Final Design Report

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TEAM 12

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Team 12: Roads to the Future
EXECUTIVE SUMMARY

Calvin College has multiple traffic related problems on its campus. Some of these include insufficient parking for vehicles and bicycles, problematic intersections and poor entrances and exits from of the East Beltline. The goal of project is to try to alleviate these problems. Team 12: Roads to the Future’s project consists of four major components:

- Parking Structure
- Intersection redesign
- East Beltline Entrances and Exits
- Bicycle Barns

These components can be broken down into two main objectives:

- To provide sufficient parking for vehicles and bicycles
- To provide a safe and transparent road system

The proposed solution to the insufficient number of parking spaces on campus for vehicles, is to design a parking structure. The parking structure will be located in the Kalsbeek-Huizinga Parking Lot which is located on the northern end of the Calvin College Campus. The parking structure will have a parking surface area of 340,000 square feet and have a capacity of 917 vehicles. The overall cost of the structure is $7.18 million which gives a cost per parking space of $7,800. The parking structure will be two levels with the upper level constructed out of precast concrete and the lower level constructed with an asphalt surface. The parking spaces will be 8.5 feet wide and will be angled at a 45 degree angle. The foundation of the structure was designed as spread square footings which will be placed on 3000 psf bearing capacity soil. The structure will require roughly $100,000 per year to maintain.

The proposed solution to the insufficient number of bicycle parking slots on campus is to design a standardized bike structure. The bicycle structure will have multiple locations on campus based bicycle parking needs. The rack for the structure will be a standard Bike-Rail that holds approximately 26 bicycles. The structure will be 8 feet wide, 26 feet long and 9ft tall. The overall cost of the structure will be $17,000 which also includes the architectural elements such as the brick base. These improvements will double each campus parking locations capacity.
The existing entrances and exits from the East Beltline are problematic and need to be updated. The first problematic entrance and exit off of the East Beltline is immediately North of the Calvin Seminary. The exit is confusing because the car exiting the campus must look upstream and downstream to decide when to go. The proposed design moves the crossover to line up with the entrance to Calvin. This will eliminate confusion for the driver exiting Calvin. An entrance will be added from the Northbound East Beltline.

The other problematic entrance/exit off the East Beltline is directly west of the Knollcrest Dining Hall. This intersection is problematic because of the very short queue length coming off of the East Beltline. This short queue length is a safety hazard. It is also not aesthetically appealing and is not designed to handle the dominant path of traffic flow. The proposed modification will move the Calvin Loop West, and increase the queue length. A larger parking lot will be added for the Knollcrest Dining Hall staff between the East Beltline and the Campus Loop Rd. Landscaping will be added to hide the loading dock on Knollcrest Dining Hall.

The last component of the project is to redesign problematic intersections on the Calvin College campus. Specific modifications are being proposed for three heavily used intersections:

- Burton St. Entrance to campus
- East Beltline Underpass Triangle
- Lake Dr. Entrance to campus

The proposed design for the Burton St. Entrance intersection is to construct a roundabout. This will reduce the points of conflict, and increase safety, efficiency, and add grandeur to Calvin’s main entrance. It will also provide safer paths for pedestrians who are crossing the intersection by adding refuge islands.

The current East Beltline Underpass Triangle forces drivers to look over their shoulder to see for whom they must stop. This is an unusual intersection which can confuse visitors. The proposed modification removes one leg of the intersection and would give the three highest traffic volume movements the free flow movements. The southern leg will be realigned to create a 90 degree intersection. This would increase safety, efficiency, and the transparency of the intersection. Pedestrian safety will greatly improve since they must only cross one leg of the intersection instead of two. A sidewalk will also be added along the north side of the intersection.
The Lake Dr. Entrance will be realigned and the Campus Loop curve will be smoothed out to create a 90° intersection. This will create better sight angles and distances than the existing layout, and be able to handle the high traffic events created by the proposed parking structure and Spoelhof Fieldhouse Complex.
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A. PARKING STRUCTURE INTRODUCTION

1 PROBLEM DESCRIPTION

Calvin College is experiencing a parking shortage. Currently the Calvin College campus has five parking lots used by campus residents, and four parking lots used by Calvin’s faculty and commuter students. An additional parking lot is allotted for the Calvin Seminary students. The DeVos Communications Building and the Prince Conference Center share one large parking lot. The capacities and percent use of these parking lots are shown below in Table 1.

<table>
<thead>
<tr>
<th>Map Key</th>
<th>Parking Lot</th>
<th>Capacity</th>
<th>Peak Hour % of Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Knollcrest East Lower Parking Lot (Small)</td>
<td>15</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>Knollcrest East Lower Parking Lot (Large)</td>
<td>195</td>
<td>84%</td>
</tr>
<tr>
<td>3</td>
<td>Knollcrest East Upper Parking Lot</td>
<td>137</td>
<td>97%</td>
</tr>
<tr>
<td>4</td>
<td>East Beltline Parking Lot</td>
<td>305</td>
<td>99%</td>
</tr>
<tr>
<td>5</td>
<td>Kalsbeek-Huizinga Parking Lot</td>
<td>524</td>
<td>83%</td>
</tr>
<tr>
<td>6</td>
<td>Fine Arts Center Parking Lot</td>
<td>333</td>
<td>98%</td>
</tr>
<tr>
<td>7</td>
<td>Science Building/Spoelhof Parking Lot</td>
<td>879</td>
<td>91%</td>
</tr>
<tr>
<td>8</td>
<td>Field House Parking Lot</td>
<td>176</td>
<td>98%</td>
</tr>
<tr>
<td>9</td>
<td>DeVos/Prince Conference Center Parking Lot</td>
<td>552</td>
<td>89%</td>
</tr>
<tr>
<td>10</td>
<td>Seminary Parking Lot</td>
<td>147</td>
<td>+100%</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>3263</td>
<td>91.5%</td>
</tr>
</tbody>
</table>

Table 1: Current Parking Lot Capacities

1.1 Supporting Evidence of Problem

Team 12 performed a parking capacity study of these parking lots during the peak hour for each location in November of 2006. The peak hour count the resident lots were taken at 12 AM when most vehicles would be in the parking lots. The peak hour for the commuter lots was taken during the day at 11:30 AM when the lots will be operating near the maximum capacity. The extra lots such as the Prince Conference Center parking lot had data taken during large events such as the January Series. This parking study showed that both the resident and commuter parking lots frequently operate over 90% of capacity. The East Beltline Parking Lot is operating at 99% of capacity and overflows into the DeVos Communications/Prince Conference Center Parking Lot on a regular basis. During
peak class hours (Monday, Wednesday, and Friday at 11:30) some commuter parking lots (Fine Arts Center Parking Lot, Science Building/Spoelhof Parking Lot, Field House Parking Lot) are filled to capacity and are overflowing into the DeVos Communications/Prince Conference Center Parking Lot. During the Calvin vs. Hope game on Saturday, November 24, 2006, the Calvin Loop Rd. between the Lake Dr. Entrance and the Field House had 44 vehicles parking along the side, which is signed as a no parking zone. Having these parking lots filled to capacity on a routine basis makes it very difficult for visitors to find parking spaces and it has the potential to cause students to be late for class on a routine basis. Also, the routine cycling of vehicles through the parking lots looking for spaces is a safety hazard for students walking through the parking lots going to class.

1.1.1 Spoelhof Recreational Facility
Calvin College just recently approved the construction of the new Spoelhof Recreational Fieldhouse Complex. This new facility will have a seating capacity of 5000 people, an 800 person increase over the current Field House. The addition of this facility will add demand for parking during large events such as sporting events at the new facility. There will also be parking spaces lost due the construction of this new facility. The proposed parking structure is in very close proximity to the new facility and would provide the needed increase in parking for this increase in demand.

1.1.2 Three Year Policy
Calvin College has been considering changing the requirement for students to live on campus from two to three years. Although this may reduce the number of students that commute to campus on a routine basis, it will also increase the number of vehicles that are parked on campus 24 hours a day as residents student parking. This will ultimately cause a shortage of parking on campus in the evenings when there are large events such as concerts in the Fine Arts Center because there will be more vehicles that will be remaining on campus. By providing more parking for resident students in the parking structure, this would help open up additional parking for these events.
2 PROBLEM SOLUTION

2.1 Objective of Solution
The objective of the construction of the parking structure is to provide Calvin’s campus with sufficient parking for resident students, visitors, commuters and large event goers.

2.2 Solution Research

2.2.1 Solution Location
A parking study was conducted on campus as well as assessing the feasibility study of building a parking structure on various locations including the East Beltline Resident Lot, the Seminary Lot, the Field House Lot and the Kalsbeek Huizinga Lot. After considering effect on neighbors, utility conflicts and overall feasibility the Kalsbeek-Huizinga Lot was determined to be the best location for the parking structure.

2.2.2 Research Material
The primary source for information on parking structure design was the Precast Concrete Institute’s “Parking Structures: Recommended Practice for Design and Construction”. This resource contains codes for the layout and design of precast concrete parking structures as well as recommendations for design. In choosing materials, the websites produced by Nitterhouse Concrete Products Inc. and Bethlehem Construction were used to determine standard sizes, dimensions, and loading capacities of different precast components that are used to construct the structure. Also, details of connections were provided by these companies which were consulted in the design of connections for the parking structure.

2.3 Conclusions
The parking structure is justifiable for the following reasons:

- Calvin is constructing a new Spoelhof Recreational Facility and there is a need for parking to provide for the 800 person increase in capacity of the facility.
- The current parking system on campus is operating at 91.5% of capacity and is incapable of handling large influxes of traffic for large events on campus.
In constructing a parking structure rather than a surface lot, green space can be preserved because the location of the structure is already an existing parking lot. It also allows for expansion of the parking system on campus without requiring more land.

3 PARKING STRUCTURE DESIGN

3.1 Material Choice Decision Matrix

There are three different materials that were considered for use to construct the parking structure. These materials are:

1) Pre-Cast Concrete
2) Post-Tension Concrete
3) Steel supported Post Tension Concrete

The decision matrix in Table 2 was used to determine which material choice would be the most feasible and effective for the Calvin College parking structure.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Steel Frame + Post Tension Deck</th>
<th>Post Tension Frame + Deck</th>
<th>Pre-Cast Frame + Deck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Control</td>
<td>11</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Surfacing</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Construction Weather Limitations</td>
<td>8</td>
<td>2</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>Curing</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Erecting Speed</td>
<td>12</td>
<td>2</td>
<td>24</td>
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</tr>
<tr>
<td>Fire Protection</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Longevity</td>
<td>13</td>
<td>2</td>
<td>26</td>
<td>3</td>
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<tr>
<td>Cost</td>
<td>14</td>
<td>2</td>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Total</strong></td>
<td><strong>169</strong></td>
<td><strong>205</strong></td>
</tr>
</tbody>
</table>

Table 2: Material Decision Matrix

3.1.1 Decision Matrix Criteria

3.1.1.1 Quality Control

There are different levels of quality control depending on where the parking structure is constructed. For the pre-cast concrete, the pieces are all fabricated indoors and are heat treated. They also are fabricated in a standardized manner. This gives it higher quality control than the post-tension options where the concrete is being cast in the field where it is more difficult to maintain quality.
3.1.2 **Surfacing**

The precast concrete has an option of pre-topped double-tees which would eliminate the need for on-site surfacing of the concrete. The post-tension concrete options would not require surfacing once the concrete is poured however the pouring process requires significant work to get a smooth enough surface. This would have already been done during fabrication with the pre-topped, pre-cast concrete.

3.1.3 **Construction Weather Limitations**

One of the disadvantages to the post-tension concrete is that it cannot be poured in the snow or rain. The precast pieces however can be cast and installed in any weather because the casting is done indoors and the pieces can be installed even when the weather is bad. For the steel option the steel could be installed in bad weather however the concrete slabs would not be able to be poured.

3.1.4 **Curing**

The curing process for the precast concrete is done by the fabricator and involves heating the concrete during the curing process so that it becomes much less penetrable and more resistant to corrosion. The curing process for the post-tension concrete must be done in the field and therefore can be affected by adverse weather conditions.

3.1.5 **Erection Speed**

Precast concrete has a much faster erection speed because all that has to be done is to pour the footings and use a crane to place the precast components and perform the joint connections. For the post-tension concrete, the speed is slower because you have to wait for the lower levels of the structure to cure before the next levels can be added. The steel erects quickly however the post-tension concrete that would be placed on it would not install quickly.
3.1.1.6 Fire Protection
Both concrete options do not require any fire protection. The post-tension concrete with the steel frame however would require fire proofing because the steel could be weakened by fire.

3.1.1.7 Corrosion Resistance
The precast concrete is the most resistant to corrosion. Because the concrete is heat treated when it is cast, it penetrability is much lower than the post-tension concrete. This protects the internal rebar in the concrete more effectively than the post-tension concrete. The steel frame would be the most susceptible to corrosion from salt and the elements because of the exposed steel frame.

3.1.1.8 Longevity
The post-tension concrete has the longest lifespan of the three different material choices. It also has the greatest structural integrity for seismic loads. Because the State of Michigan has very minimal seismic loading, the necessity for the post-tension concrete for seismic loading is lost. Precast concrete has also been shown according to the Mid-Atlantic Pre-cast Association (MAPA) to last as long as post-tension concrete or even longer if it is well maintained. The maintenance costs are also much less for the precast parking structure according to MAPA.

3.1.1.9 Slab Depth
The thickness of the slab between different floors of the parking structure has some affect on the needed height for the parking structure. The post-tension concrete with the steel faming has the thinnest concrete slab however; the thinnest overall slab would be the post-tension concrete slab. The precast concrete double-tees tend to have a deep web which would add to the amount of space needed for the slab thickness. However, there is an advantage in that all utility lines can be enclosed in the slab
area and no extra height would need to be added to account for them.

3.1.1.10 Load Deflection
The deflection of the slabs of the parking structure is a design aspect that needs to be considered. All of the materials would allow for minimal deflections however the steel frame would probably deflect to a larger extent than both pure concrete options. The post-tension concrete would also be more rigid than the precast double-tees which are designed to flex some.

3.1.1.11 Joints
The joints of the post-tension concrete design and the precast design are completely different. The post-tension joint allows for very little movement and is attached together by tying the rebar and then pouring the concrete over it. This method is much more time consuming and allows for very little expansion and contraction that would occur with changes in temperature of the concrete. The precast concrete joints involve bolts and nylon bearing pads to connect the different pieces. The advantage to the precast joint is that there is very little motion restriction which reduces the buckling and cracking that would normally occur from thermal expansion-contraction cycles.

3.1.1.12 Cost
The overall cost of construction for the precast concrete is the lowest. This is because the precast concrete can be erected much more quickly and it can be erected in all weather conditions. The on-site labor that goes into constructing the parking structure is much less since all of the casting is done by a standardized method in a fabrication shop. The only field work that is done is joints and crane work. The other two post-tension concrete options are more expensive because of the amount of labor that has to be done in the field.
3.1.2 Lower Level Surfacing Material
Asphalt was chosen as the surfacing of the lower level of the parking structure. The details of this can be seen in Appendix PS.09. This was chosen largely for economic reasons. This was also an ideal surface due to the fact that the parking structure does not have a level being placed below grade so a surface asphalt parking lot is sufficient. The life of the asphalt surface will also be increased due to the fact that it will be protected from the elements by the upper level of the parking structure and the fact that the size of vehicles will be restricted by the high restrictions of the structure. This will then not put as much wear and tear on the lower level parking lot. This reduction will increase its life expectancy over a traditional asphalt parking lot lower.

3.2 Loading
LRFD was used to calculate the factored loading of the structure. This includes multiple safety factors in the design calculations to insure the structure is structurally sound.

3.2.1 Vehicle Loads
The load that is exerted by vehicles on the structure is 40 psf. Also, a vehicle is capable of exerting a concentrated load of 2000 lbs. The vehicle loading on the structure can be limited to these quantities due to the fact that there is limited overhead clearance in the parking structure. This loading data was acquired from the PCI Parking Structures: Recommended Practice for Design and Construction.

3.2.2 Snow Loading
The structure has been designed to handle a snow load of 30 psf. This loading has been determined from maximum snowfall quantities that have occurred in the past in Grand Rapids, Michigan. This quantity also takes into account drifting of the snow on top of the structure.

3.2.3 Utility Loading
Loads from utilities on the parking structure were taken into account in the loading of the parking structure. There are loads from storm water
pipes, signs, and lighting. A load of 15 psf. was assumed for loading from utilities in the parking structure.

3.2.4 Wind Loading
For the design of the parking structure, wind speeds in Grand Rapids, Michigan can reach a maximum of 90 mph. However, given the openness of the structure, horizontal loading due to wind on the structure is minimal. All lateral loading of the structure will be transferred to the corner towers which will all be designed to handle shear loading.

3.2.5 Seismic Loading
Seismic loading within the Grand Rapids, Michigan area is considered to be negligible and therefore, seismic loading was not taken into account in the design of the parking structure.

3.3 Structural Components

3.3.1 Precast Concrete Double-Tees
There will be 340 precast concrete double-tees needed for the construction of the parking structure. These double-tees are 48 feet long and 10 feet wide. One double-tee that is near each tower will have a length of 38 feet rather than 48 feet because the tower is cut into the structure. These double-tees will be pre-topped with a 2 ½ inch layer so as to reduce the cost of adding surfacing after the parking structure has been constructed. These double-tees will need to be designed to handle a live load of 40 psf and a concentrated load of 2000 lbs. Each double-tee will weigh roughly 22 tons and will be supported by the webs. The reinforcement design of the double-tees will be completed by the precasting contractor. A drawing of the exterior design of the double-tees can be seen in Appendix PS.06.

3.3.2 Precast Concrete Beams
The parking structure will have three different sizes of precast beams.

1) 48 feet long dually loaded.
2) 48 feet long one side loaded.
3) 38 feet long one side loaded.
These beams will be designed to support the double-tees directly though a 6 inches extrusion at the base of the beam on which the double-tees to rest. This will give the beams an up side down “T” shape which will allow for more of the reinforcing to be placed at the greatest moment arm possible within the beam. A drawing detail of this can be seen in Appendix PS.07. The beams will weigh roughly 16 tons for the dually loaded beams and roughly 8 tons for the one side loaded beams. The dually loaded precast concrete beam design can be seen in Appendix PS.07. A one side loaded beam would be half of this load.

Loading of these dually loaded beams was completed with a STAAD analysis which can be seen in Appendix PS.21.

3.3.3 Precast Concrete Exterior Spandrels
The exterior of the parking structure will be lined with spandrels to cover the ends of the double-tees that would otherwise be left exposed. These precast concrete spandrels will have cast into them “dovetail” mounting brackets at 3 feet intervals and a 4” x 4” x ¼” angle steel beam attached to the base to allow for support of an exterior of red Calvin Brick. These spandrels will weigh roughly 16 tons each. They will have the exterior covered in Calvin Brick to add to the aesthetics of the parking structure. The exterior spandrel design can be seen in Appendix PS.08

An alternate to the covering of brick would be to have the exterior spandrels precast with the red Calvin Brick as a part of the spandrel itself. There are also multiple decorative faces that can be placed on the spandrel in order to give it an aesthetically pleasing appearance.

3.3.4 Precast Concrete Columns
The structure is designed with 87 separate precast concrete columns. These columns are 20 feet in length and 2 feet square. These columns have been designed to support loads as great as 617 kips. A uniform dimension on columns has been used in spite of the differing load that they columns will be bearing. This was done for architectural reasons in trying to maintain a uniform appearance to the structure. The columns are provided by the precast concrete contractor with existing bearing pads attached to the lower ends. The columns will be connected to their
footings using four 1 inch diameter anchor bolts. The columns that line the exterior of the structure will have three sides covered in red Calvin Brick to match the exterior spandrels of the structure. For connections, the precast concrete columns will be designed with bearing shelves that will protrude 6 inch out from the side of the column. These will be used to support beams and exterior spandrels.

3.4 **Precast Concrete Component Trucking**

The prominent provider of precast concrete in the Grand Rapids area is Kerkstra Concrete. This requires a trucking route of roughly 12 miles for all precast concrete components that are being brought to the parking structure construction sight.

3.5 **Foundation Design**

3.5.1 **Existing Soil Conditions**

Due to cost limitations, soil borings were not been taken for the location of the proposed parking structure. Soil borings have been taken nearby for the addition of the new Spoelhof Recreational Facility. A soil study was conducted by Material Testing Consultants. The report specified the soil bearing capacity for the fields located just east of the proposed location to be 3000 psf. This soil bearing capacity was used to design the foundations for the parking structure. MDOT (Michigan Department of Transportation) specifications were used to design the lower level parking asphalt surface. Excerpts of this report as well as detailed soil boring data for the nearby soccer field can be seen in Appendix PS.22

A concern in designing of the foundations of the parking structure is the close proximity to known peat bogs. It is recommended that soil borings of the area are performed prior to addition structural design is performed. The results of these borings may require the use of a piling foundation rather than the proposed spread footing foundation. This change in foundation design could significantly increase the cost of the structure.

3.5.2 **Water Table**

The average current water table at the proposed site for the parking structure is at an elevation of 776 feet. This information came from the
Material Testing Consultants soil testing report for the nearby area. This report can be seen in Appendix PS.22. This elevation is very close to the soil surface at our proposed construction site. The foundations need to be buried 3.5 feet for frost protection, therefore soil will have to be added to the site in order to keep the bases of the footings above the water table which will increase the life expectancy of these foundations. A topographic design for the proposed structure can be seen in Appendix PS.17.

3.5.3 Excavation
The current grading at the sight has a downward slope toward the southeast corner of the Kalsbeek-Huizinga parking lot. The maximum elevation change over the sight is 12 feet. The majority of this elevation change is due to a rise on the southwest corner of the sight which will have to be excavated. Roughly 4500 cubic yards of dirt will have to be excavated however this soil will be kept on site and used as fill for the areas of lower elevation. Some excavation on the southern side will have to go below the base level of the parking structure to allow for drainage of storm water around the parking structure. All details of this can be seen in the topographic map of the site in Appendix PS.17.

3.5.4 Soil Purchase
Sand will be purchased to raise the base level of the parking structure to keep the foundations above the water table elevation. 11,700 cubic yards of sand will be purchased to elevate the structure base to an elevation of 782 feet. This elevation will be sufficient to drain all water away from the parking structure as well as keep the foundations of the structure below the frost level and above the high water table at 776 feet. There will be a large amount of extra soil that will be generated by the construction of the new Spoelhof Recreational Facility. If the parking structure is constructed at a similar time, dirt from the Spoelhoff Recreational Facility could be used rather than purchasing more sand.
3.5.5 Footing Design
With the current design of the parking structure, there are 87 square spread footings for structure columns and spread footing foundations under the walls of the corner towers. The square spread footings have been designed to support one column each and distribute the load sufficiently so that the column can be supported by soil with a 3000 psf bearing capacity. The columns will apply their load on a 2 feet by 2 feet section of the center of the footing. The largest footing is 17.5 feet by 17.5 feet and 2.25 feet thick. This footing supports a column with a factored load of 617 kips. The smallest of the square footings are integrated into the strip footings of the tower and are 8.75 feet by 8.75 feet and 1.5 feet thick. All footings have been reinforced with a rebar mesh with 12 in to 18 in spacing on center. For design drawings see Appendix PS.09. Calculation for the design of these footings can be seen in Appendix PS.20. Rebar and concrete quantities can be seen in Table 3.

**FOOTING DESIGN TOTALS**

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<th>Rebar Area (in²)</th>
<th># of Rebar</th>
<th># of Footings</th>
<th>Volume Concrete (cu yds)</th>
<th>Length of Rebar (ft)</th>
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</table>

Table 3: Footing Design Totals

Details of dimensions and quantities of these footings can be seen in Appendix PS.11.

3.6 Interior Layout

3.6.1 Traffic Flow
The interior of the proposed two story parking structure will be entirely of one-way traffic flow. The entrance to the parking structure is on the north side of the building. Traffic will be guided through the structure through a combination of pavement markings, overhead signage and three strand galvanized guard cables. These guard cables are to be
fastened to the face of the precast columns to keep cars from driving through parking spaces. A drawing of the traffic flow layout for both levels of the proposed structure can be found in Appendix PS.15 and Appendix PS.16.

3.6.2 Signs

Each entrance and exit in the proposed parking structure will be signed accordingly with overhead signs. The entrance will also have an additional overhead or “headknocker” sign specifying the minimum clearance of 8 feet 0 inches within the structure. This sign will hang from chains mounted on the exterior spandrel above the entrance. Headknocker signs will also be attached to the base of the double tees on the lower level and on cantilevered sign structures on the upper level at each decision point for the driver. These signs will point the driver to additional parking, exits, and ramps to the other floor of the structure. All signs are to be clearly lit.

3.6.3 Lighting

Lighting surrounding and within the proposed parking structure will increase the safety and security of the structure. Lighting for the lower floor will be provided through 100W incandescent wall pack light fixtures placed on roughly 8 feet from the asphalt base on all 4 sides of interior columns. The exterior columns will have lights at the same height on all non-brick faced surfaces. Lighting on the upper floor will consist of 8 feet tall poles with two 400W metal halide fixtures. These light poles will be fastened to the tops of all the interior precast columns. This lighting plan should adequately light the structure. Further consultation with an electrical engineer is recommended for exact fixture selection and electrical grid layout. The recommended locations for the electrical and mechanical rooms are the spaces below either of the two ramps. These locations are ideal because cannot be used for parking because there is no means of exit because of the one way flow design.
3.7 Towers

3.7.1 Foundation Design
The tower’s proposed foundations consist of 2 feet wide by 1.5 feet deep strip footings. These footings will support the tower on soil with 3000 psf soil bearing capacity. These footings are located 3.5 feet below the surface of the soil to avoid freeze – thaw damage. These footings have been reinforced with rebar. Further geotechnical analysis is recommended to ensure these that the soil beneath these foundations does not consolidate under the additional loading of the towers.

3.7.2 Floor Plan
The proposed tower consists of a 22 feet by 22 feet floor plan and rises two floors to a height of 35 feet 8 inches at the peak of the roof. This tower houses an “L” – shaped staircase and a holeless hydraulic elevator which both provide access between the two levels. The user enters through the double door and can go straight up the stairs to the second level and go slightly left to continue through the tower to the elevator door and exit doors to the main structure.

3.7.3 Exterior
The proposed exterior of the tower was modeled after the towers recently constructed on Calvin’s Crossings, DeVos Communications Building and the Prince Conference Center. This exterior was chosen to keep with the high standards for uniformity of the existing Calvin architecture. Two and a half sides of this tower are enclosed by tinted glass windows for aesthetics and lighting. The tower is capped with a “Lighthouse” making the towers stand out from the rest of the structure so the users know where to locate the structures entrance points. The exterior doors are sheltered with entrance arches. These arches were again designed to be consistent with architectural elements found on recently constructed Calvin buildings.
3.7.4 Elevator Specifications
The proposed parking structure towers contain ThyssenKrupp AMEE Holeless Hydraulic Elevators. These elevators exceed the American with Disabilities Act size requirements for passenger elevators with a width of 7 feet and depth of 6 feet 3 inches. This elevator was selected because it does not require significant excavation for an elevator shaft. This is advantageous because of the high water table present throughout the entire proposed site.

3.7.5 Stair Specifications
The stairs run along two of the interior walls in an “L”-shape. The stairs are made of precast concrete and share the specifications of many of the recently constructed stairways at Calvin with a 1 foot tread and 7-3/16 inches rise. The stairs are 4 feet wide and have railings on each side to assist the user up the staircase.

3.8 Storm Water Design

3.8.1 Top Floor
The storm water system has been designed to handle a 10 year storm in the Grand Rapids, Michigan area. This gives a maximum rainfall of 3.52 inches in 60 minutes.

The upper level of the parking structure has been sloped to a 1 percent grade in order to direct storm water to a low spot near the column where drains will be located. Two of the 50 feet square sections of the structure will drain into each drain that is located on the upper floor of the structure. The drain will be located so that the amount of water that will flow over the seams in the precast components will be minimized. A drain will be located on each side of each column so that no water has to flow across the beam or column joints. The water from the drains will then be drained into a pipe running down the face of the column to the storm water pipe network under the lower level of the parking structure. The drawings for this design can be seen in Appendices PS.12 and PS.13.
The drains will be 8 inch diameter industrial grade galvanized steel drains. The pipe will be 4 inch ID PVC pipe which will be attached to the columns with galvanized steel brackets.

3.8.2 Bottom Floor
The storm water drainage system under the lower floor of the parking structure has been designed to handle flows from the upper level of the structure and any storm water that makes it to the lower level of the structure. The pipes are graded towards an existing catch basin outside the structure so as to not exceed the 2 fps maximum flow rate in the pipes. The pipes increase in diameter towards the catch basin from 4 inch ID pipes at the extremities of the structure to 18 inch ID pipes draining into the catch basin. The catch basin has two different 18” ID pipes flowing into it for redundancy in the system. The lower parking level will also be constructed with 8 inch diameter industrial grade galvanized steel on each side of the columns and there will be a 1% grading towards all drains. A layout of the storm water system on the lower level can be seen in Appendix PS.13.

3.9 Exterior Layout

3.9.1 Parking Structure Access
The prominent access route to the parking structure will be through the Lake Dr. Entrance on the North side of campus. The parking structure is also accessible from the Campus Loop Rd. There is one entrance into the parking structure and three exits. There are more exits than entrances into the parking structure because the structure has been designed to handle vehicle traffic for large events. During these events, the most congested periods will be after the event when everyone is leaving at the same time rather than before when vehicles are trickling in.

There will be access to the upper level of the structure for pedestrian traffic through three towers on the corners of the parking structure. These towers will each contain a 4000 lb hydraulic elevator and one flight of stairs. Multiple sidewalks will provide pedestrian traffic access from the parking structure to the rest of the Calvin College campus.
3.10 Construction Plan
The construction of the proposed parking structure will involve a high level of trucking traffic that will be coming from I-196/I-96. In order to accommodate the trucking traffic, the section of the campus loop road between the Physical Plant and the Boer Bennink short term parking lot will be closed to campus traffic. Traffic through campus will be rerouted during the period of precast concrete erection. The closed section of the road, as well as the northeast portion of the existing lot will be designated to the contractor as a staging area. The layout of the construction site and truck routes can be seen in Appendix PS.18.

3.11 Architectural Components

3.11.1 Red Brick Exterior
The sides of the parking structure will be covered in a red brick (“Calvin Brick”) which is consistent with Calvin College’s architecture. These bricks cost $1,270 per thousand. The bricks will be supported by 4” x 4”x 1/4” steel angle beams which will be welded to the reinforcing rebar within the exterior spandrels. They will be tied to the exterior spandrel using dovetail brackets. As shown in Appendix PS.08, the bricks covering the column faces will rest on the column footings and also be attached with dovetail brackets.
Control joints will be placed in the brick at every 20 feet and at every joint in the precast concrete components. This will reduce the cracking and buckling of the Calvin Brick on the exterior of the structure.

3.11.2 Entrance Arches
Archways have been added to the structure to cover all vehicle and pedestrian entrances into the building. These archways will make it easy to identify where the entrance points to the structure are, as well as shelter pedestrians from the elements. These archways have a steel frame and corrugated sheet metal roofing. The framing will be bolted to the exterior spandrels of the structure or the walls of the towers.
4 PERFORMANCE PREDICTIONS

4.1 Capacity
The parking structure has been designed for a capacity of 917 vehicles. This is almost double the current capacity of the parking lot which is 527 vehicles. With this capacity of the parking structure, the parking spaces have a width of 8.5 feet. Minimum regulations however require 8 feet, and therefore the width of the spaces could be reduced to 8 feet in order to increase the capacity of the parking structure. To decrease the likelihood of vehicles colliding with each other, and for the convenience of those who are parking, 8.5 feet wide parking spaces was used in the design rather than the recommended minimum of 8 feet.

4.2 Life Expectancy
The life expectancy varies greatly with amount of preventative maintenance performed on the structure. There is no set standard for the life span of a precast concrete parking structure.

5 MAINTENANCE

5.1 Cost
The parking structure will cost roughly $100,000 per year to maintain. This cost has been determined by research of multiple different existing parking structures in similar environments.

5.2 Preventative Maintenance
The goal of preventative maintenance is to reduce the corrosion effects of water and salts on the precast concrete members. Effectively reducing the corrosion of the precast concrete will significantly lengthen the life of the parking structure. The Precast/Prestressed Concrete Institute has produced a preventative maintenance schedule for precast parking structures. This schedule can be found in Table 4.
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Table 4: Suggested Preventative Maintenance Schedule

5.2.1 Semiannual Maintenance

Semiannual maintenance includes:

1. Flushing all floors with at least a 1-1/4 inch hose from the top floor down to the main floor. For the climate conditions of Grand Rapids, Michigan this flushing should be done immediately after the spring thaw to reduce the effects of corrosive deicing salts.

2. Inspecting all floors for cracks and wear. Cracks should be routed to non-corroded surfaces, and filled with concrete sealant.
3. Inspecting expansion joints for wear, especially due to damage from snow plows. These joints should be repaired as needed.

4. Inspecting and cleaning floor drains and drainage pipes.

5.2.2 Annual Maintenance

Annual (Spring) maintenance includes:

1. Inspecting mortar joints and replacing loose mortar with new sealant.

2. Inspecting and replacing each sealant joint as needed.

3. Inspecting all structural connections. Cracks should be sealed with an epoxy injection. If the crack appears to be a “moving” crack, the structural engineer should be called in to inspect.

4. Tightening strain guard rails.

Also on a five to eight year basis a penetrating sealer should be applied to the precast members. The asphalt lower level should also be sealed every two years and milled and filled every five years. Abiding to a preventative maintenance schedule like this will insure the parking structure will last for the entirety of its expected life and beyond.

5.3 Vehicle Washer

One alternative proposed by the CEAC board members to lower the maintenance of the parking structure would be to add a spray washer that cleans the salt off the underside of the vehicles entering the parking structure. This will reduce the damage due to corrosion of rebar within the parking structure and increase the parking structure’s life sufficiently to pay for itself.

6 ADDITIONAL PROPOSALS

6.1 Athletic Field

One concept that was considered in the design of the parking structure was to place an athletic field over a section of the parking structure that would be underground.
This idea was discontinued due to the high water table which prevents the structure from having underground levels and due to the 315 psf load that would be applied on the structure from the athletic field.

6.2 Dormitory on Top of Structure
There was an idea proposed to have a dormitory placed on the top of the parking structure to make better use of the space used the parking structure. This idea was discontinued due to the structural design of the parking structure. The precast concrete design of the structure would not be able to handle the loading or moments that would be generated by a building on the top of the structure.

6.3 Heated Upper Level For Snow Melt
There was an idea to have the upper level floor of the parking structure heated so that snow removal would not be necessary. This idea was discontinued due to the fact that it was not cost effective to try to install heating coils in the precast concrete components of the structure. The snow can be easily plowed to a few parking structure parking spaces as is standard procedure for parking lots.

7 DESIGN NORMS

7.1 Transparency
In designing the parking structure, achieving a layout that is transparent to the user was of great importance. We did not want the user to be confused on directions of traffic flow, or how to enter or exit the parking structure. We want the user to feel confident in using the parking structure so that the structure will be a preferred method of parking their vehicle.

7.2 Stewardship
In the design of the parking structure, there was an effort made to keep our design as basic and inexpensive as possible. The parking structure has been designed to serve its purpose, but without extra money spent on things that are not needed. Quality in the design however was also of great importance and was not sacrificed to make the structure inexpensive.

We also tried to be good stewards of the world within our design. The whole concept of a parking structure is that less land is used to park vehicles. This
preserves green space on campus which would otherwise have to be cleared to make room for more parking on campus. Through the addition of this parking structure, there will be green space added due to the fact that the parking structure has a smaller footprint than the existing Kalsbeek/Huizinga Parking Lot.

7.3 Integrity
Integrity in the design is the core of the engineering aspect of the parking structure design. All design calculations and drawings must be checked by other team members to try to insure their accuracy. Also, all calculations must be honestly presented so that all known information is provided.

8 PROJECT COST BREAKDOWN

8.1 Source
The 2007 Mean’s Construction Cost Data Manual was used to determine all costs except the cost for “Calvin Brick”. Our contingency cost was determined based on advice from Prof. David Wunder. A detailed budget analysis can be seen in Appendix PS.19.
### 8.2 Breakdown

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<td>Site Survey</td>
<td>3.902662994</td>
<td>$6,203</td>
</tr>
<tr>
<td></td>
<td>Asphalt and CurbRemoval</td>
<td>20426</td>
<td>$177,611</td>
</tr>
<tr>
<td></td>
<td>Excavation (200 HP Dozer 300’ haul)</td>
<td>4283.49</td>
<td>$87,513</td>
</tr>
<tr>
<td></td>
<td>Dirt Purchase</td>
<td>11741</td>
<td>$219,974</td>
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<tr>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Precast Concrete</td>
<td>Double Tee 34”x10”x48’</td>
<td>340</td>
<td>$2,026,620</td>
</tr>
<tr>
<td></td>
<td>Precast 46”x24”x48’ Beam</td>
<td>76</td>
<td>$544,976</td>
</tr>
<tr>
<td></td>
<td>Precast 1 Story Column 2’x2’x20’</td>
<td>87</td>
<td>$322,846</td>
</tr>
<tr>
<td></td>
<td>Exterior Spandrel 1’x8.5’x48’</td>
<td>14668</td>
<td>$161,209</td>
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<tr>
<td></td>
<td>Asphalt</td>
<td>170000</td>
<td>$1,124,829</td>
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<tr>
<td></td>
<td>Curbs</td>
<td>7140</td>
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<tr>
<td></td>
<td>Joint Sealant</td>
<td>23800</td>
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</tr>
<tr>
<td></td>
<td>Tower CMU</td>
<td>6300</td>
<td>$123,606</td>
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<tr>
<td></td>
<td>Entrance Arches</td>
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<td>Rebar #8</td>
<td>35.8</td>
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<td></td>
<td>Rebar #6</td>
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<td>$278</td>
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<tr>
<td></td>
<td>Rebar #5</td>
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<td></td>
<td>Concrete (Pumped)</td>
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<td></td>
<td>Form Work</td>
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<tr>
<td>Architectural</td>
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<td>$756,513</td>
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<tr>
<td></td>
<td>Control Joint</td>
<td>945</td>
<td>$4,610</td>
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<tr>
<td></td>
<td>Aluminum Framing</td>
<td>66</td>
<td>$48,494</td>
</tr>
<tr>
<td></td>
<td>Tower Plexiglas (1/2”)</td>
<td>3252</td>
<td>$89,422</td>
</tr>
<tr>
<td></td>
<td>Grout/Morter</td>
<td>1895.2</td>
<td>$18,178</td>
</tr>
<tr>
<td></td>
<td>Tower Roof Steel</td>
<td>1701</td>
<td>$13,692</td>
</tr>
<tr>
<td></td>
<td>Top Floor Railing (galvanized)</td>
<td>1800</td>
<td>$66,535</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Elevator (4000lb)</td>
<td>3</td>
<td>$210,432</td>
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<tr>
<td></td>
<td>Roof Lighting (Al 8’ poles)</td>
<td>87</td>
<td>$176,968</td>
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<tr>
<td></td>
<td>Lower Level Lighting (wall mt. 100W)</td>
<td>348</td>
<td>$79,240</td>
</tr>
<tr>
<td></td>
<td>Barrier Cables</td>
<td>3500</td>
<td>$148,399</td>
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<td>Miscellaneous</td>
<td>Stairs</td>
<td>60</td>
<td>$12,631</td>
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<td>Stair Landing</td>
<td>366</td>
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<td>96</td>
<td>$5,563</td>
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<td></td>
<td>Paint</td>
<td>26477.5</td>
<td>$14,637</td>
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<td></td>
<td>Storm Water Pipe (4”)</td>
<td>672</td>
<td>$7,351</td>
</tr>
<tr>
<td></td>
<td>Storm Water Pipe (8”)</td>
<td>1125</td>
<td>$28,662</td>
</tr>
<tr>
<td></td>
<td>Storm Water Pipe (14”)</td>
<td>200</td>
<td>$7,305</td>
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<tr>
<td></td>
<td>Storm Water Pipe (16”)</td>
<td>75</td>
<td>$2,654</td>
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<tr>
<td></td>
<td>Storm Water Pipe (18”)</td>
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<td>$20,689</td>
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<td>Storm Water Drains</td>
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<td></td>
<td>Storm Water Drain</td>
<td>450</td>
<td>$33,579</td>
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<tr>
<td></td>
<td>Signs</td>
<td>32</td>
<td>$3,337</td>
</tr>
<tr>
<td></td>
<td>Wall Railing</td>
<td>1740</td>
<td>$107,469</td>
</tr>
<tr>
<td></td>
<td>Doors</td>
<td>6</td>
<td>$3,233</td>
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</tbody>
</table>

**TOTAL** $7,433,236  
**FACTORED** $6,191,856  
**ENGINEERING** $61,919  
**PROJECT MGMT.** $154,797  
**TOTAL PROJ. COST** $6,408,602  
**CONTINGENCY** $769,032  
**TOTAL COST** $7,177,634  
**PER SPACE** $7,827
8.3 Scaling Factors
The 2007 Mean’s Construction Data Manual provides scaling factors for different locations in the United States. The scale factor for Grand Rapids, Michigan was 83.3 percent of the Mean’s Data costs. An additional engineering cost of 1 percent was added to the overall project to cover the cost of engineering. An additional 2.5 percent was added to cover the cost of project management of the project. A contingency of 12 percent was added to the total cost to account for unexpected expenses.

9 ACKNOWLEDGEMENTS
Team 12 would like to thank a few people for their help in designing the parking structure. Leonard DeRooy provided guidance with the structural and foundation analysis for the structure. Our industrial consultant, Mike DeVries provided professional recommendations for the traffic movements through the structure. Also we would like to thank our client, Phil Beezhold for providing us with the campus survey and the soils testing results.
B. BIKE STRUCTURE INTRODUCTION

10 Abstract

The need for bicycle parking has increased on Calvin Colleges campus. The goal of this design project is to design a standard bicycle storage system to meet the future and current needs of bicycle storage on the campus of Calvin College. This system will be comprised of a bicycle rack system as well as a structure to cover the rack and bicycles from the elements.

11 Problem Description

Currently the Calvin College Campus has a total of 414 parking slots for bicycles. There are 243 resident bicycle parking slots, and 171 campus building slots. These bicycle slots are used by students, faculty, and staff. The bicycle locations typically have a standard bicycle rack that is unique to Calvin College made by DERO. The DERO RR4H is designed to hold up to nine bicycles, but is often cluttered with many more. When the capacity of the RR4H is met, finding a place to lock the extra bicycles becomes difficult and frustrating. The current capacities of bicycle storage can be found in Appendix BB.01.

Figure 1: Old bicycle rack in front of BHT
Figure 2: Dero bicycle rack in front of Science Building

The bicycle racks are in continuous use and are usually running near or over capacity. Furthermore, in poor weather conditions where the cyclist’s seat could be wet, cyclists are more inclined to bring the bicycle into the campus buildings which Calvin College would discourage.

12 Problem Solution

12.1 Objective of Solution

The goal of this project is to design a standardized bicycle structure that will be accessible to all campus bicyclists. It must meet the current and future demands of Calvin College. The bicycle structure should be identifiable to bicyclists as a structure to store bicycles. Also, the bicycle structure will be designed such that it can be easily implemented on any location on campus. Therefore, the design must account for worst case scenarios rather than a specific design for each location. The design must also account for varying weather conditions.
12.2 Solution Research

12.2.1 Rack Choice
There are three main types of rack configuration that were proposed for the bicycle parking structure. These types are shown in the figures below:

1. Hanger

![Figure 3: Hanger Rack](image)

2. Conventional Stand

![Figure 4: Conventional Stand](image)
3. Round Tube (current style)

![Round Tube Parking](image)

**Figure 5: Round Tube Parking Currently Used on Campus**

12.2.1.1 *Space required*

The bicycle rack system must be able to fit in the required space. Where there are bicycle systems already the rack must be able to adapt to that spacing. Also, the rack should not require excessive heights or large widths. The existing rack system is approximately 111 inches long, and with bicycle in place on each side it has a width of approximately 95 inches.

12.2.1.2 *Usability*

The rack that will be chosen must be user friendly. It must be intuitive to use and as well as accessible to all users. Typically lifting a whole bicycle off the ground to hang it is difficult. Furthermore, when there are more bicycles than capacity, which may occur, the rack must be able to have more bicycles placed on it rather than restricting the usage to specific bicycle parking locations.

12.2.1.3 *Aesthetics*

Calvin College has specific constraints for what the architecture on campus may look like. The rack must be aesthetically pleasing as well as have some consistency with the campus architecture.
12.2.1.4 Cost
The bicycle rack must be cost effective but of high quality. The rack should have similar powder coating that is currently on campus, and it would be desirable if they come galvanized.

12.2.1.5 Storage Capability
The new bicycle rack must be able to store more bicycles than the current bicycle storage system. Multiple racks can be used, but using one rack would be beneficial for limiting the space required to be covered by the bicycle structure.

Table 5 shows the decision matrix used to determine which rack choice would be the most feasible and effective for the Calvin College Campus bicycle parking structure.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Rating</th>
<th>Score</th>
<th>Rating</th>
<th>Score</th>
<th>Rating</th>
<th>Score</th>
<th>Rating</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Required</td>
<td>20</td>
<td>4</td>
<td>80</td>
<td>10</td>
<td>200</td>
<td>10</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usability</td>
<td>20</td>
<td>4</td>
<td>80</td>
<td>13</td>
<td>260</td>
<td>13</td>
<td>260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aesthetics</td>
<td>15</td>
<td>10</td>
<td>150</td>
<td>15</td>
<td>150</td>
<td>15</td>
<td>180</td>
<td></td>
<td></td>
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<tr>
<td>Cost</td>
<td>15</td>
<td>8</td>
<td>120</td>
<td>8</td>
<td>120</td>
<td>8</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage Capability</td>
<td>30</td>
<td>10</td>
<td>300</td>
<td>22</td>
<td>660</td>
<td>17</td>
<td>510</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>730</strong></td>
<td><strong>1390</strong></td>
<td><strong>1270</strong></td>
<td><strong>730</strong></td>
<td><strong>1390</strong></td>
<td><strong>1270</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Decision Matrix for Rack Method

The decision matrix determined that the conventional stand would be most appropriate for campus, because it is one of the easier racks to use as well as having the highest storage capacity.

12.2.2 Sizing
The size of the structure was determined through research on the estimation of angle of deflection of rain and head space required. The estimation of angle of decent of rain showed that average wind driven rain, in storms, was approximately 50 degrees, but light rain fall occurrences had wind driven rain at approximately 20 degrees. These angles of decent have a large factor on the size of the roofing needed. It was determined that the height of the structure should exceed 84 inches to meet head space requirements.
12.2.3 Loading
The design of the structure was based off the ASCE-07 code. Significant research was done to ensure that the structure follows code. For example, the bicycle structure is not a simple calculation for loads; specific changes are evident in the code because it is an open structure with a pitched roof. Furthermore, rather than the calculated snow load 30 psf, a larger load, was used by recommendation of a professional engineer. The code was also researched so that the largest value of the LRFD factors was used to ensure the structure stability of the bicycle barn.

13 Bike Barn Design

13.1 Location
There are various locations on campus that currently have bicycle racks. The locations where the purposed bicycle structures are to be built are based off current demand and existing conditions. Therefore, the dormitories on campus will not need bicycle structures because there are existing locations to store the bicycles outdoors as well as indoors with minimal maintenance or cleaning required. Furthermore, structures built should not be in locations where a significant amount of rerouting utilities are required.

![Figure 6: Inside location at RVD](image)
The bicycle structures are then determined to be placed in locations shown on the campus map Appendix BB.02. The specific placement of each bicycle structure is show in Appendix BB.03 through Appendix BB.06.

13.2 Rack Choice

The current Dero rack on campus is not efficient nor is it easy to use. Through research into a large amount of competitive rack designers and manufacturers the Bike-Rail from Bike Security Racks Co. was selected. This selection was made because the Bike-Rail has excellent features. Bike-Rail comes in six standard sizes, but the BR-24.9 with a capacity of 26 was selected to meet the demands. The BR-24.9 has a size of 2 feet-10 inches tall by 18 feet-1 inch wide. The
features of Bike-Rail that makes it so promising is that it comes with a 10mm thermoplastic powder coat in Calvin maroon, as well as utilizing surface mounts. Ultimately, Bike-Rail is an easy to use bicycle rack with a long lasting finish.

13.3 Architectural Components
The bicycle structure must maintain the Calvin architectural style. Therefore, as an added architectural element to the bicycle structure there is a brick bench that encloses the columns of the structure. This bench will be useful for cyclists to ready themselves for cycling as well as blend into the Calvin College architectural style due to the Calvin brick. The roofing was also selected to closely match other metal roofing on campus. The roof pitching is also a similar pitch to other buildings in campus. As a whole, the bicycle structure is consistent with campus style of architecture as seen in Figure 9.

![Figure 9: Bicycle Barn Sketchup Model](image)

13.4 Sizing
The sizing of the structure is determined first by the size of the rack that must fit underneath the structure. There is also a two foot space between the Bike-Rail and the brick architectural element to allow room to walk to the other side of the structure. The size of the roof was determined based from the angle of decent of wind driven rain. It is determined that in light rain conditions cyclists will still bike
to campus, however, in storm conditions public transit, or automobiles will be used. Furthermore, in storm conditions the cyclist is mostly wet and the structure will just be a means to lock the bicycle. Therefore, it is determined that the structure must be able to keep bicycle seats dry in wind driven rain of light conditions. The structure must also be high enough to allow adequate room for head space. The height of the roof was determined to be approximately 92 inches to allow for the head space, but also deter users from trying to climb the structure. From this judgment, it is determined that a 8 feet wide by 26 foot long roof with a 2 to 1 pitch is adequate in deterring the light rain from wetting the bicycles.

13.5 Loads
The loads that the bicycle structure was designed for was determined from the ASCE-07. The structure had been designed to handle its self weight, determined by the HSS tube schedule. The structure has been designed to handle a snow load of 30 psf. This loading has been determined from maximum snowfall quantities that have occurred in the past in Grand Rapids, Michigan. This quantity also takes into account drifting of the snow on top of the structure. Also, the structure has been designed to handle ice loads, determined from a minimum thickness of 1.1 inches for the Grand Rapids area. For the design of the bicycle structure, wind speeds in Grand Rapids, Michigan can reach a maximum of 90 mph. Wind loads were determined from an open structure, with and enclosed roof. Furthermore, a live load of 30 psf was used in the event that a user climbs on the roof or some maintenance is needed. Seismic Loading within the Grand Rapids, Michigan area is considered to be negligible and therefore, seismic loading was not taken into account in the design of the parking structure. LRFD was used in calculating the factored loading of the structure. This includes a sufficient safety factor in the design to keep the structure structurally sound.

13.6 Structural Elements
The initial design called for a curved roof that consisted of a continuous curved beam over the columns. Due to cost restrictions the curved roof design was eliminated, and a pitched roof was selected. The structural elements were determined through a program called STAAD Pro. The bicycle structure, loads, and
load factors were modeled in STAAD Pro and it analyses the structure to see if it passes code. Furthermore, a optimize solution was determined through STAAD Pro. When it optimizes the solution it does not account for the connections that need to be made within the structure. Therefore, to ensure that the connections can withstand the loads and shear a common HSS tube schedule of 6 inches was used as outlined in drawing Appendix BB.07, BB.08 and BB.09. All connections are welded with a ¼ inches weld which is a standardized weld that will suffice. All connections and structural elements have been verified by a professional engineer as well as teammates.

13.7 Soils

The soils on campus vary depending on location. Most bicycle structures were located in a soil area determined to be urban land. Figure 10 shows the Natural Resource Conservation Service (NRCS) the soil map and Table 7 describes the soils found on Calvin’s campus.

Figure 10: Soil Map for Calvin College
### Table 6: Soil Descriptions For Calvin College

<table>
<thead>
<tr>
<th>Map Unit Symbol</th>
<th>Map Unit Name</th>
<th>Acres in AOI</th>
<th>Percent of AOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Cohoctah loam, 2 to 6 percent slopes</td>
<td>3.3</td>
<td>0.2</td>
</tr>
<tr>
<td>12B</td>
<td>Tustin loamy fine sand, 2 to 6 percent slopes</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td>12C</td>
<td>Tustin loamy fine sand, 6 to 12 percent slopes</td>
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<td>0.1</td>
</tr>
<tr>
<td>15</td>
<td>Sloan loam</td>
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<td>0.1</td>
</tr>
<tr>
<td>17C</td>
<td>Chelsea loamy fine sand, 6 to 12 percent slopes</td>
<td>1.2</td>
<td>0.1</td>
</tr>
<tr>
<td>18B</td>
<td>Glynwood loam, 2 to 6 percent slopes</td>
<td>134.2</td>
<td>9.9</td>
</tr>
<tr>
<td>18C</td>
<td>Glynwood loam, 6 to 12 percent slopes</td>
<td>32.4</td>
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</tr>
<tr>
<td>19B</td>
<td>Blount loam, 2 to 6 percent slopes</td>
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<td>20</td>
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<td>24A</td>
<td>Abscota loamy sand, 0 to 3 percent slopes</td>
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<td>0</td>
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<tr>
<td>31</td>
<td>Wallkill silt loam</td>
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<td>Marlette loam, 2 to 6 percent slopes</td>
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<td>36E</td>
<td>Marlette loam, 18 to 25 percent slopes</td>
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</tr>
<tr>
<td>39C</td>
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<td>45E</td>
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<td>5.9</td>
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<td>47</td>
<td>Pewamo loam</td>
<td>21.4</td>
<td>1.6</td>
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<td>51B</td>
<td>Oakville fine sand, loamy substratum, 0 to 6 percent slopes</td>
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<td>0.4</td>
</tr>
<tr>
<td>68C</td>
<td>Saylesville silt loam, 6 to 12 percent slopes</td>
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</tr>
<tr>
<td>74</td>
<td>Dumps</td>
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<td>0.2</td>
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<tr>
<td>75</td>
<td>Udorthents, loamy</td>
<td>90.6</td>
<td>6.7</td>
</tr>
<tr>
<td>76</td>
<td>Udipsamments, nearly level to steep</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>78</td>
<td>Urban land</td>
<td>59</td>
<td>4.4</td>
</tr>
<tr>
<td>79</td>
<td>Houghton muck, ponded</td>
<td>11.8</td>
<td>0.9</td>
</tr>
<tr>
<td>82B</td>
<td>Urban land-?Perrinton complex, 0 to 8 percent slopes</td>
<td>422.4</td>
<td>31.3</td>
</tr>
<tr>
<td>82C</td>
<td>Urban land-?Perrinton complex, 8 to 15 percent slopes</td>
<td>20.4</td>
<td>1.5</td>
</tr>
<tr>
<td>W</td>
<td>Water</td>
<td>8.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Based from the interpolation of the parking structure and its most recent soil bearings, and accounting for worst case scenarios, the soil bearing pressure has been determined to be 3000 psf. This bearing pressure will ensure that the foundation and structural elements of the bicycle structure will be adequate.

### 13.8 Foundation

The foundation was designed based from the soil bearing pressures. The foundation was designed to be 28 feet by 12 feet inches by 18 inches deep, as found in Appendix BB.10. The foundation has much more capacity than the required for the bike barn, however due to design constraints it is required to be that size. The design constraints were that a minimum depth of 18 inches was required, as well as
the structure needed a concrete flooring to enable the surface mounting of the bicycle rack. The concrete foundation also includes #5 rebar to resist the tensional loads within concrete. Standard ½ inches diameter by 12 inches length anchor bolts are used to anchor the structure to the foundation as suggested by a professional engineer.

14 Performance Predictions
The bicycle structure will meet the current demands of the campus with capacity for future needs. Once a system of bicycle storage is in place, it can be adopted throughout campus as a place to store bicycles. Therefore, with the rise of gasoline prices in the United States of America, these bicycle structures can be easily implemented to meet the needs and demands of the campus.

15 Project Design Norms

15.1 Stewardship
The proposed bicycle parking structures are designed to minimize the negative effects on the surrounding areas. The bicycle structure promotes stewardship through encouraging cycling rather than driving. Furthermore, the structure is economically designed.

15.2 Integrity
The proposed bicycle parking structures are pleasing and intuitive to use. Bicycle racks can be confusing and difficult to use. The bicycle parking structure is designed for easy use by the end user. Also, the bicycle parking structure has met the necessary form verses function balance. The design is a good design because it maintains Calvin College’s architectural style, as well as being a functional bicycle parking structure.

15.3 Transparency
The design of the bicycle parking structure is transparent to the user. It is second nature to use, and visible to all as a place to park their bicycles.

16 Project Cost Breakdown
Costs were determined from the 2007 Mean’s Construction Cost Data Manual with the exception of the Calvin Brick. The cost of the bicycle structure includes overhead and profit as well as a 12 percent contingency. The concrete costs including excavation, framework and rebar totaled to approximately $5,400. The actual structure including welds, anchor bolts and roofing is approximately $8,600. The architectural elements added to the structure were approximately $3,000. The total estimated cost of the structure found in Appendix BB.13 is $17000. The specific cost data can be found in Appendix BB.14.
C. ENTRANCES AND EXITS INTRODUCTION

17 Problem Description

The Calvin Seminary Entrance is currently accessible from southbound on the East Beltline. The Entrance allows access to the Seminary and Campus Loop. The exit currently is aligned slightly to the north of the existing Michigan left turn. The light for the southbound East Beltline is partially visible to the driver sitting at the exit but the driver is past the stop bar. This creates confusion for the drivers exiting Calvin College. It is unclear when a right turn is permitted. The driver is required to yield to the crossover traffic and as a result is forced to look upstream and downstream to check for cars before exiting.

The Knollcrest Entrance currently has a queue length of two cars and intersects the Calvin Loop behind the Knollcrest Dining Hall. The short queue length is causing backups onto the East Beltline during high traffic events. The driver entering Calvin sees the back of the Knollcrest Dining Hall which is not an aesthetically pleasing sight. This does not create a good impression with visitors to the campus and prospective and new students. The straightness of the campus loop encourages excessive speeds reducing safety of the road. The parking lot for the Knollcrest Dining Hall employees is insufficient. As a result the employees park anywhere they can which is neither safe nor looks attractive. Team member Nate Maack was in charge of this section of the project.

18 Problem Solution

18.1 Objective

The East Beltline entrances and exits will be redesigned to meet MDOT codes and Calvin College Physical Plant requirements. Driver confusion at the Calvin Seminary Exit will be eliminated. The flow of the Knollcrest entrance and exit will be improved. The safety of each intersection will be increased by improving sight distance, traffic flow and increase car queue lengths. The Knollcrest entrance is the primary entrance for students and visitors coming south on the East Beltline and should have a more aesthetically pleasing look. Parking should be added for the Knollcrest Dining Hall staff.
18.2 Justification

18.2.1 Safety
The number one priority for any project is safety. By redesigning the seminary entrance and exit drivers leaving Calvin will only have to look to the left to decide when they can turn. The crossover traffic light will be north of the exit from Calvin so the driver will not be confused if they are allowed to go or not. The Calvin underpass under the East Beltline is not the regulation 14 foot height but is 12 feet tall. There have been instances in the past of trucks getting stuck under the bridges and having to be pulled out. Adding the entrance into Calvin will give an additional route for trucks entering Calvin to take.

18.2.2 Aesthetics
Having aesthetically pleasing entrances will improve everyone’s impressions of Calvin. The entrance behind Knollcrest Dining Hall is not very pleasing to the eye. The first thing seen at this entrance is the loading dock at the dining hall as well as the many cars parked wherever they can.

19 Seminary Entrance and Exit

19.1 Final Design
Figure 11 shows the final design of the Seminary Entrance and Exit. The exit from Calvin was moved 10 feet south. The crossover was moved 120 feet north to line up with the existing entrance. The crossover will now be 660 feet from the intersection. This will eliminate confusion for drivers at this intersection because drivers leaving Calvin will be south of the traffic light and only need to look to their left to yield. An entrance from the crossover was added to Calvin College. This is similar to Knapp’s Corner or Celebration Cinema. An additional left turn bay was added to the crossover to compensate for the increased traffic.
19.2 Movement of Crossover and Addition of Entrance to Calvin

19.2.1 MDOT Traffic Safety Notes
MDOT specifies that crossovers be 660 feet from the intersection plus or minus 100 feet. The current crossover is 540 feet from Burton St. Another MDOT code says that any driveway cannot be located in a dedicated turn lane. Since the entrance and exit to Calvin is a driveway it could not be relocated to line up with the crossover. The crossover was moved to follow MDOT code and line it up with Calvin’s entrance.
19.2.2 Knapp’s Corner
The Meijer store located at Knapp’s Corner and the Celebration Cinema complex both have a design similar to the one being proposed for the Seminary Entrance. This is not a new design to the East Beltline and MDOT has approved this type of design before. Crash data for these two intersections and the existing Seminary Exit should be obtained from MDOT before proceeding to final approval for the design.

19.2.3 Synchro Model
MDOT requires that a Synchro Model be made for any project on a major trunk line. The model must show that there will be no negative change in traffic flow. In the case of the seminary entrance the model must show that the added entrance into Calvin does not create a longer queue that backs up out of the dedicated left turn lanes. The addition of a second left turn lane was to prevent the added traffic from causing back ups onto the East Beltline. The Synchro Model proved that during the highest traffic volumes cars would not back up onto the East Beltline. A traffic study of the East Beltline and Burton Street was done and the results can be found in the Appendix. The results were used to make the Synchro model. The results can be seen the Appendix. The average delay at the new intersection is 22 seconds which is better than the 25 seconds.

19.3 Geometry
The MDOT Traffic and Safety Note specified that all crossovers be designed to accommodate a WB-62 vehicle. This is a single unit semi-truck that is a 68 feet in length. Since there were no notes on how to design the turns for the existing entrance and exit a WB-62 was used as the design vehicle. The design vehicle dictated the curb radii. For the crossover the lane width was increased so that the design vehicle could fit through. All other lane widths were set at 16 feet. Traffic and Safety Note 507A regarding the crossover spacing can be found in Appendix SEM.10.
19.4 Materials
The materials were chosen according to the MDOT construction specifications book and the highway design manual. Since the East Beltline is a major trunk line, MDOT specifies that the road be made from 12 inch thick un-reinforced concrete. This is on top of 6 inches of Class II sand. Since only concrete is being removed, concrete is the material that shall be put back for the new drives. Asphalt would be less expensive but has a shorter life span. Asphalt’s lifespan is reduced even more by heavy vehicle traffic.

19.5 Intersection Control

19.5.1 Traffic Light
The new traffic light located at the intersection will be the standard wire hung traffic lights preferred by MDOT. Appendix SEM.9 shows the signal timing plan for the three traffic lights.

19.5.2 Signage
Yield signs will be placed at the right turn entrance from the Southbound East Beltline since the cars trickle in and at the exit so that cars are only forced to stop if there are cars coming. Lane control signs showing what the two turn lanes will be placed on the approach and at the light. Figure 12 shows the lane controls signs similar to the ones required. The required sign will have the complete U-turn instead of left turn. Signs showing vehicles where to stop at the lights should be placed next to the stop bar for the traffic light. Figure 13 shows the stop location sign. The official sign letter and number are marked on the plans.

Figure 12: Lane Control Sign
19.5.3 Pavement Markings
A 24 inch wide white pavement marking should be placed everywhere a driver is required to stop. All lane dividers between continuing lanes should have a 50 foot skip pattern where there are 12.5 feet of 4 inch solid white line and 37.5 feet of nothing in between. Turn lanes should have a 4 inch solid white line marking. The two left turn lanes should have the arrows indicating where cars will be allowed to go once they reach the intersection. All pavement markings are found in the pavement marking plan. The pavement marking plan can be seen in Appendix SEM.6.

19.6 Landscaping
Since the crossover is only moving a little ways not much landscaping is lost. The island that is to be replaced on Calvin’s campus should be covered in top soil so that flowers and other plants can be placed there as the Calvin gardening staff specifies. Grass should be placed in the middle of the East Beltline where needed. The grass is hydroseed and should meet MDOT standards. The landscaping plan can be seen in Appendix SEM.5.

19.7 Construction
A construction plan will need to be made in cooperation with MDOT. For Calvin the best option is to close the seminary entrance at the start of the summer and try and have the entrance and exit finished as fast as possible. The entrance behind Knollcrest Dining Hall and the main entrance off of Burton Street can be used by anyone coming to Calvin.
19.8 Budget

19.8.1 Quantities
The quantities for the Seminary Entrance are based off of the MDOT quantities list which can be found in the MDOT Construction Specifications book. The cost sheet is based off of a program called MERL, which is a program developed by MDOT for engineers. The copy of MERL at the City of Wyoming was used to generate the estimate sheet and get prices. Jeff Oonk and Carlos Caceres, engineers for the City of Wyoming, also reviewed the cost analysis and quantities for these projects.

19.8.2 Cost Breakdown
The costs breakdown for the Seminary Entrance can be found in Appendix SEM.7. The estimated cost was $145,000 which includes a ten percent contingency cost. The amount used for the quantities are based on prices taken from bids for current contracts. Removal and placement of pavement and curb and gutter make up sixty percent of the cost while the remaining cost is from landscaping, and site grading. MDOT could be convinced to pay a portion of the cost because the safety of these intersections is being improved. Since the project will be working on part of the East Beltline MDOT will require that the project cost be broken down according to their standards.

20 Knollcrest Entrance and Exit

20.1 Final Design
Figure 14 shows the final design for the Knollcrest Entrance and Exit. The Appendix KDH.1-7 shows all the drawings for the Knollcrest Entrance and Exit. The campus loop was shifted to the West and the entrance and exit was moved to the south. This will add queue length to the entrance; the new queue length can hold four cars. A new parking lot in between the East Beltline and the campus loop will be added with space for 20 cars which is 8 more that the existing parking lot. A raised crosswalk will provide safety for the workers crossing the campus loop. Landscaping was added to an area between the path and the campus loop. This will
give enough room to place a directional sign as well as bushes, trees and flowers to try and hide the Knollcrest Dining Hall loading dock. This design was chosen to maintain the current operation of the intersection as specified by Calvin Physical Plant. If the operation of the intersection is to be changed then simply rearranging where stop signs are located is the best solution. This was not chosen because drivers entering tend to stop regardless of whether they need to or not.

20.2 Moving the Campus Loop
The Campus Loop will be moved to the west. This will increase the length of the entrance queue to 100 feet which is 4 cars in length. This adds two additional vehicle lengths to the current entrance. This is enough length to prevent cars from
backing up onto the Beltline. A Synchro model was built based off of data from a traffic study that was done. The Synchro model proves that this is a good alternative.

### 20.3 Knollcrest Dining Hall Parking Lot
The parking lot will need to be moved in between the campus loop and the East Beltline in order to move the campus loop west. The parking lot will hold 20 cars which is 8 more spaces than the existing lot. No parking study was done but informal observation shows that only about 6 additional spaces are needed. Since the employees will now have to cross the campus loop to get to the dining hall a raised crosswalk will be added to force cars to slow down and make drivers more alert to watch for pedestrians. The traffic in the parking lot is designed for one way flow. This will keep exiting cars away from the entrance and create less confusion for the drivers. The advantage to this parking lot is that the design can be expanded easily should it be deemed that more parking is needed.

### 20.4 Geometry
The entrance and exit were designed to accommodate a WB-62 truck. All the curb radii everywhere except the parking lot were designed for a WB-62 truck. The radii of the reverse curves used to realign the campus loop were designed for the WB-62 truck and by AASHTO guidelines for reverse curves. The parking lot was designed for the standard AASHTO passenger car. The standard AASHTO passenger car is 19 feet long and 7 feet wide.

### 20.5 Material Choice
The materials were chosen according to the MDOT construction specifications book and the highway design manual. Since the East Beltline is a major trunk line MDOT specifies that the road be made from 12 inch thick un-reinforced concrete. This is on top of 6 inches of Class II sand. On Calvin’s campus the roads are made of asphalt so once roads on Calvin’s right of way were designed for asphalt. The asphalt will be a 1.5 inch grade 4b base with a 1.5 inch grade 3b top course. This is the general specification for most local roads designed to accommodate a little heavy vehicle traffic. This should weather just as Calvin’s other roads do. The raised crosswalk will be made out of asphalt just like the crosswalk next to the
DeVos Communications Building. The ends on the crosswalk should be tapered down to the existing road level to let water run past as is done with the speed bumps on Calvin’s campus.

20.6 Intersection Control

20.6.1 Signage
A stop sign should be placed for the exit to the parking lot and the entrance to Calvin. A Calvin directional sign should be placed at the entrance to tell visitors where they need to go. And pedestrian crossing signs should be placed before the sidewalk so that drivers know to watch for pedestrians. One way and do not enter signs should be placed in and around the parking lot so that drivers know which way to go.

20.6.2 Pavement Markings
A 24 inch stop bar should be placed at the entrance stop to let drivers know where to stop. Right turn only arrows should be placed in the right turn lane on the East Beltline. Straight only arrows should be placed in the parking lot so that drivers know which way to go. And the white crosswalk hatch should be placed at the raised crosswalk. The pavement marking plan can be seen in Appendix KDH.7.

20.7 Landscaping
The new alignment of the campus loop will force the movement or removal of some trees. New trees should be planted in the old alignment to make the new alignment look better. Grass should be placed on any new areas. A garden area between the road and the path was placed to hide the back of Knollcrest Dining Hall. Trees, bushes and flowers could be planted in this area to hide the back of the dining hall. This will give a more aesthetically pleasing sight to anyone entering Calvin’s campus at this location. The new landscaping plan can be seen in Appendix KDH.5.

20.8 Utilities
Since the Campus loop is shifting, lighting and storm sewer catch basins will be moved. The existing light poles can be salvaged and placed at their new locations. They will need to be connected to the existing electrical system for the lights but
they are all close to the existing lines so this should not be an issue. Two catch basins will be removed since they are in the old alignment. They will be replaced with two new catch basins in the new alignment in a similar location to the old alignment. Two catch basins will be added at the end of the parking lot to drain the new parking lot. It was assumed that since the overall area of pavement was decreasing the existing system would be able to handle the flows. MDOT will be responsible for determining if any storm sewer will need to be moved, but there are no catch basins in any of the work areas so this should not be required. The Utilities Plan can be seen in Appendix KDH.6.

20.9 Construction
A construction plan will need to be made in cooperation with MDOT. For the work being done on Calvin’s campus the best option is to close half of the campus loop and realign that part while maintaining traffic to the dining hall and doing the other half of the loop. If this is not possible to be done in one summer then the work should be done all at once while trying to maintain some kind of temporary access to the dining hall. The entrance and exit should be shut down. Cars can use the Lake Drive Entrance or the Seminary Entrance to enter Calvin.

20.10 Budget

20.10.1 Quantities
The quantities for the Knollcrest Entrance are based off of the MDOT bid list which can be found in the MDOT Construction Specifications book. The cost sheet is based off of a program called MERL, which is a program developed by MDOT for engineers. The copy of MERL at the City of Wyoming was used to generate the estimate sheet and get prices. Jeff Oonk and Carlos Caceres, engineers for the City of Wyoming, also reviewed the cost analysis and quantities for these projects.

20.10.2 Cost Breakdown
The costs breakdown for the Knollcrest Entrance can be found in Appendix KDH.8. The estimated cost was $141,000 which includes a ten percent contingency cost. The removal and placement of pavement and curb and gutter account for sixty percent of the project, while landscaping, utilities and site grading.
The amount used for the quantities are based on prices taken from bids for current contracts. As with the Seminary Entrance and Exit, MDOT could be convinced to pay a portion of the cost because the safety of these intersections is being improved. Since the project with be working on part of the East Beltline MDOT will require that the project cost be broken down according to their standards.

21 Design Norms

21.1 Transparency
The transparency of either intersection is important. Drivers must be able to interpret what they see and be able to make decisions based upon this information quickly. All the entrances and exits must be very intuitive, simple and easy to understand for any driver.

21.2 Stewardship
The two entrances must be good stewards of money and the environment. The entrances should be designed to be as inexpensive as possible without sacrificing quality and lifespan. This was a major factor in the choice of materials. The materials chosen should not cause harm to the environment and the removal of trees was minimized. Additional trees were planted in the new green space areas.

21.3 Cultural Appropriateness
The entrances and exits were designed to match exiting Calvin entrances and exits. This will be done by designing the entrances and exits out of the same materials and adding the same features. The designs will be easy to use and be designed for easy storm water and snow removal.

22 Schedule
The initial project schedule for the completion of the entrance and exit design process can be seen in Figure 15. The design of both entrances was supposed to take 20 hours each and be done before spring break. The rest was available to finish presentations, and the final report.
Figure 15: Entrances and Exits Project Schedule

The actual project schedule did not allow enough time for design, unexpected trips or other things not planned on originally. The drawings and design took on the order of two to three times as long as allowed for in the original schedule. Some parts of the original schedule were removed based on changes of what the group wanted for design night. Things took longer just because of inexperience of design and additional time needed to look through MDOT codes and guidelines.

23 Summary

At the Seminary Entrance and Exit the crossover will be moved to line up with Calvin’s Entrance. The Exit will be moved south. This will eliminate driver confusion because the driver will be south of the traffic light and will only have to look to the left to yield. An entrance to Calvin from the Northbound East Beltline will be added. This will allow drivers entering Calvin more options. Landscaping will be preserved to keep an aesthetically pleasing look to the entrance.

The Knollcrest Entrance will have the queue lengthened to hold four cars. This will be done by shifting the campus loop to the west. The longer queue length will keep cars from backing up onto the East Beltline without changing the operation of the intersection. A parking lot for the Knollcrest Dining Hall staff will be added in between the campus loop and the East Beltline. The parking lot will have twenty spaces which is eight more than there are currently. This will fix the problem of insufficient parking for the Dining Hall staff. A landscaping area for a Calvin directional sign, trees, shrubs and flowers will be added to hide the loading dock at the dining hall.
ACKNOWLEDGEMENTS

Jeff Oonk and Carlos Caceres from the City of Wyoming Engineering Department helped out with design and cost analysis for the Entrances and Exits. Mike DeVries from URS Corp. helped out with some of the traffic engineering and called attention to problems in the design. The 2003 MDOT Constructions Specifications Manual and the text book Traffic and Highway Engineering by Garber and Hoel were used for the design of the Entrances and Exits. Thanks to Bob DeKraker for ordering and installing Synchro for us.
D. INTERSECTION INTRODUCTION

25 Problem Description

There are a few intersections on the campus of Calvin College that do not provide the safety and efficiency that should be expected at a respected college. This project looked into three intersections and proposals have been completed. The recommendations for each intersection can be found in the following section. These intersections are the Burton Street Entrance Intersection, the East Beltline Underpass, and the Lake Drive Entrance Intersection. Team member Justin Pipe has been given the task of researching and designing these intersections.

26 Problem Solution

26.1 Objective

These intersections will be redesigned so as to increase the safety, efficiency and aesthetics. Driver confusion will be eliminated at the Burton Street Entrance Intersection. The safety for pedestrians will be greatly increased at the East Beltline Underpass. The Lake Drive Entrance will be able to handle high traffic events. These will all be designed to copy common intersections to be readily identifiable by all users.

26.2 Justification

26.2.1 Safety

Safety is the most important reason to update these intersections. There are odd geometries and angles that drivers must deal with. The proposed designs use more common intersections, with $90^\circ$ angles. The roundabout will reduce the points of conflict and drivers only need to yield for vehicles inside the roundabout. The safety of drivers and pedestrians will increase with the redesigned East Beltline underpass. Pedestrians only need to cross one leg of the intersection, and drivers will not need to look over their shoulders to see oncoming vehicles. The
Lake Drive entrance will be able to handle future flows better than the current intersection.

26.2.2 Efficiency

The redesigned intersections will be able to handle the traffic flows on campus more efficiently. All intersections have been designed to give the highest traffic volume movements free flow, or is made safer. This will increase the efficiency of the intersection. This is important because these intersections face hundreds of cars every day during the school year.

27 Burton Street Entrance Intersection

27.1 Existing Conditions

The problems at this intersection are those of safety, efficiency, and aesthetics. There are many points of conflict, the intersection has grown too large, and the unusual movements lead to confusion among drivers. Drivers do not know who has the right-of-way or who must stop for whom. The stop signs have been moved since the beginning of the 2006-07 year, leading to this uncertainty. This entrance is a main entrance to Calvin and sees high traffic volumes. The highest traffic volume is the movement from Burton Street going west on the campus loop road. The traffic study data can be found in the Appendix B.12. This movement must stop at the intersection and then yield to pedestrians. The current layout is shown in Figure 17.

![Figure 16: Burton St. Entrance Intersection Layout](image-url)
27.2 Proposed Solution

Team 12 recommends that a roundabout be placed at this intersection. The access to the parking lot will be moved from the intersection and placed before it along the entrance and exit roads. A roundabout will be able to safely and efficiently handle the flows produced by this intersection. Our proposed Burton St. Entrance Intersection is shown in Figure 18.

![Figure 17: Burton St. Roundabout](image)

27.2.1 Roundabout

A roundabout was chosen for this intersection due to the high periodic traffic volume and the size of the intersection. Roundabouts are able to handle high traffic volumes very well with minimal delay and points of conflict. This will make the intersection safer and more efficient. Drivers need only to yield for vehicles already in the roundabout. This means they will only need to check for vehicles to their left. The stop signs for this intersection were moving further and further apart, providing the space needed to construct a roundabout.
27.2.2 Exclusive Left Tune Lane
The access to the parking lot to the West of this intersection was closed off in order to design the roundabout. The access to the parking lot was added along the entrance drive by way of an exclusive left turn lane. This allows vehicles coming from Burton Street going to the parking lot to avoid the intersection completely.

27.2.3 Models
This intersection was modeled in software programs to check different aspects of the roundabout’s design. Rodel was used to model traffic volumes and calculate the average vehicle delay. URS Corporation made this program available for our use. Synchro was used to simulate flows through the intersection. AutoTurn was used to verify the design vehicle’s path and ability to move through the roundabout. This program was used in cooperation with the City of Wyoming’s Engineering Department.

27.2.3.1 Rodel
Rodel is a computer program used to calculate the level of service of a roundabout and the average vehicle delay for an intersection. The size of the roundabout, the geometries of the approaches, and traffic volumes are used to determine the delay. The average delay per vehicle was 3 – 6 seconds. This is an acceptable delay and an improvement on the current intersection. The software output can be found in the Appendix B.13.

27.2.3.2 Synchro
Synchro is a traffic software that is used to simulate traffic flows and volumes through an intersection. The intersection is set up with the correct lengths and traffic flows. This is then used with SimTraffic to animate flows and give a visual representation of the intersection. This program gave a Level of Service A for the proposed roundabout. The software output can be found in the Appendix B.14.
27.2.3.3 AutoTurn
The radiuses of the curves were designed for a large tour bus (BUS 40) and intermediate semitrailers (WB-40). AutoTurn was used to verify that these radiuses were correct and that the vehicles would be able to make it through the intersection without too many problems. These vehicles were able to drive safely through the intersection. The center of the roundabout is designed with a concrete apron so that passenger cars are discouraged to use it, but allows these larger design vehicles to roll up on the apron. The pedestrian islands were designed with rolled curbs in case a vehicle needs more space. The software output can be found in the Appendix B.15.

27.2.4 Storm Sewer
The storm sewer system of this intersection will need to be reconstructed with the proposed roundabout. The total area of pavement at this intersection is being reduced so it was assumed no storm water runoff calculations are required. The proposed storm sewer system will connect into existing system.

The storm sewers at this intersection presented a slight problem. The storm sewers from the AutoCAD file of the campus did not match the layout of the actual intersection. The existing storm sewers were drawn into the file for the intersection. The design and cost were based on the storm sewer layout as best as could be assumed. Before construction begins, the storm sewer system must be verified and checked against assumptions. The storm sewer improvements can be found in the Appendix B.5.

27.2.5 Lighting
The proposed lighting plan for the proposed roundabout will increase the lighting at the intersection considerably. Currently, there are three light poles on the outside of the intersection. The optimal lighting for a
roundabout calls for lighting at each entrance and exit of the roundabout. This will increase the light poles to seven in the intersection. The existing three will be salvaged and placed, and four new light poles will need to be furnished. The lighting plan can be found in the Appendix B.6.

27.2.6 Pavement Marking/Signage
The pavement markings and signage for this intersection will need to be upgraded. With the proposed left turn added, there will need to be pavement markings and signage to communicate this. Also, the roundabout will need yield legends and stop bars at each of the entrances. Yield and crosswalk signs will need to be added, as well as a Calvin directional sign prior to the intersection. The signage will need to be able to help in teaching drivers how to use a roundabout, but not overwhelm them. The geometries of the roundabout will force the flows in the correct direction, and signage will reinforce this. The pavement marking and signage plans can be found in the Appendix B.9 and B.10.

27.2.7 Aesthetics
The proposed roundabout allows for more greenspace at this intersection. The middle of the roundabout will be able to hold whatever landscaping Calvin desires. This can also add to the grandeur of Calvin’s main entrance.

27.2.8 Pedestrian Tunnel
With the high pedestrian volumes, a pedestrian tunnel was researched. The tunnel researched is similar to the pedestrian tunnel at Western Michigan University in Kalamazoo, Michigan. After researching further, the tunnel would not be feasible for use at Calvin. The path would not meet the American’s with Disabilities Act (ADA), there would be issues with storm water, it would add to the total cost of the project considerably, and was not specified by Calvin. The information for this tunnel can be found in the Intersection Appendix B.16.
27.2.9 Cost
The total constructed cost of the proposed improvements will be $296,000. This includes construction costs, maintenance of traffic, storm sewer, light poles, and contingencies. Half of the cost is removing and placing asphalt and curb and gutter. The other half comes from the storm sewer improvements, lighting, sight grading, and landscaping. The detailed budget can be found in the Intersection Appendix B.11.

28 East Beltline Underpass

28.1 Existing Conditions
The problems at this intersection are efficiency and driver and pedestrian safety. This intersection is unusual and confusing. Drivers are forced to look over their shoulder and through back windows in order to check for conflicting vehicles. Traffic studies show that the second highest traffic volume movement must stop for the lowest. These can be found in the Appendix EB.9. Pedestrians going to the residents’ parking lot must cross two legs of this intersection. Also, the sidewalk along the north side of the intersection ends at the underpass. The existing layout of the East Beltline underpass is shown in Figure 19.

Figure 18: East Beltline Underpass
28.2 Proposed Solution

Team 12 recommends removing one of the legs of the triangle and realigning the southern leg to form a T-intersection. This will create better sight angles and distances and give the three highest traffic volume movements free flow. The proposed intersection eliminates one of the legs pedestrians must cross, and the sidewalk along the north side was continued. Figure 20 shows our proposed design.

![Proposed East Beltline Underpass](image)

Figure 19: Proposed East Beltline Underpass

28.2.1 “T” Intersection

This intersection has been redesigned as a T-intersection so as to give the highest flows free flow and to make the intersection more standard and easy to understand for current and prospective students, families, and visitors.

28.2.2 Models

This proposed intersection has been modeled with AutoTurn to check the radii of the curves. This verified the paths of the design vehicle through
each approach of the intersection. This software was used in cooperation with the City of Wyoming Engineering Department.

28.2.2.1 AutoTurn
The radiiuses of the curves were designed for a large tour bus (BUS 40) and intermediate semitrailers (WB-40). AutoTurn was used to verify that these radiiuses were correct and that the vehicles would be able to make it through the intersection without problems. These vehicles were able to drive safely through the intersection. The software output can be found in the Appendix EB.10.

28.2.3 Sidewalk
A sidewalk was added to the proposed redesign so as to increase pedestrian safety. The existing sidewalk ends at the east side of the underpass, so pedestrians going to the parking lot must either cross the street, walk in the grass, or walk along the side of the road. This added sidewalk will give the option of not having to cross any leg of the intersection, and continuing on safely to the residents’ parking lot. This sidewalk matches the current Calvin sidewalk design of asphalt.

28.2.4 Storm Sewer
The storm sewer system designed will drain the proposed intersection and connect to the existing system. The area of asphalt was reduced and landscaping was added so it was assumed no storm calculations were needed. The new system uses the pipe sizes of the current system. The storm sewer presented the greatest problem at this intersection. Only manholes were shown on the campus AutoCAD file. The Director of Calvin’s Physical Plant, Phil Beezhold, was contacted and made the campus utilities plans available for examination. The existing layout was determined by inspection of the job site and current utilities plans on file at the Physical Plant. The existing layout must be verified before
construction begins. The storm sewer improvements can be found in the Appendix EB.5.

28.2.5 Cost
The total constructed cost of the proposed improvements will be $102,000. This includes construction costs, maintenance of traffic, storm sewer, and contingencies. Half of the cost is removing and placing asphalt and curb and gutter. The other half comes from the storm sewer improvements, lighting, sight grading, and landscaping. The detailed budget can be found in the Appendix EB.8.

29 Lake Drive Entrance Intersection

29.1 Existing Layout

The current intersection does not have great problems of safety, but mainly those of efficiency. The highest traffic volume movement must make a smaller than 90° turn, which presents poor sight angles. The traffic study can be found in the Appendix LD.9. The redesign of this intersection will focus on improving the sight angles and adding lanes to handle predicted higher flows. These higher flows will be due to the new Spoelhof Fieldhouse Complex, the proposed parking garage in the adjacent lot, and the closing of Ring Road. The current layout of this intersection is shown in Figure 21.
29.2 Proposed Solution

Team 12 recommends realigning the Lake Drive entrance, giving a uniform radius to the campus loop, and adding exclusive turn lanes. This will be able to handle the high traffic events created by the parking garage and new Fieldhouse complex as well as the increased traffic flow due to the closing of Ring Road. Figure 22 shows the recommended design for the Lake Drive entrance.
29.2.1 “T” Intersection
Realigning the Lake Drive entrance and smoothing out the Campus Loop creates a 90° intersection. The Campus Loop has been given free flow to handle the expected higher volumes. Exclusive turn lanes were added to the Lake Drive entrance so that the left turn lane will not impede the right turn movement. These will also aid in splitting traffic for high traffic events, such as games at the new complex. An exclusive right turn lane was added to the Campus Loop to keep it flowing freely.

29.2.2 Models
This proposed intersection has been modeled with AutoTurn to check the radii of the curves. This verified the paths of the design vehicle through each approach of the intersection. This software was used in cooperation with the City of Wyoming Engineering Department.

29.2.2.1 AutoTurn
The radiiuses of the curves were designed for a large tour bus (BUS 40) and intermediate semitrailers (WB-40). AutoTurn was used to verify that these radiiuses were correct and that the vehicles would be able to make it through the intersection without problems. These vehicles were able to drive safely through the intersection. The software output can be found in the Appendix LD.10.

29.2.3 Storm Sewer
The storm sewer system designed will drain the proposed intersection and connect to the existing system. The area of asphalt was reduced and landscaping was added so no storm calculations were needed. The new system uses the pipe sizes of the current system. The storm sewer layout from the AutoCAD file matched a visual inspection of the job site. However, the layout must be determined with a more thorough inspection before construction begins. The storm sewer improvements can be found in the Appendix LD.5.
29.2.4 Landscaping
The landscaping at this intersection will need to be removed and replaced. The Calvin directional sign will need to be salvaged and replaced. The bushes and plants near this intersection will also need to be placed for the proposed intersection. Calvin’s Physical Plant workers should be involved in this step.

29.2.5 Cost
The total constructed cost of the proposed improvements will be $85,000. This includes construction costs, maintenance of traffic, storm sewer, and contingencies. Half of the cost is removing and placing asphalt and curb and gutter. The other half comes from the storm sewer improvements, lighting, sight grading, and landscaping. The detailed budget can be found in the Appendix LD.8.

30 Project Design Norms

30.1 Stewardship
With the design of these intersections, we wanted to reduce the costs while still preserving quality of construction and design. We wanted to increase safety, reduce fuel consumption by improving efficiency, and increase green space of Calvin’s intersections. We are confident that our designs have achieved these goals.

30.2 Transparency
We feel that transparency is of the utmost importance for our designs. All drivers visiting Calvin’s campus must be able to recognize immediately the intersections and what they must do. With appropriate signage, geometries, and uniformity, we feel that our designs have achieved transparency.
30.3 Humility
In designing these intersections, it was important to remain humble and recognize that we are fallible. Thus, incorporated into the design were checks by fellow teammates, mentors, clients, and professors.

31 PROJECT SCHEDULE
The initial project schedule had the design work for these intersections completed halfway through the semester, leaving the rest of the semester for modeling and preparing the final report and presentations. The original project schedule can be found in Figure 23.

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Predecessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Design – Burton St. Intersection</td>
<td>3 weeks</td>
<td>Mon 1/29/08</td>
<td>Sun 2/16/08</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Design – East Beltline Underpass</td>
<td>2 weeks</td>
<td>Mon 2/19/08</td>
<td>Sun 3/16/08</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Design – Lake Dr. Intersection</td>
<td>2 weeks</td>
<td>Mon 3/25/08</td>
<td>Sun 4/1/08</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Site Plans</td>
<td>1 week</td>
<td>Mon 3/17/08</td>
<td>Fri 3/21/08</td>
<td>7,8</td>
</tr>
<tr>
<td>11</td>
<td>Cost Analysis</td>
<td>1 week</td>
<td>Mon 3/24/08</td>
<td>Fri 3/28/08</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Modeling – Burton St. Intersection</td>
<td>1 week</td>
<td>Mon 4/2/08</td>
<td>Fri 4/6/08</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Modeling – East Beltline Underpass</td>
<td>1 week</td>
<td>Mon 4/9/08</td>
<td>Fri 4/13/08</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Modeling – Lake Dr. Intersection</td>
<td>1 week</td>
<td>Mon 4/16/08</td>
<td>Fri 4/20/08</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Interactive Models</td>
<td>4 weeks</td>
<td>Fri 3/30/08</td>
<td>Thu 4/5/08</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Final Report</td>
<td>4 weeks</td>
<td>Thu 4/11/08</td>
<td>Wed 4/17/08</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 22: Original Project Schedule**

The actual project schedule was not as clean cut as proposed. The design of the roundabout took longer than originally thought. This delayed the start of East Beltline underpass and Lake Drive entrance. The modeling and presentations were pushed to the end of the semester so as to make room for the design of these intersections. The reason for the designs taking longer than thought is believed to be inexperience with designing intersections, as well as time constraints. The design of East Beltline underpass and Lake Drive entrance took much shorter due to the less intense design and things learned from the Burton Street entrance.

32 DESIGN SUMMARY
Team 12 recommends placing a 115 ft. diameter roundabout at the Burton Street entrance intersection. This will be able to safely and efficiently handle the current traffic flows. This will add some grandeur to the main Calvin entrance. The parking lot access would be moved to the Burton Street entrance road via a direct left turn.
For the East Beltline underpass, we propose removing one of the legs of the intersection and realigning the southern leg. This will give the three highest traffic volume movements free flow and increase pedestrians safety greatly. Pedestrians will only need to cross one leg of the intersection, and the sidewalk along the north side of the intersection has been extended to the residents’ parking lot.

For the Lake Drive entrance intersection, we propose realigning the Lake Drive entrance and smoothing out the campus loop. Exclusive turn lanes will be added to handle high traffic events created by the proposed parking garage and new Spoelhof Fieldhouse Complex. This redesign will create better sight angles and distances and make a 90° intersection.

33 ACKNOWLEDGEMENTS

Team 12 would like to thank a few people for their help in designing these intersections on Calvin’s campus. The City of Wyoming Engineering Department allowed us to use their computers and software. Carlos Caceres and Jeff Oonk from the City have helped with the intersection designs and cost analysis. Mike Devries and Matt Wiersma from URS Corporation have helped us as well. Mike Devries was the Industrial Consultant for Team 12. Matt Wiersma helped specifically with the design of the roundabout and Rodel software. Rob Van Uffelen from Nolte helped in researching designs for roundabouts. Without the help of these people, the designs of these intersections would not be.

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