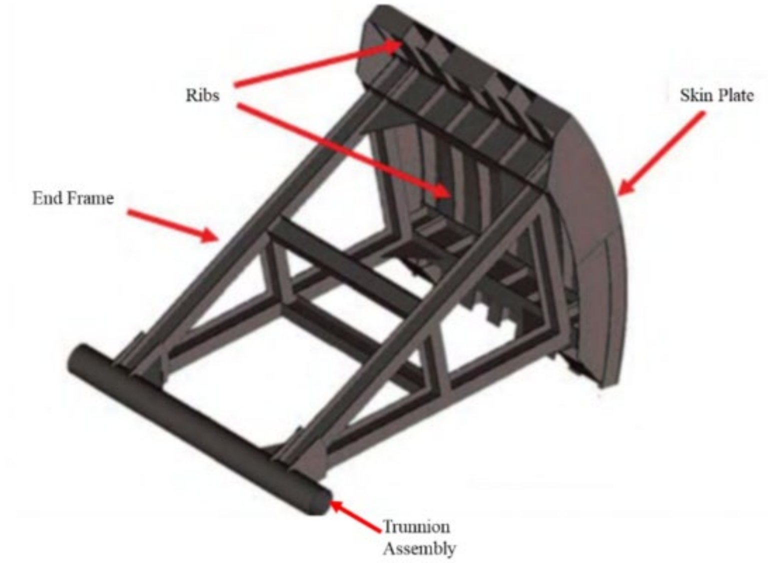
The conceptual gate designs presented hereafter in Section 4 are compliant with USACE Engineering Manual (EM) 1110-2-2107. The manual details design procedures for HSS, which includes loads and load combinations, material standards, detailing of connections, and fatigue/fracture design requirements.

4.1.1 Tainter Valves

Tainter valves are commonly used in outlet works of dams and lock chambers. The design of these valves follows the same design methodologies as conventional ogee spillway Tainter gates (otherwise known as radial gates), albeit with further guidance on connection design and fatigue loading parameters (due to flow-induced vibrations). Tainter valves have been commonly used in North America since the early 1900's and have been developed for use with high-head applications at dam outlet works, in conditions that are similar to the FRE-FC condition.

Typical Tainter valves include the structural components of a skin plate, ribs, end frame, and the trunnion assembly, as shown in Figure 3. The skin plate is a radial-arc steel plate member that is in contact with water on the upstream side and subjected to differential hydrostatic pressure. The ribs are usually curved vertical members, or horizontal built-up steel section models, that the skin plate is continuously welded to. The ribs then transfer the load to horizontal girders that are connected to end frames, primarily in combined compression and flexure, into the trunnion assembly. The trunnion assembly is the point at which the gate rotates about and connects to the main superstructure. Since the gate rotates about this point, the operating mechanism must not only overcome the gate self-weight but also overcome the frictional resistance from the trunnion bearings and gate seals.

Figure 3. Typical Tainter Valve Components



Source: EM 1110-2-2107, USACE (2022)

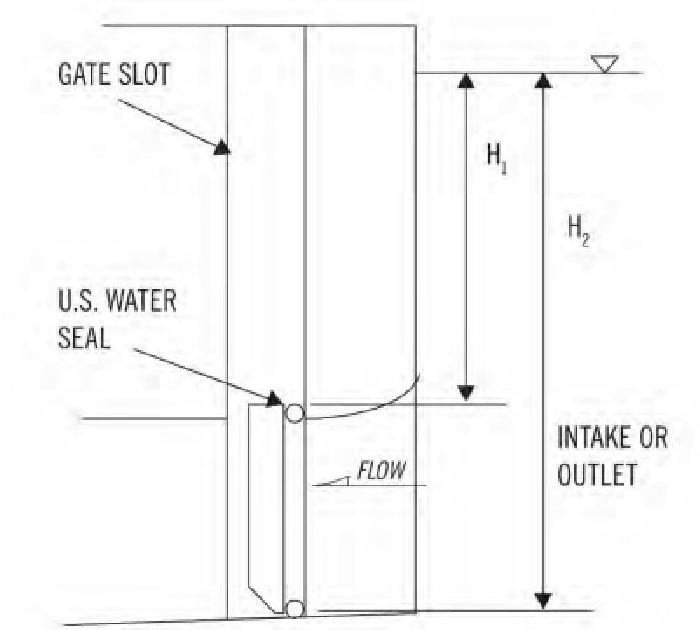
Traditional advantages include the efficient transfer of hydrostatic forces to the trunnion due to the radial shape (as the centroid of hydrostatic loading is always coincident with the trunnion axis of symmetry), and the lack of sedimentation-prone slots, due to the typical configuration of perimeter seals. Disadvantages include difficulty in inspecting trunnion anchorages (which includes the concrete deadman areas, or prestressing anchor rods encased in concrete), substantial blockouts required to accommodate end frames and trunnion anchorages, and difficulty of seal designing under high-head applications.

An alternative sealing mechanism that can be utilized with a Tainter valve is an eccentric trunnion, otherwise known as a positive engagement trunnion This arangement utilizes a separate hydraulic cylinder, that upon closing of the gate, forces the entire gate upstream, compressing seals between the skin plate and the structure, providing an effective sealing force under high-head applications. This design feature and its merits may be considered as the design progresses.

4.1.2 Vertical Lift Gates

Vertical lift gates are a type of gate that can be used in most applications of water retention. For the high-head loading requirements of the FRE-FC condition, any selected gate or gate type will be under significant loading. Vertical gates are usually raised via hydraulic or wire rope hoists and typically employ a dogging device that can be used to hold the gate at a specific elevation. Rollers may be required for larger gates or applications under high-head. An example of this gate in an application similar to the LLO is shown in Figure 4. Three types of vertical gates evaluated within this report, which are vertical wheel-mounted gates, vertical slide gates, and vertical bulkhead gates are described in Sections 4.1.2.1, 4.1.2.2, and 4.1.2.3, respectively.

Figure 4. Typical Vertical Lift Outlet Gate Configuration



Source: USACE

The general framing system for the vertical lift gates consists of horizontally oriented framing or vertically oriented framing. Horizontal framing is preferred due to the ability to transfer load to the side supports more efficiently. The framing members can be girders, built-up tee sections, trusses, or tied arches, all dependent on design criteria such as span and loading. The application of a vertical lift gate for an outlet requires a sloping bottom or flat bottom with a lip extension on the downstream side to reduce hydrodynamic down-pull forces while operating under high-velocity flows.

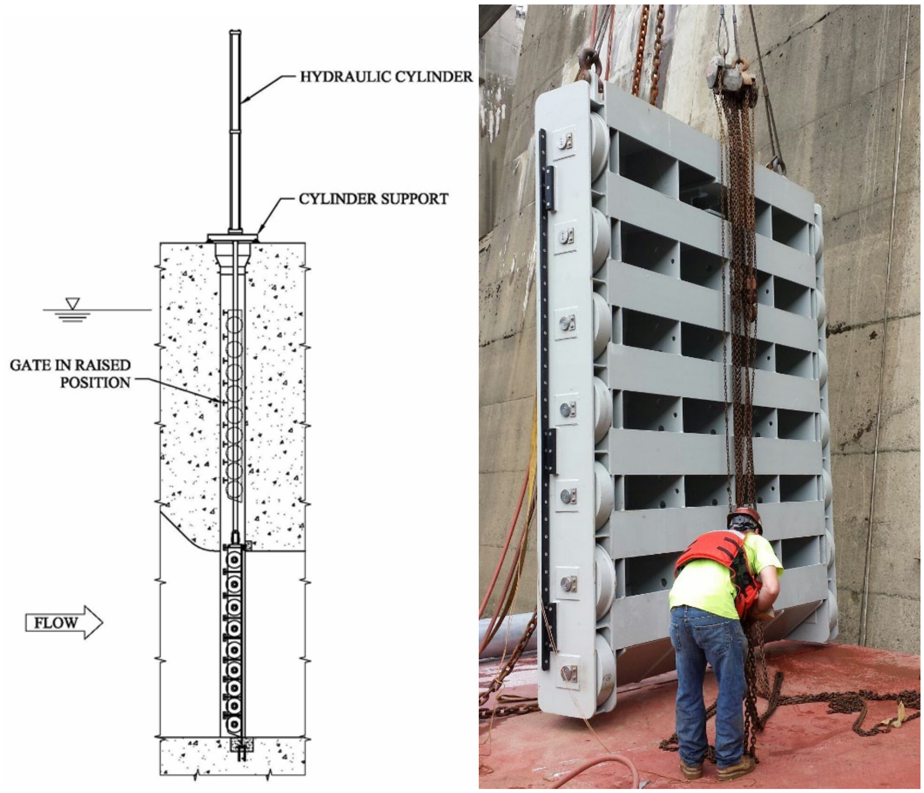
Advantages of vertical lift gates include ease of construction and maintenance, the ability to distribute loads to larger surface areas, and efficiency in sealing. Disadvantages include the requirement for gate slots (which often clog from debris or sedimentation) and a higher hoisting capacity needed for a heavier structure. For both the FRE and FRE-FC conditions, it is important to note that a tall shaft containment structure would be required. This shaft would be located within or through the entire dam, with the purpose to access and store the gates when open.

4.1.2.1 Vertical Wheel-Mounted Gates

Wheel-mounted gates are a subset of vertical lift gates, with a roller-type support system that transfers hydraulic load to the sides of the given gate slot. The wheel-mounted gates can be operated under full or partial differential heads and can also be used for emergency closure applications. Examples of wheel-mounted gates are shown in Figure 5.

The structural components that make up a wheel-mounted gate include a flat structural gate with a series of independent wheels mounted on each side of the gate spanning the height. The wheels sit in a steel track on the downstream side of the gate slot that is embedded into the concrete. This connection is where the hydrostatic forces are transferred between the gate and the slots in the concrete side walls of a conduit. Under hydrostatic head and flow conditions, the wheels provide minimal resistance to being raised or lowered. The wheels will typically contain roller bearings, bronze bushings, or self-lubricating bearings.

Figure 5. Typical Wheel-Mounted Gate Configuration



Source: Foltz (2010), Steel-Fab Inc.

Vertical lift gates have the option for an upstream seal or a downstream seal; whichever side the skin plate is located on, is the side the seal will be located. The seals are commonly made of rubber attached to the skin plate and seal against the gate slot. Utilizing an upstream sealing mechanism is common where there is heavy silt and debris. The skin plate would protect the framing members and wheels/rollers from the debris. The bottom seal is commonly a bar-type seal that is sealed against an embedded steel plate on the floor of the conduit.

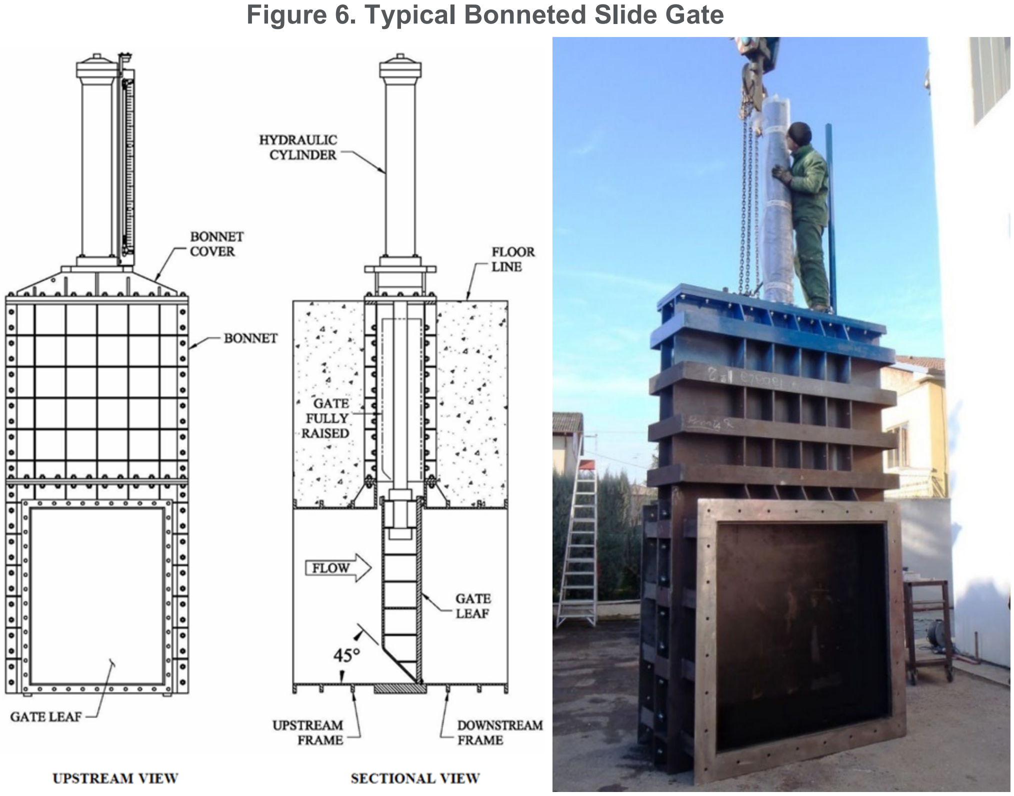
There are several options for hoist mechanisms for these types of gates. The options include both permanent and temporary traveling hoists. Due to flow control, the hydraulic cylinder approach is the most viable route to help push the gate closed if needed (as opposed to a chain or wire rope hoist configuration). Utilizing rollers minimizes the friction when operating the gate, allowing for the hoist mechanism to require comparatively less force than a similar gate that just slides within the slots. The gates can be used in any facet of the head range, including high-head applications, as expected for the FRE-FC condition. However, the rollers will have to be periodic serviced due to expected wear from the gate's continuous water exposure. Such maintenance would require hoisting the gate to above the water surface, which may serve as a disadvantage due the complex operation required during a high-head, FRE-FC condition. The other option is to have an emergency bulkhead upstream of the gate that can be activated for maintenance of the damaged gate.

4.1.2.2 Bonneted Slide Gates

Slide gates constitute a variety of flat gates which slide against bearing surfaces during operation, rather than rolling on wheels as in wheel-mounted gates. These gates are commonly used in high-head applications for flow regulation and emergency closure, as are required for the FRE-FC conditions. They are a simple form of gate due to the lack of moving parts. They can be quite large when a gate is operated only in a balanced head condition but have size limitations when required to open under high-head or control flow. This limitation is governed mainly by the friction produced by a larger gate and the capacity of the hoist mechanism.

Bonneted slide gates are a type of slide gate that are located within a self-contained, single fabricated assembly and do not require gate slots that extends up to the free surface of the dam. The assembly consists of a sealing frame around the perimeter of the conduit opening and contains all the slots, sealing and bearing surfaces for gate operation. The frame and the majority of the bonnet are embedded in the concrete, while the cover which is removable, and the hydraulics are in a separate dry chamber above the conduit, to allow for maintenance. The bonnet structure is very heavily ribbed to prevent distortion while subject to high internal pressures. The gates usually do not contain rubber seals due to the difficulty of maintenance access.

Figure 6. Typical Bonneted Slide Gate

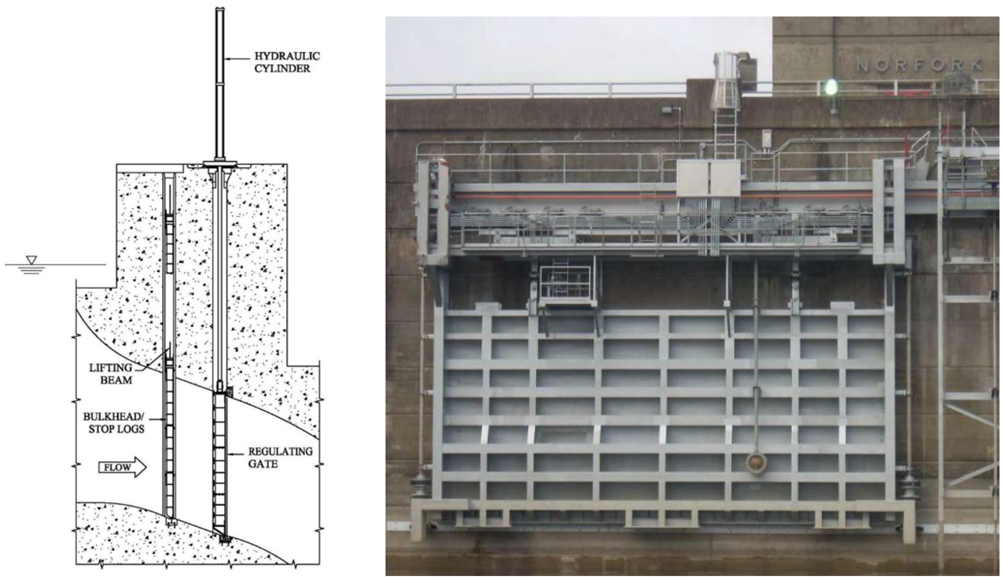


Source: Foltz (2010), Vortex Hydra Dam

4.1.2.3 Vertical Bulkhead Gates

A bulkhead is the simplest and the most common vertical gate type. The gate can be a single large frame or separate individual pieces, commonly known as stop logs. They are commonly made of steel due to high strength-to-weight ratios. These gates are commonly sealed with rubber seals around the perimeter of the gate that seal against the opening on the water passage. The bulkhead usually slides into place through slots and is operated by an overhead hoist. The hoists usually consist of mobile lifting devices similar to gantry cranes, monorail hoists, or mobile cranes. They also can be hoisted using a more permanent lifting system similar to a hoist attached to a lifting beam.

Figure 7. Typical Bulkhead Configuration



Source: Foltz (2010) & Garver

4.1.3 LLO Gate Type Recommendations

4.1.3.4 Gate Recommendation: Tainter Valve

A Tainter valve was selected for the conduit structure's primary fish passage for the following purposes:

- Tainter valves would reduce operator load friction on seating surfaces. Vertical lift gates (roller gates, bulkheads) would require hoist machinery with a capacity to overcome not only the dead load of the gate but also the friction of the gate and the sealing surfaces when hoisted.
- Tainter valves would be advantageous regarding sediment in the water flow. It was stated in previous reports that sediment would be moving through this conduit with the water since it is a river basin. The use of a Tainter valve would allow for sluicing sediment at a river level and the natural curvature of the gate helps direct flow and thus sediment and debris past the gate. Utilizing a Tainter valve would also eliminate the need for gate slots. The gate slots would be problematic since sediment can accumulate within and cause issues with gate operation, as well as an ongoing maintenance item.

- Tainter valves would also allow for more reliable control to allow for different water flow regulations during flooding conditions. The geometry of the Tainter valve lip also benefits the hydrodynamic down pull when the gate is in operation. Most vertical gates must be specially designed at the bottom of the gate to reduce operational problems, but the Tainter valve has the geometry already built into its design.

Drawbacks that arise with the implementation of a Tainter valve would be the sealing mechanism of the gate. Traditional J-bulb rubber seals, as are typically used for spillway Tainter gates, are often problematic at hydraulic head differentials at or exceeding 100 feet. Alternative sealing mechanisms, or the introduction of an eccentric trunnion configuration can be implemented to seal the gate as needed if leakage is considered an issue during reservoir impoundment.

4.1.3.5 Gate Recommendation: Bonneted Slide Gates

A bonneted slide gate was selected for the adjacent fish passage LLOs for the following reasons:

- A cast-in-place bonneted slide gate will allow for the vertical gate to have a sealing mechanism with a steel-on-steel connection, rather than a rubber gasket or other seal configuration. At the high-head applications required for the FRE and FRE-FC conditions, traditional gate sealing for other types of vertical gates would be insufficient, if not outright ineffective.
- A bonneted slide gate would eliminate the need for gate slots within the concrete conduit structure, thereby prohibiting sedimentation buildup that would render gate-closing operations difficult. Mechanisms can be installed to introduce air to “blow out” trapped sediment in the bonnet before the gate is closed.
- A built-in piston, common to bonneted gate designs and used for gate operations, removes the need for full-height maintenance or operation shafts to be formed through the entire RCC dam geometry. A large vertical shaft through an RCC cross-section creates formwork, constructability, and seepage issues that need to be avoided as much as possible. The pistons are present and work within the bonnet, allowing for ease of installation in place. A dry chamber above the gate will still be needed for gate access and maintenance.

Disadvantages associated with bonneted slide gates regard the maintenance that would have to be completed to provide sustained functionality. The bonneted slide gates may cause a possible difficulty for inspection. There would have to be an isolation bulkhead upstream, as well as a confined space entry. There will be a dry chamber above the gates to ensure maintenance and access can be completed.

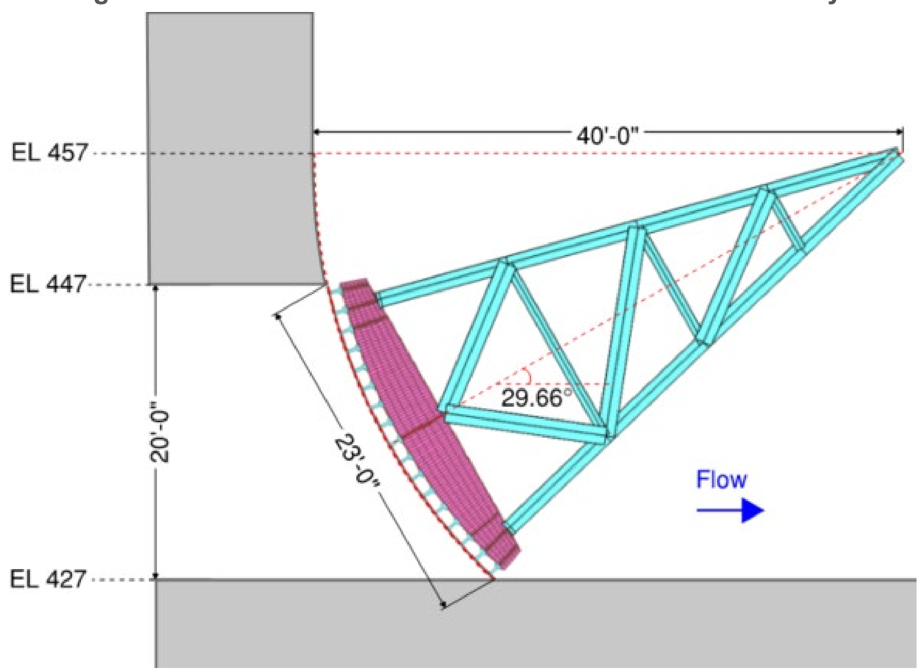
The bonneted slide gate’s sealing, construction, and application advantages far outweigh the disadvantages, and it is recommended that these be chosen for the LLO structure. As the design progresses, hydrodynamic loading, and a perfromance specification will be developed for a a gate manufacturer.

4.2 Conceptual Gate Size and Arrangement: Tainter Valve

A proof-of-concept analytical model for a Tainter valve was created in SAP2000 per the conceptual cross-section of the RCC dam and outlet works as shown in Figure 1 and Figure 2.

Tainter valve trunnions are typically offset upwards to avoid extreme hydrodynamic water jets from corroding or damaging the trunnions and hoist machinery. This configuration requires a gate that is slightly taller than the actual conduit opening. In this case, the conduit opening is 20 feet tall, but the actual gate height is approximately 23 feet due to a 30-degree skew present. The approximate trunnion centerline was evaluated as EL 457 feet (NAVD88), though it is understood that this may be an optimizable parameter as the design progresses.

Figure 8. Schematic Cross Section of the Tainter Valve Study



4.2.1 Conceptual Tainter Valve Sizing and Analysis: 12-Foot Wide Model

A proof-of-concept 20-foot high by 12-foot wide gate model showed satisfactory design ratios in the three-dimensional structural analysis software program SAP2000™. This gate, shown in Figure 9, consists of a 1-inch thick skin plate, 17 built-up tee section horizontal ribs, 2 plate girders, 2 end frames (which constitute the strut arms and strut arm bracing), and cross-bracing in the cross-river direction. This is shown in Figure 9. Refined trunnion modeling will be pursued as the design progresses. The material strengths for all steel sections were evaluated as ASTM A709, Grade 50 steel (per EM 1110-2-2107 requirements), which has a yield strength of 50 ksi. Preliminary sections for the 20-foot high by 12-foot wide gate model are shown in Table 3.

Figure 9. Denotation of Member Types in Conceptual Tainter Valve

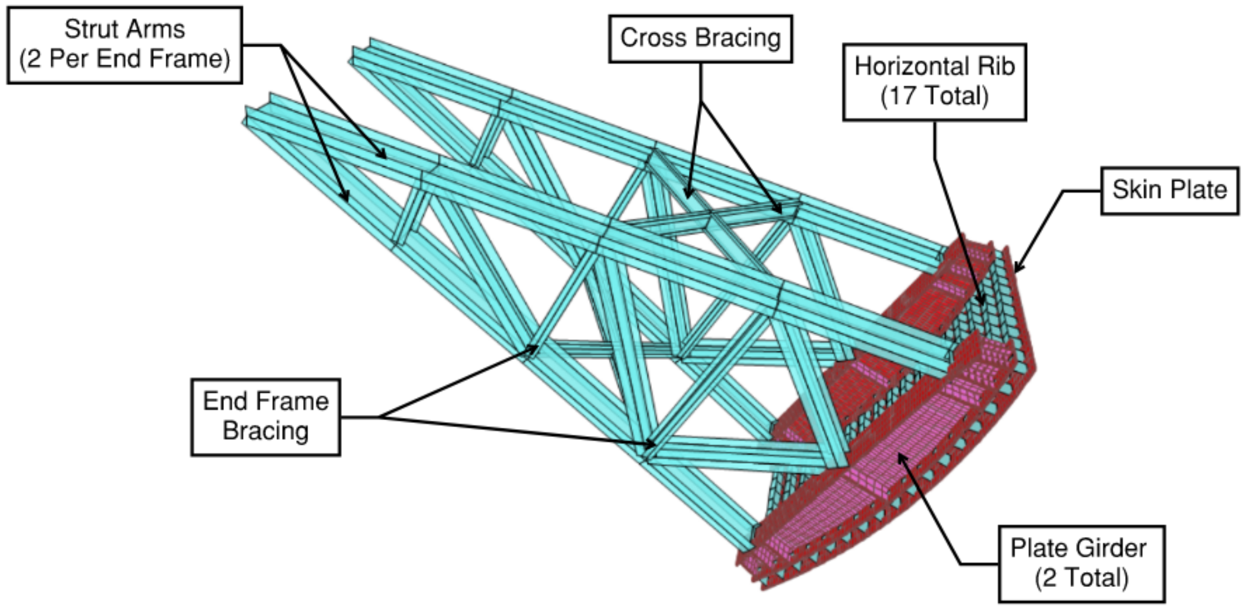


Table 3. Structural Element Member Designation

Member	Type	AISC Commercially Available Section?
Strut Arms	W21x223	Yes
Diagonal End Frame Bracing	W14x120	Yes
Vertical End Frame Bracing	W18x50	Yes
Cross Bracing	W14x74	Yes
Horizontal Girders	User-Defined Tee Section	No – T section consists of 10" overall height and 6" flange width, both 1-3/4" thick
Plate Girder	User-Defined Girder Section	No – Plate girder consists of (2) a 23.4" wide flange of 1-1/2" thickness, a web of variable height and 1-1/2" thickness, with intermittent 1-3/4" thick web stiffeners
Skin Plate	1" Thick, Entire Surface Area	Yes

The conceptual design sizes of the Tainter valve structural members were selected by the application of various design loads. **The load types and a brief description of each is listed below:**

4.2.1.6 Dead Load (D)

The dead load for the analysis was developed using several methods. For the standard shapes and user-defined members, the dead load is internally generated in SAP2000. Dead loads for all main structural members are increased by 5 percent to account for mill tolerances, bolts, welds, gusset plates, and paint. Dead load for the skin plate elements is internally generated based on the surface area and as-designed plate thickness.

4.2.1.7 Gravity Load (G)

Gravity loads can occur from mud and ice accumulating on top of the web and within the flanges of the horizontal ribs, knee braces, and struts. For this level of analysis, mud weight, and Ice weight were considered zero in this analysis. These assumptions will be revisited as the design progresses.

4.2.1.8 Hydrostatic Load (Hs)

Hydrostatic loads consist of water pressure on the gate considering both upstream reservoir and downstream tailwater pool elevations. Hydrostatic loading was applied as a surface pressure normal to the surface of the skin plate elements. EM 1110-2-2107 defines three water surface elevations used in the analysis of the existing gates, which are called usual, unusual, and extreme elevations, respectively. The water surface elevations used in this gate analysis are listed in Table 4. It is worth noting that the contents of Table 4 are identical to those of Table 2, with the only difference being the renaming of the conditions. The FRE-FC-Usual Pool corresponds to H_{S1} – Usual, and similarly, the FRE-FC- Extreme Pool corresponds to H_{S2} - Unusual, and the FRE-FC Extreme Pool corresponds to H_{S3} – Extreme. These events are renamed hereafter, to be consistent with USACE EM 1110-2-2107 abbreviations and methodology.

Table 4. Headwater/Tailwater Elevations: Tainter Valve

Condition	Return Interval (Years)	Headwater Elevation (feet-NAVD88)	Tailwater Elevation (feet-NAVD88)	Head Differential at Bottom of Gate Invert (feet)
HS_1 - Usual	0 to 10	628.0	427.0 (No Tailwater)	201.0
HS_2 - Unusual	10 to 750	687.0	427.0 (No Tailwater)	260.0
HS_3 - Extreme	750+	709.0	427.0 (No Tailwater)	282.0

4.2.1.9 Earthquake Load (EQ)

When earthquake loading occurs, seismic accelerations occur that can be in both the vertical and horizontal directions. Per USACE ER 1110-2-1806 (USACE, 2016) and EM 1110-2-2107, two seismic conditions are required to be evaluated on HSS: the Operational Basis Earthquake (OBE) and Maximum Design Earthquake (MDE). The OBE and MDE are defined as the maximum site-specific ground acceleration with an average return period of 145 years and 950 years, respectively. Ordinarily, a load factor of 1.5 is applied to the OBE, and 1.25 is applied to the MDE. However, EM 1110-2-2107 permits the usage of a 1.0 load factor in the presence of site-specific seismicity data. For Chehalis Dam, these values are presented in Table 5, as determined from the Chehalis Preliminary Design Earthquake Time Histories report (S&W, 2015).

Two separate load classifications occur on a gate during a seismic load event. The first is called hydrodynamic loading from the accelerated mass of the water column. For the gate modeling a Westergaard distribution, which approximates an inertial dynamic force of the water was used in the analysis. The Westergaard load is applied as a lateral gravity inertial load on the structure itself. Second, inertial amplification loads are applied to the gate self-weight in both the horizontal and vertical direction, for each return interval as indicated in Table 5. Both horizontal and vertical ground accelerations are evaluated concurrently as per the “Percentage combination method” as outlined in Equations 3-1 and 3-2, EM 1110-2-6053 (USACE, 2007). **For this report and results presented in Table 6, this corresponds to the following equation:**

$$\text{Total Gate Inertial Seismic Load} = 1.0(PGA_{Horizontal}) + 0.3(PGA_{Vertical})$$

Due to the high seismicity of the project site, and for analysis from a risk-informed perspective, additional analyses were conducted with seismic loads that exceed the USACE requirements. The Tainter valve analysis evaluated an additional 2,500-year and 5,000-year event, noted as Load Case 5B.2 and 5B.3 in Section 4.2.2.12.

Table 5. Seismic Acceleration for FRE-FC Condition

Return Interval (Years)	Peak Horizontal Ground Acceleration (g)	Peak Vertical Ground Acceleration (g)
1,000	0.70	0.31
2,500	1.13	0.76
5,000	1.54	0.90
10,000	1.92*	1.22*

*Note: Per the design assumption that the Tainter valve will be decommissioned for the FRE-FC condition, the Tainter valve is exempted from the 10,000-year event. This data is included for use with the bonneted slide gates, which are discussed in Section 4.3.1.16

4.2.1.10 Miscellaneous Loads

Omitted from this current stage of design, which will be revisited as the design progresses, are the following load classifications:

- Operational loads include side seal friction loads, hoist machinery opening and closing loads, and trunnion friction loads. Note: when the outlet was reconfigured (in the conceptual design) to limit the head differential for operation on the Tainter valve, the operating loads became less critical on a wider gate configuration, and conceptual sizing could be achieved by looking at static and seismic loading only. Additional miscellaneous loads include, but are not limited to:
  - Hydrodynamic loads due to down pull and flow-induced vibrations
  - Wave loading

4.2.2 Load Combinations

Six load combinations were evaluated for this report, per EM 1110-2-2107 Section 12.2 Loads and Load Combinations of Tainter Valves. All six evaluate the gate in a closed position and utilize load factors as outlined below. The support conditions for the gate consisted of non-linear gap elements perpendicular to the sill surface, with both trunnions' translation and rotation fully restrained, rotation about the trunnion pin released on both sides and a gravity up/down restraint at the presumed locations of two hydraulic cylinders at the top webs of both plate girders.

These six load cases were selected for evaluation at the conceptual level, due to the high-head loading that serves as a reasonable benchmark for gate configuration optimization.

4.2.2.11 Strength Limit State, Valve Closed

- Load Case 1A: 1.2D + 1.5HS_1
- Load Case 1B: 1.2D + 1.4HS_2
- Load Case 1C: 1.2D + 1.3HS_3

4.2.2.12 Strength Limit State, Earthquake, Valve Closed

- Load Case 5B.1: 1.2D + 1.0HS_1 + 1.0(EQ- MDE)
- Load Case 5B.2: 1.2D + 1.0HS_1 + 1.0(EQ-2500-year event)
- Load Case 5B.3: 1.2D + 1.0HS_1 + 1.0(EQ- 5000-year event)

4.2.3 Tainter Valve Results and Discussion: 12-Foot-Wide Model

The structural members configured for the 12-foot-wide gate meet the static and seismic load cases up through the 2500-year event (LC5B.2). At 5000-year events there begins to be slight overstressing of the plate girders and skin plate meaning that the gate could see deformation of the steel. Though for the usual cases of loading the conceptual members are within acceptable design stress ranges.

4.2.4 Tainter Valve Results and Discussion: 14- and 16-Foot-Wide Models

The 14-foot and 16-foot-wide gates as configured for structural members meet the static and seismic load cases up through the 2500-year event (LC5B.2) by upsizing the strut arms to a rolled W21X248 section. Similar to the 12-foot-wide gate, at 5,000 year events there begins to be slight overstressing of the plate girders and skin plate meaning that the gate could see deformation of the steel. The 16-foot gate also began to show overstressing of the vertical plate girder for the 2500-year event and other members began to reach 90% utilization indicating that all sizes would need to be increased for wider gates.

4.3 Conceptual Gate Size and Arrangement: Bonneted Slide Gates

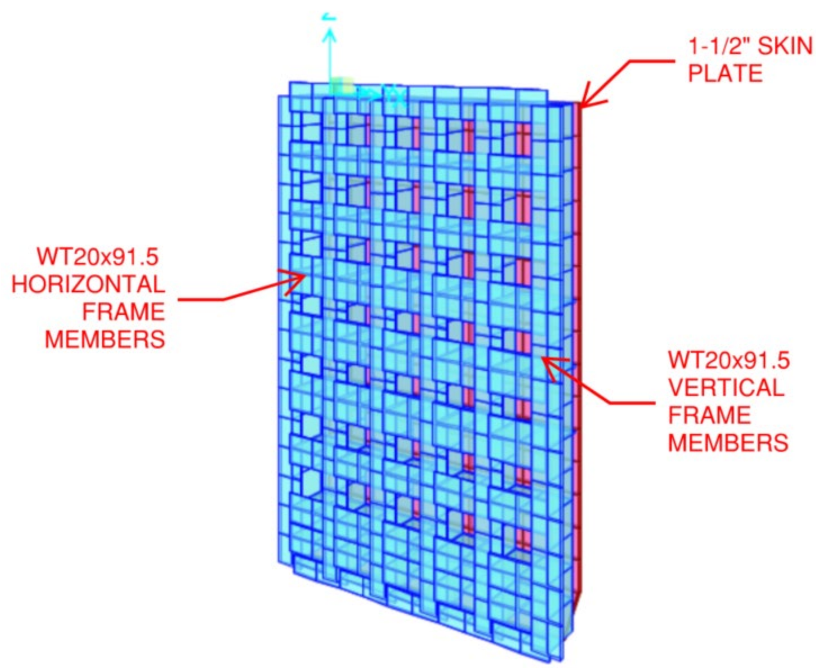
As noted in Section 2, and shown in Figure 1, the LLO will have two fish passage conduits on either side of the Tainter Valve. The fish passage conduits will all be the same initial conceptual size with dimensions of 10 feet wide by 16 feet tall. The expectation is that a pair of these gates will be able to be operated at the highest water capacity (FRE-FC), while the Tainter valve, and two of the four bonneted slide gates, would be decommissioned. In this conceptual stage of gate design, the High Head Vertical Gate will be analyzed at the FRE-FC water level. A visual of the orientation of the fish passage LLOs is shown in Figure 1 above. The base of the fish passage LLOs will be located at an elevation of 430 feet (NAVD88) and the top of the LLO will be at an elevation of 446 feet (NAVD88).

4.3.1 Gate Size Analysis

A 16-foot high x 10-foot wide gate was modeled in SAP2000™. The gate consisted of a 1.5-inch thick skin plate, 8 built-up tee section horizontal girders, 4 built-up tee section vertical girders, and 4 built-up tee sections for the top, bottom, and sides. This is shown in Figure 10. The material strengths for all steel sections were evaluated as ASTM A709, Grade 50 steel (per EM 1110-2-2107 requirements), which has a yield strength of 50 ksi. Sectional properties of the model are shown in Table 3 in Section 4.3.

Note, that the conceptual model developed was used to evaluate the feasibility and performance of a gate under such loading conditions and estimate gate weight. The overall optimization and design would be produced as the design progresses. The goal of the current model was to get approximate dimensioning and layout for the conceptual gates. The bonnet structure was not modeled in this phase of conceptual design.

Figure 10. Schematic Cross Section of the High Head Bonneted Slide Gate Conduit



4.3.1.13 Dead Load (D)

The dead load application for the bonneted slide gates is evaluated identically to the Tainter valve, see Section 4.2.1.6.

4.3.1.14 Gravity Load (G)

The dead load application for the bonneted slide gates is evaluated identically to the Tainter valve, see Section 4.2.1.7. Similar to the Tainter valve methodology, mud, and Ice weight were considered zero and will be revisited as the design progresses.

4.3.1.15 Hydrostatic Load (Hs)

Hydrostatic loads consist of water pressure on the gate considering both the upstream reservoir and downstream tailwater pool elevations. As noted in Section 4.1 and Figure 1, the inverts of the (4) bonneted slide gates are 3 feet higher than that of the Tainter valve. Accordingly, the head differentials across these gates are slightly smaller than the Tainter valve - see Table 6.

Table 6. Headwater and Tailwater Elevations: Bonneted Slide Gates

Condition	Return Interval (Years)	Headwater Elevation (feet-NAVD88)	Tailwater Elevation (feet-NAVD88)	Head Differential at Bottom of Gate Invert (feet)
H_{S1} - Usual	0 to 10	628.0	430.0 (No Tailwater)	198.0
H_{S2} - Unusual	10 to 750	687.0	430.0 (No Tailwater)	257.0
H_{S3} – Extreme	750+	709.0	430.0 (No Tailwater)	279.0

4.3.1.16 Earthquake Load (EQ)

The dead load application for the bonneted slide gates is evaluated identically to the Tainter valve, see Section 4.2.1.9. The singular exception is that for the bonneted slide gate analysis, a return period of 10,000 years was evaluated as well. Two of the bonneted slide gates are expected to be able to be operated at (or after) all extreme loading conditions. This includes the H_{S3} water level and the most extreme seismic acceleration. These values are listed in Table 5, and employ the same “Percentage combination method” as outlined in Equations 3-1 and 3-2, EM 1110-2-6053 (USACE, 2007).

4.3.2 Load Combinations

Four load combinations were evaluated for this report, per EM 1110-2-2107 Section 13.5 Loads and Load Combinations (of Vertical Gates). All four evaluate the gate in a closed position and utilize load factors as required (USACE, 2022). The support conditions for the gate consisted of non-linear gap elements perpendicular to the sill surface. The sides and top of the gate frame were restrained in translation. These restraints are to simulate the bonnet frame that the gate will sit in.

These four load cases were selected for evaluation at the conceptual level, due to the extreme hydrostatic loading that serves as a reasonable benchmark for gate configuration optimization.

4.3.2.17 Strength Limit State, Bonneted Slide Gate Closed

- Load Case 1A: $1.2D + 1.6HS_1$

- Load Case 1B: 1.2D + 1.6HS_2
- Load Case 1C: 1.2D + 1.6HS_3

4.3.2.18 Strength Limit State, Earthquake (Bonneted Slide Gate Closed)

- Load Case 5B: 1.2D + 1.0(EQ)*

  *10,000-year seismic event evaluated for this load case, as this is the worst-case loading scenario for this phase in design of the bonneted slide gates. As the design progresses, the lesser response spectrum will be taken into consideration.

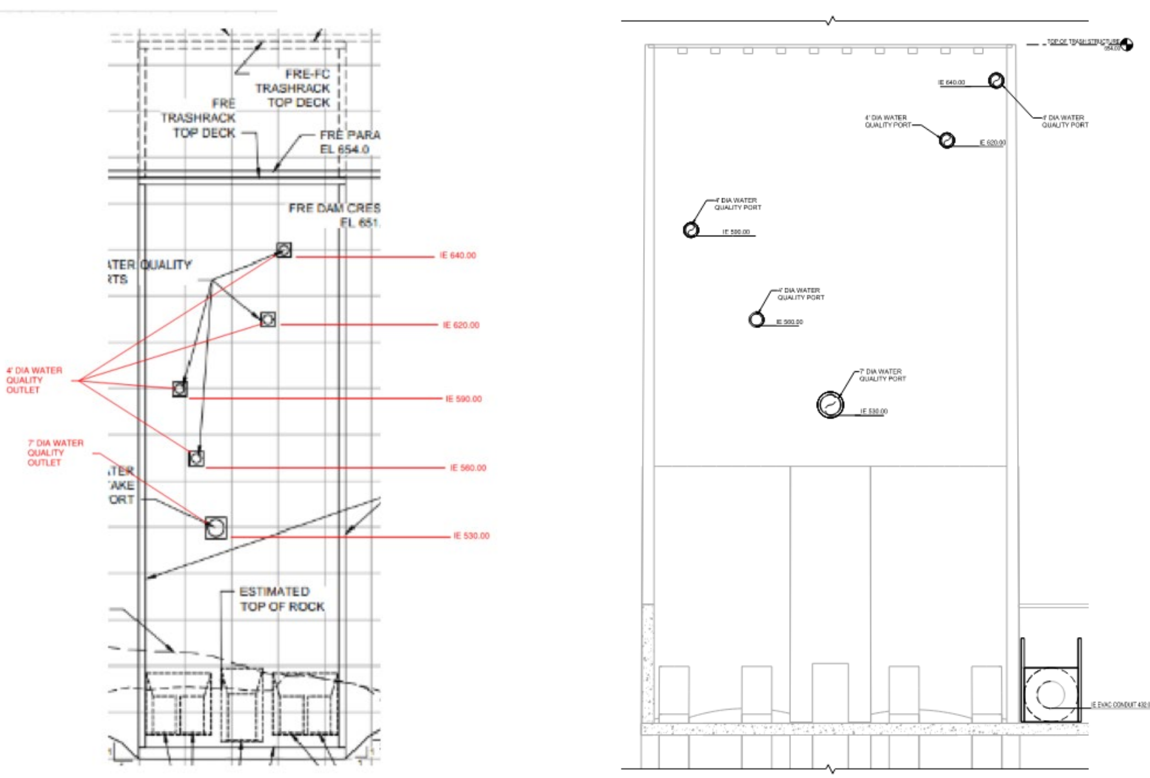
4.3.3 High Head Bonneted Vertical Gate Results and Discussion

All the structural steel members of the conceptual high-head bonneted vertical gate met the minimum stress ratio requirements detailed in USACE EM1110-2-2107. The members passed for both the static and seismic load cases through the 10,000-year event (LC5B). The structural steel can be further optimized as the design progresses to create a more efficient design. Hydraulic cylinder design, bonnet design, seal design, and structural connection design will be addressed as the design progresses.

5 Water Quality Ports

This section discusses the water quality ports at the conduit structure. The purpose of the water quality ports is to achieve the desired temperature discharge conditions downstream of the dam for the FRE-FC condition. This is achieved through a system of conduits that convey water from varying elevations of the forebay pool. The inlets of the water quality ports are positioned at various elevations at the upstream face of the LLO to adjust the downstream water temperature and turbidity. Figure 11 shows the arrangement of the water quality ports at the LLO, which consists of four 1-foot diameter orifice, and one 7-foot diameter orifice, at the variable inlet elevations as shown.

Figure 11. Water Quality Ports Arrangement Upstream Elevation View



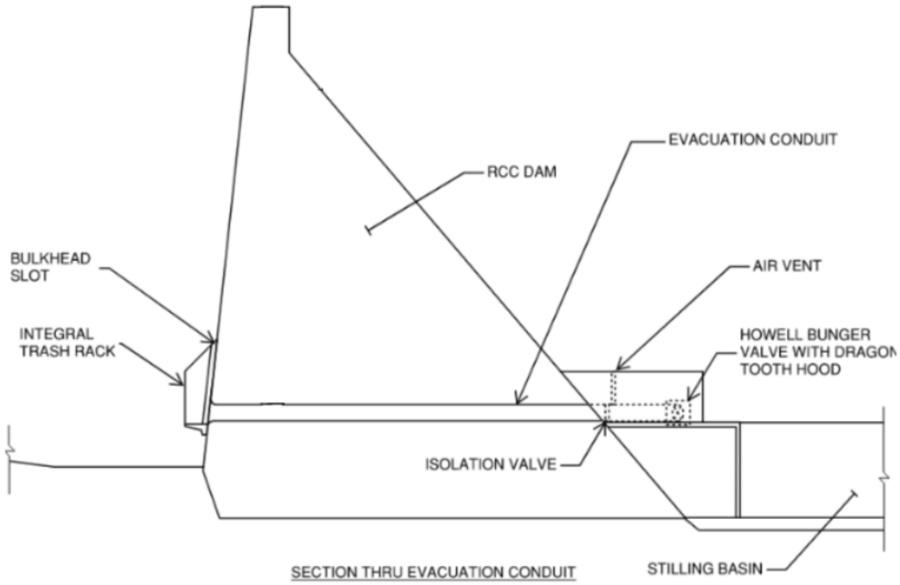
As indicated in Table 1, the water quality ports will not be functional for FRE conditions and will be blind flanged until the possible FRE-FC condition is constructed. If the FRE-FC condition were to progress into permitting, design, and construction, valves, trashracks, and features to accommodate maintenance bulkhead installation would be installed. A mixing manifold would also be constructed upstream of the Flood Fish Passage Facility.

6 Evacuation Conduit

6.1 Introduction

The purpose of the evacuation conduit is to provide reservoir evacuation post-flood event or for emergency drawdown. The evacuation conduit for FRE and FRE-FC conditions is made up of a bell mouth intake, a trashrack, a bulkhead slot, a steel-lined and concrete-encased pipe, an isolation valve with a vent, a hooded energy dissipation valve and a valve house structure tied to the training walls of the spillway. There is a bend along the steel lined concrete encased pipe that will require a thrust block to handle thrust forces when the conduit is in operation. Figure 12 below shows a general arrangement of the evacuation conduit. The purpose of each of these features is to provide a smooth flow profile into the conduit and filter debris from entering the conduit. As the project progresses, energy dissipation will be evaluated.

Figure 12. Evacuation Conduit Layout



6.2 Design Criteria

The evacuation conduit discharges into a stilling basin. There is an isolation valve upstream of the fixed cone valve to provide upstream isolation for maintenance and repair activities. The inlet of the evacuation conduit has bulkhead slots for installing a bulkhead upstream of the isolation valve. A fixed cone valve, otherwise known as the Howell-Bunger valve, is planned for energy dissipation of the water entering the stilling basin.

6.3 Conduit

The evacuation conduit is a 9-foot circular cross-section, concrete-encased, steel-lined pipe used to evacuate the reservoir upstream of the dam at a flow rate of 500 cfs. The inlet of the evacuation conduit is located on the upstream face of the dam and 12 feet to the right of the nearest fish passage conduit so that the conduit does not interfere with any of the dam joints. The outlet of the conduit is located above the floor of the spillway stilling basin. There is currently no slope along the conduit from the inlet to the outlet because it will only operate in pressurized conditions. The evacuation conduit will discharge through an energy dissipation valve that will spill into the spillway's stilling basin. To protect the valve from spillway flows, the valve must not protrude past the spillway training wall, but instead be in a recessed area. The recessed area housing the valve and its equipment, and tying into the spillway training wall make up the evacuation conduit's valve house. The valve house will be made of reinforced concrete. Intake

The intake of the evacuation conduit is bell mouthed cast directly into the dam face. The bell mouth intake is there to provide hydraulic efficiency of the system. The Conduit structure has an integral coarse trashrack with a debris-clearing working deck for debris removal. The coarse trashrack has clear openings of 2-foot by 2-foot. The evacuation conduit will have a localized trashrack in front of the bell mouth intake to provide higher level of protection for the associated downstream equipment attached to the conduit. Each trashrack is designed to accommodate hydraulic pressure based on an estimated USACE EM 1110-2-2400 velocity head loss value of 5 feet. The trashrack is designed to withstand loading from debris impact, clogging, and ice loading. The structure has bulkhead guide rails to allow for bulkhead installation from an access road. The bulkhead will allow the evacuation conduit to be dewatered and accessed for inspection, maintenance, or repair. The bulkhead will be installed from the service road with a crane. The manual bulkhead operation from the service road will only be used for the FRE since. During the design phase of the FRE-FC, the bulkhead and localized trashrack will need to be replaced with a gate that can be accessed and operated from the top of the FRE-FC dam deck.

6.4 Isolation Valve

Upstream of the energy dissipation valve is an isolation gate valve . Primarily designed for on-off services, gate valves are a suitable choice for isolating flow. Gate valves have little obstruction to flow when opened and have a small pressure drop compared to other valve types. Gate valves are linear motion valves in which the gate leaf slides into the fluid way. Shut-off is achieved once the gate leaf is fully seated in the valve seat. Manufacturers such as DeZurik design and fabricate gate valves to be used specifically as isolation valves, which can be closed under full free-discharge flow. These types of valves are suitable for pressures up to 500 feet of head which covers the maximum pressure for FRE or FRE-FC conditions.

6.5 Energy Dissipation Valve

The flow from the outlet works requires a means to dissipate the energy from the high-velocity fluid stream exiting. The risk of downstream channel degradation is reduced by providing appropriate energy dissipation features. Energy dissipation valves allow for the control of flow while simultaneously dispersing the fluid stream of the outlet flow. A proven energy dissipation valve design is the fixed cone valve. Fixed cone valves have been used in USBR and USACE projects for applications at outlet works in similar service to the proposed Chehalis design. Examples of similar applications include the New Exchequer Dam in Mariposa County, California, and the Old Mud Mountain Dam in King County, Washington. Both projects used similarly sized fixed cone valves for flow regulation and energy dissipation at their outlet works. An advantage of the fixed cone valve is its ability to operate without cavitation at small openings. This is advantageous for providing minimal flows downstream of the outlet works.

Flow is controlled by the movement of an external sleeve. The sleeve seals against the valve body with a drip-tight metal-to-metal shut-off against a seat. As flow passes through the valve body, a cone diverts the flow into a radially discharging conical expanding spray. The flow is discharged directly to the atmosphere and the hood contains the spray area. The energy dissipation valve is recessed into the spillway in a contained structure. A portion of the valve will extend past the spillway wall far enough to prevent cavitation damage to the structure.

6.6 Air Vent

An air vent is immediately downstream of the intake isolation valve. The purpose of the air vent is to provide airflow to the evacuation conduit during operation. This is to prevent a low-pressure area on the downstream side of the isolation valve during operating conditions that could potentially increase cavitation and vibration potential. By introducing air from the surface, the pressure in the conduit will stay near atmospheric conditions, significantly reducing these issues. The method for sizing air vents is taken from the USACE Engineering Manual 1110-2-1602. This manual uses empirical data to provide recommended design criteria for air vent sizing. The conceptual number for the required air vent cross-sectional area for the evacuation conduit is 12 square feet.