The University of Iowa
IOWA INITIATIVE
FOR SUSTAINABLE COMMUNITIES

FINAL DELIVERABLE

Title	Marquette Trail Underpass
Completed By	Max Abbott, Mason Welter, Ben Witzig, and Shimin Xu
Date Completed	May 2023
UI Department	Department of Civiil and Environmental Engineering
Course Name	Project Design and Management CEE:4850
Instructor	Paul Hanley
Community Partners	City of Marquette, Driftless Wetlands Center

This project was supported by the Iowa Initiative for Sustainable Communities (IISC), a community engagement program at the University of Iowa. IISC partners with rural and urban communities across the state to develop projects that university students and IISC pursues a dual mission of enhancing quality of life in Iowa while transforming teaching and learning at the University of Iowa.

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Design Proposal Report

PEDESTRIAN TRAIL DEVELOPMENT MARQUETTE, IA

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THE UNIVERSITY OF IOWA

Table of Contents

Executive Summary

We are a group of students at the University of Iowa with backgrounds in civil and environmental engineering as well as a variety of experiences with relevant design projects and coursework. This project was facilitated through our senior design capstone course and involved coordination with the City of Marquette, IA, and the Driftless Area Wetland Center.

The City of Marquette expressed interest in expanding their existing trail systems to provide safe alternative transport for pedestrians and bicyclists to and from their downtown area. The city requested three areas be connected via trail: the Driftless Area Wetland Center, Bloody Run Campground, and Timber Ridge Subdivision. Our project to meet Marquette's overall goal of increased connectivity was divided into two separate phases. Phase One involves connecting an existing trail that runs along Edgar Street to the Driftless Area Wetland Center. The key challenge presented during the design of this phase was the crossing of U.S. Highway 18. The design for Phase Two involves connecting the expanded trail from Phase One to the Bloody Run Campgrounds and the Timber Ridge Subdivisions which are located west of the wetland center.

Through our research, consideration of constraints, and coordination with the Iowa Department of Transportation (DOT) and Department of Natural Resources (DNR), we have divided the potential trail routes into segmented alternatives that can accomplish the City's goals. Moreover, through our investigation of potential crossing methods we have identified three viable alternatives. Alternative One utilizes an existing box culvert that =crosses the highway; Alternative Two involves installation of a new box culvert that will function as an underpass; and Alternative Three implements a surface pedestrian crossing. We have utilized 3D modeling to visually compare the alternative routes and compiled cost estimations for financial comparisons/considerations. In addition to this design report, we have provided design drawings, a slide presentation, and a design summary poster.

The challenges we faced during our design process included navigating property ownership and existing utilities around the site, crossing a U.S. highway, and the presence of wetlands along with other challenging terrain. Our constraints included a strict submission deadline and the location of the highway, surrounding railroad network, and wetlands as these cannot be moved.

Design commenced February 6, 2023, and all deliverables were finished and submitted on May 5, 2023. The total project cost will depend on the selected trail segments and crossing method however, we have prepared a recommended comprehensive trail system. The total project cost for our recommended trail route/crossing method is $757,000.

Organization Qualifications and Experience

<u>Organization and Design Team Description</u>

We are a group of Civil and Environmental Engineering students in the design capstone class at the University of Iowa.

Name: Max Abbott

Team Role: Project Manager

Area of Study: Environmental Engineering

Lead Category: Coordination and Hydrology

Name: Ben Witzig

Team Role: Technology Service

Area of Study: Civil Engineering

Lead Category: Transportation design and Water Resources

Name: Shimin Xu

Team Role: Report Production (graphics)
Area of Study: Civil Engineering
Lead Category: Transportation design and practice

Name: Mason Welter

Team Role: Report Production (text)
Area of Study: Civil Engineering
Lead Category: Structural

Design Services

Project Scope

The overall objective of this project was to provide feasible design alternatives for a trail that connects the downtown area of Marquette, IA ,to three key locations: the Driftless Area Wetland Center (DAWC), the Timber Ridge Subdivision, and the Bloody Run Campground. The routing of the designed trail system is centered around the mandatory crossing of U.S. Highway 18 that is required to connect an existing trail segment that cuts off North of the highway to the DAWC located south of the highway. Key locations are shown in Figure 1.

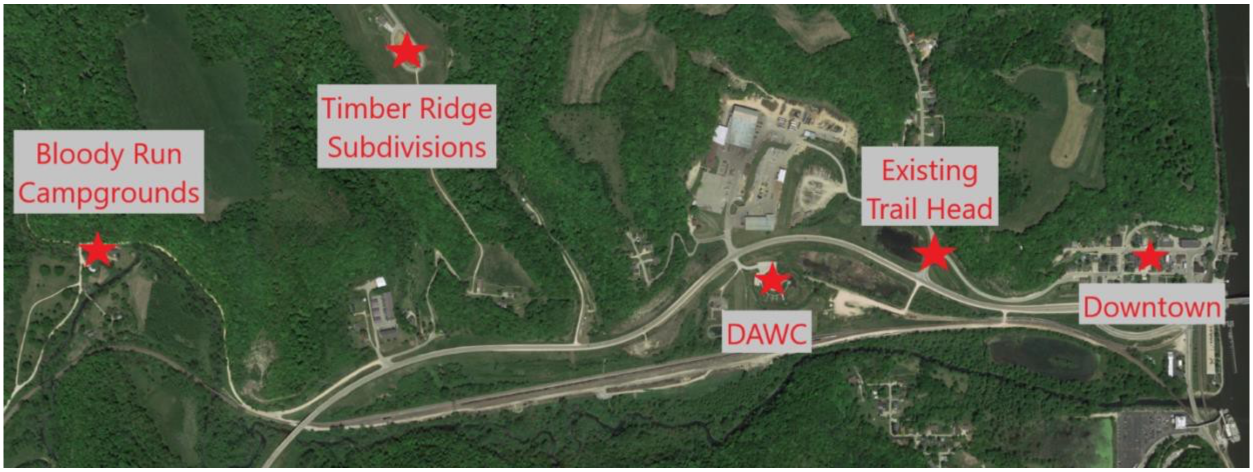


Figure 1: Key locations to increase connectivity in Marquette.

A crucial component of this project was to determine valid methods for accomplishing this crossing. Additionally, we sought to identify permits, potential property acquisitions, and trail features/components required to initiate and accomplish the construction of the designed trail routes.

Work Plan

A time breakdown of the design work phases is shown in Figure 2.

Project Planner

Period Highlight: 1

Plan Duration | Actual Start

ACTIVITY	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Proposal Phase	1	2	0%
Research Phase- Trail Routes (Shimin, Ben)	3	2	0%
Research Phase-Underpass Design (Mason, Max)	3	2	0%
Design Phase-Trail Routes (Shimin, Ben)	5	7	0%
Design Phase- Underpass Desing (Mason, Max)	5	6	0%
Revisions to Designs (Whole Team)	10	5	0%
Deliverable Generation (Whole team)	11	4	0%

Figure 2: Project work phase breakdown.

Methods and Design Guides

The team used the following guidelines and standards to complete this project:

- Iowa Statewide Urban Design and Specifications
- AASHTO Greenbook
- Manual on Uniform Traffic Control Devices
- AASHTO LRFD Bridge design Specification, 8th edition
- Iowa DOT Precast Box Culvert Standards

Constraints, Challenges, and Societal Impact

Although the City of Marquette granted the team creative freedom, the project had many constraints and challenges. The project was required to provide an alternative mode of transportation between the city's downtown area and the Driftless Area Wetlands Center (DWAC) that is safe, walkable, bikeable, and cost efficient. The project also needed to expand the existing trail systems around DAWC to connect with the Bloody Run Campground and Timber Ridge Subdivision. Unfortunately, Highway 18 and the Canadian Pacific Railroad runs between the downtown area and the DAWC. This limited the routing possibilities of the proposed trail expansion because the City of Marquette does not have authority to disrupt the highway or railroad. Another challenge presented during this project was the various wetland protected areas at the site. Building a trail through a wetland protected area is difficult because it requires permission from the IDNR and adherence to strict design standards. Our team also had to plan around the existence of a storm sewer network located along Highway 18.

This project has the potential to have a great impact on the people of the surrounding community. Members of the community who utilize the trails will receive many low-cost health benefits from walking and biking. Easier access to the DAWC can help provide people with an educational experience about their local environment. The expanded trail system will also have great impacts on the community's economy. Easy, low-cost access from the downtown area to existing trail systems and subdivisions will increase the flow of commerce, create and support employment, and reduce the cost of commuting within the community. The project may even increase public revenues as trails add value to properties within the community.

Design Alternatives

Because we were not provided with an initial project budget, our group took the approach of designing multiple alternatives to give the city flexibility with the future handling of this project. We have categorized our alternative design concepts based on potential crossing methods. The trail can be linked together using different segments to achieve the City's connectivity goals depending on the selected crossing method. In total there are three potential crossing methods/locations and each crossing alternative presents unique challenges and upsides. The potential crossing methods include utilization of an existing box culvert, construction of a new box culvert, and construction of a pedestrian surface crossing. The location of these crossings will affect the combination of trail segments that connect the trail to key locations. Utilizing the existing culvert will require the trail to run north of Highway 18. The challenges associated with routing the trail using segments north of Highway 18 include navigating a protected wetland, commercially owned property, and utilizing the DOT right of way while still maintaining an appropriate buffer between the road and the trail. The other two crossing alternatives (new culvert and pedestrian surface crossing) will allow the trail to run south of Highway 18. Challenges associated with the southern oriented trail segments include avoiding the railroad right of way and crossing a small creek. The southern trail routes are favorable due to the avoidance of wetlands and commercially owned property.

Challenges associated with utilizing the existing 10 FT. X 12 FT. culvert include raising the culvert to allow for proper drainage, grading of the trail leading into the culvert to comply with ADA requirements and providing adequate lighting within the culvert for nighttime usage. Because the existing culvert is located roughly 0.3 miles west of the DAWC this crossing alternative would require the trail to backtrack and add additional time of travel for people to access safe crossing to/from the DAWC to the main trail. The location along with an image of the existing culvert and potential ground elevation measures are shown in Figures 3 and 4.

Figure 3: Location of existing culvert.

Figure 4: Existing culvert and proposed ground elevation technique.

Installation of a new culvert will cost the most out of the three alternatives. Depending on the method of installation the highway may need to be shut down. A trenchless installation via hydraulic jacking would not require a complete shutdown but open-cut excavation would require a complete shutdown and detouring of the highway. However, this alternative will allow for the crossing to take place closer to the DAWC than other alternatives. Our selected location for the installation of a new culvert is shown in Figure 5 and an example of what this culvert may look like after construction is presented in Figure 6.

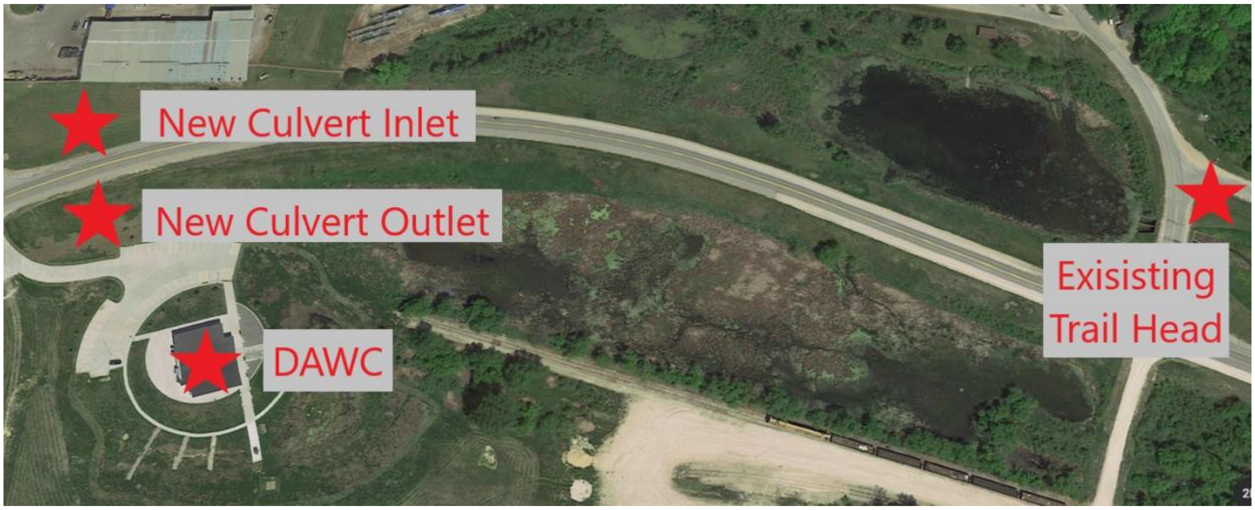


Figure 5: Proposed new culvert location.

Figure 6: Conceptual visual of new culvert.

Using a pedestrian crosswalk to cross the highway will require additional permitting and clearance with the DOT regarding safety concerns. This alternative allows for crossing to take place relatively close to the DAWC. Additionally, the costs associated with this alternative are low compared to other alternatives. We recommend that if this alternative is pursued by the city, a speed limit reduction from 45/55 mph to 35 mph is requested from the DOT. Ultimately, this will be a decision that must be cleared by the DOT but can be initially requested by anyone. The proposed location for the surface crossing is shown in Figure 7 and a visual of what the crossing may look like is shown in Figure 8.

Figure 7: Proposed pedestrian crossing location.

Figure 8: Conceptual visual of new pedestrian crosswalk.

Assuming funding is not a constraint on the trail design, our group recommends Alternative 2, installation of a new box culvert, as the preferred crossing method. We believe this is the most efficient, safe, and viable crossing method.

Final Design Details

<u>Shared Use Trail</u>

Trail

The trail was designed using Civil 3D and following Iowa SUDAS 12B-2 design guidelines. It was considered a Type 3 recreational trail. Figure 9 shows a typical cross section of the trail.

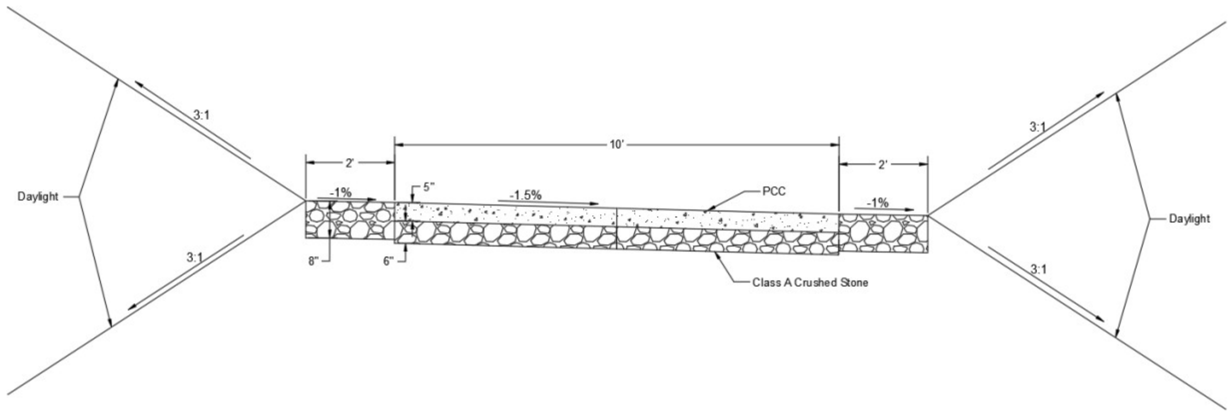


Figure 9

The trail was designed in segments to allow for flexibility in the final routing of the trail. The segment breakdown is given in Figure 10.

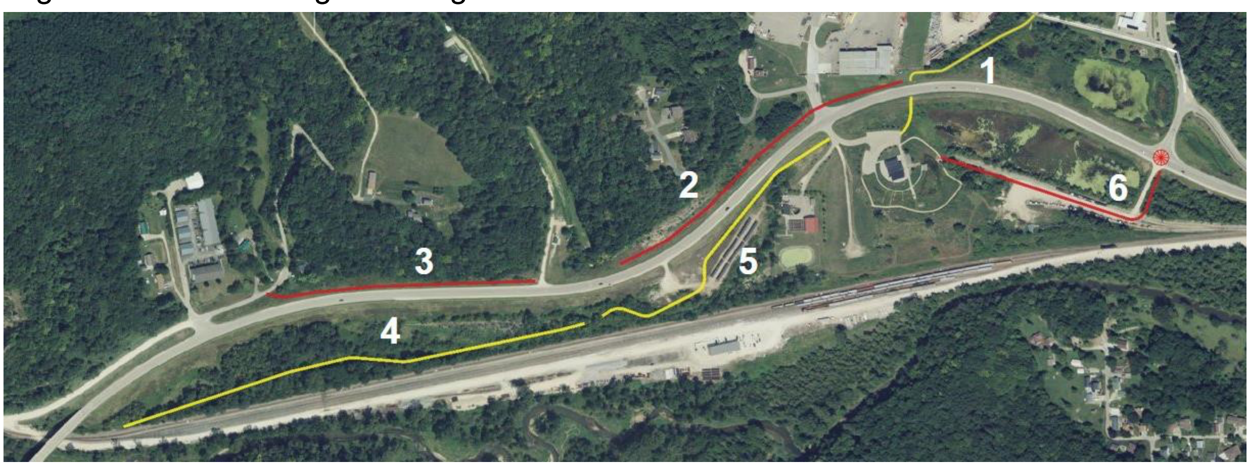


Figure 10: Trail segment breakdown.

Depending on the selected crossing alternative, different trail segments can be utilized to assemble a final design route. We have provided a recommended trail route that we think is the safest, most efficient, and most scenic route. This route requires installation of a new box culvert and is shown in Figure 11.

Figure 11: Recommended trail route.

Small Culverts

Utilization of the southern trail segments requires crossing a small stream to get to the Bloody Run Campground. To accomplish this, two small culverts are implemented into the design to allow the trail to cross over the stream without disturbing its flow. The culverts were sized using flow data obtained from StreamStats in combination with the Hydraflow Civil 3D extension. These culverts are considered to be minor project features; thus they were designed using 50% flood flow of 96.6 cfs. After inputting required flow and elevation data Hydraflow returned a necessary culvert diameter of 12' to accomplish the stream crossing without significantly disrupting flow. A safety factor of 1.25 was used to arrive at final culvert diameters of 15'. Corrugated metal culverts were selected for ease of installation.

Highway Crossing

Existing Culvert

The existing culvert is a 10 FT. X 12 FT. box culvert. According to the city, it rarely has consistent water flow. However, to accommodate potential low flow conditions, the trail surface will be raised using galvanized steel safety grate grip struts. Additional lighting is recommended for the existing culvert to promote safety and nighttime trail usage.

New Box Culvert

The installation of a new boxed culvert, allowing pedestrians to travel underneath US Highway 18, involves the use of a trenchless construction method called hydraulic jacking. The proposed design of the culvert is a 10' x 10' pre-cast reinforced concrete boxed culvert that will span 60-70 feet. The dimensions were chosen to allow ample space for both walking and biking. This design follows the Iowa DOT Standard Design for Single Precast Reinforced Concrete Boxed Culverts. A typical cross section of the barrel section design is included in Appendix B, as well as the design dimensions and reinforcement requirements. The final barrel design was developed by following the Barrel and End Section Design Methodology in the Iowa DOT Precast Box

Culvert Standards. A LRFD software for boxed culverts, called Eriksson Culvert, was used for determining and analyzing resistance factors, reinforcing layout, critical sections, reinforcing wire diameter and maximum spacing, strength-level flexural reinforcing requirements, crack control requirements, minimum and maximum reinforcing requirements, and shear capacity. All calculations in the program operate in accordance with AASHTO LRFD Bridge Design Specifications 8th Edition. All physical dimensions, material properties, and loads that were input into the program are pictured in Appendix C. All design analysis is summarized in a report located in Appendix D.

Surface Pedestrian Crossing

The least costly alternative for crossing Highway 18 involves implementation of a pedestrian surface crossing. Our team coordinated with the Iowa DOT to determine the best location for a potential surface crossing and what would be needed to successfully install one. We were informed that the Iowa DOT would cover the cost for signage and handle installation. In total, four signs would be installed. Examples of these signs are shown in Figure 12.

Figure 12: Required dot pedestrian crossing signage.

However, before the DOT approves a new crosswalk, it would need to be painted, meet ADA requirements, and additional coordination with the DOT regarding safety would need to take place. There are two options for additional lighting to increase crosswalk safety and visibility. Option 1: Intersection lighting will require a permit from the DOT and installation and operation (electricity) would have to be paid for by the city (Figure 13).

Figure 13: Conceptual street lighting visual.

Option 2: Rectangular Rapid Flashing Beacon (RRFB) also requires a permit from the DOT and costs for initial purchase, installation, maintenance, and operation (Figure 14).

Figure 14: Example of a Rectangular Rapid Flashing Beacon (RRFB).

Both lighting options, which provide necessary safety, are included in our final design costs.

Permitting Summary

Various permits will be required during the pursuit of trail construction. A summary of required permits is presented in Table 1.

Table 1: Required Permits

Purpose	**Permit**	**Link**
Construction in and around wetlands/floodplains	Joint Application Permit	- Form: https://www.iowadnr.gov/Portals/idnr/uploads/forms/5423234.pdf - Fact Sheet: https://www.nrcs.usda.gov/sites/default/files/2022-09/Permit%20Fact%20Sheet%20January%202020.pdf
Trail within DOT Right-Of-Way	Form 632007: Application for Use of Highway Right of Way for Recreational Trail Operation	- https://iowadot.seamlessdocs.com/sc/?size=n_10_n&q=632007&filters%5B0%5D%5Bfield%5D=type&filters%5B0%5D%5Btype%5D=any&filters%5B0%5D%5Bvalues%5D%5B0%5D%5B0%5D=Form - Search "632007"
Utilities accommodations in Right-Of-Way, including addition of intersection lighting and RRFBs.	Form 810025: Utility Accommodation Permit	- Search "810025"

Engineer's Cost Estimate

Cost estimates are provided for each potential trail segment and crossing alternative. Additionally, we have provided a cost estimate for our comprehensive recommended trail design which includes the installation of a new box culvert, a southern-based trail route, and other minor features such as small stream crossing culverts and fencing. Our cost data was obtained from Iowa DOT bid tabs, an example cost estimate provided to us by a city engineer from Iowa City, RSmeans cost handbook, and online vendors. Our estimates include materials, equipment, overhead, profit, and labor. The following tables summarize our cost estimate, and the comprehensive cost breakdowns are provided in Appendix A.

Table 2: Crossing Alternative Cost Estimates

Crossing Alternative	Cost
New Underpass	$261,000
Existing Underpass	$53,000
Crosswalk	$15,000

Table 3: Trail Segment Cost Estimates

Trail Segment	Cost
1	$71,000
2	$128,000
3	$85,000
4	$166,000
5	$132,000
6	$51,000

Table 4: Recommended Trail Cost Estimate

Design Element	Cost
Trail and Trail Elements	$370,000
New Underpass	$261,000
Total Project Cost	$631,000
Total Project Cost (20% Contingency)	$757,000

Appendices

Appendix A

The raw cost data and contributing line items are provided below. Cost data was obtained from Iowa DOT bid tabs, an example cost estimate provided to us by a city engineer from Iowa City, RSmeans cost handbook, and online vendors.

Marquette Trail Cost Estimate - 4/23
Trail Segment Costs

Northeast Trail Segment	**556.18**	**ft**			
Item	Quantity	Unit	Unit Price	Total	
Clearing and Grubbing	0.35	ACRE	$4,531	$1,575	
Excavation - class 12					
Cut/fill	626.98	CY	$48	$30,070	
soil compaction	20.60	CY	$1	$22	
Pavement					
5" PCC	617.98	SY	$42	$25,881	
6" class A crushed stone	272.53	Ton	$32	$8,675	
Pavement Marking	384.52	STA	$12	$4,614	
				$70,837	Subtota
North Central Trail Segment	**1599.1**	**ft**			
Item	Quantity	Unit	Unit Price	Total	
Clearing and Grubbing	0.67	ACRE	$4,531	$3,045	
Excavation - class 12					
Cut/fill	527.52	CY	$48	$25,300	
soil compaction	59.23	CY	$1	$63	
Pavement					
5" PCC	1776.78	SY	$42	$74,411	
6" class A crushed stone	783.56	Ton	$32	$24,941	
				$127,761	Subtotal
Northwest Trail Segment	**1234.09**	**ft**			
Item	Quantity	Unit	Unit Price	Total	
Clearing and Grubbing	0.66	ACRE	$4,531	$3,000	
Excavation - class 12					
Cut/fill	101.74	CY	$48	$4,879	
soil compaction	45.71	CY	$1	$49	
Pavement					
5" PCC	1371.21	SY	$42	$57,426	
6" class A crushed stone	604.7041	Ton	$32	$19,248	
				$84,603	Subtotal
Southwest Trail Segment	**2173.2**	**ft**			
Item	Quantity	Unit	Unit Price	Total	
Clearing and Grubbing	0.88	ACRE	$4,531	$4,003	
Excavation - class 12					
Cut/fill	568.15	CY	$48	$27,248	
soil compaction	80.49	CY	$1	$86	
Pavement					
5" PCC	2414.67	SY	$42	$101,126	
6" class A crushed stone	1064.868	Ton	$32	$33,895	
				$166,358	Subtotal
South Central Trail Segment	**1454.43**	**ft**			
Item	Quantity	Unit	Unit Price	Total	
Clearing and Grubbing	0.81	ACRE	$4,531	$3,689	
Excavation - class 12					
Cut/fill	738.94	CY	$48	$35,440	
soil compaction	53.87	CY	$1	$58	
Pavement					
5" PCC	1616.03	SY	$42	$67,679	
6" class A crushed stone	712.6707	Ton	$32	$22,684	
Post fence (wood)	261.66	ft	$8	$2,093	
				$131,643	Subtotal
Total width	14	ft			
Pavement Width	10	ft			
Soil compaction					
Base depth	0.5	ft			
Clear zone width	2	ft			
Cross Area	1	sq. ft.			
6" class A crushed stone					
Depth	0.5	ft			
Density	140	lb/ft^3			
South East Trail Segment		**ft**			
Item	Quantity	Unit	Unit Price	Total	
Clearing and Grubbing	0.14	ACRE	$4,531	$653	
Excavation - class 12					
Cut/fill	247.00	CY	$48	$11,846	
soil compaction		CY	$1	$0	
Pavement					
5" PCC	441.00	SY	$42	$18,469	
6" class A crushed stone	618	Ton	$32	$19,671	
				$50,639	SubtiotL
Total width	14	ft			
Pavement Width	10	ft			
Soil compaction					
Base depth	0.5	ft			
Clear zone width	2	ft			
Cross Area	1	sq. ft.			
6" class A crushed stone					
Depth	0.5	ft			
Density	140	lb/ft^3			

Marquette Trail Cost Estimate - 4/23
Underpass Alternative Costs

Alt. 1 - Existing Culvert

Item	Quantity	Unit	Unit Price	Total
Underpass Lighting	1	LS	$ 9,450.00	$ 9,450.00
24" wide x 2 x 12GA Galvanized Steel Safety Grate / Grip Strut	70	EACH	$ 622.00	$ 43,540.00
Total				$ 52,990

Alt. 2 New Underpass

Item	Quantity	Unit	Unit Price	Total
Precast Concrete Box Culvert, 10 FT. X 10 FT.	60	LF	$ 2,200.00	$132,000.00
Precast Concrete Box Culvert Straight End Section, 10 FT. X 10 FT.	2	Each	$ 31,500.00	$ 63,000.00
Lighting	1	LS	$ 9,450.00	$ 9,450.00
Excavation	250	CY	$ 35.00	$ 8,750.00
Temporary Shoring	1	LS	$ 20,000.00	$ 20,000.00
Anti-Graffiti Coating	300	SY	$ 25.00	$ 7,500.00
Steel Guardrail	200	LF	$ 100.00	$ 20,000.00
				$260,700.00

Alt. 3 Surface Pedestrian Crossing

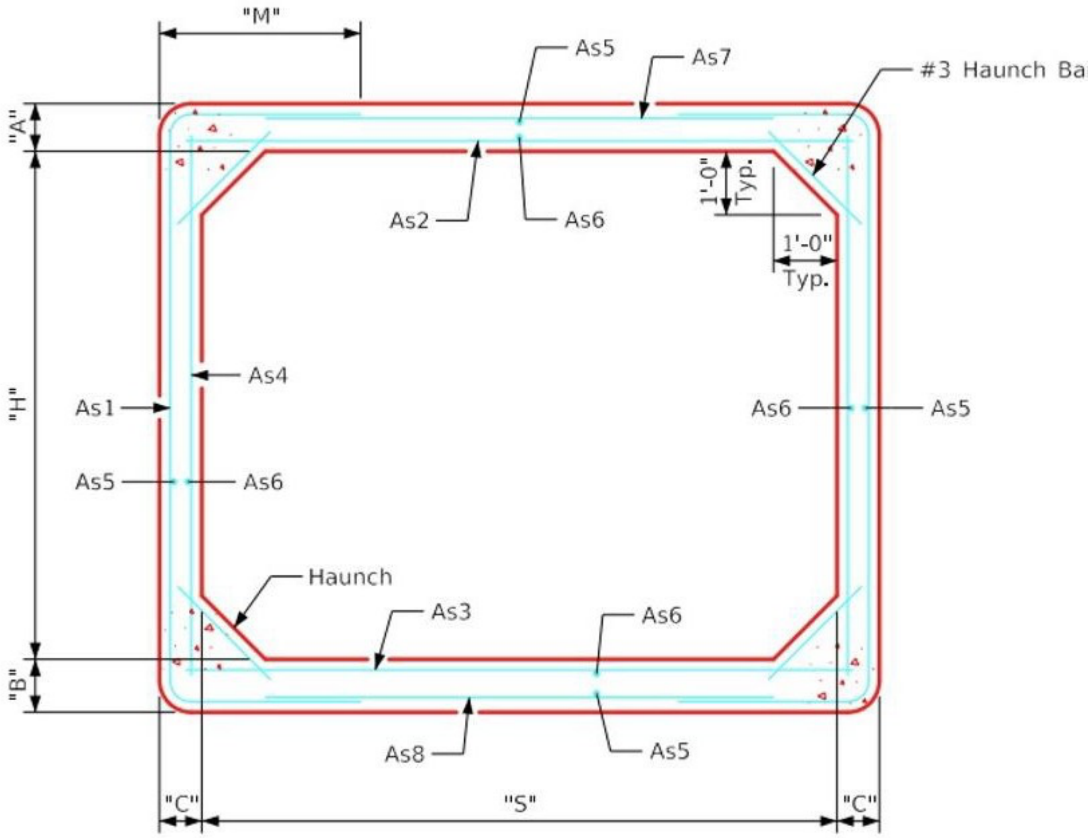
Item	Quantity	Unit	Unit Price	Total
Rectangular Rapid Flash Beacon	2	Each	$ 3,680.00	$ 7,360.00
Lighting Poles	2	Each	$ 3,685.00	$ 7,370.00
Paint	1	Sta	$ 250.00	$ 250.00
Total				$ 14,980.00

Project Recommendation Cost Estimate					
Trail	**Total Trail Length = 4183.81**	**ft**			
Item	Quantity	Unit	Unit Price	Total	
Clearing and Grubbing	2.04	ACRE	$4,531.41	$9,267	
Excavation - class 12					
Cut/fill	1934.07	CY	$47.96	$92,758	
soil compaction	154.96	CY	$1.07	$166	
Pavement					
5" PCC	4648.68	SY	$41.88	$194,687	
6" class A crushed stone	2050.07	Ton	$31.83	$65,254	
Pavement Marking	384.521	STA	$12.00	$4,614	
Post fence (wood)	261.6635	ft	$8.00	$2,093	
				$368,838	Subtotal
Small Culverts					
Item	Quantity	Unit	Unit Price	Total	
CULVERT, CORRUGATED METAL ENTRANCE PIPE, 15 IN. DIA.	28	LF	$40.00	$1,120	
				$1,120	Subtotal
Box Culvert (Underpass)					
Item	Quantity	Unit	Unit Price	Total	
Precast Concrete Box Culv	60	LF	$ 2,200.00	$132,000	
Culvert Straight End Section, 10 FT. X 10 FT.	2	Each	$31,500.00	$63,000	
Underpass Lighting	1	LS	$9,450.00	$9,450	
Excavation - class 12	250	CY	$ 35.00	$8,750	
Temporary Shoring	1	LS	$20,000.00	$20,000	
Anti-Graffitti Coating	300	SY	$25.00	$7,500	
Steel Gaurdrail	200	LF	$100.00	$20,000	
				$260,700	Subtotal
			Construction Subtotal	$630,658	
			Contingencies (10%)	$126,132	
			Total Project Cost	$756,790	

<u>Appendix B</u>

Typical cross section of the of barrel section design with summary of dimensions and reinforcement strength.

Dimensions							
Size	f'c (KSI)	Fill (FT)	S (IN)	H (FT)	A (IN)	B (IN)	C (IN)
10'x10'	5	2-11	10	10	9	10	8



Reinforcement Requirements													
As1			As2		As3		As4		As5/As6		As7/As8		
Area (IN^2/FT)	Length	M	Area (IN^2/FT)	Length	Area (IN^2/FT)	Length	Area (IN^2/FT)	Length	Area (IN^2/FT)	Length	Area (IN^2/FT)	Length
0.54	16'-7"	2'-10"	1.04	10'-6"	1.13	10'-6"	0.2	10'-6"	0.12	10'	0.24	9'-4"

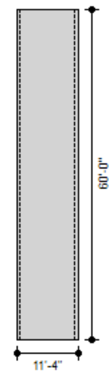
Appendix C

Physical dimensions, material properties, and load assumptions utilized in the Eriksson Culvert program for the design of culvert.

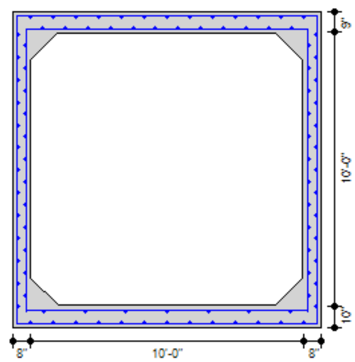
Spec.: LRFD 8th ed.
Type of Culvert: Precast

Physical Dimensions

Clear Span:	10'-0"
Clear Height:	10'-0"
Top Slab:	9"
Bottom Slab:	10"
Ext. Wall:	8"
Fill Depth:	10.00 ft
Length:	60'-0"
Skew Angle:	0.00 deg
Bottom Slab Support:	Full Slab
Top Haunch, Width:	1'-0"
Top Haunch, Height:	1'-0"
Bottom Haunch, Width:	1'-0"
Bottom Haunch, Height:	1'-0"



Plan View



Typical Section

Material Properties

Concrete	
Strength, f'c:	5.000 ksi
Density:	0.150 kcf
Elasticity, Ec:	4287 ksi
Type:	Normal wt
Steel	
Yield, fy:	70 ksi
Allow Stress:	42 ksi
Elasticity, Es:	29000 ksi
Soil	
Density:	0.120 kcf
Exposure Factor	
Class 2 Exposure	
Reinforcement Covers	
Ext. Cover Top Slab:	2"
Ext. Cover Bottom Slab	2"
Ext. Cover Walls	2"
Int. Cover Walls	2"
Int. Cover Top Slab	2"
Int. Cover Bottom Slab	2"

Controlling Ratings

Inventory Rating: 2.08
Operating Rating: 2.70

Loads

Live Load	
Vehicle Names:	HL-93
Traffic Direction:	Parallel
Eq. Height of Soil:	2.00 ft (Calc'd)
Dead Load	
Future Wearing Surface:	0.000 klf
Additional Dead Load:	0.000 klf
Concentrated Loads:	none
Interior Water Pressure:	no
Exterior Water Pressure:	no

Lateral Soil Loads	
Eq. Fluid Press. Max:	60.00 pcf
Eq. Fluid Press. Min:	30.00 pcf

Appendix D

Analysis and results for culvert resistance factors, reinforcing layout, critical sections, reinforcing wire diameter and maximum spacing, strength-level flexural reinforcing requirements, crack control requirements, minimum and maximum reinforcing requirements, and shear capacity developed from Eriksson Culvert software.

```
CULVERT PROPERTIES
==================
Type of Culvert: Precast              Specification : LRFD 8th Edition
Operating Mode : Design

Physical Dimensions
-------------------
No. of Boxes: 1              Name: BoxCulvert
Clear Span  : 10.0000 ft     Fill Depth  :  10.00ft
Clear Height: 10.0000 ft     Skew Angle  :  0.00 deg
Length      : 60.0000 ft     Bottom Slab Support: Full Slab
Haunches: Top, Length: 12.0000 in     Height: 12.0000 in
       Bottom, Length: 12.0000 in     Height: 12.0000 in
Minimum Thicknesses:         Top Slab:  9.0000 in      Bot Slab: 10.0000 in
                             Ext Wall:  8.0000 in
Wall Joint: None

Material Properties
-------------------
Concrete: Strength,f'c :  5.000 ksi   Density     :  0.150 kcf   Elasticity,Ec:   4287 ksi
          Type         : Normal Weight            Density Modification Factor :   1.00
          Fr Factor    :   0.24       Gamma1      :   1.60       Gamma3       :   1.00 (user defined)
Steel:    Yield,fy     :  70.00 ksi   fss Limit   :  0.60fy      Elasticity,Es:  29000 ksi
          Yield,fyv    :  60.00 ksi   Diameter    :  1.000 in    Type         : Mesh
Soil:     Density      :  0.120 kcf   Slope Factor:  1.000
          Poisson's    :  0.5
          Fe Factor    :  1.150 (Maximum for Compacted Fill)
Serviceability, Gamma-e:  0.75

Loads
-----
Live Load:  Vehicle: (AA) HL-93 - Design Vehicle
                     Axle No.    Weight(k)   Dist. From Previous(ft)
                        1          8.00            0.00
                        2         32.00           14.00
                        3         32.00           14.00
                     Gage Width: 6.00 ft, Tread Width: 20.00 in, Tread Length: 10.00 in
                     Include Tandem: yes
                     Tandem: Axle 1: 25.00 k, Axle 2: 25.00 k, Axle Spacing: 4.00 ft
                     Lane Load: 0.00 klf, P-Moment: 0.00 k, P-Shear: 0.00 k
                     Combine: Truck + Lane Or Tandem + Lane
                     Inventory Rating Load Factor: 1.75  Operating Rating Load Factor: 1.35
                     Design Load Combinations: Strength I
                     Override MPF: no
                     Override DLA: no
            Include Lane Load      : no         Max. No. of Lanes: Computed by Program
            Traffic Direction      : Lanes Parallel to Main Reinforcement
            Neglect Live Load for Large Fill Depths: no
            Apply Surcharge at Fill Depths > 2 ft  : yes
            Compute Surcharge Depth: yes
Dead Load:  Future Wearing Surface :  0.00 klf   Add. Dead Load    :  0.00 klf
            Concentrated Loads     : none
Lateral Soil Loads: Max. Equiv. Fluid Press.: 60.00 pcf   Min. Equiv. Fluid Press.  : 30.00 pcf
Include Additional Uniform Horiz. Load: no
Include Additional Uniform Vert. Load: no
Buoyancy Check    : no
Fluid Pressures   : Apply Water Press.  : no
Foundation Model  : Uniform Loads
Seismic Analysis  : Do not include

Load and Resistance Factors
---------------------------
     Max      Min
DC: 1.250    0.900
DW: 1.500    0.650
EV: 1.300    0.900
EH: 1.350    0.900
WA: 1.000
EQ: 1.000
LL I      : 1.750   LL II     : 1.350   LL Legal     : 1.750   LL Extreme : 0.500
Ductility: 1.000   Importance: 1.000   Redundancy, non-earth: 1.000   Redundancy, earth: 1.050
Condition: 1.000   System     : 1.000
Phi Shear: 0.900   Phi Moment: 1.000   PM Compression: 0.750   PM Tension    : 0.900
Load Factor Multipliers, Design Mode: 1.00 Analysis Mode: 1.00
```

```
Reinforcement
-------------
Reinforcement Covers  :  Exterior      Interior
              Top Slab:  2.0000 in     2.0000 in
              Walls   :  2.0000 in     2.0000 in
              Bot Slab:  2.0000 in     2.0000 in

Design Options
--------------
Member Thickness  : Top Slab : Fixed                       Bottom Slab: Fixed
                    Ext. Wall: Fixed
LL Analysis       : Automatically Set Traffic Direction to Account for Skew Effects: no
                    Limit LL Distribution Width to Culvert Length for: None
                    Combine Longitudinal Axle Distribution Overlaps: Yes, Max of 2 Axles
                    Combine Transverse Axle Distribution Overlaps: No
                    Axle Placement Increment for Moving Load Analysis: 20
                    Include Impact on Bottom Slab: yes
                    Always Distribute Wheel Load: yes
                    Deflection Criteria     : 1/800
                    Approach Slab will be Used: no
Reinforcement     : Always Include Distribution Steel: no
                    Distribution Slab Provided: no
                    User Defined Longitudinal Steel: no, Follow Specification
                    Ind. Top and Bottom Slab Design: yes
                    Max. As used in Vc Calcs: 2.00 in2/ft
                    Distribute Minimum Reinforcement per Face: yes
                    Use individual Member Thicknesses for Min Steel: no
                    Epoxy coat steel: no
                    Use M-dimension for bar length calcs.: no
Slenderness       : Checked       K Factor: 2.00
Analysis Modeling : Use Haunches in the Structural Analysis Model: yes
Critical Sections : Flexure critical section location: end of haunch
                    Shear critical section location: dv beyond support
                    Use Max. Moment with Max. Shear at the Critical Section for Shear: no
                    Include depth of haunch for critical sections: no
Flexure           : Ignore Axial Thrust: no
                    Use Eq. 12.10.4.2.4a-1: yes   Nu Multiplier: 1.00
Shear             : Always Check Iterative Beta Method
Environmental     : Apply duribility factors: no
Load Combinations : LRFD min/min: no
```

DESIGN RESULTS

Top Slab Thickness = 9.00 in
Bottom Slab Thickness = 10.00 in
Exterior Wall Thickness = 8.00 in

Modular Ratio (N) = 6.76 Max. Steel Ratio = 0.020
Design Span = 10.67 ft Design Height = 10.79 ft
Design Fill Depth = 10.00 ft

Volume of Concrete: 1.233 cy/ft

Note: Design and analysis results do not include force effects from stipping and handling stages

M dimension = 2' 3" (method of equivalent capacity)
= 4' 10" (method of contraflexure - ASTM)

Reinforcing Steel Schedule

Location	Mat Mark		Sheets Included	Layers	As,prv (in2/ft)	As,str (in2/ft)	Truck
Top Slab (int)	A100	(AS2)	Top	1	0.600	0.515	AA
Bot Slab (int)	A200	(AS3)	Bot	1	0.645	0.541	AA
Top Slab (ext)	A300	(AS7)	L&R	1	0.330	0.240	AA
Bot Slab (ext)	A400	(AS8)	L&R	1	0.330	0.240	AA
Corner Top-U	A1	(AS1)	L&R	1	0.330	0.275	AA
Corner Bottom-U	A2	(AS1)	L&R	1	0.330	0.257	AA
Ext Wall (int)	B1	(AS4)	Top	1	0.600	0.240	AA
Ext Wall (ext)	B2	(AS1)	T&B	1	0.330	0.240	AA
Top Slab (int- 1)	C100	(AS5)	Top	1	0.120	0.110	AA
Bot Slab (int- 1)	C200		Bot	1	0.067	0.110	AA
Temperature (1)	C1	(AS6)	L&R	1	0.120	0.110	AA
Temperature (1)	C1	(AS6)	L&R	1	0.120	0.110	AA
Temperature (1)	C1	(AS6)	L&R	1	0.120	0.110	AA
Temperature (1)	C1	(AS6)	T&B	1	0.120	0.110	AA

Note: A denotes flexural steel, B denotes vertical steel, C denotes longitudinal steel

AS Bar Marks

Location	Governing Mode	As Gvrn in2/ft
Transverse Side Wall - Outside Face (AS1)	c	0.330
Transverse Top Slab - Inside Face (AS2)	b	0.600
Transverse Bottom Slab - Inside Face (AS3)	b	0.645
Transverse Side Wall - Inside Face (AS4)	c	0.600
Distribution Top Slab - Inside Face (AS5)		0.120
Distribution Top Slab - OutSide Face (AS6)		0.120
Transverse Top Slab - Outside Face (AS7)	c	0.330
Transverse Bottom Slab - Outside Face (AS8)	c	0.330

Sheet Inventory

Interior sheets - 2 sheet layout with laps located in the wall

Sheet Loc.	Line Wires: Mat Mark	Zone	Size	Spac. (in)	Length (ft-in)	Area (in2/ft)	H leg (ft-in)	V leg (ft-in)	Cross Wires (L,tot=59-11): Mat Mark	Size	Spac. (in)	Area (in2/ft)	Wgt (lbs)
Top	A100	Base	D10	2.00	21-12	0.600	10- 4	5-10	C100	D10	10.00	0.120	2934
	B1	Base	D10	2.00	21-12	0.600	10- 4	5-10	C1	D10	10.00	0.120	489
									(1) sheets, Total weight:				3423
Bot	A200	Base	D21.5	4.00	22- 5	0.645	10- 4	6- 1	C200	D10	18.00	0.067	3087
	B1	Base	D10	2.00	21-12	0.600	10- 4	5-10	C1	D10	10.00	0.120	489
									(1) sheets, Total weight:				3576

Exterior sheets - 2 sheet layout with laps located in the slab

Sheet Loc.	Line Wires: Mat Mark	Zone	Size	Spac. (in)	Length (ft-in)	Area (in2/ft)	H leg (ft-in)	V leg (ft-in)	Cross Wires (L,tot=59-11): Mat Mark	Size	Spac. (in)	Area (in2/ft)	Wgt (lbs)
L&R	A300	Base	D5.5	2.00	23- 7	0.330	6- 2	11- 3	C1	D10	10.00	0.120	1586
	A400	Base	D5.5	2.00	23- 7	0.330	6- 2	11- 3	C1	D10	10.00	0.120	551
	A1	Base	D5.5	2.00	5-10	0.330	4- 0	1-10	C1	D10	10.00	0.120	-----
	B2	Base	D5.5	2.00	23- 7	0.330	6- 2	11- 3	C1	D10	10.00	0.120	571
	A2	Base	D5.5	2.00	6- 0	0.330	4- 1	1-11	C1	D10	10.00	0.120	-----
									(2) sheets, Total weight:				5416

Weight of Steel: 207 lb/ft   Total weight of all sheets:12415

Notes:
- Epoxy coating may be needed for A1, A300, and some C1 reinforcement, check with governing agency.
- L&R - left and right, TC - top corner, BC - bottom corner, INT - interior walls, EXT - exterior walls
- Nested line wires are additive to the base line wires, but nested cross wires replace base cross wires.
- Adder sheets may require cross wires, check with mesh supplier.

Summary of Ratings Table:

Truck	Flexure: Fill	Member	Location	IR	OR	Shear: Fill	Member	Location	IR	OR
(AA) HL-93	10.00	2	MID	2.08	2.70	10.00	1	BOT	2.14	2.78

Critical Sections Summary: Flexure

Member 1: (Exterior Wall), Thickness = 8.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	OR	Truck	Fill Depth (ft)
BOT	17.00	-11.79	13.02	10.86	5.87	14.57	1.00	0.33 a	9.16	3.12	4.04	AA	10.00
MID	64.75	5.95	6.96	18.93	5.82	20.74	1.00	0.60 c	9.16	NC	NC	AA	10.00
MID-	64.75	-6.03	13.02	10.86	5.87	14.57	1.00	0.33 c	9.16	6.34	8.21	AA	10.00
TOP	16.50	-12.31	13.02	10.86	5.87	14.57	1.00	0.33 a	9.16	2.56	3.32	AA	10.00

Member 2: (Top Slab), Thickness = 9.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	OR	Truck	Fill Depth (ft)
LT	16.00	-7.53	7.43	12.78	6.87	15.25	1.00	0.33 c	11.59	6.20	8.03	AA	10.00
MID	64.00	19.38	2.87	22.43	6.82	23.31	1.00	0.60 b	11.59	2.08	2.70	AA	10.00
RT	16.00	-7.53	7.43	12.78	6.87	15.25	1.00	0.33 c	11.59	6.20	8.03	AA	10.00

Member 4: (Bottom Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	OR	Truck	Fill Depth (ft)
LT	16.00	-8.87	9.40	14.71	7.87	18.20	1.00	0.33 c	14.31	6.64	8.61	AA	10.00
MID	64.00	23.76	3.59	27.45	7.74	28.67	1.00	0.64 b	14.31	2.16	2.81	AA	10.00
RT	16.00	-8.87	9.40	14.71	7.87	18.20	1.00	0.33 c	14.31	6.64	8.61	AA	10.00

As Controlled By: a - Flexure, b - Crack Control, c - Minimum Steel, d - Fatigue

Critical Sections Summary: Vertical Shear

Member 1: (Exterior Wall), Thickness = 8.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn	Beta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	OR	Truck	Fill Depth (ft)
BOT	10.76	7.68	14.8	13.02	5.76	8.79	2.000	9.77 b	0.00	0.00	0.00	2.14	2.78	AA	10.00
MID	64.75	0.15	6.0	6.96	5.76	13.94	3.171	15.49 a	0.00	0.00	0.00	99.99	99.99	AA	10.00
MID-	64.75	0.15	6.0	13.02	5.76	13.18	2.999	14.65 a	0.00	0.00	0.00	99.99	99.99	AA	10.00
TOP	10.26	-6.46	14.9	13.02	5.76	8.79	2.000	9.77 b	0.00	0.00	0.00	3.01	3.90	AA	10.00

Member 2: (Top Slab), Thickness = 9.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn	Beta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	OR	Truck	Fill Depth (ft)
LT	10.48	10.81	11.0	7.43	6.87	15.72	n/a	17.47 c	0.00	0.00	0.00	3.82	4.95	AA	10.00
MID	64.00	0.50	19.4	2.87	6.82	15.62	n/a	17.35 c	0.00	0.00	0.00	30.97	40.15	AA	10.00
RT	10.48	10.81	11.0	7.43	6.87	15.72	n/a	17.47 c	0.00	0.00	0.00	3.82	4.95	AA	10.00

Member 4: (Bottom Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn	Beta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	OR	Truck	Fill Depth (ft)
LT	11.20	11.85	11.8	9.40	7.87	18.01	n/a	20.01 c	0.00	0.00	0.00	4.61	5.98	AA	10.00
MID	64.00	0.01	23.8	3.59	7.74	17.72	n/a	19.68 c	0.00	0.00	0.00	99.99	99.99	AA	10.00
RT	11.20	11.85	11.8	9.40	7.87	18.01	n/a	20.01 c	0.00	0.00	0.00	4.61	5.98	AA	10.00

Vc Calculation By: a - Iterative Beta, b - Constant Beta, c - Box Culvert, d - Standard/Arema

Design Results: Fill Depth = 10.00 ft

Load Parameters:

Fe = 1.15   Surcharge Depth : 2.00 ft

Applied Horizontal Loads: (k/ft)

Load Description	Bottom of Wall	Top of Wall
Live Load Surcharge	0.120	0.120
Internal Water Pressure	0.000(0.0in)	0.000(0.0in)
External Water Pressure	0.000(0.0in)	0.000(0.0in)
Horizontal Earth Load	1.270	0.623

Applied Uniform Bottom Slab Loads: (k/ft)

Load Description	
Dead Load	0.338
Vertical Earth	1.380
Wearing Surface	0.000

Unfactored Moments due to All Loads: (k-ft) / Unfactored Shears due to All Loads: (k)

M-PT	Mdc	Mev	Mdw	Meh	Mls	Mwa	Mgw	Vdc	Vev	Vdw	Veh	Vls	Vwa	Vgw
Member 1: (Exterior Wall)														
Bottom														
1- 0	-1.62	-4.60	0.00	-7.70	-0.94	0.00	0.00	0.13	-0.20	0.00	5.87	0.67	0.00	0.00
1- 1	-1.48	-4.82	0.00	-2.08	-0.30	0.00	0.00	0.13	-0.20	0.00	4.54	0.54	0.00	0.00
1- 2	-1.34	-5.03	0.00	2.13	0.21	0.00	0.00	0.13	-0.20	0.00	3.27	0.41	0.00	0.00
1- 3	-1.20	-5.24	0.00	5.01	0.58	0.00	0.00	0.13	-0.20	0.00	2.07	0.28	0.00	0.00
1- 4	-1.06	-5.45	0.00	6.64	0.81	0.00	0.00	0.13	-0.20	0.00	0.95	0.15	0.00	0.00
1- 5	-0.92	-5.66	0.00	7.10	0.90	0.00	0.00	0.13	-0.20	0.00	-0.11	0.02	0.00	0.00
1- 6	-0.78	-5.87	0.00	6.45	0.85	0.00	0.00	0.13	-0.20	0.00	-1.09	-0.11	0.00	0.00
1- 7	-0.64	-6.09	0.00	4.77	0.66	0.00	0.00	0.13	-0.20	0.00	-2.01	-0.24	0.00	0.00
1- 8	-0.49	-6.30	0.00	2.15	0.33	0.00	0.00	0.13	-0.20	0.00	-2.86	-0.37	0.00	0.00
1- 9	-0.35	-6.51	0.00	-1.36	-0.14	0.00	0.00	0.13	-0.20	0.00	-3.63	-0.50	0.00	0.00
1-10	-0.21	-6.72	0.00	-5.66	-0.75	0.00	0.00	0.13	-0.20	0.00	-4.34	-0.63	0.00	0.00
Top														
Member 2: (Top Slab)														
Left														
2- 0	-0.21	-6.72	0.00	-5.71	-0.75	0.00	0.00	0.73	7.36	0.00	0.00	0.00	0.00	0.00
2- 1	0.43	0.34	0.00	-5.71	-0.75	0.00	0.00	0.49	5.89	0.00	0.00	0.00	0.00	0.00
2- 2	0.88	5.84	0.00	-5.71	-0.75	0.00	0.00	0.36	4.42	0.00	0.00	0.00	0.00	0.00
2- 3	1.20	9.76	0.00	-5.71	-0.75	0.00	0.00	0.24	2.94	0.00	0.00	0.00	0.00	0.00
2- 4	1.39	12.12	0.00	-5.71	-0.75	0.00	0.00	0.12	1.47	0.00	0.00	0.00	0.00	0.00
2- 5	1.45	12.90	0.00	-5.71	-0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2- 6	1.39	12.12	0.00	-5.71	-0.75	0.00	0.00	-0.12	-1.47	0.00	0.00	0.00	0.00	0.00
2- 7	1.20	9.76	0.00	-5.71	-0.75	0.00	0.00	-0.24	-2.94	0.00	0.00	0.00	0.00	0.00
2- 8	0.88	5.84	0.00	-5.71	-0.75	0.00	0.00	-0.36	-4.42	0.00	0.00	0.00	0.00	0.00
2- 9	0.43	0.34	0.00	-5.71	-0.75	0.00	0.00	-0.49	-5.89	0.00	0.00	0.00	0.00	0.00
2-10	-0.21	-6.72	0.00	-5.71	-0.75	0.00	0.00	-0.73	-7.36	0.00	0.00	0.00	0.00	0.00
Right														

Member 4: (Bottom Slab)
Left

4- 0	-1.62	-4.60	0.00	-7.70	-0.94	0.00	0.00	1.80	7.36	0.00	0.00	0.00	0.00	0.00
4- 1	0.11	2.46	0.00	-7.70	-0.94	0.00	0.00	1.44	5.89	0.00	0.00	0.00	0.00	0.00
4- 2	1.46	7.96	0.00	-7.70	-0.94	0.00	0.00	1.08	4.42	0.00	0.00	0.00	0.00	0.00
4- 3	2.42	11.88	0.00	-7.70	-0.94	0.00	0.00	0.72	2.94	0.00	0.00	0.00	0.00	0.00
4- 4	3.00	14.24	0.00	-7.70	-0.94	0.00	0.00	0.36	1.47	0.00	0.00	0.00	0.00	0.00
4- 5	3.19	15.02	0.00	-7.70	-0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4- 6	3.00	14.24	0.00	-7.70	-0.94	0.00	0.00	-0.36	-1.47	0.00	0.00	0.00	0.00	0.00
4- 7	2.42	11.88	0.00	-7.70	-0.94	0.00	0.00	-0.72	-2.94	0.00	0.00	0.00	0.00	0.00
4- 8	1.46	7.96	0.00	-7.70	-0.94	0.00	0.00	-1.08	-4.42	0.00	0.00	0.00	0.00	0.00
4- 9	0.11	2.46	0.00	-7.70	-0.94	0.00	0.00	-1.44	-5.89	0.00	0.00	0.00	0.00	0.00
4-10	-1.62	-4.60	0.00	-7.70	-0.94	0.00	0.00	-1.80	-7.36	0.00	0.00	0.00	0.00	0.00

Right

Unfactored Thrusts due to All Loads: (k)

Member	Pdc	Pev	Pdw	Peh	Pls	Pwa
1	0.73	7.36	0.00	0.00	0.00	0.00
2	-0.13	0.20	0.00	4.34	0.63	0.00
4	0.13	-0.20	0.00	5.87	0.67	0.00

-- Analysis Truck, HL-93 --------------------------------------

Vehicle	Axle No.	Weight (k/ft)	Length (ft)	Dist. From Previous (ft)
Truck	1	0.049	10.83	
	2	0.194	10.83	14.00
	3	0.194	10.83	14.00
Tandem	1	0.221	14.83	

***Distributed loads may have been intensified due to axle overlap between lanes

Live Load Parameters:

Traffic Direction is Parallel to Main Reinforcement
Distribution Width : 18.27 ft
Impact Factor : 1.00
Truck MPF : 1.20 Tandem MPF : 1.20
Lane Load Distribution Width : 0.00 ft
Lane Load: 0.000 k/ft

Truck Positions That Cause Maximum Results:

Maximum +Moment in Top Slab

Vehicle	Axle No.	Weight (klf)	Length (ft)	Dist. From Left End (ft)
Truck	1	0.049	10.83	19.42
	2	0.194	10.83	5.42
	3	0.194	10.83	-8.58

Maximum +Moment : 1.81 k-ft
Corresponding Moment at End : -0.95 k-ft
Coincident Bottom Slab Load : 0.19 k/ft

Maximum -Moment in Top Slab

Vehicle	Axle No.	Weight (klf)	Length (ft)	Dist. From Left End (ft)
Truck	1	0.049	10.83	19.95
	2	0.194	10.83	5.95
	3	0.194	10.83	-8.05

Maximum -Moment : -0.95 k-ft
Corresponding Moment at Mid : 1.79 k-ft
Coincident Bottom Slab Load : 0.18 k/ft

Maximum +Shear in Top Slab

Truck	1	0.049	10.83	19.42
	2	0.194	10.83	5.42
	3	0.194	10.83	-8.58

Maximum +Shear : 1.03 k
Corresponding Shear at Mid : 0.00 k
Coincident Bottom Slab Load : 0.19 k/ft

Maximum -Shear in Top Slab

Truck	1	0.049	10.83	19.42
	2	0.194	10.83	5.42
	3	0.194	10.83	-8.58

Maximum -Shear : -1.03 k
Corresponding Shear at Mid : 0.00 k
Coincident Bottom Slab Load : 0.19 k/ft

Maximum +Moment in Top Slab
Tandem 1 0.221 14.83 7.42
Maximum +Moment : 2.07 k-ft
Corresponding Moment at End : -1.08 k-ft
Coincident Bottom Slab Load : 0.22 k/ft

Maximum -Moment in Top Slab
Tandem 1 0.221 14.83 8.00
Maximum -Moment : -1.09 k-ft
Corresponding Moment at Mid : 2.04 k-ft
Coincident Bottom Slab Load : 0.21 k/ft

Maximum +Shear in Top Slab
Tandem 1 0.221 14.83 7.42
Maximum +Shear : 1.18 k
Corresponding Shear at Mid : 0.00 k
Coincident Bottom Slab Load : 0.22 k/ft

Maximum -Shear in Top Slab
Tandem 1 0.221 14.83 7.42
Maximum -Shear : -1.18 k
Corresponding Shear at Mid : 0.00 k
Coincident Bottom Slab Load : 0.22 k/ft

Unfactored Moments and Shears due to Truck Loads: (k-ft, k)

	Truck				Tandem				Lane			
M-PT	Mll+	Mll-	Vll+	Vll-	Mll+	Mll-	Vll+	Vll-	Mll+	Mll-	Vll+	Vll-
Member 1: (Exterior Wall)												
Bottom												
1- 0	0.00	-0.65	0.01	-0.04	0.00	-0.74	0.01	-0.04	0.00	0.00	0.00	0.00
1- 1	0.00	-0.68	0.01	-0.04	0.00	-0.77	0.01	-0.04	0.00	0.00	0.00	0.00
1- 2	0.00	-0.71	0.01	-0.04	0.00	-0.81	0.01	-0.04	0.00	0.00	0.00	0.00
1- 3	0.00	-0.74	0.01	-0.04	0.00	-0.84	0.01	-0.04	0.00	0.00	0.00	0.00
1- 4	0.00	-0.77	0.01	-0.04	0.00	-0.87	0.01	-0.04	0.00	0.00	0.00	0.00
1- 5	0.00	-0.80	0.01	-0.04	0.00	-0.91	0.01	-0.04	0.00	0.00	0.00	0.00
1- 6	0.00	-0.83	0.01	-0.04	0.00	-0.94	0.01	-0.04	0.00	0.00	0.00	0.00
1- 7	0.00	-0.86	0.01	-0.04	0.00	-0.98	0.01	-0.04	0.00	0.00	0.00	0.00
1- 8	0.00	-0.89	0.01	-0.04	0.00	-1.01	0.01	-0.04	0.00	0.00	0.00	0.00
1- 9	0.00	-0.92	0.01	-0.04	0.00	-1.05	0.01	-0.04	0.00	0.00	0.00	0.00
1-10	0.01	-0.95	0.01	-0.04	0.01	-1.09	0.01	-0.04	0.00	0.00	0.00	0.00
Top												
Member 2: (Top Slab)												
Left												
2- 0	0.01	-0.95	1.03	0.00	0.01	-1.09	1.18	0.00	0.00	0.00	0.00	0.00
2- 1	0.27	-0.22	0.84	-0.01	0.30	-0.25	0.96	-0.01	0.00	0.00	0.00	0.00
2- 2	0.82	0.00	0.66	-0.04	0.94	0.00	0.75	-0.04	0.00	0.00	0.00	0.00
2- 3	1.37	0.00	0.50	-0.09	1.57	0.00	0.57	-0.10	0.00	0.00	0.00	0.00
2- 4	1.70	0.00	0.37	-0.16	1.94	0.00	0.42	-0.18	0.00	0.00	0.00	0.00
2- 5	1.81	0.00	0.25	-0.25	2.07	0.00	0.29	-0.29	0.00	0.00	0.00	0.00
2- 6	1.70	0.00	0.16	-0.37	1.94	0.00	0.18	-0.42	0.00	0.00	0.00	0.00
2- 7	1.37	0.00	0.09	-0.50	1.57	0.00	0.10	-0.57	0.00	0.00	0.00	0.00
2- 8	0.82	0.00	0.04	-0.66	0.94	0.00	0.04	-0.75	0.00	0.00	0.00	0.00
2- 9	0.27	-0.22	0.01	-0.84	0.30	-0.25	0.01	-0.96	0.00	0.00	0.00	0.00
2-10	0.01	-0.95	0.00	-1.03	0.01	-1.09	0.00	-1.18	0.00	0.00	0.00	0.00
Right												
Member 4: (Bottom Slab)												
Left												
4- 0	0.00	-0.65	1.03	0.00	0.00	-0.74	1.18	0.00	0.00	0.00	0.00	0.00
4- 1	0.35	0.00	0.83	0.00	0.40	0.00	0.94	0.00	0.00	0.00	0.00	0.00
4- 2	1.12	0.00	0.62	0.00	1.28	0.00	0.71	0.00	0.00	0.00	0.00	0.00
4- 3	1.67	0.00	0.41	0.00	1.91	0.00	0.47	0.00	0.00	0.00	0.00	0.00
4- 4	2.00	0.00	0.21	0.00	2.28	0.00	0.24	0.00	0.00	0.00	0.00	0.00
4- 5	2.11	0.00	0.01	-0.01	2.41	0.00	0.01	-0.01	0.00	0.00	0.00	0.00
4- 6	2.00	0.00	0.00	-0.21	2.28	0.00	0.00	-0.24	0.00	0.00	0.00	0.00
4- 7	1.67	0.00	0.00	-0.41	1.91	0.00	0.00	-0.47	0.00	0.00	0.00	0.00
4- 8	1.12	0.00	0.00	-0.62	1.28	0.00	0.00	-0.71	0.00	0.00	0.00	0.00
4- 9	0.35	0.00	0.00	-0.83	0.40	0.00	0.00	-0.94	0.00	0.00	0.00	0.00
4-10	0.00	-0.65	0.00	-1.03	0.00	-0.74	0.00	-1.18	0.00	0.00	0.00	0.00
Right												

Note: Unfactored live load results computed at 10.00 ft and 0 ft fill depths, per LRFD 3.6.1.2.6

Serviceability Check: Crack Control

Bar Mark	Location	Moment (k-ft)	Thrust (k)	Fss (ksi)	Spacing (in)	Allow (in)
A1	Top Corner Bar	-8.7	9.27	41.02	2.00	4.16
A2	Bot Corner Bar	-8.4	9.27	39.23	2.00	4.54
A100	Top Slab (int)	13.6	2.22	41.56	2.00	4.32
A200	Bot Slab (int)	16.8	2.83	41.71	4.00	4.36
B1	Ext Wall (int)	1.4	8.09	0.03	2.00	99.99
B2	Ext Wall (ext)	-4.1	9.27	10.93	2.00	27.35

Strength Limit State at Critical Sections: Flexure

Member 1: (Exterior Wall), Thickness = 8.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)		Mcr (k-ft)	Load Ratings IR	Load Ratings OR
BOT	17.00	-11.79	13.02	10.86	5.87	14.57	1.00	0.33	a	9.16	3.12	4.04
MID	64.75	5.95	6.96	18.93	5.82	20.74	1.00	0.60	c	9.16	NC	NC
MID-	64.75	-6.03	13.02	10.86	5.87	14.57	1.00	0.33	c	9.16	6.34	8.21
TOP	16.50	-12.31	13.02	10.86	5.87	14.57	1.00	0.33	a	9.16	2.56	3.32

Member 2: (Top Slab), Thickness = 9.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)		Mcr (k-ft)	Load Ratings IR	Load Ratings OR
LT	16.00	-7.53	7.43	12.78	6.87	15.25	1.00	0.33	c	11.59	6.20	8.03
MID	64.00	19.38	2.87	22.43	6.82	23.31	1.00	0.60	b	11.59	2.08	2.70
RT	16.00	-7.53	7.43	12.78	6.87	15.25	1.00	0.33	c	11.59	6.20	8.03

Member 4: (Bottom Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)		Mcr (k-ft)	Load Ratings IR	Load Ratings OR
LT	16.00	-8.87	9.40	14.71	7.87	18.20	1.00	0.33	c	14.31	6.64	8.61
MID	64.00	23.76	3.59	27.45	7.74	28.67	1.00	0.64	b	14.31	2.16	2.81
RT	16.00	-8.87	9.40	14.71	7.87	18.20	1.00	0.33	c	14.31	6.64	8.61

As Controlled By: a - Flexure, b - Crack Control, c - Minimum Steel, d - Fatigue

Notes: Mu - Resisting moment under pure flexure, Ma - Allowable moment under applied axial load

Strength Limit State at Critical Sections: Vertical Shear

Member 1: (Exterior Wall), Thickness = 8.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)		Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	Load Ratings OR
BOT	10.76	7.68	14.8	13.02	5.76	8.79	2.000	45.00	9.77	b	0.00	0.00	0.00	2.14	2.78
MID	64.75	0.15	6.0	6.96	5.76	13.94	3.171	31.85	15.49	a	0.00	0.00	0.00	99.99	99.99
MID-	64.75	0.15	6.0	13.02	5.76	13.18	2.999	32.53	14.65	a	0.00	0.00	0.00	99.99	99.99
TOP	10.26	-6.46	14.9	13.02	5.76	8.79	2.000	45.00	9.77	b	0.00	0.00	0.00	3.01	3.90

Member 2: (Top Slab), Thickness = 9.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)		Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	Load Ratings OR
LT	10.48	10.81	11.0	7.43	6.87	15.72	n/a	n/a	17.47	c	0.00	0.00	0.00	3.82	4.95
MID	64.00	0.50	19.4	2.87	6.82	15.62	n/a	n/a	17.35	c	0.00	0.00	0.00	30.97	40.15
RT	10.48	10.81	11.0	7.43	6.87	15.72	n/a	n/a	17.47	c	0.00	0.00	0.00	3.82	4.95

Member 4: (Bottom Slab), Thickness = 10.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)		Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	Load Ratings OR
LT	11.20	11.85	11.8	9.40	7.87	18.01	n/a	n/a	20.01	c	0.00	0.00	0.00	4.61	5.98
MID	64.00	0.01	23.8	3.59	7.74	17.72	n/a	n/a	19.68	c	0.00	0.00	0.00	99.99	99.99
RT	11.20	11.85	11.8	9.40	7.87	18.01	n/a	n/a	20.01	c	0.00	0.00	0.00	4.61	5.98

Vc Calculation By: a - Iterative Beta, b - Constant Beta, c - Box Culvert, d - Standard/Arema

Load Combination Results at Tenth Points: (k-ft, k)

M-PT	+Moment	-Moment	+Axial	-Axial	+Shear	-Shear
Member 1: (Exterior Wall)						
Bottom						
1- 0	-13.260	-22.167	10.953	13.019	9.438	3.594
1- 1	-8.934	-13.250	6.961	13.019	7.318	2.736
1- 2	-2.133	-8.584	6.961	13.019	5.297	1.922
1- 3	2.547	-6.902	6.961	13.019	3.375	1.153
1- 4	5.206	-6.025	6.961	13.019	1.553	0.429
1- 5	5.951	-5.906	6.961	13.019	-0.152	-0.301
1- 6	4.890	-6.494	6.961	13.019	-0.786	-1.926
1- 7	2.129	-7.743	6.961	13.019	-1.375	-3.452
1- 8	-2.225	-9.603	6.961	13.019	-1.920	-4.878
1- 9	-8.071	-13.334	6.961	13.019	-2.419	-6.205
1-10	-13.065	-20.688	10.953	13.019	-2.873	-7.434
Top						

Member 2: (Top Slab)

Left						
2- 0	-13.094	-20.754	2.873	7.434	13.019	6.961
2- 1	-2.137	-8.841	2.873	7.434	10.317	5.484
2- 2	7.034	-3.616	2.873	7.304	7.796	4.109
2- 3	13.894	0.037	2.873	7.304	5.323	2.739
2- 4	18.010	2.228	2.873	7.304	2.892	1.370
2- 5	19.382	2.959	2.873	7.304	0.504	-0.504
2- 6	18.010	2.228	2.873	7.304	-1.370	-2.892
2- 7	13.894	0.037	2.873	7.304	-2.739	-5.323
2- 8	7.034	-3.616	2.873	7.304	-4.109	-7.796
2- 9	-2.137	-8.841	2.873	7.434	-5.484	-10.317
2-10	-13.094	-20.755	2.873	7.434	-6.961	-13.019
Right						

Member 4: (Bottom Slab)

Left						
4- 0	-13.260	-22.167	3.594	9.405	14.368	7.932
4- 1	-0.755	-10.353	3.594	9.438	11.495	6.346
4- 2	9.969	-4.430	3.594	9.438	8.621	4.759
4- 3	17.633	-0.200	3.594	9.438	5.747	3.173
4- 4	22.230	2.339	3.594	9.438	2.874	1.586
4- 5	23.763	3.185	3.594	9.438	0.012	-0.012
4- 6	22.230	2.339	3.594	9.438	-1.586	-2.874
4- 7	17.633	-0.200	3.594	9.438	-3.173	-5.747
4- 8	9.969	-4.430	3.594	9.438	-4.759	-8.621
4- 9	-0.755	-10.353	3.594	9.438	-6.346	-11.495
4-10	-13.260	-22.167	3.594	9.405	-7.932	-14.368
Right						