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St. Paul District

Appendix F: Structural Design & Criteria

Fargo Moorhead Metropolitan Area
Flood Risk Management Project

Maple River Aqueduct

Engineering and Design Phase

P2# 370365

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Appendix F: Structural Design & Criteria

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ATTACHMENTS

None

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Appendix F: Structural Design & Criteria

F.1GENERAL

F.1.1 Maple River Aqueduct Design Criteria

The Design Documentation Report (DDR) outlines the Preliminary Engineering Report (PER) submittal assumptions and methods for both analysis and design specific to the Maple River Aqueduct (MRA) of the Fargo Moorhead Metro Project. The structural features involved in the MRA are the culvert/aqueduct structure, diversion upstream and downstream walls, aqueduct upstream and downstream walls, downstream apron, maintenance bridges, spillway weir, ice/debri control structure and heating control building. See

F.1.1.1 Design Guidance

Analysis and design for the Preliminary Engineering Review level is being performed using the guidance of several USACE engineering manuals, design guidelines, codes and the Project Design Guidance. A selected list of the critical design criteria documents are listed below.

a. ECB No. 2014-24 Issued 7 Nov 2014 (Revision and Clarification of EM 1110-2-2100 and EM 1110-2-2502)
b. EM 385-1-1 Safety and Health Requirements (September 2008)
c. EM 1110-2-1612, Ice Engineering (October 2002)
d. EM 1110-2-2100, Stability Analysis of Concrete Structures (December 2005)
e. EM 1110-2-2102, Water Stops and Other Preformed Joint Materials for Civil Works Structures (September 1995)
f. EM 1110-2-2104, Strength Design of Reinforced Concrete Hydraulic Structures (June 1992) with change 1 August 2003
g. EM 1110-2-2502, Retaining and Floodwalls (September 1989)
h. EM 1110-2-2504, Design of Sheet Pile Walls (March 1994)
i. EM 1110-2-2902, Conduits, Culverts, and Pipes (October 1997) with change 1 March 1998
j. EM 1110-2-2906, Design of Pile Foundations (January 1991)
k. ACI 318-14, Building Code Requirements for Structural Concrete
l. AISC Manual of Steel Construction, 14th Edition
m. AASHTO LRFD Bridge Design Specifications 2012 6th Edition
n. T-Wall Design Procedure (08 May 2009, based on revisions from 05 May 2008)
o. DRAFT Project Design Guidelines Version 3 2013 Fargo Moorhead Metropolitan Area Flood Risk Management Project Engineering and Design Phase.

F.1.1.2 Material Properties

Various materials will be required for the different structural features. A general list of materials and any associated specifications is listed below:

Bearing Piles: The foundation will be pile founded and at this time the type of pile (HP 14x73, HP 14x89 and Pipe Pile) are still being evaluated.A pile type evaluation is still being finalized. It is anticpated a mix of both HP and pipe pile will be required.

Concrete: Normal weight concrete is used for all features. A compressive strength of 4500 psi. Various mix designs will be required

Concrete Reinforcement: ASTM A615, Grade 60 deformed steel bars

Sheet pile: ASTM A572 grade 50 and the size of the sheet piles will be determined later in the design process.

Below is a list of unit weights and material properties used in design:

- Water: 62.5 pcf
- Concrete: 150 pcf
- Steel: 490 pcf

F.1.1.3 Loads, Load Cases and Design Factors

a. Loads. Dead Load(D): Dead weight of structure based on unit weights. Weight of pile will be neglected.

Live Load(L): Vehicle, maintenance equipment, constructiuon equipment, pedestrians

Hydraulic(H): Hydrostatic load

Uplift(U): Hydrostatic or seepage uplift load

Rebound(R): Long term loads from soil rebound

Wave(WA): Increased hydrostatric and dynamic loading from a wave train set-up infront of a structure.

Ice(I): Loads from ice expansion/crushing or inertial loads from ice floes

Wind(W): Pressures applied to projected surfaces exposed to wind

b. Load Cases. Load cases are listed in the table below.

MAPLE RIVER AQUEDUCT LOAD CASES					
	Water Elevations				
Load Case	Head water	Tail water	Head	Aqueduct	Load Type

1. Construction - Dry	NA	NA	NA	NA	Unusual
2. Normal – Low Flow	NA	NA	NA	NA	Usual
3a. 100 year event + Wave (Low MR)	895.5	894	1.5	881	Unusual
3b. 100 year event + Ice (Low MR)	895.5	894	1.5	881	Unusual
4a. 500 year event + Wave (Low MR)	897	895	2	885	Unusual
4b. 500 year event + Ice (Low MR)	897	895	2	885	Unusual
4b. 500 year event, Blocked Culvert	897	895	2	885	Unusual
5a. SPF Diversion Flow + Wave	903	899	4	899	Extreme
5b. SPF Diversion Flow + Ice	903	899	4	899	Extreme
5c. SPF Diversion Flow, Blocked Culvert	903	899	4	899	Extreme
6a. 100 year event + Wave (Low Div)	881	881	NA	896.7	Unusual
6b. 100 year event + Ice (Low Div)	881	881	NA	896.7	Unusual
7a. 500 year event + Wave (Low Div)	885	885	NA	898	Unusual
7b. 500 year event + Ice (Low Div)	885	885	NA	898	Unusual
8a. SPF Maple River Flow +Wave	893	892	1	901	Extreme
8b. SPF Maple River Flow + Ice	893	892	1	901	Extreme

F.1.1.4 Reinforced Concrete Design

Reinforced concrete design will be in accordance with EM 2104 for Hydraulic Structures. Other concrete features not associated with the flow will be in accordance with ACI and ASSHTO. Concrete Design Load Factors for hydraulic structures are given in the "Fargo-Moorhead Flood Risk Management Project Design Guidelines" Appendix F Section F.4 Table F-2 on page F-6(see table below).

CONCRETE DESIGN LOAD FACTORS				
Load Case	Load Factor	Hydraulic Factor	Overstress Factor	Net Factor
Usual	1.70	1.30	1.00	2.21
Unusual	1.70	1.30	1.33	1.70
Extreme	1.70	1.30	1.75	1.30

F.1.1.5 Bearing Pile Design

Because the base of structural features are founded in the soft and weak Brenna clay layer deep pile foundations are recommended. The pile foundation will limit settlement, control differential settlement and provide adequate bearing resistance. Geotech indicated that soils are corrosive. The piles will be fully embedded in existing soil thus limiting availability of oxygen. Additionally, the structures will experience soil rebound which will eliminate exposure to atmosphere from settlement below pile caps. Corrosion mitigation will be provided by providing additional sacrificial steel. Corrosion rates are conservatively assumed to be 0.0005/year assuming a design life of 100 years.

a. Pile Capacities: Pile geotechnical capacities and other pile parameters were obtained from geotech branch. Structural capacities are based on allowable stresses as presented in
EM-1110-2-2906. The glacial till layer is very dense or hard and the structural capacities govern in some instances. Pile Design Geotechnical FOS are used from EM 1110-2-2906, 1991 based on verifying theoretical capacities by conducting a pile load test.

PILE DESIGN FACTORS OF SAFETY(FOS)		
Load Case	Minimum Factor of Safety	
	Compression	Tension
Usual	2.0	2.0
Unusual	1.5	1.5
Extreme	1.15	1.15

There is some uncertainty in the strength of the glacial till and pile load test will not be performed until construction. Pile design FOS are being evaluated to account for uncertainty in the strength of the glacial till and will be finalized for the next submittal(DTR).

b. Pile Type Evaluation: The feasibility report recommended HP and pile pile based on local experience and assumed HP14X73. The report recommended evaluating larger piles for economy. Concrete pile was not addressed in the feasibility report. An evaluation is being conducted looking at HP,pipe, and square concrete pile. Factors being evaluated include type, size, capacity, availability, corrosion, cost and drivability. A summary of evaluation factors are listed in the table below. Preliminary results indicate larger pipe pile may be more economical for compression loading (note the 20" pipe pile is most efficient by weight). The completed evaluation will be included for the DTR submittal.

SUMMARY: Pile Type Evaluation Factors						
	Pile Type					
	HP14X73	HP14X89	Pipe ½"X24	Pipe 3/8"X20	Pipe 3/8"X16	Concrete 14" Square
Lbs/ft	73	89	126	79	63	
Compression:						
Geotechnical Ult. Capacity	500	510	770	565	420	425
Capacity/lbs	6.87	5.74	6.13	7.18	6.71	
Allowable Geotechnical(FOS=2, kips)	250	255	385	283	210	213
Allowable Geotechnical(FOS=3, kips)	167	170	257	188	140	142
Allowable Structural	333	TBD	TBD	TBD	TBD	TBD
Tension:						
Geotechnical Ult. Capacity	TBD	TBD	TBD	TBD	TBD	TBD
Capacity/lbs	TBD	TBD	TBD	TBD	TBD	TBD
Allowable Geotechnical(FOS=2)	TBD	TBD	TBD	TBD	TBD	TBD
Allowable Geotechnical(FOS=3)	TBD	TBD	TBD	TBD	TBD	TBD
Allowable Structural	TBD	TBD	TBD	TBD	TBD	TBD
Other:						
Cost/ft driven	TBD	TBD	TBD	TBD	TBD	TBD
Corrosion	2 sides	2 sides	1 side	1 side	1 side	Good
Availability	Good(lead time)	Good(lead time)	Good(lead time)	Good(lead time)	Good(lead time)	Good(Not Stocked Locally)
Drivability	Good	Good	Medium	Medium	Medium	Medium-Difficult

b. Structural Strength: Structural capacities are based on allowable stresses as presented in EM-1110-2-2906.

F.1.2 Alternatives Considered for Preliminary Engineering Report

F.1.2.1 Number and Size of Culverts

The Maple River Aqueduct is 300 feet wide which changed from the feasibility model of 250 feet wide with eight unequal culvert widths. Per the physical model there were ten culverts; eight equal sized culverts at the interior and a half size culvert at each end. After discussion with Hydraulics equal culverts were more desired, noting that the middle culvert should be centered at the centerline of the diversion channel. For structural design the best option was to have nine equal width culvert s of 33'4". The culvert height opening changed from the feasibility design of 7'0" to 9'8".

F.1.2.1.1 Approach Walls

The upstream diversion approach walls were curved in the feasibility design. Hydraulics determined they were unnecessary and due to higher construction costs they were changed from curved to straight and flared for the preliminary design. The downstream walls remain unchanged except for the length of wall. This was determined by what was needed for grading behind the walls.

The upstream and downstream aqueduct walls were originally designed in feasibility as straight walls parallel to the channel. Per the physical model they were changed to a flared wall and that is what will be used in preliminary design. There were discussions of combining the upstream diversion walls with the walls at the aqueduct. Due to the geometry and the access roads that option is not feasible and will not be looked at any further.

F.1.2.2 Vehicle Service and Pedestrian Bridge

The feasibility study showed the Service Bridge on the downstream side of the aqueduct. To make the geometry for the access roads work the bridge was moved to the upstream side of the aqueduct. This also allows for the access roads to avoid crossing the spillway. To allow for potential larger vehicles to cross over the bridge and access the diversion channel the bridge width was increased to 15'0" clear.

F.1.2.3 Spillway Weir

The feasibility design was based on a rock weir. As part of physical modeling, the spillway weir now includes a reinforced concrete capped sheetpile with associated abutment walls at the terminus of the weir. This design will be developed as part of the next submittal (DTR).

F.1.3 Structural Features

F.1.3.1 Maple River Aqueduct Structure

a. Pile Foundation. The piling will be designed utilizing the Soil Stratigraphy and Soil Design Properties received from geotech. A preliminary analysis of the structure taking a representative section was completed using HP14X73 piles and the configuration can be seen on sheet S-102. The analysis was completed using GROUP v2014.

b. Sub-Structure. The sub-structure consists of the base slab, culvert walls and aqueduct channel. The base slab will either be separated into independent footings or kept as a large mat foundation with contraction joints to reduce the amount of temperature and shrinkage cracks. There are (9) 33’4” wide culverts with (8) 3 foot wide piers and two abutment walls that are parallel to the diversion channel. See sheet S-201 for an elevation view of the structure.

   The low flow aqueduct channel was a box-like structure within the channel at the feasibility level. In the initial physical model it was a V-shaped in the middle of the channel. After consideration with hydraulics the final geometry will be a trapezoidal shape that is 2 feet deep, 4 feet wide at the base and 8 feet wide at the top also centered on the aqueduct channel.

   The aqueduct channel is the same as in the feasibility study at 50 feet wide. The walls of the aqueduct will be set at 3 feet thick and the heights are based on water elevations provided by Hydraulics. The pier support at the outside of the aqueduct walls will extend to the top of the aqueduct wall or the bottom side of the bridge slab. The foundation at the centerline of the diversion will be formed with a low point similar to the diversion. There will also be a concrete apron on the downstream side of the aqueduct, however; there may be riprap in lieu of the concrete apron in final design. See sheet S-101 for details.

F.1.3.2 Vehicle Service and Pedestrian Bridge

The service bridge will provide uncontrolled access for persons across the aqueduct for access to the maintenance trail, onsite operations, inspections of the structure and other uses as needed. The feasibility study was unclear as to the bridge width. After talk with the design team a 15 foot clear width was appropriate for this structure and will be used for design. The bridge will also have a concrete barrier on each side to protect vehicular traffic with an ornamental railing attached at the top for pedestrians. The deck will overhang the aqueduct on the upstream side and not into the aqueduct channel. See sheet S-301 for a typical section of the structure.

F.1.3.3 Upstream and Downstream Walls

The approach walls at the diversion channel protect the embankment on the upstream and downstream side of the aqueduct structure and support the maintenance road. The approach walls will be designed as cantilever cast-in-place concrete retaining walls with pile foundations with unbalanced forces. A preliminary design was completed with preliminary loads from the geotechnical engineers and the most economical pile type is 20” pipe pile. For comparison, 12 rows of pile were required when using HP14X117 H-pile whereas 9 rows are required for the pipe pile. During the design technical review final analysis will look into using other pile configurations when official loads are received. For a preliminary section of the tallest portion of wall and footing layout of the wall system see sheet S-302 and S-102, respectively.

The current layout of the walls is shown in the plan view on sheet S-101. The downstream walls are straight, parallel to the diversion. However, during the design technical review phase shortening the walls and flaring them into the embankment after the scour zone will be investigated since they are not needed for hydraulics past that point.

F.1.3.4 Downstream Apron

The downstream apron will be reinforced Concrete and the design will be developed as part of the next submittal (DTR).

F.1.3.5 Mechanical Building and Heating System

There is strong potential for freezing of the low flow Maple River channel in the aqueduct. To avoid this there will be heating elements run in the low flow channel of the aqueduct. The types being considered are gas heated or geothermal.

A small control building will be required to house the mechanical and electrical equipment for the heating system in the aqueduct. The location and size is yet to be determined and will be a contractor design.

F.1.3.6 Ice Retention Structure

Concept level design alternatives was just provided by CRREL and the design will be developed as part of the next submittal (DTR).

F.1.3.7 Spillway Wier

The feasibility design was based on a rock weir. As part of physical modeling, the spillway weir now includes a reinforced concrete capped sheetpile with associated abutment walls at the terminus of the weir. This design will be developed as part of the next submittal (DTR).

F.1.3.8 Aesthetics

The FMM Diversion Authority (DA) has stated that there will be some required aesthetics for the aqueduct structure. The actual aesthetics have yet to be determined. As aesthetics requirements become available they will be incorporated into subsequent review submittals.

F.1.4 Reference Documents

Links to or copies of the following documents are on the project Extranet site at: https://extranet.dse.usace.army.mil/sites/Divisions/MVD/MVP/FargoMoorhead/ [accessible within USACE] or https://onecorps.usace.army.mil/sites/Divisions/MVD/MVP/FargoMoorhead/ [accessible outside of USACE]
Fargo Moorhead Metropolitan Area Flood Risk Management Project; Oxbow, Hickson, Bakke Ring Levee Attachment D-1 Geotechnical Engineering Parameters dated 7 April 2014 for soil design properties.