CENTRAL CITY PARKWAY TRAIL DEVELOPMENT PLAN

A report submitted to the University of Colorado at Denver, Civil Engineering Department in partial fulfillment of the Senior Design Course

Spring 2021
Submitted May 3, 2021
Acknowledgments

The Meraki Engineering team would like to thank Dr. Wesley Marshall, Ph.D., PE, and clients for the advice, support, and feedback. We would also like to thank Dr. David Mays, Ph.D., PE, for his time and assistance in understanding and navigating the complicated drainage that this project presented. Finally, we wish to thank Mr. Peter Marxhausen, MS, PE, and the Civil Engineering Department at the University of Colorado Denver for the training to get to this point in our academic and professional lives. Your students greatly appreciate your efforts.

Most importantly, Meraki Engineering would like to sincerely thank our clients Lisa Roemhildt and Ray Rears at Central City for the opportunity to study and design and provide recommendations for a recreation path that can help your community. Completing this project has been a good learning experience for us to further our careers in engineering with the goal to give you beneficial information to help Central City.
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May 3, 2021

Ray Rears and Lisa Roemhildt
141 Nevada Street
PO Box 249 (City Hall, Ground Floor)
Central City, Colorado 80427

Re: Final report of findings and recommendations
Central City Parkway Recreation Trail Development Plan
The trail runs from Young Ranch Road to the intersection of Clear Creek

Dear Ray Rears and Lisa Roemhildt:

The Meraki Engineering Team would like to show our appreciation for allowing us the opportunity to study, analyze, and design the Central City Parkway Recreation Trail. The word meraki is a modern Greek word that is untranslatable and is used to describe performing something with soul, creativity, and love. Because of those characteristics, we decided to name our team Meraki Engineering. Our understanding of the project is to create a recreation path adjacent to the Central City Parkway on the Southside of the highway. The scope of this project focuses on the path starting near Young Ranch Road and will travel southeast, continuing down the mountain and end at the overarching Central City Parkway sign near the intersection of I-70.

One day, the end goal is to connect the Central City Parkway Recreation Trail to the Peak to Plains Trail at the bottom to make one cohesive path. At the intersection of Young Ranch Road, the goal is to have a way to safely cross the Parkway and connect our recreation path to the existing dirt road, Lake Gulch Road. The path will continue northwest into Central City, where the path users can enjoy some lunch or gamble within the city limits.

Our responsibilities included creating a hydrological model of the existing drainage basins, creating a safe, effective, and sustainable path design that users can enjoy for years to come.

As part of our research, we did an initial site visit with Lisa Roemhildt on February 2, 2021, to obtain the background information needed and further solidify the idea of the path. Meraki Engineering team did an additional site visit on February 20, 2021, and March 20, 2021, to finalize a few ideas for exact locations and take measurements to help the design plans become a reality. This report contains our findings, conclusions, and recommendations.
1. Project Background:

1.1 Central City Parkway

The proposed route of the recreation trail follows the southern edge of Central City Parkway, an existing four-lane highway in Central City, Colorado. The Parkway connects I-70 to Central City, Colorado. Central City Parkway was opened in November 2004. The proposed path will travel on the southern edge of Central City Parkway between the traveled portion of the roadway and the Right-of-way boundary in most cases. The length of the Parkway is around eight miles long. The road has an interchange that leads to the Hidee Gold Mines and other closed mines. An aerial view of the Parkway is shown in Figure 1 below.

![Aerial view of Central City Parkway and Lake Gulch Road](image)
2. Central City, Colorado

Central City is also known as the City of Central and is a municipality in Colorado, United States. The city was once considered one of the most populated cities in Colorado. The population was reported to be 663 on the 2010 United States Census. In 2019, the population grew slightly to 713 people. The population has fluctuated throughout the years because of vast gold reserves in and around Central City in the 1860s. The city became known as "the Richest Square Mile on Earth" because of the many gold mines.

2.1 History

Central City is located in Gilpin County, Colorado, and is known as a historic mining town founded in 1859 by John H. Gregory. Gregory was a discovery miner. On May 6, 1859, John H. Gregory was walking along Clear Creek to look for gold. He stopped and pulled the low tree branch out of the way and struck gold near the North Fork of Clear Creek. Gregory is credited for discovering "The Gregory Lode," a gulch between Black Hawk and Central City. After a week, the news started to spread to Denver. Almost instantaneously, more than 4,000 prospectors were living in their tents around Gregory Gulch, in the center of the mining district.
The influx of miners formed different communities that were eventually divided into three towns named Black Hawk, Nevadaville, and Central City. The population increased during a time when mining was booming. When mining became more difficult and fewer claims for gold were made, the city's popularity declined, resulting in a significant decrease in the city's population. At the time, Central City was one of the most populated cities in Colorado for a brief period until Denver surpassed Central City in population. Central City remained a political and cultural hub of Colorado until the 1870s.

After the initial discovery of gold in 1859, several other mineral discoveries were made in the subsequent years. Often, the harsh weather in the area forced some miners to return to lower elevation areas, lowering the population. With the immense popularity of Central City, the Gilpin County commissioned Central City as the county seat in 1861. Later in the 1860s, the initial area around Central City and Black Hawk became much harder to process because they contained gold mixed with sulfides.

Beyond gold, ore was also discovered. The ore quality in the area required a smelting process to separate the concentrated metals from the impurities. This process required special machinery, which was not available in the area. This process further enhanced the construction activities in the area. With more construction of buildings within the city, it was unfortunate when in 1874, a fire caused massive destruction in the area, which required reconstruction. During the rebuilding of the city, the buildings were rebuilt with bricks and stones in place of wood as one of the requirements by the city.
Mining ended in Central City during World War II as the federal government ordered to shut down commercial mining of gold and the metal from the mines were used to support the war effort.

The Central City Opera House became a vital entity to preserve the historical culture of Central City. The Central City Opera House Company was formed in 1929 to manage the production in the theater. Twenty-eight historic properties in the area are now managed by The Central City Opera House Company including the Coeur d'Aliene Mine. The owners of the Coeur d'Aliene Mine donated the mine to the Central City Opera in the 1940s (Mountain Ear: 2012). The mine has been restored by the historical society and now offers tours. The Coeur d'Aliene Mine played an important role for the success of Central City. The mine employed many women as shown by this sign as you enter Central City. The restored mine can be seen in the distance in the photo below.

Figure 2 - Coeur d'Alene Mine
The present feel of Central City resembles its 100-year-old appearance due to the preservation of the historical buildings in the great depression. In the 1990s, gambling was legalized and became an essential attraction to the area. Gaming brought more tourism to a city but more importantly proceeds from gaming taxes were given to the historical societies for preservation.

2.2 Population

According to the U.S. Census Bureau, the population of Central City was about 713 in 2019. The population comes from 261 households. This population kept changing dramatically over time due to the changing popularity of the area. The population peaked in the 1890s when it reached up to 10,000 people (Census: 2021). Central City is about 35 miles west of Denver. Moreover, the city has direct access to I-70 and connect to the Highway 119, the Peak to Peak scenic byway. The city has an elevation of 8,510 feet above sea level and has an area of 2.45 square miles of land. The population is primarily white, with a small percentage of black people with women outnumbering the men. There is a wide age gap of people in Central City where people from every age group are represented. The median age of the people in the city is 39 years of age. The area became known for arts/culture, heritage tourism, and gaming in the six casinos in Central City.
3. Purpose

The purpose of the recreation path is to enhance outdoor recreation opportunities by building a trail connection along the Central City Parkway from the City core to the base of I-70, with a longer-term goal of connecting to the regional trail network like the Peak to Plains Trail. The Colorado Department of Transportation is constructing the Peak to Plains Trail. The purpose of this report is to show the engineering analysis and recommendations of the recreation path. The Central City Parkway Trail will likely connect with the Peak to Plains Trail at the base of the Central City Parkway, where it intersects with I-70. Central City's goal by creating this path is to encourage recreation in Central City for the existing residents while also creating a recreation option for the outdoor enthusiasts in Colorado. By connecting Central City to existing trails, there is hope that this trail can help guide additional tourism into Central City and promote the residents and visitors healthy living. Objective 4 in the city's comprehensive plan states, "Invest in fiscally sustainable infrastructure and provide sustained public services that will support the other primary goals and promote the general health and welfare" (Central City: 2020). The goal of the trail is to promote outdoor recreation for current residents and outdoor enthusiasts in Colorado.

Due to the score of this project, this paper is considering a 5-mile starting at Young Ranch Road traveling southeast in the right-of-way of Central City Parkway until the intersection with I-70. At Young Ranch Road, the trail will cross under the Parkway via a tunnel. After crossing under the highway, there is a large hill that cyclists will need to traverse safely to get to the bottom to continue their ride on Lake Gulch Road into the heart of Central City. The design will be completed while also embracing the historical nature of Central City.
Engineering for the trail is needed because of the unique and varying terrain of the mountain.

To be able to create a recreation path next to an existing parkway safely, the University of Colorado Denver senior design team will present Central City with:

1) A hydrological report to show existing drainage and the drainage under or around the created recreation path.

2) An evaluation of the path safety for both motorists and cyclists.

3) A designed path that can connect Lake Gulch Road to the bottom of the Parkway.

4) A designed tunnel for path uses to cross under the Parkway safely.

5) Suggestions about how to improve Lake Gulch Road to be suitable for cyclists to use.

6) A preliminary estimate of costs for the project.

4. Jurisdiction Having Authority:

All projects being constructed within the boundaries of Central City shall follow all the applicable codes and requirements set forth by the City of Central and Gilpin County. All construction projects are required to obtain a Building Permit and follow the Standard and Specifications of Construction. The Community Development Department would facilitate this project, though City Council would need to appropriate funds. The Land Development Code allows for multi-use recreational trails, so Planning Commission would not need to weigh in on that. All applicable permits for a construction project shall be obtained before construction from appropriate county and city officials. All public projects that entail building a road or a path shall be within the City's Rights of Way.
As the highest government body with jurisdiction and authority over projects comprised of roads, paths, or bridges within the borders of the State of Colorado, all rules, regulations, and design guides written by the Colorado Department of Transportation need to be followed.

5. Applicable Building Codes:

Building codes have been developed through many years of research and experience to ensure the quality of engineering services provided to the clients and customers and protect the public's health, safety, and welfare. Building codes are regulations set forth by the local or regional authorities or government bodies to govern and guide the design, construction, and maintenance of structures. In simple words, building codes are the minimum requirements that need to be met for a structure to be safe and compliant. The following building codes are applicable for the Central City recreational trail design project:

2. ACI 318 – American Concrete Institute, 5th Edition.
3. CUHP – Colorado Urban Hydrograph Procedure.
5. ADAAG – Americans with Disabilities Accessibility Guidelines.
7. CCSSDC – Central City Standards and Specifications for Design and Construction
6. Findings:

6.1.1 Hydrology

Under the Central City Standards and Specifications for Design and Construction (CCSDC), we followed criteria set forth by the Urban Drainage and Flood Control District. We analyzed the hydrology of the area along the proposed bike path. The following section will focus on the watershed area, the generated watershed analysis, the hydrographs generated using Colorado Urban Hydrograph Procedure (CUHP) and discuss the existing drainage and impact and the proposed design on runoff and imperviousness, concluding with drainage design suggestions.
6.1.2 General Location and Description of Site

The area being analyzed for drainage purposes is in Gilpin County and belongs to the Clear Creek Watershed shown in Figure 3 and is made up of 575-square miles with 400 square miles or about two-thirds lying within the boundaries of the Arapaho and Roosevelt National Forest. The area of the proposed design is highlighted in blue in Figure 4 and encompasses 1.96 square miles or 1258 acres of land. The drafted drainage analysis follows Central City Parkway, from the Central City Parkway archway to the end of the bike path in total 5.1 miles. Much of the land is located on a mountainous landscape. Runoff flows into the Clear Creek drainage basin, which is considered part of a major drainage system with runoff draining into the South Platte River. In compliance with Central City Standards and Specifications for Design and Construction, a major drainage system serves to "minimize life and health hazards, damage to structures or improvements and interruption of emergency vehicular traffic" and consists of any combination of roadside ditches and culverts, storm sewers, and inlets.

**The Geography of the Clear Creek Watershed**

![Clear Creek Watershed Diagram](image-url)
6.1.3 Planning

The area being developed is made up of 90 drainage basins, they were calculated using the watershed feature in Computer Automated Design Civil 3D (CAD Civil 3D) shown in Figure 3. A table of the 90 basins generated in CAD Civil 3D can be found in Exhibit 5, Table 5. Along the Central City Parkway there are sixteen 6-foot culverts (outlined in magenta on Figure 3). A more detailed image is available as a CAD pdf drawing in sheet number 42.
Because this is an undeveloped area, the historic flow analysis recommended is 2% imperviousness, according to table 6-3, shown in Exhibit 6, Figure 33.

The process to find the present runoff and imperviousness for the design will focus on modeling four of the basins in line with criteria set forth by the Urban Drainage and Flood Control District. Basins 62, 37, 61, 63 outlined in red, where cut and fill will be implemented to achieve a reasonable and safe slope for users. When looking for Floodplain information provided by the Environmental Protection Agency (EPA), only part of our area was available digitally, shown in Figure 4, where the green polka dot hatch indicates No Digital Data Available.

*Figure 5-FEMA Floodplain Map*
6.1.4 Soil Information

In this project, the type of soil we are dealing with had to be researched. Obtaining information about the soil type was crucial for the design of the tunnel and the hydrological analysis. The hydrological analysis is needed to analyze potential flooding risks from the construction of an eight-foot path. The path could increase the impervious area resulting in increased flow and potential for flooding if heavy rain or snow event does occur. Additionally, having the soil type information is crucial when designing retaining walls for the tunnel since the angle of internal friction and unit weight of soil are required for calculations.

An excellent resource for extracting soil information needed for our project was the National Resources Conservation Service (NRCS) website, the map shown in figure 5 on the next page. The United States government website provides general soil information, including soil chemical and physical properties, soil health properties and erosion factors, and soil water features. For our purpose, we needed soil physical properties to design the tunnel and conduct the hydrological analysis needed for this project.

After gathering the soil data, our analysis concluded that most of the soil we are dealing with is classified as the hydrological NRCS soil type D. The soil was found to have a unit weight of 140 lb/ft³ and has an angle of internal friction of 40 degrees. This information was sufficient to carry out calculations and design the retaining walls for the tunnel and bike path.
Figure 6-USDA Soil Survey
6.1.5 Drainage Basins

The design will focus on data generated from Basins 62, 37, 61, 63 outlined in red featured in figure 6. Basin 62 is made up of 158.16 acres, Basin 37 is made up of 65.30 acres, Basin 63 is made up of 60.78 acres, and Basin 61 is made up of 42.78 acres. These basins were chosen to minimize calculations. All basins are located in mountainous rural areas. The traffic along the Central City Parkway is less than 2,000 vehicles per day and provides primary access to Central City. These characteristics classify the road as Rural Local with a Drainage Classification of A according to Central City Standards and Specifications for Design and Construction shown in Table 6.2.6.3A, Street Classification located in Exhibit 6, Table 7. The runoff expected with the proposed development is minimal. Drainage Classification A determines that flow must not encroach the shoulder or the Right of Way in the event of a storm as defined by Table 6.2.8.3B, located in Exhibit 6, Table 8. The water drop feature in CAD Civil 3D was used to determine the runoff path, which flows from left to right, sending stormwater into North Clear Creek.
Figure 7-Drainage Basins
6.1.6 Hydrological Criteria

In compliance with Urban Drainage and Flood Control District (UDFCD) standards, we used the Colorado Urban Hydrograph Procedure (CUHP) for generating hydrographs. Colorado Urban Hydrograph Procedure was used because basin 62 was larger than 90 acres, and we wanted to keep all calculations consistent. The calculations are shown in Table 8 in Exhibit 6. We calculated the runoff, imperviousness, and peak flow from the rainfall data obtained from National Oceanic and Atmospheric Agency (NOAA) website and watershed data generated in CAD Civil 3D. To determine rainfall depth-duration-frequency values, we used Atlas 14 provided by the NOAA, shown in Exhibit 6, Table 9. We concluded that the 1-hour, 100-year interval was chosen and input into the CUHP Raingage Management in the CUHP Analysis workbook provided by UDFCD.

The proposed impervious percentage was determined by multiplying the length of the road along the selected watershed by ten. This calculation incorporated the path and the concrete barriers resulting in minimal changes, only increasing the imperviousness from .05% to .76%, as shown in Table 1.

Table 1 - Proposed Impervious Percentage Table

<table>
<thead>
<tr>
<th>Sub-Basin Name</th>
<th>Sub-Basin Area (acres)</th>
<th>Sub-Basin Area (sq. ft)</th>
<th>Pavement Area</th>
<th>Natural Area (acre)</th>
<th>C Composite</th>
<th>C10-y</th>
<th>C25-y</th>
<th>C50-y</th>
<th>C100-y</th>
<th>C250-y</th>
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<td>3718.37</td>
<td>685,731.28</td>
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<td>2193.80</td>
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6.1.7 Hydrograph

A Hydrograph was built using the Colorado Urban Hydrograph Procedure CUHP 2005 Version 2.0.1 workbook from Urban Drainage and Flood Control District. To be conservative, we rounded the impervious percentage to 3%, as shown in Table 2, and calculated the present and potential runoff after the increased imperviousness. We used CAD Civil 3D to determine the area, centroid, the length to the centroid, and the length of each basin.

Table 2 - CUHP 2005 Version 2.0.1 Excel workbook
Table 3 shows a time series for the hydrologic model that shows peak flow at 40 and 45 minutes. The flow increased by one cubic foot per second, resulting in an insignificant increase in runoff.

### Table 3 - Storm Water Hydrograph

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>Proposed G2</th>
<th>Proposed G3</th>
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6.1.8 Existing Culverts:

The goal for all hydrological analyses that the Meraki Engineers carried out was to make sure that the existing culverts in the City of Central are capable of handling an increase in runoff or flow due to building an asphalt paved bike path that would have affected the existing culverts flow capacity. It was found that there are 16 existing culverts in the City of Central with a diameter of 6 feet.

The culverts have been designed conservatively because the city is located in a mountainous region with a considerable amount of snow during the winter season, leading to potential flooding if the culverts were not designed for such capacity. The hydrological analysis found that the existing culverts can handle a full pipe flow of 85 cubic feet per second. Certainly, this analysis is for the extreme case assuming flooding does occur, and the culverts have a full flow which rarely happens.

Finally, Meraki Engineers concluded that the runoff would only increase by one cubic foot per second due to building the proposed path, which only shows a 1.17% increase in flow for the culverts. Therefore, the existing culverts can easily handle the 1.17% increase in flow, and there will be no need to build additional hydraulic structures.
6.2 Rest Areas

According to Central City Comprehensive Plan 2020, their vision statement is: "Water, sanitation/wastewater, streets, public transportation, public parking, law enforcement, fire, protection, hazard safety, revenue generated for public service and recreational amenities are fundamental components of day-to-day quality of life for current and prospective residents, visitors and businesses." One of their revenues, the top priority will be the basic infrastructure and facilities for short and long-term services investments.

The design of the recreation trail includes amenities that help accommodate the user's needs to feel comfortable, convenient, and safe to socialize and exercise. Based on the suggestion for rest area locations, we chose four out of six locations. These exact locations can be seen in Exhibit 5. We were able to utilize the location for each of these areas using AutoCAD and measure how large each area is to plan accordingly for the design of the rest areas. We followed the Trail Design Guide 2 prepared by the Manual on Uniform Traffic Control Devices for the design criteria. Our design will consist of six-inches by six-inch wood posts that are five feet tall. The signage is placed at least three feet away from the edge of the path for increased safety. An illustration of trail cross-section can be found in Exhibit 7.
At the first site visit, we observed that the path has a significant slope change from 2% - 10%. Hence, it will not meet the Americans with Disabilities Act (ADA) and could be unsafe for people with disabilities to access sections of this path because of the steep grades. We were able to design a path that is eight feet wide path and going in both directions. However, some portions of the path are narrower and can accommodate a path around six feet wide.

We followed the Manual on Uniform Traffic Control Devices MUTCD 2009 edition standards for bicycle facilities to place the warning signage system at appropriate locations. For example, plaques of 90-degree turn (W1-1), sharp turn (W1-2 – W1-5) would help to alert the cyclists to be aware of a sharp turn and slow down. Other signs to consider in our design are the steep grade (W7-5) and path narrows (W5-4a) to increase safety. Examples of these signs can be seen in Exhibit 6.

In our opinion, we expect this path will be used by more athletically fit and experienced bike riders because of the slope and altitude, which adds difficulty to a ride. Additionally, the path will be used by hikers and pedestrians. Consequently, we can install a 22-32 gallon trash receptacle; heavy-duty, bear-resistance at each location should suffice.

Installing and solar power lights to illuminate the rest areas when it dark will increase overall trail access, safety, and convenience while providing a sense of security when approaching the rest areas. In addition, a bike fixing kit station including a bike pump and the necessary tools to repair a broken bike will be placed at every other location. This feature would accommodate the cyclists if they got flat or something wrong with their bike during the ride.
The bike tools add security when out on a long ride. We designed concrete footings to provide a strong foundation for amenities such as trash receptacles, benches, and bike racks. The rest area ground will be covered with small gravel. This surface was chosen because it is cheaper than concrete and will not add to the impervious area, which does not change the existing drainage.

To demonstrate the rest area, we used Sketch-Up, software to help design the layout for the rest areas. An illustration of the location can be seen in Exhibit 7. More importantly, for our design, we included boundary fencing around each of the rest area locations to prevent the path users from falling into potential hazards and keeping them from trespassing onto private property. The height of the fence is approximately three feet tall and is made from wood.

Central City of Colorado has a significant history of Native Americans and Mining. The Ute tribe are some of the oldest residents of Colorado. The Ute tribe is the largest tribe of Native Americans who occupied Colorado back in the 16th century (Mountains, W. 2021). Meraki Engineering decided to revive Colorado's long history of Native Americans on our bike path by installing some placards that remind people about the long history that this state has.
Meraki Engineering has designed the rest areas to include five wood benches that have some Native American Art. The art will represent the local Native American history. The rest areas will also have four flags made of a piece of cloth representing the Ute Tribe. The flags will give the rest areas a sense of beauty and shape and make path users along the path want to stop and take pride in this long history of Colorado. We plan to have on our interpretive signage illustrating some historical facts and pictures of the Ute tribe and a brief history of Central City Mining that will educate path users about the history of this land and Colorado Native Americans.

6.3 Path Design

Our findings for the path were developed after three site visits. Our whole team visited the Parkway on February 2, 2021 and were given the general overview by Central City members. Justin and Ivan did two follow-up site visits on February 20, 2021, and March 20, 2021, to take photos and measurements to identify possible tunnel locations and discuss ideas for the path design. We discovered that designing a tunnel under Central City Parkway connected to a prefabricated staircase would be a suitable option to connect our path to Lake Gulch Road. The designs for the tunnel and staircase are discussed below in sections 6.1 and 6.3, respectively. Additionally, we found that some areas along the Parkway were narrow, steep, or obstructed for a path to be constructed without improvements.
For the design of the recreational path, we decided to use some of the existing Parkway pavement and concrete barriers to keep construction costs down without having to cut into the mountainside or changing the existing drainage. The proposed path is an eight-foot path made of asphalt that joins with the current Parkway shoulder. The existing shoulder is nine feet wide from the concrete barriers to the white painted line. Our plan calls for moving the concrete barriers in three feet to create a six-foot shoulder. Moving the barriers will create room for the path without changing the existing drainage. The remaining three feet of the shoulder are converted into the recreation path. The three-foot existing shoulder is used, and the additional five feet will be paved with asphalt to create an eight-foot path. The design of the asphalt is discussed below in section 6.4.

For the majority of the Parkway, the path will be eight feet wide. There are spots where the path may narrow to six feet to maintain a path without altering the existing drainage. There are also places where the roadway is wide because of turn lanes. When the Parkway is more expansive, the existing shoulder could be used as the path without paving the path. For motorist safety and path user safety, concrete barriers will be placed along the entire path between the traffic and the constructed path. In most places along the five-mile path, concrete barriers already exist. We discovered from our site visits that there are about two miles of barriers that will need to be installed during our site visits. There are parts of the path where existing street light poles are obstructing the path. In these instances, the existing light poles will be removed and replaced with an aluminum light pole mounted on top of the concrete barrier. These new streetlights will light the Parkway and the path simultaneously.
There are parts of the path that need to cross large ravines. In these instances, we have designed a path that follows the contours of the land down into the ravine. The path continues as an eight-foot path with a designed retaining wall on one side, discussed in section 6.2 below, to hold back the hillside and a guard rail 42 inches tall on the other side. The guard rail meets Colorado Department of Transportation guidelines.
7. Recommendations

7.1 Tunnel

Meraki Engineers propose constructing a tunnel that will connect the existing dirt road, Lake Gulch Road, on the north side of the Parkway to the south side of the Central City Parkway, where the proposed path will be built. After several site visits and conducting feasibility research and analysis, Meraki Engineers concluded that a tunnel would be the safest and most feasible option to connect the south and north side of the Parkway. An alternative to a tunnel would have been a bridge. A bridge would have served the same purpose but was ignored by Meraki Engineers due to lack of space for the bridge, height clearance, wind load considerations, and the likelihood of not being used by the path users due to its height, appearance, and less attractiveness.

The construction cost and time of a tunnel are much longer than a bridge. Still, it eliminates the danger of being on a bridge in a mountainous region and provides cover during storms or warfare, and is much more attractive and safer for the path users. The proposed tunnel will have a width of eight feet and a height of ten feet and will be constructed of reinforced concrete gravity retaining walls with a slab as the roof. Asphalt pavement, steel deck, prefabricated staircase, footings, joists, ledgers, and connections are other essential components of the tunnel.
7.2 Retaining Walls

There are two types of retaining wall design for this project, a gravity retaining wall, and a cantilever retaining wall. A gravity retaining wall is designed for the tunnel connecting the south side of the Central City Parkway and to the north side with a total length of 75 feet. This tunnel aims to provide a path for the bikers to safely cross the road from the north side without endangering themselves and the traffic.

The gravity retaining wall was the right choice for the tunnel due to its weight and strength compared to the other types of retaining walls. This type of retaining wall is the most robust retaining wall with a high factor of safety against overturning and other types of moments due to applied active and passive earth pressure. The gravity retaining walls are reinforced with grade 60 steel and have passed all design requirement checks, including stability, toe, heel, and stem checks to withstand design shears and moments.

These retaining walls are designed for 11 feet of height and can carry a surcharge dead load pressure of 1.59 kips/foot and a live surcharge load of 10 kips/foot. A 12-inch-thick slab will be placed on top of these retaining walls that will provide an underpass for the bikers to reach the north side of Central City Parkway without having to cross the road. The combination of gravity retaining walls and slab will serve the purpose and functionality of a tunnel for this project without spending too much money on constructing a modern tunnel.
A cantilever retaining wall needed to be designed for those ravines along the path that would have made it dangerous for bikers otherwise. These cantilever retaining walls that will be placed along the south side of the Central City Parkway are designed to protect the bikers from the street edge and possible landslides that can occur along those ravines. To cover those ravines along the path, 1667 linear feet of cantilever retaining wall will be needed. These retaining walls will consume a big chunk of the budget for the path and move the concrete barriers and four-inch-thick asphalt pavement. The gravity retaining wall will be constructed from concrete with a compressive design strength of 4000 psi.

The cantilever retaining walls are designed for 19 feet of height and 12 inches of stem width. Unlike the gravity retaining walls for the tunnel, a cantilever retaining is much lighter and is sufficient to serve its purpose along the path. The retaining wall is reinforced along its stem, toe, and heel with grade 60 steel and passed all the design requirements, including stability, toe, heel, and stem checks. The cantilever retaining wall will be constructed from concrete with a compressive design strength of 3000 pounds per square inch.
7.3 Prefabricated Staircase

Meraki Engineers decided on the construction of a tunnel over the alternative bridge construction after conducting extensive analysis and research on the constructability and engineering aspects of the two alternatives present on the desk. Meraki Engineers know that constructing a tunnel requires more resources and time but appeared to be the most viable option. Since the south side of the Central City Parkway is where the path is and is where bikers need to connect to the north side where Lake Gulch Road is. With a very steep side slope, the tunnel position needs to be elevated vertically to limit the excavation quantity and provide connectedness to the north side of the Parkway. The main hurdle is to connect the dirt road on the south side of the Parkway to the high tunnel.

Meraki Engineers came up with two solutions for this hurdle. The options include having switchbacks or a prefabricated staircase to connect to the tunnel. Switchbacks were ruled out as an option once it was found to require more land and a more significant footprint to construct. The more feasible option was a prefabricated staircase that can serve the same purpose as switchbacks but with less land needed to perform the same function.

A prefabricated staircase that is eight feet wide with four ten-foot landings and a max drop of 12 feet is designed to comply with the International Building Codes requirements. Bar grate stair trade is used to prevent snow accumulation during the winter and prevent slipping. A channel for bikes is also considered an integrated part of the prefabricated staircase that provides an effortless experience for the bikers while carrying bikes to the tunnel.
7.4 Footings

A footing is a vital engineering aspect of column stability and must be considered when column supports are used for a structure. The steel deck, which will be the integrated part of the tunnel on the north side of the Parkway, will be supported by 15 feet tall and 8 inches by 8 inches Redwood columns that reinforced concrete footings must support. The designed square footings are three feet by three feet and have a thickness of 12 inches with three different steel reinforcements, including longitudinal steel bars, dowels, and ties. The design specifications and calculations of the reinforced concrete footing, including steel bar sizes and spacing requirements, are provided in exhibit 4 of this report. All design calculations and assumptions are based on ACI 318 and IBC 2015.

7.5 Slab

Meraki Engineers designed a slab to be placed on top of the gravity retaining walls to complete the construction of the tunnel. The slab will serve the same purpose as the roof of a house and is designed to withstand the soil pressure above the tunnel. The designed slab will have a length of 75 feet and a width of 15 feet, and a 12-inch thickness. The slab is designed to have two types of reinforcement, including main steel that takes most of the load, and temperature steel prevents the concrete from shrinking and cracking during radical temperature changes. All design calculations and assumptions are based on ACI 318 provided in exhibit 4 of this report.
7.6 Steel Deck

A 256 square feet of steel deck is to be attached on the north side of the tunnel and Central City Parkway. The steel deck improved the overall look and aesthetics of the tunnel and was found to be necessary for the bikers to slow down and not overshoot the tunnel. The steel deck was mainly designed because of safety considerations. The perimeter of the deck is covered with redwood posts to prevent bikers from ending up in the wrong direction. This deck is the main indication for the bikers to slow down and change direction carefully.

The steel deck is supported by concrete footings 15 feet below the ground and 64 square inches Redwood columns. Meraki Engineers was able to choose a steel deck over a wood deck due to maintenance, durability, and economic considerations. After doing material research, it was found that a steel deck is more durable and has fewer maintenance costs compared to an alternative wood deck.

Because the project location is in a mountainous region where it snows a lot, moisture considerations were one of Meraki Engineers' deciding factors to choose a steel deck over a wood deck because of maintenance issues that a wood deck can have regarding moisture. It is also more economical to have a steel deck instead of a wood deck, considering that a steel deck costs less compared to a wood deck.
Another reason why Meraki Engineers decided to use a deck at the north end of the tunnel instead of using switchbacks was because when discussing the hill on the north side of the road with the City of Central, Central City owns the right of way of the parkway but lake gulch road is out of the city limits. After doing some research online using GIS (Geographic Information System) website to determine the city limits for Central City and Black Hawk, it was inconclusive if that land on the north side of the road belongs to Black Hawk or Central City. Meraki Engineers also used google maps and came up with the same answer of inconclusive who owns that land. Since more research needs to be done to determine who that land belongs to, we decided a deck would be the idea that requires less disruption of the land. We understand that this will not meet the ADA requirements since it will need stairs to get off the deck and onto Lake Gulch Road, cyclist will have to walk their bikes down the stairs, for this Meraki Engineers decided to add a bridge to the stairs where the tires of the bike will go to facilitate going up or down the stairs. There will be a short distance where bikers will need to dismount and walk their bike down the stairs using the bike channel for assistance. Switchbacks can be an addition to the project if that is decided later by City Council. The use of switchbacks would require long stretches of retaining walls due to the slope of the road's side to meet the Americans with Disabilities Act (ADA).
7.7 Asphalt Pavement

Six-inch thick plant-mix asphalt is designed for the 75 feet length of the tunnel to give bikers and path users a pleasant experience inside the tunnel. Even though it was not required to pave the tunnel, Meraki Engineers considered paving the tunnel for riding comfort and overall aesthetics and looks of the tunnel. It was also found that it only costs $5024 to pave 75 feet of the tunnel, and it is worth it to improve the overall looks of the tunnel with this cost.

Our path design consists of 4-inch thick asphalt. This depth is used to match the thickness of the pavement of the existing Parkway. The path design includes using part of the existing shoulder as part of the path. To match the pavement surfaces, the thickness of the path needs to match the pavement thickness of the Parkway. The Colorado Department of Transportation Pavement Design Guide 2010 Table 3.5, as shown in Exhibit 6, recommends an aggregate base course of six inches under hot mix asphalt that is this thick. The aggregate base course recommended from Table 3.3 from The Colorado Department of Transportation Pavement Design Guide 2010 is a base course with an R-value ≥ 83 or a design resilient modulus of 38,721 psi (Pounds per square inch).
The asphalt cement grade recommended by The Colorado Department of Transportation Pavement Design Guide 2010 Table 3.10 is an unmodified asphalt PG 64-22. These numbers represent the temperature range in Celsius that the pavement performs well. The recommended asphalt will perform from 64°C (147.2° F) to minus 22°C (-7.6°F). To get the best performance of the asphalt over its lifetime, preventative maintenance on the surface is preferred. Maintaining a path clear of debris will allow the path users the most pleasant experience while also prolonging the life of the path. It is recommended that cracks are sealed promptly after noticing them prevent water from getting to the subgrade and enlarging the cracks. Wide or uneven cracks in the asphalt can cause an unsafe riding surface for bikers. Meraki Engineers recommends inspecting the path every year for damage. This can be performed simultaneously with Parkway maintenance or if maintenance is being performed in the city.
7.8 Lake Gulch Road

To fully connect the path to downtown Central City, improvements to Lake Gulch Road will need to occur. As it stands now, Lake Gulch Road is an unpaved dirt road. This road would be passable for mountain bike riders and pedestrians but not for the riders who have a road bike with skinny tires. To complete the implementation of the recreation path, we suggest paving Lake Gulch road and providing bike lane markings and signage to signal to drivers that bikers could be present on the road. Another suggestion is to improve the road conditions with recycled road millings. If the city is repairing roads within their city limits at any point, the road millings can be stored, reheated, and laid on top of the dirt road for a more impervious surface without doing complete paving of the road. Reusing the millings is a way to be eco-friendly and possibly saving money until complete paving can be performed.

Merkai Engineers understands that Central City does not own Lake Gulch Road, and the right-of-way would need to be obtained to complete the suggestions listed above. The use of Lake Gulch Road was the suggested route during the initial site visit by Lisa Roemhildt and Ray Rears as a continuation of the proposed path. Meraki Engineers designed the stairs and tunnel in the location chosen based on the information given.
7.9 Earthwork

Using AutoCAD Civil 3D, we were able to calculate the volume of earthwork performed along the path. The net cut is 99,504 cubic yards. The total earthwork comes from four sections along the path that include retaining walls. These areas are next to the tunnel and the three sections that the path goes down into the ravine. These four sections require earthwork cut to install the retaining walls to make the hillsides passable for a recreation path. The earthwork table is listed in Exhibit 4. The first line for full earthwork cut path sections is an exaggeration performed by AutoCAD. Therefore, the total mentioned above for the four sections is a more accurate estimate.
8. Construction Sequence/Implementation Sequence:

Our design is split up into three sections. The first section is the bike path from the bottom of Central City Parkway to Young Ranch Road. The second section is the tunnel connecting the north of the Parkway to the south side of the Parkway. Finally, the retaining walls will be placed in the ravine areas where the slope of the side of the road is less than ideal for our design to have a path. We believe that to not disturb traffic flow into downtown because this project aims to get people to the city, the tunnel should be constructed and excavated without closing the Parkway. We understand that this might extend the duration of the tunnel's construction but allow the traffic to flow freely.

Not being an expert in tunnels and construction, Meraki Engineers still believes that the tunnel and the path should begin simultaneously because both the path and the tunnel will be useless alone. The idea is for the path and the tunnel to end simultaneously, so no delays occur waiting for either the tunnel to be finish or the other way around. The bike path is around five miles in length. The longest part of the construction will be excavating and setting up the forms for the concrete walls. We believe that this will be the longest in time because of the machinery that needs to be used to excavate and compact the ground to its required density. With a soil report from a geotechnical engineer, it would be easier and more accurate to determine what density of subsoil we need to avoid heaving and damaging the asphalt of the path. Being that the path is around five miles in length, we would recommend that the construction firm have different crews working on different sections of the path. This would help speed up the process.
The retaining walls can be completed either when the path starts by building the forms and having the rebar inspected by a structural engineer or city official to make sure the walls are being built to plans. Or the retaining wall can wait until the final months of construction. Having them connect to the actual path can limit errors and make sure the slopes and depth is correct. The most important is inspecting the rebar and forms of the walls to make sure the construction is being done per plan.

Meraki Engineers believe that the biggest challenge for construction will be the tunnel. We, the engineers, did not have a soil report done, and we made a lot of assumptions when designing our tunnel. One of the assumptions we made is that the soil bearing pressure is 3000 psf (pounds per square foot). This assumption is not conservative at all, and if the soil pressure is less than that, the design of the retaining walls we designed will have to be redesigned to make sure it is safe for the public.

The final part of the design was the deck attached to the north end of the tunnel. There are a few ways to construct the tunnel. The first option we as a team discussed was to cut and cover tunnels, this style of building tunnels, according to the Standard Handbook for Civil Engineers 5th edition, is used when the tunnel is in shallow depth (Ricketts, Loftin and Merritt, 2004). The construction method could be more time-consuming for Central City because it would mean that a section of the Parkway would have to be closed to excavate the trenches of the tunnel and have the forms built for the retaining walls and installing the rebar. The method we recommend is top-down because the walls will have to be built first, and then the rest of the tunnel can be constructed, the reason why.
As a team, we believe this is the best way to build the tunnel is because the retaining walls of the tunnel are the most significant support, and the members that are handling the total pressure of the soil and weight coming down the Parkway. To avoid hazards, please follow OSHA standards for tunnels and excavation construction. Another option for building the tunnel is by digging the tunnel from the sides, preferably from the north side, since it has road access. Using this method would involve more skilled labor.

Construction would start by digging a hole on the south side of the Parkway and using trench braces to retain the soil. This process is happening at the same time as the construction of the forms for the retaining walls. This construction process might take longer because once the concrete is poured, the concrete needs to cure for 28 days to reach maximum compressive strength. There are times when the curing time can be a full 56 days to handle the load that soil and traffic will place on it. Doing it this way would limit the disruption of traffic and keep the casinos and visitors happy. Our tunnel design will have a slope to the north to keep water from staying in the tunnel and possibly causing damage to the concrete or the asphalt. With a 2% slope, it will allow the water to run north. Out the tunnel, also, our tunnel has been designed to be able to fit a small maintenance vehicle during winter; this will be helpful to clear the snow from the path and deck.
The deck is the final touch to the project. It will be a prefabricated steel deck. We chose a prefabricated steel deck because it would be cheaper and faster to build and install. The important part of the deck and stair is that the footing is designed to handle the snow loads and live loads. Please take a look at Exhibit 4 to view the dimensions of the footings. The location of the footings will have to be field measured due to the limited data we were given. To have a correct location, a surveyor would be helpful. Due to the slope of the Parkway side, the stairs have to be installed or built correctly to avoid breaking any codes.

As mentioned earlier, Meraki Engineers are not experts in construction sequence or schedules. The suggestions above are based on our limited experience with construction and the scheduling sequence for constructing the path, retaining walls, and tunnel. We recommend consulting a general contracting firm to have a master schedule created. When designing the tunnel, deck, and path, we used the 2015 International Building Code (IBC) and amendments used by Central City.
9. Costs:

The cost estimation for a project is one of the crucial aspects of a project. A precise cost estimate will give our client, the Central City, a good idea of how much they should budget for the entire project. Therefore, our team did their best to develop a reasonable estimate and used RS Means online to calculate the cost for the entire project. RS Means cost estimation includes material cost, labor cost, and equipment cost. RS Means considers all costs related to a work package or construction activity as well as the difference in prices of material, labor, and equipment cost by each city and state across the United States.

A complete breakdown of all costs is shown below in figure 10, where the entire project's cost is divided into two main sections. The costs related to the path include excavation, retaining walls, asphalt pavement, jersey barriers, and the total cost of four rest areas. The cost related to the tunnel include excavation, fill, retaining walls, prefabricated staircase, slab, asphalt, and footings. The Miscellaneous costs include steel deck, joists, ledgers, bolts, connections, and posts used in the tunnel construction. A 1% civil engineering design cost and 5% contingency cost are also considered for the cost of this project. The entire project will cost $4,121,651. The table breakdown is on the next page.
Table 4—Total cost estimate for the trail design and construction

<table>
<thead>
<tr>
<th>Category</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
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<tr>
<td><strong>Bike Path</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Excavation</td>
<td>128,211</td>
<td>CY</td>
<td>$1,282,110</td>
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<tr>
<td>Retaining Walls</td>
<td>1,667</td>
<td>LF</td>
<td>$877,882</td>
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<tr>
<td>Asphalt Pavement</td>
<td>14,666</td>
<td>SY</td>
<td>$735,206</td>
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<td>Jersey Barriers</td>
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<td>Rest Areas</td>
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<td><strong>Tunnel</strong></td>
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<td>Contingency Costs</td>
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<td>$4,121,651</td>
</tr>
</tbody>
</table>


10. Future Work/Study:

It is recommended that a licensed Professional Civil Engineer analyze and look through calculations.

11. References:


Census, U., 2021. [online] Available at: <https://www.census.gov/search-


12. Disclaimer:

The assumptions, findings, calculations, and conclusions expressed and described in this report and its exhibits were developed by undergraduate civil engineering students who are not licensed professional engineers. This report was prepared as an academic exercise as partial fulfillment of the Civil Engineering Senior Design course. Pursuant to C.R.S. §12-25, no part of this report should be used for planning, budgeting, construction, or related fiscal decisions without a complete review and written endorsement from an independent, qualified, and licensed engineer who can assume responsible charge of the project and who is willing and able to become the engineer of record for all aspects of the study, calculations, findings, recommendations, and the project in part and in whole.

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13. Conclusion and Summary:

Central City is a historic mining town located about an hour west of Denver, Colorado. The area has a rich history for reasons beyond just gold mining. The city is over 150 years old with beautiful historic buildings. When mining slowed in the area, the city has been finding new ways to preserve the history and entice people to enjoy the great city. The introduction of live performances at the Central City Opera house and the introduction of gaming has produced a new wave of people to enjoy time in the mountain city.

The proposed Central City Recreation Trail is a trail that will run adjacent to Central City Parkway and is yet another way that current Central City Residents, current Colorado residents, and tourists can get to downtown Central City to visit. The path will begin at the overarching Central City Parkway sign at the bottom of the Parkway and travel northwest next to the Parkway until the intersection of Young Ranch Road. At the intersection of Young Ranch Road, path users need to be a safe way to cross the Parkway.

We propose creating an eight-foot-wide path that uses part of the existing Parkway shoulder. The existing Parkway will remain intact except for three feet of the shoulder and some light poles. The four existing travel lanes will remain 12-feet wide. The existing shoulder is nine feet wide, so we propose to move the existing concrete barriers towards the centerline of the Parkway three feet. Moving the barrier will create three feet of existing asphalt pavement for the path. The remaining five feet will be paved with asphalt and maintain the existing 2% cross slope for drainage. The path will consist of 6 inches of aggregate base course paved over with 4 inches of asphalt to match the height of the existing parkway pavement.
When the path reaches a ravine that needs to be crossed, the path will follow the topography, and the earth will be cut out to level the road.

Retaining walls were designed to hold back the existing hillside, and railings are placed on the downhill side of the path for protection from falling off the path. As the path reaches the middle of the Parkway near Young Ranch Road, another retaining wall has been designed to hold back the earth as it is cut away to get down to the level of the path for the designed tunnel. A tunnel has been designed for a safe way for path users to cross from one side of the Parkway to another. An eight-foot-wide prefabricated staircase has been recommended to connect the road to Lake Gulch Road at the bottom of a very steep hill. The staircase has a channel to make traveling up and down the stairs with a bike easier. The staircase connects the designed path to the existing dirt roadway, Lake Gulch Road, leading into downtown Central City. These proposed designs are additional ways of promoting tourism into Central City while also giving the residents an option for recreation.
Meraki Engineering would like to sincerely thank our clients Lisa Roemhildt and Ray Rears at Central City for the opportunity to study and design and provide recommendations for a recreation path that can help your community. Please contact us directly if there are any questions or concerns.

Sincerely,

Justin Gaumond
Justin Gaumond, E.I.

Ivan Zorrilla Alcala
Ivan Zorrilla Alcala E.I.

Abdullah Alfailakawi
Abdullah Alfailakawi

Tai Le
Tai Le

Karla Sanchez
Karla Sanchez

Mir Zabihullah Qureshi
Mir Zabihullah Qureshi E.I.
14. Exhibits
Exhibit 1: Site Map
Figure 8: Site map of Central City and Central City Parkway
Exhibit 2: Aerial Photograph
Figure 9-Aerial Photograph of the lower section of Central City Parkway with recreation path outlined in red.
Figure 10-Aerial Photo showing the proposed location for the tunnel
Figure 11 - Zoomed in aerial photo of proposed Tunnel location
Exhibit 3: Site Photographs
Figure 12 - Existing section of Central City Parkway with extended shoulder

Figure 13 - Current condition of light poles in drainage ditch where proposed trail will be constructed
Figure 14-One of four large ravines needed to be considered in the design. Also, the far side is one of the locations of the rest areas.

Figure 15-Second of four large ravines needed to be considered in the design.
Figure 16 - A measurement of the existing culverts along the highway

Figure 17 - Placement of stairs coming out of tunnel connecting to Lake Gulch Road
Figure 18: Area for the path leading into the tunnel travelling up the parkway
Figure 19-Location for the South entrance of the tunnel
Exhibit 4: Calculations

Retaining Wall Design for Tunnel

The calculations for retaining wall design for the tunnel were done using software called QuickRWall. We used a demo version, so we did not have to pay for the license. We wanted higher accuracy in calculations by using a computer program instead of doing it by hand. A summary of calculations is shown below.

Retaining Wall for Bike Path:

The calculations for retaining wall design for the bike path were done using software called QuickRWall. A summary of calculations is shown below.
Tunnel Design

Slab Design

Retaining Wall Design
Slab Design

L/20 = (15ft/20)(12in/1ft) = 9 inches       use 12 inches  d = h – 1 = 12 – 1 = 11 in.
b = 12 in , h = 12 in, d = 11 in

\[ W_{\text{self}} = b \times h \times \gamma = (0.15 \text{kips/ft}^3) (12 \text{in})(12 \text{in})(1 \text{ft}^2/144 \text{in}^2) = 0.15 \text{kips/ft} \]

\[ 1.2D + 1.6L = 1.2(0.15 \text{kips/ft} + 0.106 \text{kips/ft}) + 1.6(0.666) = 1.3728 \text{kips/ft} \]

\[ M_u = WL^2/8 = (1.3728 \text{kips/ft})(15 \text{ft})^2/8 = 53 \text{ ft-kip} \]

\[ M_n = \text{phi} = 0.9 \quad M_{n,\text{required}} = M_u/\text{phi} = (53 \text{ ft-kip}/0.9)(12\text{in}/\text{ft}) = 706.66 \text{ kip-in} \]

\[ P = (0.85f'c/fy)(1 - \sqrt{1 - \left(\frac{2M_n}{0.85f'cbd^2}\right)}) \]

\[ P = (0.85 \times 5 \text{ksi}/60 \text{ksi})(1 - \sqrt{1 - (2 \times 706.66 \text{kip-in}/0.85 \times 5 \times 12 \times 11 \times 11)}) = 0.00863 \]

\[ P = 0.00863 \]

Main Steel: \( A_{\text{steel}} \): \( Pbd = (0.00863)(12')(11') = 1.14 \text{ in}^2 \)

Use #6 bar at 4.5 inch spacing

Temperature Steel: \( A_{\text{steel}} \): \( 0.0018bh = (0.0018)(12')(11') = 0.2376 \text{ in}^2 \)

Use #4 bar at 10 inch spacing
### Design Detail

Concrete $f'_c = 4000$ psi  
Rebar $F_y = 60000$ psi  
Unit Weight = 150 lb/ft$^3$

#### Check Summary

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Check</th>
<th>Provided</th>
<th>Required</th>
<th>Combination</th>
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<td>Overturning</td>
<td>6.98</td>
<td>1.50</td>
<td>1.2D + 1.0L + 1.0H</td>
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<td>0.413</td>
<td>Sliding</td>
<td>3.63</td>
<td>1.50</td>
<td>1.2D + 1.0L + 1.0H</td>
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<tr>
<td>0.125</td>
<td>Bearing Pressure</td>
<td>3.00 psf</td>
<td>2.78 psf</td>
<td>1.2D + 1.0L + 1.0H</td>
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<tr>
<td>0.05</td>
<td>Bearing Eccentricity</td>
<td>2.75 in</td>
<td>22 in</td>
<td>1.2D + 1.0L + 1.0H</td>
</tr>
</tbody>
</table>

#### Toe Checks

- **Shear**
  - 0.431 Shear: 6.99 k/ft  
  - 0.568 Moment: 11.8 ft k/ft  
  - 0.088 Min. Strain: 0.0456  
  - 0.114 Development: 10 in  
  - 0.067 S&T Max. Spacing: 12 in  
  - 0.418 S&T Min. Rho: 0.0043

#### Heel Checks

- **Shear**
  - 0.540 Shear: 11.03 k/ft  
  - 0.452 Moment: 13.2 ft k/ft  
  - 0.078 Min. Strain: 0.0512  
  - 0.000 Min. Steel: 0.03 in$^2$  
  - 0.067 S&T Max. Spacing: 12 in  
  - 0.418 S&T Min. Rho: 0.0043

#### Stem Checks

- **Moment**
  - 0.093 Moment: 219 ft k/ft  
  - 0.052 Shear: 92.85 ft k/ft  
  - 0.017 Max. Steel: 0.2327  
  - 0.000 Min. Steel: 0.05 in$^2$  
  - 0.078 Base Development: 9 in  
  - 0.000 Horz. Bar Rho: 0.0000  
  - 0.067 Horz. Bar Spacing: 12 in

### Criteria

- Use basic criteria from common project. Yes
- Building Code
  - IBC 2018  
  - Concrete Load Combs: IBC 2018 (Strength)  
  - Masonry Load Combs: ASCE 7-16 (ASD)
- Stability Load Combs: IBC Retaining Wall St...
- Apply Sds Factor to Seismic Combinat...No
- Soil Reaction Modulus: 172800 lb/ft³  
- Friction Coefficient: 0.35  
- Wall Friction Angle: 25°  
- Req'd Bearing Location: Middle third  
- Has Different Safety Factors for Seismic No
- Required F.S. for Sliding: 1.50  
- Required F.S. for OT: 1.50  
- Use Toe Passive Pressure for Bearing No
- Use Passive Force for OT Yes
- Use Vertical Comp. for Sliding No
- Neglect Bearing at Heel Yes
- Neglect Soil Over Toe No
- Neglect Backfill Wt. for Coulomb No
- Factor Soil Weight As Dead Yes
- Use Passive Force for OT Yes
- Assume Pressure To Top Yes
- Extend Backfill Pressure To Key Bottom No
- Use Toe Passive Pressure for Bearing No
- Required F.S. for OT: 1.50  
- Required F.S. for Sliding: 1.50  
- Allowable Bearing Pressure: 3000 psf  
- Reqd Bearing Location: Middle third  
- Wall Friction Angle: 25°  
- Friction Coefficient: 0.35  
- Soil Reaction Modulus: 172800 lb/ft³
### Loading Options/Assumptions
- Passive pressure neglects top 0 ft of soil.

### Load Combinations

#### IBC 2018 (Strength)
- DL = 1.59 k/ft, LL = 10 k/ft
- (additional 5 ft backfill)

#### Loading Options
- \( \gamma = 140 \text{ lb/ft}^3 \)
- \( \phi = 40^\circ \)
- \( c = 0 \text{ psf} \)

#### Load Combinations

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Stem M-applied (ft·k/ft)</th>
<th>Stem M-allow (ft·k/ft)</th>
<th>Stem V-applied (k/ft)</th>
<th>Stem V-allow (k/ft)</th>
<th>Stem Min. Id (in)</th>
<th>Stem Actual Id (in)</th>
<th>Stem Min. strain</th>
<th>Stem Actual strain</th>
<th>Stem Min. steel (in²/in)</th>
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<td>0.2327</td>
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#### Stability Check Results Summary

### QuickRWall 5.0 (iesweb.com)
Backfill Pressure

Lateral Earth Pressure

Rankine Active Earth Pressure Theory

\[ K_a = \tan^2 \left( 45^\circ - \frac{\phi}{2} \right) = \tan^2 \left( 45^\circ - \frac{40^\circ}{2} \right) = 0.2174 \]

\[ \sigma_a = \gamma H K_a - 2 c \sqrt{K_a} = (140 \text{ lb/ft}^2)(11 \text{ ft})(0.2174) - 2(0 \text{ psf})\sqrt{0.2174} = 334.9 \text{ psf} \]

\[ \alpha_p = \alpha = 0^\circ \quad \text{(resultant force angle with horizonal)} \]

Lateral Earth Pressure (stem only)

\[ \sigma_a = \gamma H K_a - 2 c \sqrt{K_a} = (140 \text{ lb/ft}^2)(10 \text{ ft})(0.2174) - 2(0 \text{ psf})\sqrt{0.2174} = 304.4 \text{ psf} \]

\[ \alpha_p = \alpha = 0^\circ \quad \text{(resultant force angle with horizonal)} \]
### Passive Pressure

\[ K_p = \tan^2 \left( 45^\circ + \frac{\theta}{2} \right) = \tan^2 \left( 45^\circ + \frac{40^\circ}{2} \right) = 4.5989 \]

\[ \sigma_p = \gamma H K_p + 2 c = (140 \text{ lb/ft}^3)(3.25 \text{ ft})(4.5989) + 2(0 \text{ psf})4.5989 = 2093 \text{ psf} \]

### Lateral Earth Pressure

#### Uniform Surcharge Pressure

- **Rankine Active Earth Pressure Theory**
  
  \[ K_a = \tan^2 \left( 45^\circ - \frac{\theta}{2} \right) = \tan^2 \left( 45^\circ - \frac{40^\circ}{2} \right) = 0.2174 \]

  \[ \sigma_{sur} = K_a q = (0.2174)(700 \text{ psf}) = 152.2 \text{ psf} \]

- **Lateral Surcharge Pressure**
  
  \[ q = \gamma H_{sur} = (140 \text{ lb/ft}^3)(5 \text{ ft}) = 700 \text{ psf} \]

- **Lateral Earth Pressure**
  
  \[ \sigma_{sur} = K_a q = (0.2174)(700 \text{ psf}) = 152.2 \text{ psf} \]
Wall/Soil Weights

Bearing Pressure Calculation

Friction

F = \mu R = (0.350)(2229 \text{ lb/in}) = 780.2 \text{ lb/in}

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<th>...offset</th>
<th>Horiz Force</th>
<th>...offset</th>
<th>OT Moment</th>
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<tr>
<td>Backfill Weight</td>
<td>-233.33 lb/in</td>
<td>10 ft</td>
<td>0 lb/in</td>
<td>-</td>
<td>-336000 in·lb/ft</td>
</tr>
<tr>
<td>Backfill Weight</td>
<td>-233.33 lb/in</td>
<td>10 ft</td>
<td>0 lb/in</td>
<td>-</td>
<td>-257800 in·lb/ft</td>
</tr>
<tr>
<td>Backfill Weight</td>
<td>-233.33 lb/in</td>
<td>10 ft</td>
<td>0 lb/in</td>
<td>-</td>
<td>-3707.2 in·lb/ft</td>
</tr>
<tr>
<td>Backfill Weight</td>
<td>-233.33 lb/in</td>
<td>7.67 ft</td>
<td>0 lb/in</td>
<td>-</td>
<td>-1691747.66 in·lb/ft</td>
</tr>
</tbody>
</table>

\( \frac{-1691747.66 \text{ in·lb/ft}}{2229 \text{ lb/in}} = 5.27 \text{ ft} \)

\( \frac{-2229 \text{ lb/in}}{780.2 \text{ lb/in}} = 2.75 \text{ in} \)
## Stability Checks \([1.0D + 1.0L + 1.0H]\)

### Overturning Check

#### Overturning Moments

<table>
<thead>
<tr>
<th>Force Location</th>
<th>Force (lb/in)</th>
<th>Distance (ft)</th>
<th>Moment (in·lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill pressure (horz)</td>
<td>153.5</td>
<td>3.67</td>
<td>81037</td>
</tr>
<tr>
<td>Surcharge (uniform) lateral pressure</td>
<td>139.6</td>
<td>5.5</td>
<td>110504</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>191541</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>

#### Resisting Moments

<table>
<thead>
<tr>
<th>Force Location</th>
<th>Force (lb/in)</th>
<th>Distance (ft)</th>
<th>Moment (in·lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surcharge (uniform) vertical pressure</td>
<td>116.7</td>
<td>10</td>
<td>168000</td>
</tr>
<tr>
<td>Passive pressure @ toe</td>
<td>-293.4</td>
<td>-0.17</td>
<td>-660.64</td>
</tr>
<tr>
<td>Axial dead load</td>
<td>-125.2</td>
<td>4.5</td>
<td>65644</td>
</tr>
<tr>
<td>Stem Weight</td>
<td>-125</td>
<td>4</td>
<td>81000</td>
</tr>
<tr>
<td>Stem Weight</td>
<td>-250</td>
<td>6.33</td>
<td>228000</td>
</tr>
<tr>
<td>Key Weight</td>
<td>-18.23</td>
<td>5.5</td>
<td>14437</td>
</tr>
<tr>
<td>Backfill Weight</td>
<td>-233.33</td>
<td>10</td>
<td>336000</td>
</tr>
<tr>
<td>Soil over toe Weight</td>
<td>-24.5</td>
<td>1.05</td>
<td>3707</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1336488</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>

F.S. = \[ \frac{RM}{OTM} = \frac{1336488}{191541} = 6.878 > 1.50 \text{ (OK)} \]

### Sliding Check

#### Sliding Force(s)

<table>
<thead>
<tr>
<th>Force Location</th>
<th>Force (lb/in)</th>
<th>Distance (ft)</th>
<th>Moment (in·lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill pressure</td>
<td>153.5</td>
<td>-</td>
<td>-4095</td>
</tr>
<tr>
<td>Surcharge (uniform) lateral pressure</td>
<td>139.5</td>
<td>1</td>
<td>4358</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>291541</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>

#### Resisting Force(s)

<table>
<thead>
<tr>
<th>Force Location</th>
<th>Force (lb/in)</th>
<th>Distance (ft)</th>
<th>Moment (in·lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive pressure @ toe</td>
<td>283.4</td>
<td>1</td>
<td>1064</td>
</tr>
<tr>
<td>Friction</td>
<td>780.2</td>
<td>1</td>
<td>1064</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1064</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>

F.S. = \[ \frac{RF}{SF} = \frac{1064}{293} = 3.630 > 1.50 \text{ (OK)} \]

### Bearing Capacity Check

Bearing pressure < allowable (2736 psf < 3000 psf) - OK
Bearing resultant eccentricity < allowable (2.75 in < 22 in) - OK

### Wall Top Displacement

(based on unfactored service loads)

<table>
<thead>
<tr>
<th>Deflection Type</th>
<th>Deflection (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection due to stem flexural displacement</td>
<td>0.001</td>
</tr>
<tr>
<td>Deflection due to rotation front/settlement</td>
<td>0.038</td>
</tr>
<tr>
<td><strong>Total deflection at top of wall (positive towards toe)</strong></td>
<td><strong>0.039</strong></td>
</tr>
</tbody>
</table>
Stem Flexural Capacity

Capacity (ACI 318-14 11.5.2.2, +22.3, +22.2) @ 0 ft from base [Negative bending]
\[
a = \frac{A_s f_y}{0.85 f_c} = \frac{0.05 \text{ in}^2 / \text{in} (60000 \text{ psi})}{0.85 (4000 \text{ psi})} = 0.88 \text{ in}
\]
\[\varepsilon M_n = \phi A_s f_y (d - a / 2) = (0.90) (0.05 \text{ in}^2 / \text{in}) (60000 \text{ psi}) [(81.56 \text{ in}) - (0.88 \text{ in}) / 2] = 219 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, +22.3, +22.2) @ 0 ft from base [Positive bending]
\[
a = \frac{A_s f_y}{0.85 f_c} = \frac{0.05 \text{ in}^2 / \text{in} (60000 \text{ psi})}{0.85 (4000 \text{ psi})} = 0.88 \text{ in}
\]
\[\varepsilon M_n = \phi A_s f_y (d - a / 2) = (0.90) (0.05 \text{ in}^2 / \text{in}) (60000 \text{ psi}) [(81.56 \text{ in}) - (0.88 \text{ in}) / 2] = 219 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, +22.3, +22.2) @ 7.92 ft from base [Negative bending]
\[
a = \frac{A_s f_y}{0.85 f_c} = \frac{0.05 \text{ in}^2 / \text{in} (60000 \text{ psi})}{0.85 (4000 \text{ psi})} = 0.88 \text{ in}
\]
\[\varepsilon M_n = \phi A_s f_y (d - a / 2) = (0.90) (0.05 \text{ in}^2 / \text{in}) (60000 \text{ psi}) [(24.5 \text{ in}) - (0.88 \text{ in}) / 2] = 64.97 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, +22.3, +22.2) @ 7.92 ft from base [Positive bending]
\[
a = \frac{A_s f_y}{0.85 f_c} = \frac{0.05 \text{ in}^2 / \text{in} (60000 \text{ psi})}{0.85 (4000 \text{ psi})} = 0.88 \text{ in}
\]
\[\varepsilon M_n = \phi A_s f_y (d - a / 2) = (0.90) (0.05 \text{ in}^2 / \text{in}) (60000 \text{ psi}) [(24.5 \text{ in}) - (0.88 \text{ in}) / 2] = 64.97 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, +22.3, +22.2) @ 10 ft from base [Negative bending]
\[
a = \frac{A_s f_y}{0.85 f_c} = \frac{0.05 \text{ in}^2 / \text{in} (60000 \text{ psi})}{0.85 (4000 \text{ psi})} = 0 \text{ in}
\]
\[\varepsilon M_n = \phi A_s f_y (d - a / 2) = (0.90) (0.05 \text{ in}^2 / \text{in}) (60000 \text{ psi}) [(9.56 \text{ in}) - (0 \text{ in}) / 2] = 0 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, +22.3, +22.2) @ 10 ft from base [Positive bending]
\[
a = \frac{A_s f_y}{0.85 f_c} = \frac{0.05 \text{ in}^2 / \text{in} (60000 \text{ psi})}{0.85 (4000 \text{ psi})} = 0 \text{ in}
\]
\[\varepsilon M_n = \phi A_s f_y (d - a / 2) = (0.90) (0.05 \text{ in}^2 / \text{in}) (60000 \text{ psi}) [(9.56 \text{ in}) - (0 \text{ in}) / 2] = 0 \text{ ft·k/ft}
\]
Shear Capacity (ACI 318-14 11.5.5.1, 22.5.1.1, 22.5.5.1) @ 0 ft from base [Positive shear]
\[ \lambda = 1.0 \quad \text{(normal weight concrete)} \]
\[ V_c = 2 \lambda \sqrt{F_c} d = 2 (1.0) \sqrt{4000 \text{ psi}} (81.56 \text{ in}) = 123.8 \text{ k / ft} \]
\[ \phi V_n = \phi V_c = (0.750)(123.8 \text{ k / ft}) = 92.85 \text{ k / ft} \]

Shear Capacity (ACI 318-14 11.5.5.1, 22.5.1.1, 22.5.5.1) @ 0 ft from base [Negative shear]
\[ \lambda = 1.0 \quad \text{(normal weight concrete)} \]
\[ V_c = 2 \lambda \sqrt{F_c} d = 2 (1.0) \sqrt{4000 \text{ psi}} (9.56 \text{ in}) = 14.51 \text{ k / ft} \]
\[ \phi V_n = \phi V_c = (0.750)(14.51 \text{ k / ft}) = 10.89 \text{ k / ft} \]

Shear Capacity (ACI 318-14 11.5.5.1, 22.5.1.1, 22.5.5.1) @ 10 ft from base [Positive shear]
\[ \lambda = 1.0 \quad \text{(normal weight concrete)} \]
\[ V_c = 2 \lambda \sqrt{F_c} d = 2 (1.0) \sqrt{4000 \text{ psi}} (9.56 \text{ in}) = 14.51 \text{ k / ft} \]
\[ \phi V_n = \phi V_c = (0.750)(14.51 \text{ k / ft}) = 10.89 \text{ k / ft} \]

Shear Capacity (ACI 318-14 11.5.5.1, 22.5.1.1, 22.5.5.1) @ 10 ft from base [Negative shear]
\[ \lambda = 1.0 \quad \text{(normal weight concrete)} \]
\[ V_c = 2 \lambda \sqrt{F_c} d = 2 (1.0) \sqrt{4000 \text{ psi}} (9.56 \text{ in}) = 14.51 \text{ k / ft} \]
\[ \phi V_n = \phi V_c = (0.750)(14.51 \text{ k / ft}) = 10.89 \text{ k / ft} \]
## Stem Development/Lap Length Calculations

**Main vertical stem bars (bottom end) - Development Length Calculation (ACI 318-14 11.7.1.2, 25.4.2.3, 25.4.3)**

- $\psi_\ell = 1.0$ (uncoated hooked bars)
- $\psi_c = 0.70$ (based on side cover and extension cover)
- $\psi_t = 1.0$ (no confining reinforcement)
- $\lambda = 1.0$ (normal weight concrete)

$$l_{th} = \left( \frac{\psi_c \psi_t \psi_\ell}{50 \lambda \sqrt{f_c}} \right) d_b = \left[ \frac{(60000 \text{ psi})(1.0)(0.70)(1.0)}{50 (1.0) 4000 \text{ psi}} \right] (0.88 \text{ in}) = 11.82 \text{ in}$$

$$8 d_b = 8 (0.88 \text{ in}) = 7.0 \text{ (minimum limit, does not control)}$$

**Main vertical stem bars (top end) - Development Length Calculation (ACI 318-14 11.7.1.2, 25.4.2.3, 25.4.3)**

- $\psi_t = 1.0$ (bars not horizontal)
- $\psi_\ell = 1.0$ (bar not epoxy coated)
- $\psi_s = 1.0$ (bars are #7 or larger)
- $\lambda = 1.0$ (normal weight concrete)

$$s/2 = (12 \text{ in})/2 = 6 \text{ in}$$

- $c_b + d_b/2 = (2 \text{ in}) + (0.88 \text{ in})/2 = 2.44 \text{ in}$
- $c_b = 2.44 \text{ in}$
- $K_t = 0.0$ (no transverse reinforcement)

$$c_b + K_t = (2.44 \text{ in}) + (0.0) = 2.7857$$

$$l_d = \left( \frac{3}{40} \frac{f_y}{\sqrt{f_c}} \psi_t \psi_\ell \psi_s \right) d_b = \left[ \frac{3}{40} \frac{(60000 \text{ psi})(1.0)(1.0)(1.0)}{4000 \text{ psi}} \right] (2.44 \text{ in}) = 24.9 \text{ in}$$

**2nd curtain vertical bars (top end) - Development Length Calculation (ACI 318-14 11.7.1.2, 25.4.2.3, 25.4.3)**

- $\psi_t = 1.0$ (bars not horizontal)
- $\psi_\ell = 1.0$ (bar not epoxy coated)
- $\psi_s = 1.0$ (bars are #7 or larger)
- $\lambda = 1.0$ (normal weight concrete)

$$s/2 = (12 \text{ in})/2 = 6 \text{ in}$$

- $c_b + d_b/2 = (2 \text{ in}) + (0.88 \text{ in})/2 = 2.44 \text{ in}$
- $c_b = 2.44 \text{ in}$
- $K_t = 0.0$ (no transverse reinforcement)

$$c_b + K_t = (2.44 \text{ in}) + (0.0) = 2.7857$$

$$l_d = \left( \frac{3}{40} \frac{f_y}{\sqrt{f_c}} \psi_t \psi_\ell \psi_s \right) d_b = \left[ \frac{3}{40} \frac{(60000 \text{ psi})(1.0)(1.0)(1.0)}{4000 \text{ psi}} \right] (2.44 \text{ in}) = 24.9 \text{ in}$$
Toe Checks \([1.2D + 1.6L + 1.6H]\)

**Controlling Moment**
Design moment \(M_t\) for toe need not exceed moment at stem base:

- \(M_{toe} = 6.7\) ft·k/ft < \(M_{stem} = 20.29\) ft·k/ft
- \(M_t = 6.7\) ft·k/ft (stem moment does not control)

**Flexure Check (ACI 318-14 13.3.2.1, 7.5.2.1, \#22.3, \#22.2, 7.5.1.1a)**

\[
a = \frac{A_s f_y}{0.85 f_c} = \frac{0.03\text{ in}^2/\text{in} \times 60000\text{ psi}}{0.85 \times 4000\text{ psi}} = 0.46\text{ in}
\]

\[
\phi M_u = 6.7\text{ ft} \cdot \text{k ft} < \frac{M_{toe}}{20.29\text{ ft} \cdot \text{k ft}} = \frac{M_{stem}}{0.29\text{ ft} \cdot \text{k ft}}
\]

**Shear Check (ACI 318-14 13.3.2.1, 7.5.3.1, \#22.5.1, \#22.5.5, 7.5.1.1b)**

\[
\lambda = 1.0 \text{ (normal weight concrete)}
\]

\[
V_c = 2 \lambda \frac{f_c}{12} d = 2(1.0) \times \frac{4000}{12}\text{ psi} \times 8.69\text{ in} = 13.19\text{ k ft/ft}
\]

\[
\phi V_n = \phi V_c = \frac{0.750(13.19\text{ k ft/ft})}{9.89\text{ k ft/ft}} = 0.756
\]

\[
\phi V_n \geq V_u = 4.27\text{ k ft/ft}
\]

**Minimum Strain Check (ACI 318-14 13.3.2.1, 7.3.3.1)**

\[
\phi M_n \geq M_u = 6.7\text{ ft} \cdot \text{k ft}
\]

**Minimum Steel Check (ACI 318-14 13.3.2.1, 9.6.1)**

\[
\rho_{ST_{prov}} \geq \rho_{ST_{min}} = 0.0018
\]

18 inch limit governs

**Shrinkage and Temperature Steel (ACI 318-14 13.2.8.1, 7.6.4.1, 24.4.3.2, 24.4.3.3)**

\[
\rho_{ST_{prov}} \geq \rho_{ST_{min}} = 0.0018
\]

18 inch limit governs

**Development Check (ACI 318-14 13.2.8.1, 25.4.2.3, 25.4.10)**

\[
\frac{M_{toe}}{M_{stem} \times 0.5679} = \frac{6.7\text{ ft} \cdot \text{k ft}}{11.8\text{ ft} \cdot \text{k ft}} = 0.5679 \text{ (ratio to represent excess reinforcement)}
\]

\[
\frac{\phi M_u}{\phi M_n} = \frac{6.7\text{ ft} \cdot \text{k ft}}{11.8\text{ ft} \cdot \text{k ft}} = 0.5679
\]

\[
\psi_t \psi_e \psi_s = \frac{0.85}{1.0} \times \frac{0.63\text{ in}}{14.23\text{ in}} = 0.0456
\]

\[
\psi_t \psi_e \psi_s \geq 0.004
\]

QuickRWall 5.0 (iesweb.com) C:\Users\izorrilla\OneDr...\retaining walls for tunnel (DL).rwd Page 10 of 15 Saturday 03/06/21 2:25 PM
Heel Checks  \([1.2D + 1.6L + 1.6H]\)

### Controlling Moment
Design moment \(M_u\) for heel need not exceed moment at stem base:
\[
M_{\text{heel}} = 5.96 \text{ ft·k} < M_{\text{stem}} = 20.29 \text{ ft·k} \quad \text{and} \quad M_a = 5.96 \text{ ft·k} \quad \text{(stem moment does not control)}
\]

**Flexure Check (ACI 318-14 13.3.2.1, 7.5.2.1, 22.3, 22.2, 7.5.1.1a)**
\[
a = \frac{A_{s f} f_y}{0.85 f_c} = \frac{(0.03 \text{ in}^2/\text{in})(60000 \text{ psi})}{0.85(4000 \text{ psi})} = 0.46 \text{ in}
\]
\[
M_{\text{heel}} = \varepsilon f_y (d - a/2) = (0.90)(0.03 \text{ in}^2/\text{in})(60000 \text{ psi})(0.96 \text{ in})(0.46 \text{ in}/2) = 13.2 \text{ ft·k} / \text{ft} \geq M_u = 5.96 \text{ ft·k} / \text{ft}
\]

**Shear Check (ACI 318-14 13.3.2.1, 7.5.3.1, 22.5.1, 22.5.5, 7.5.1.1b)**
\[
\lambda = 1.0 \quad \text{(normal weight concrete)}
\]
\[
V_C = 2 \lambda f_y d = 2(1.0)(4000 \text{ psi})(0.69 \text{ in}) = 14.7 \text{ k} / \text{ft}
\]
\[
\phi V_n = \phi V_C = (0.750)(14.7 \text{ k} / \text{ft}) = 11.03 \text{ k} / \text{ft} \geq V_u = 5.96 \text{ k} / \text{ft}
\]

**Minimum Strain Check (ACI 318-14 13.3.2.1, 7.3.3.1)**
\[
\beta = 0.85 \quad \text{for} \quad f_c < 4000 \text{ psi}
\]
\[
a = \frac{A_{s f} f_y}{0.85 f_c} = \frac{(0.03 \text{ in}^2/\text{in})(60000 \text{ psi})}{0.85(4000 \text{ psi})} = 0.46 \text{ in}
\]
\[
\epsilon_t = 0.003 \left( \frac{d}{\lambda} - 1 \right) = 0.003 \left( \frac{0.46 \text{ in}}{1.0} - 1 \right) = 0.0052
\]
\[
\epsilon_t = 0.0052 \geq 0.004 \quad \checkmark
\]

**Minimum Steel Check (ACI 318-14 13.3.2.1, 9.6.1)**
\[
M_n = 13.2 \text{ ft·k} / \text{ft} \geq \frac{4}{3} M_u = \frac{4}{3}(5.96 \text{ ft·k} / \text{ft}) = 7.95 \text{ ft·k} / \text{ft}
\]

Check is waived per ACI 9.6.1.3

### Shrinkage and Temperature Steel (ACI 318-14 13.2.8.1, 7.6.4.1, 24.4.3.2, 24.4.3.3)
\[
P_{ST \text{ prov}} = \frac{A_{ST}}{f_y} = \frac{(0.62 \text{ in}^2/\text{in})(12 \text{ in})(12 \text{ in})}{(60000 \text{ psi})} = 0.0043
\]
\[
P_{ST \text{ prov}} = \frac{A_{ST}}{f_y} = \frac{(0.62 \text{ in}^2/\text{in})(12 \text{ in})(12 \text{ in})}{(60000 \text{ psi})} = 0.0043
\]
\[
0.0018(60000) = 0.0018
\]
\[
P_{ST \text{ min}} = 0.0018
\]
\[
P_{ST \text{ prov}} = 0.0043 \geq P_{ST \text{ min}} = 0.0018 \quad \checkmark
\]

18 inch limit governs
\[
s_{ST \text{ max}} = 18 \text{ in}
\]
\[
s_{ST} = 12 \text{ in} \leq s_{ST \text{ max}} = 18 \text{ in} \quad \checkmark
\]

**Development Check (ACI 318-14 13.2.8.1, 25.4.2.3, 25.4.10)**
\[
\frac{M_n}{M_u} = \frac{13.2 \text{ ft·k} / \text{ft}}{5.96 \text{ ft·k} / \text{ft}} = 0.4516 \quad \text{(ratio to represent excess reinforcement)}
\]
\[
\gamma_t = 1.0 \quad \text{(12 inches or less cast below - 0.38 inches)}
\]
\[
\gamma_a = 1.0 \quad \text{(bar not epoxy coated)}
\]
\[
\lambda_s = 0.80 \quad \text{(bars are #6 or smaller)}
\]
\[
\lambda = 1.0 \quad \text{(normal weight concrete)}
\]
\[
s/2 = (12 \text{ in})/2 = 6 \text{ in}
\]
\[
cover + d_b/2 = (2 \text{ in}) + 0.63 \text{ in})/2 = 2.31 \text{ in}
\]
\[
\gamma_b = 2.31 \text{ in} \quad \text{(lesser of half spacing, ctr to surface)}
\]
\[
K_d = 0.0 \quad \text{(no transverse reinforcement)}
\]
\[
\phi \gamma_b + K_d = (2.31 \text{ in}) + (0.0) = 3.70
\]
\[
I_d = \left( 3 \left( \frac{1}{0.63 \text{ in}} \right) \frac{f_y}{f_c} \frac{\gamma_a \gamma_b}{2.5} \right) d_b = \left[ 3 \left( \frac{1}{0.63 \text{ in}} \right) \frac{(60000 \text{ psi})}{(1.0)(4000 \text{ psi})} \frac{(1.0)(1.0)(0.80)}{2.5} \right] 0.63 \text{ in} = 14.23 \text{ in}
\]

Factoring \(l_d\) by the excess reinforcement ratio(0.4516) per 25.4.10: \(l_d = 6.43 \text{ in} \)

12 inch minimum controls
\[
l_d \text{ prov} = 106 \text{ in} \geq l_d = 12 \text{ in} \quad \checkmark
\]
### Stem Forces \([1.2D + 1.6L + 1.6H]\)

**Stem Internal Forces**

- **Moment**
  - At stem base: \(-452.23\) psf
  - \(-243.54\) psf

- **Shear**
  - \(-20.29\) k/ft

**Stem Joint Force Transfer**

- **Location**: @ stem base
- **Force**: 4.87 k/ft

**Stem Internal Forces**

- **Moment**
  - At stem base: \(-452.23\) psf
  - \(-243.54\) psf

- **Shear**
  - \(-20.29\) k/ft
Stem Moment Checks \[1.2D + 1.6L + 1.6H\]

Check (ACI 318-14 11.5.5.1b) @ 0 ft from base
\[ \phi M_n = 219 \text{ ft·k/ft} \geq M_u = 20.29 \text{ ft·k/ft} \]

Check (ACI 318-14 11.5.5.1b) @ 7.92 ft from base
\[ \phi M_n = 64.97 \text{ ft·k/ft} \geq M_u = 0.63 \text{ ft·k/ft} \]

Check (ACI 318-14 11.5.5.1b) @ 7.98 ft from base
\[ \phi M_n = 63.25 \text{ ft·k/ft} \geq M_u = 0.58 \text{ ft·k/ft} \]
Stem Shear Checks \([1.2D + 1.6L + 1.6H]\)

**Shear Check (ACI 318-14 11.5.5.1c) @ 0 ft from base**

\[ \varphi V_n = 92.85 \text{ k/ft} \geq V_u = 4.87 \text{ k/ft} \quad \checkmark \]
Stem Miscellaneous Checks \([1.2D + 1.6L + 1.6H]\)

Minimum Steel Check (ACI 318-14 9.6.1) @ 0 ft from base \([\text{Stem in negative flexure}]\)

\[
\phi M_n = 219 \text{ ft}\cdot\text{k ft} \geq \frac{4}{3} [\frac{4}{3}] (20.29 \text{ ft}\cdot\text{k ft}) = 27.06 \text{ ft}\cdot\text{k ft}
\]

Check is waived per ACI 9.6.1.3  

Minimum Steel Check (ACI 318-14 9.6.1) @ 10 ft from base \([\text{Stem in negative flexure}]\)

\[
\phi M_n = 0 \text{ ft}\cdot\text{k ft} \geq \frac{4}{3} [\frac{4}{3}] (0 \text{ ft}\cdot\text{k ft}) = 0 \text{ ft}\cdot\text{k ft}
\]

Check is waived per ACI 9.6.1.3  

Maximum Steel Check (ACI 318-14 9.3.3.1) @ 0 ft from base \([\text{Stem in negative flexure}]\)

\[
\beta_1 = 0.85 \quad \text{if} \quad f' \leq 4000 \text{ psi}
\]

\[
a = \frac{0.85 F'_c}{0.85 (40000 \text{ psi})} = 0.88 \text{ in}
\]

\[
\kappa_1 = 0.003 \left( \frac{d}{a/\beta_1} - 1 \right) = 0.003 \left[ \frac{0.88 \text{ in}}{0.850} - 1 \right] = 0.2327
\]

\[
\kappa_1 = 0.2327 \geq 0.004 
\]

Maximum Steel Check (ACI 318-14 9.3.3.1) @ 10 ft from base \([\text{Stem in negative flexure}]\)

\[
\beta_1 = 0.85 \quad \text{if} \quad f' \leq 4000 \text{ psi}
\]

\[
a = \frac{0.85 F'_c}{0.85 (40000 \text{ psi})} = 0.88 \text{ in}
\]

\[
\kappa_1 = 0.003 \left( \frac{d}{a/\beta_1} - 1 \right) = 0.003 \left[ \frac{0.88 \text{ in}}{0.850} - 1 \right] = 0.0246
\]

\[
\kappa_1 = 0.0246 \geq 0.004 
\]

Wall Horizontal Steel (ACI 318-14 11.6.1, 11.7.3)

\[
\rho_t = \frac{A_{s_{\text{horz}}}}{t} = \frac{0.62 \text{ in}^2}{(84 \text{ in})} = 0.0006
\]

\[
\rho_{t_{\min}} = 0.0020 \quad \text{[bars No. 5 or less, not less than 60 ksi]} \quad < \rho_t \quad \text{\texttimes}
\]

3 h = 3 (12 in) = 36 in

18 inch limit governs

\[
s_{\text{horz}} = 12 \text{ in} \leq s_{\text{horz_max}} = 18 \text{ in} 
\]

Development Check (ACI 318-14 11.7.1.2, 25.4.2.3, 25.4.10)

\[
\frac{M_{\text{ex}}}{M_{\text{en}}} = \frac{20.29 \text{ ft}\cdot\text{k ft}}{219 \text{ ft}\cdot\text{k ft}} = 0.0927 \quad \text{(ratio to represent excess reinforcement)}
\]

\[
\psi_e = 1.0 \quad \text{[uncoated hooked bars]}
\]

\[
\psi_c = 0.70 \quad \text{[based on side cover and extension cover]}
\]

\[
\psi_r = 1.0 \quad \text{[no confining reinforcement]}
\]

\[
\lambda = 1.0 \quad \text{[normal weight concrete]}
\]

\[
\delta_b = \left( \frac{50 \lambda}{50} \right) \left( \frac{F'_c}{40000 \text{ psi}} \right) = \frac{(60000 \text{ psi})(0.70)(1.0)}{50} \left( \frac{0.88 \text{ in}}{50 \text{ in}} \right) = 11.62 \text{ in}
\]

Factoring \(\delta_b\) by the excess reinforcement ratio(0.0927) per 25.4.10: \(\delta_b = 1.08 \text{ in}\)

8 \(\delta_b = 8 (0.88 \text{ in}) = 7.0\)

8\(\delta_b\) minimum controls

\[
\delta_{\text{prov}} = 9 \text{ in} \geq \delta_b = 7 \text{ in} \quad \text{\textcheckmark}
\]
Deck and Stair Design
Design Detail

Check Summary

<table>
<thead>
<tr>
<th>Ratio Check</th>
<th>Provided</th>
<th>Required</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Flexure (-Z)</td>
<td>720.3 in k</td>
<td>22.95 in k</td>
<td>1.2D + 1.6S</td>
</tr>
<tr>
<td>X Flexure (+Z)</td>
<td>720.3 in k</td>
<td>22.95 in k</td>
<td>1.2D + 1.6S</td>
</tr>
<tr>
<td>Z Flexure (-X)</td>
<td>824.9 in k</td>
<td>22.95 in k</td>
<td>1.2D + 1.6S</td>
</tr>
<tr>
<td>Z Flexure (+X)</td>
<td>824.9 in k</td>
<td>22.95 in k</td>
<td>1.2D + 1.6S</td>
</tr>
<tr>
<td>Shear (-Z)</td>
<td>17.26 ft k</td>
<td>2.11 ft k</td>
<td>1.2D + 1.6S</td>
</tr>
<tr>
<td>Shear (+Z)</td>
<td>17.26 ft k</td>
<td>2.11 ft k</td>
<td>1.2D + 1.6S</td>
</tr>
<tr>
<td>Shear (-X)</td>
<td>19.42 ft k</td>
<td>1.66 ft k</td>
<td>1.2D + 1.6S</td>
</tr>
<tr>
<td>Shear (+X)</td>
<td>19.42 ft k</td>
<td>1.66 ft k</td>
<td>1.2D + 1.6S</td>
</tr>
<tr>
<td>Min Steel Z</td>
<td>3.1 in²</td>
<td>0.78 in²</td>
<td>1.4D</td>
</tr>
<tr>
<td>Min Steel X</td>
<td>3.1 in²</td>
<td>0.78 in²</td>
<td>1.4D</td>
</tr>
<tr>
<td>Min Strain Z</td>
<td>0.0055</td>
<td>0.0040</td>
<td>1.2D + 1.6S</td>
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<tr>
<td>Min Strain X</td>
<td>0.0055</td>
<td>0.0040</td>
<td>1.2D + 1.6S</td>
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<tr>
<td>Punching Shear</td>
<td>189.7 psi</td>
<td>20.84 psi</td>
<td>1.2D + 1.6S</td>
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</tbody>
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Pedestal

<table>
<thead>
<tr>
<th>Ratio Check</th>
<th>Provided</th>
<th>Required</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial</td>
<td>777.8 k</td>
<td>24.2 k</td>
<td>1.2D + 1.6S</td>
</tr>
<tr>
<td>Biaxial Bending</td>
<td>0.000</td>
<td>1.000</td>
<td>1.4D</td>
</tr>
<tr>
<td>Shear X</td>
<td>77.74 k</td>
<td>0 k</td>
<td>1.4D</td>
</tr>
<tr>
<td>Shear Z</td>
<td>77.74 k</td>
<td>0 k</td>
<td>1.4D</td>
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</tbody>
</table>

Interface

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<th>Ratio Check</th>
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<th>Combination</th>
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</thead>
<tbody>
<tr>
<td>Bearing (footing)</td>
<td>1685 k</td>
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<tr>
<td>Bearing (pedestal)</td>
<td>977.6 k</td>
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<td>1.2D + 1.6S</td>
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<tr>
<td>Tension</td>
<td>129.6 k</td>
<td>0 k</td>
<td>1.4D</td>
</tr>
<tr>
<td>Dowel Dev (ftg)</td>
<td>6 in</td>
<td>0 in</td>
<td>1.4D</td>
</tr>
<tr>
<td>Dowel Dev (ped)</td>
<td>22.5 in</td>
<td>0 in</td>
<td>1.4D</td>
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<tr>
<td>Min Steel</td>
<td>2.4 in²</td>
<td>2 in²</td>
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</table>

Stability

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<tr>
<th>Ratio Check</th>
<th>Provided</th>
<th>Required</th>
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</thead>
<tbody>
<tr>
<td>Bearing Pressure</td>
<td>3000 psf</td>
<td>2020 psf</td>
<td>1.0D + 1.0S</td>
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<tr>
<td>Overturming-X</td>
<td>Infinite</td>
<td>1.500</td>
<td>1.0D + 1.0S</td>
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<tr>
<td>Overturming-Z</td>
<td>Infinite</td>
<td>1.500</td>
<td>1.0D + 1.0S</td>
</tr>
<tr>
<td>Sliding-X</td>
<td>Infinite</td>
<td>1.500</td>
<td>1.0D + 1.0S</td>
</tr>
<tr>
<td>Sliding-Z</td>
<td>Infinite</td>
<td>1.500</td>
<td>1.0D + 1.0S</td>
</tr>
<tr>
<td>Uplift</td>
<td>Infinite</td>
<td>1.500</td>
<td>1.0D + 1.0S</td>
</tr>
</tbody>
</table>

Loads Summary (Service Loads)

<table>
<thead>
<tr>
<th>Load Set Name</th>
<th>Source</th>
<th>P</th>
<th>Mx</th>
<th>Mz</th>
<th>Vx</th>
<th>Vz</th>
<th>Overburden</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Load Set</td>
<td>Snow</td>
<td>10 k</td>
<td>0 in k</td>
<td>0 in k</td>
<td>0 k</td>
<td>0 k</td>
<td>0 psf</td>
</tr>
<tr>
<td>New Load Set</td>
<td>Dead</td>
<td>6 k</td>
<td>0 in k</td>
<td>0 in k</td>
<td>0 k</td>
<td>0 k</td>
<td>0 psf</td>
</tr>
<tr>
<td>New Load Set</td>
<td>Dead</td>
<td>5 k</td>
<td>0 in k</td>
<td>0 in k</td>
<td>0 k</td>
<td>0 k</td>
<td>0 psf</td>
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<tr>
<td>New Load Set</td>
<td>Live</td>
<td>10 k</td>
<td>0 in k</td>
<td>0 in k</td>
<td>0 k</td>
<td>0 k</td>
<td>0 psf</td>
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### Strength Check Results Summary

#### Load Combination

<table>
<thead>
<tr>
<th>Set: New Load Set</th>
<th>1.4D</th>
<th>1.2D + 1.6S</th>
<th>1.2D + 0.5S</th>
<th>1.2D + 0.2S</th>
<th>1.2D</th>
<th>1.2D + 1.6L</th>
<th>1.2D + 0.5L</th>
<th>1.2D</th>
<th>0.5D</th>
<th>0.9D</th>
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<tbody>
<tr>
<td>Factored Axial</td>
<td>10.18</td>
<td>12.2</td>
<td>13.17</td>
<td>10.51</td>
<td>8.73</td>
<td>6.55</td>
<td>8.94</td>
<td>7.2</td>
<td>5.35</td>
<td>0.6D</td>
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<tr>
<td>Factored Moment-X</td>
<td>10.18</td>
<td>22.95</td>
<td>22.95</td>
<td>12.2</td>
<td>8.73</td>
<td>6.55</td>
<td>8.94</td>
<td>7.2</td>
<td>5.75</td>
<td>0.6D</td>
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<tr>
<td>Factored Moment-Z</td>
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<td>1.66</td>
<td>0.95</td>
<td>0.76</td>
<td>0.63</td>
<td>0.47</td>
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<tr>
<td>Factored Shear-X</td>
<td>0.93</td>
<td>2.11</td>
<td>1.21</td>
<td>0.76</td>
<td>0.63</td>
<td>0.47</td>
<td>0.45</td>
<td>0.8</td>
<td>0.53</td>
<td>0.55</td>
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<tr>
<td>Factored Shear-Z</td>
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<td>11.37</td>
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<td>9.96</td>
<td>0.8</td>
<td>0.6</td>
<td>0.6</td>
<td>0.7</td>
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<td>0.7</td>
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<tr>
<td>Overburden</td>
<td>3.87</td>
<td>20.94</td>
<td>10.7</td>
<td>4.33</td>
<td>3.32</td>
<td>2.49</td>
<td>2.2</td>
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<td>1.66</td>
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<td>Mu depl (channel)</td>
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<tr>
<td>Mu depl (pedestal)</td>
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<td>Mu depl max (channel)</td>
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<tr>
<td>Mu depl max (pedestal)</td>
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#### Stability Check Results Summary

<table>
<thead>
<tr>
<th>Set: New Load Set</th>
<th>1.4D</th>
<th>1.2D + 1.6S</th>
<th>1.2D + 0.5S</th>
<th>1.2D + 0.2S</th>
<th>1.2D</th>
<th>1.2D + 1.6L</th>
<th>1.2D + 0.5L</th>
<th>1.2D</th>
<th>0.5D</th>
<th>0.9D</th>
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<tbody>
<tr>
<td>Factored Axial</td>
<td>16</td>
<td>23.2</td>
<td>12</td>
<td>9.2</td>
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<td>7</td>
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<td>7.96</td>
<td>5.75</td>
<td>4.5</td>
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<td>Factored Moment-X</td>
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<tr>
<td>Overburden (psf)</td>
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<td>1.35</td>
<td>1.35</td>
<td>1.35</td>
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<td>1.35</td>
<td>1.35</td>
<td>1.35</td>
<td>1.35</td>
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<tr>
<td>Mu depl (channel)</td>
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<td>0.83</td>
<td>0.83</td>
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<td>Mu depl (pedestal)</td>
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<td>Max Applied Bearing (psf)</td>
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### Allowable Bearing

<table>
<thead>
<tr>
<th>Footing</th>
<th>Overturning-X</th>
<th>Overturning-Z</th>
<th>Sliding-X</th>
<th>Sliding-Z</th>
<th>Uplift</th>
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</thead>
<tbody>
<tr>
<td>Mu depl max (channel)</td>
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<tr>
<td>Max Applied Bearing (psf)</td>
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</table>
Deck and stairs

Capacity Calcs

Footing X-Direction Capacity

General Section Calcs (ACI 318-14 13.3.3.1n, 7.5.2.1n, 22.3n, 22.2)

$\lambda = 1.0$ (normal weight concrete)

$M_n = \psi M (d - a / 2) = (0.90)(3.1 \text{ in})(60000 \text{ psi})\left[\frac{5.69 \text{ in}}{1.52 \text{ in}}\right] = 824.9 \text{ in\cdot k}$

$V_c = \phi \lambda F_c b w d = (0.750) 2 (1.0) (4000 \text{ psi})(36 \text{ in})(5.69 \text{ in}) = 19.42 \text{ k}$

A_{min} = \frac{0.0018(60000)}{(60000 \text{ psi})} = 0.0018 \text{ in}^2

$\nu = 0.003 \left[\frac{d}{\beta_1} - 1\right] = 0.003 \left[\frac{5.69 \text{ in}}{(1.52 \text{ in})(0.850)} - 1\right] = 0.0065$

Capacity Calcs (ACI 318-14 13.3.3.1n, 7.5.2.1n, 7.5.3.1n, 22.3n, 22.2, 7.6.1.1, 22.5.5.1, 19.2.4, 21.2)

$\psi_t = 1.0$ (12 inches or less cast below - 6.00 inches)

$\psi_e = 1.0$ (bar not epoxy coated)

$\psi_s = 0.80$ (bars are #6 or smaller)

$\lambda = 1.0$ (normal weight concrete)

$s / 2 = (2.34 \text{ in}) / 2 = 1.17 \text{ in}$

$\gamma_0 = 1.17 \text{ in}$ (less of half spacing, ctr to surface)

$K_{tr} = 0.0$ (no transverse reinforcement)

$d = \frac{3}{40} f_y \frac{\psi_t \psi_e \psi_s \gamma_0}{F_c (\frac{d_a}{\beta_1})} d_b = \frac{3}{40} \left[\frac{(60000 \text{ psi}) (1.0)(1.0)(0.80)}{(1.0)(1.0)(0.80)}\right] (0.63 \text{ in}) = 19.02 \text{ in}$

Development (ACI 318-14 13.2.8.1n, 25.4.2)

$\nu_t = 1.0$

$\nu_e = 1.0$

$\nu_s = 0.80$

$\lambda = 1.0$

$s / 2 = (2.34 \text{ in}) / 2 = 1.17 \text{ in}$

$\gamma_0 = 1.17 \text{ in}$

$K_{tr} = 0.0$

$d = \frac{3}{40} f_y \frac{\psi_t \psi_e \psi_s \gamma_0}{F_c (\frac{d_a}{\beta_1})} d_b = \frac{3}{40} \left[\frac{(60000 \text{ psi}) (1.0)(1.0)(0.80)}{(1.0)(1.0)(0.80)}\right] (0.63 \text{ in}) = 19.02 \text{ in}$
Capacity Calcs (continued)

Footing Z-Direction Capacity

General Section Calcs (ACI 318-14 13.3.3.1m, 7.5.2.1m, 22.3m, 22.2)

\[
a = \frac{A_s f_y}{0.85 f_c b_w} = \left(\frac{3.1 \text{ in}^2}{[60000 \text{ psi}]}\right) \left(\frac{0.85 \text{ in}}{4000 \text{ psi}}\right) = 1.52 \text{ in}
\]

\[
\beta_t = 0.850 \quad \left(F_c \leq 4000 \text{ psi}\right)
\]

\[
x = \frac{a}{\beta_t} = \left(\frac{1.52 \text{ in}}{0.850}\right) = 1.79 \text{ in}
\]

Capacity Calcs (ACI 318-14 13.3.3.1m, 7.5.2.1m, 7.5.3.4m, 22.3m, 22.2, 7.6.1.1, 22.5.5.1, 19.2.4, 21.2)

\[
\lambda = 1.0 \quad \text{(normal weight concrete)}
\]

\[
e\omega = \varphi A_s f_y (d - a / 2) = (0.90)(3.1 \text{ in}^2)(60000 \text{ psi})\left(\frac{5.06 \text{ in}}{1.52 \text{ in}}\right) = 720.3 \text{ in} \cdot \text{k}
\]

\[
e\omega = \varphi A_c \lambda F_c b_w d = (0.750) \left(\frac{1.0}{1.0}\right)(4000 \text{ psi})(36 \text{ in})(5.06 \text{ in}) = 17.29 \text{ k}
\]

\[
A_{min} = \frac{0.0018(60000)}{(60000 \text{ psi})} = 0.0018 \text{ in}^2
\]

\[
\nu_t = 0.003 \left[ \frac{d}{a / \beta_t} \right] = 0.003 \left[ \frac{5.06 \text{ in}}{1.79 \text{ in}} \right] = 0.0055
\]

Development (ACI 318-14 13.2.8.1m, 25.4.2)

\[
\psi_t = 1.0 \quad \text{(12 inches or less cast below - 6.00 inches)}
\]

\[
\psi_e = 1.0 \quad \text{(bar not epoxy coated)}
\]

\[
\psi_s = 0.80 \quad \text{(bars are #6 or smaller)}
\]

\[
\lambda = 1.0 \quad \text{(normal weight concrete)}
\]

\[
s / 2 = (2.34 \text{ in}) / 2 = 1.17 \text{ in}
\]

\[
c + d_b / 2 = (6 \text{ in}) + (0.63 \text{ in}) / 2 = 6.31 \text{ in}
\]

\[
C_p = 1.17 \text{ in} \quad \text{(lesser of half spacing, ctr to surface)}
\]

\[
h = 0.0 \quad \text{(no transverse reinforcement)}
\]

\[
l_d = \frac{3}{40} \lambda \left(\frac{f_y}{F_c}\right) \left(\frac{\psi_t \psi_e \psi_s}{d_b}ight) = \frac{3}{40} \left(\frac{60000 \text{ psi}}{1.0}(1.0)(0.80)\left(\frac{0.63 \text{ in}}{0.63 \text{ in}}\right)\right) = 19.02 \text{ in}
\]
**Deck and Stairs**

**Capacity Calcs (continued)**

### Footing Punching Shear Capacity

#### Punching Shear (ACI 318-14 13.3.3.1, 8.5.3.1.2, 22.6.5, 22.6.1.2, 21.2.1)

- \( \alpha_d = 40.0 \) (interior column)
- \( \lambda = 1.0 \) (normal weight concrete)

\[(a) \quad v_c = 4 \lambda \frac{F_c}{f} = 4(1.0) \frac{4000 \text{ psi}}{253 \text{ psi}} = 37.95 \text{ psi} \]

\[(b) \quad v_c = \left[ 2 + \frac{4}{(1.0)} \lambda \frac{F_c}{f} = \left[ 2 + \frac{4}{(1.0)} \frac{253 \text{ psi}}{4000 \text{ psi}} \right] \right] (1.0) \frac{4000 \text{ psi}}{253 \text{ psi}} = 37.95 \text{ psi} \]

\[(c) \quad v_c = \left( 2 + \frac{4}{(1.0)} \lambda \frac{F_c}{f} = \left[ 2 + \frac{4}{(1.0)} \frac{25.38 \text{ in}}{101.5 \text{ in}} \right] \right) (1.0) \frac{4000 \text{ psi}}{253 \text{ psi}} = 260.5 \text{ psi} \]

\[\phi v_n = v_c = 253 \text{ psi} = 189.7 \text{ psi} \]

**Values needed for check (ACI 318-14 8.4.4.2.2, 8.4.2.3.2, R8.4.4.2.3)**

\[\gamma_x = 1 - \frac{1}{1 + \frac{2}{3} \frac{d_y}{b_x}} = 1 - \frac{1}{1 + \frac{2}{3} \frac{25.38 \text{ in}}{25.38 \text{ in}}} = 0.40 \]

\[\gamma_z = 1 - \frac{1}{1 + \frac{2}{3} \frac{d_y}{b_z}} = 1 - \frac{1}{1 + \frac{2}{3} \frac{25.38 \text{ in}}{25.38 \text{ in}}} = 0.40 \]

\[J_x = 59204 \text{ in}^4 \quad \text{(calculated from ACI 318 R8.4.2.2.3)} \]

\[J_y = 59204 \text{ in}^4 \quad \text{(calculated from ACI 318 R8.4.2.2.3)} \]

### Pedestal Shear Capacity

#### Shear - X (ACI 318-14 22.5.6.1, 22.5.10.5.3, 22.5.1.1, 21.2)

\[\phi V_C = \phi V_s = \phi V_n = \phi V_f = \phi V_t = \phi V_s \quad \text{(calculated from ACI 318 R8.4.2.2.3)} \]

\[\phi V_n = \phi V_C + \phi V_s = (33.56 \text{ k}) + (43.78 \text{ k}) = 77.34 \text{ k} \]

#### Shear - Z (ACI 318-14 22.5.6.1, 22.5.10.5.3, 22.5.1.1, 21.2)

\[\phi V_C = \phi V_s = \phi V_n = \phi V_f = \phi V_t = \phi V_s \quad \text{(calculated from ACI 318 R8.4.2.2.3)} \]

\[\phi V_n = \phi V_C + \phi V_s = (33.56 \text{ k}) + (43.78 \text{ k}) = 77.34 \text{ k} \]
### Deck and stairs

#### Capacity Calcs (continued)

**Pedestal Axial + Flexural Capacity**

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<thead>
<tr>
<th>Moment (in·k)</th>
<th>Axial (k)</th>
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<tr>
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</tr>
<tr>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Axial (ACI 318-14 22.4.2)**

\[
P_0 = 0.85 \frac{f'_c}{f_y} \left(A_g - A_{st}\right) + f_y A_{st}
\]

\[
= 0.85 \frac{4000}{60000} \left(2.78 \text{ ft}^2 - 2.4 \text{ in}^2\right) + 2.4 \text{ in}^2
\]

\[
= 1496 \text{ k}
\]

\[
e P_{nmax} = 0.80 e P_0 = 0.80 \left(0.650 \times 1496 \text{ k}\right) = 777.8 \text{ k}
\]

\[
\rho_g = A_g / A_{st} = (2.4 \text{ in}^2) / (2.78 \text{ ft}^2) = 0.0060
\]

\[\gamma_{axis} = 0.7688 \quad \text{(ratio extreme bar distance } Z \text{ to width } X)\]

\[\gamma_{Zaxis} = 0.7688 \quad \text{(ratio extreme bar distance } X \text{ to width } X)\]
Capacity Calcs (continued)

Footing-Pedestal Interface Capacity

Compressive Force Transfer (Footing) (ACI 318-14 16.3.3.4, 16.3.1.2, 22.6.3.2)

\[ A_2 = 9 \text{ ft}^2 \] (modified footing area)
\[ A_1 = 2.78 \text{ ft}^2 \] (column area)

\[ \frac{\sqrt{A_2}}{A_1} \cdot (0.85 F_{c} A) = 0.60 (2.78 \text{ ft}^2)(0.85 (4000 \text{ psi})(2.78 \text{ ft}^2)) = 2448 \text{ k} \] (within controls)
\[ 2 (0.85 F_{c} A) = 2 (0.85 (4000 \text{ psi})(2.78 \text{ ft}^2)) = 2720 \text{ k} \]
\[ \phi P_{n} = \phi A_n f_y = (0.650)(2448 \text{ k}) = 1591 \text{ k} \]
\[ \phi P_{cs} = \phi A_n f_y = (0.650)(2.4 \text{ in}^2)(60000 \text{ psi}) = 98.6 \text{ k} \]
\[ \phi P_{int} + \phi P_{cs} = (1591 \text{ k}) + (98.6 \text{ k}) = 1689 \text{ k} \]

Dowel Development Into Footing (Compression) (ACI 318-14 25.4.9)

\[ \psi_f = 1.0 \] (no confining reinforcement)
\[ \lambda = 1.0 \] (normal weight concrete)

\[ l_{bs} = \left[ \left( \frac{f_y}{\psi_f \frac{50}{F_{c}}} \right) d_b \right] = \left[ \left( \frac{60000 \text{ psi}}{(1.0)(0.70)(50)} \right) \right] = 0.88 \text{ in} = 11.82 \text{ in} \]
\[ l_{bs} = 0.0003 f_y d_b = 0.0003(60000 \text{ psi})(1.0)(0.88 \text{ in}) = 15.75 \text{ in} \]
\[ l_{bc} = 16.6 \text{ in} \] (maximum governs)

Dowel Development Into Footing (Tension) (ACI 318-14 13.2.8.1a, 25.4.3)

\[ \psi_t = 1.0 \] (uncoated hooked bar)
\[ \psi_t = 0.70 \] (based on side cover and extension cover)
\[ \psi_t = 1.0 \] (no confining reinforcement)
\[ \lambda = 1.0 \] (normal weight concrete)

\[ l_{bs} = \left[ \left( \frac{f_y}{\psi_t \frac{50}{F_{c}}} \right) d_b \right] = \left[ \left( \frac{60000 \text{ psi}}{(1.0)(50)} \right) \right] = 0.88 \text{ in} = 11.82 \text{ in} \]
\[ l_{bs} = 0.0003 f_y d_b = 0.0003(60000 \text{ psi})(1.0)(0.88 \text{ in}) = 15.75 \text{ in} \]
\[ l_{bc} = 16.6 \text{ in} \] (maximum governs)

Compressive Force Transfer (Column) (ACI 318-14 16.3.3.4, 16.3.1.2, 22.8.3.2)

\[ B_n = 0.85 F_{c} A_1 = 0.85(4000 \text{ psi})(2.78 \text{ ft}^2) = 1360 \text{ k} \] (supporting surface not larger than loaded area)
\[ \phi P_{n} = \phi B_n = (0.650)(1360 \text{ k}) = 884 \text{ k} \]
\[ \phi P_{cs} = \phi A_n f_y = (0.650)(2.4 \text{ in}^2)(60000 \text{ psi}) = 93.6 \text{ k} \]
\[ \phi P_{int} = \phi P_{cs} = (884 \text{ k}) + (93.6 \text{ k}) = 977.6 \text{ k} \]

Tension Force Transfer (ACI 318-14 16.3.1.2, 22.4.3.1)

\[ \phi P_{nt} = \phi f_y A_{nt} = (0.90)(60000 \text{ psi})(2.4 \text{ in}^2) = 129.6 \text{ k} \]

Minimum Steel Across Interface (ACI 318-14 16.3.4.1)

\[ A_{nom} = 0.005 A_1 = 0.005(2.78 \text{ ft}^2) = 2 \text{ in}^2 \]

Dowel Development Into Pedestal (Compression) (ACI 318-14 25.4.9)

\[ \psi_t = 1.0 \] (no confining reinforcement)
\[ \psi_t = 1.0 \] (normal weight concrete)
\[ l_{bs} = \left[ \left( \frac{f_y}{\psi_t \frac{50}{F_{c}}} \right) d_b \right] = \left[ \left( \frac{60000 \text{ psi}}{(1.0)(0.70)(50)} \right) \right] = 0.88 \text{ in} = 11.82 \text{ in} \]
\[ l_{bs} = 0.0003 f_y d_b = 0.0003(60000 \text{ psi})(1.0)(0.88 \text{ in}) = 15.75 \text{ in} \]
\[ l_{bc} = 16.6 \text{ in} \] (maximum governs)

Dowel Development Into Pedestal (Tension) (ACI 318-14 13.2.8.1a, 25.4.2.3)

\[ \psi_t = 1.0 \] (bars are not horizontal)
\[ \psi_t = 1.0 \] (bar not epoxy coated)
\[ \psi_t = 1.0 \] (bars are #7 or larger)
\[ \lambda = 1.0 \] (normal weight concrete)
\[ s/2 = (16.4 \text{ in})/2 = 8.2 \text{ in} \]

cover + \( d_b / 2 = (1.5 \text{ in}) + (0.88 \text{ in})/2 = 1.94 \text{ in} \)
\[ c_b = 1.94 \text{ in} \] (lesser of half spacing, ctr to surface)
\[ K_{nt} = 0.0 \] (no transverse reinforcement)

\[ l_b = \left[ \frac{3 f_y}{\lambda} \frac{l_{bs}}{F_{c}} \cdot \frac{f_y d_b}{s + c_b} \right] = \left[ \frac{3}{40} \left( \frac{60000 \text{ psi}}{1.0} \right) \right] = \left[ \frac{1.94 \text{ in}}{0.70} \right] \]

\[ l_{bc} = 28.12 \text{ in} \]
Strength Checks [Load Set: New Load Set] Combination: 1.2D + 1.6S

Factored Loads

- Axial Force: 23.2 k
- Moment X: 0 in·k
- Moment Z: 0 in·k
- Shear X: 0 k
- Shear Z: 0 k
- Overburden: 0 psf
- Footing Weight: 1.62 k
- Pedestal Weight: 1 k

Resultant = 25.82 k (factored)

Resultant location (X,Z) = (0 ft, -0 ft)

Max pressure (factored) = 2869 psf (includes effects of overburden and footing weight)

Reinforcement Limits

- Min Steel Check (ACI 318-14 7.6.1.1)
  \[ A_t \geq A_{\text{min}} \]  
  \[ 3.1 \text{ in}^2 \geq 0.78 \text{ in}^2 \]  

- Min Strain Check (ACI 318-14 7.3.3.1)
  \[ \varepsilon_t \geq \varepsilon_{\text{min}} \]  
  \[ 0.0065 \geq 0.0040 \]  

Footing Flexure

- Z-Flexure (+X side)
  \[ M_{z1} = R_{z1} d_{z1} = (5738 \text{ lb}) (4 \text{ in}) = 22.95 \text{ in} \cdot \text{k} \]  
  \[ \varepsilon_{M1} = 824.9 \text{ in} \cdot \text{k} \geq M_{u} = 22.95 \text{ in} \cdot \text{k} \]  

- Z-Flexure (-X side)
  \[ M_{z1} = R_{z1} d_{z1} = (5738 \text{ lb}) (4 \text{ in}) = 22.95 \text{ in} \cdot \text{k} \]  
  \[ \varepsilon_{M1} = 824.9 \text{ in} \cdot \text{k} \geq M_{u} = 22.95 \text{ in} \cdot \text{k} \]  

- X-Flexure (+Z side)
  \[ M_{x2} = R_{x2} d_{x2} = (5738 \text{ lb}) (4 \text{ in}) = 22.95 \text{ in} \cdot \text{k} \]  
  \[ \varepsilon_{M2} = 720.3 \text{ in} \cdot \text{k} \geq M_{u} = 22.95 \text{ in} \cdot \text{k} \]  

- X-Flexure (-Z side)
  \[ M_{x2} = R_{x2} d_{x2} = (5738 \text{ lb}) (4 \text{ in}) = 22.95 \text{ in} \cdot \text{k} \]  
  \[ \varepsilon_{M2} = 720.3 \text{ in} \cdot \text{k} \geq M_{u} = 22.95 \text{ in} \cdot \text{k} \]
Footing Shear

Shear (+X side)
\[ V_{x2} = R_{x4} = (1659 \text{ lb}) = 1.66 \text{ k} \]
\[ \varepsilon V_n = 19.42 \text{ k} \geq V_u = 1.66 \text{ k} \]

Shear (-X side)
\[ V_{x4} = R_{x2} = (1659 \text{ lb}) = 1.66 \text{ k} \]
\[ \varepsilon V_n = 19.42 \text{ k} \geq V_u = 1.66 \text{ k} \]

Shear (+Z side)
\[ V_{z2} = R_{z4} = (2107 \text{ lb}) = 2.11 \text{ k} \]
\[ \varepsilon V_n = 17.29 \text{ k} \geq V_u = 2.11 \text{ k} \]

Shear (-Z side)
\[ V_{z4} = R_{z2} = (2107 \text{ lb}) = 2.11 \text{ k} \]
\[ \varepsilon V_n = 17.29 \text{ k} \geq V_u = 2.11 \text{ k} \]

Footing Punching Shear

Punching Shear Check (ACI 318-14 8.5.1.1(d), R8.4.4.2.3)
\[ P_{\text{punching}} = P_{\text{total}} - P_{\text{perimeter}} = (23.2 \text{ k}) + (1 \text{ k}) - (12.83 \text{ k}) = 11.37 \text{ k} \]
\[ V_u = \frac{V_u}{\gamma_d} = \frac{11.37 \text{ k}}{0.35} \]
\[ J = \frac{101.5 \text{ in}}{5.38 \text{ in}} \times 12.69 \text{ in} \times 4 \]
\[ J = 59204 \text{ in}^4 \]
\[ \gamma_v J = 0.40 \times 0 \text{ in} \times 12.69 \text{ in} \times 4 \]
\[ \gamma_v J = 0 \text{ in}^4 \]
\[ \varepsilon V_n = 189.7 \text{ psi} \geq \gamma_v J = 20.84 \text{ psi} \]
Strength Checks [Load Set: New Load Set]  
Combination: 1.2D + 1.6S] (continued)

**Interface**

**Compressive Force Transfer (Footing) (ACI 318-14 22.8.3.1, 16.3.1.2a)**
\[ \phi P_{nh} = 1685 \text{ k} \geq P_{ub} = 24.2 \text{ k} \]

**Tension Force Transfer (ACI 318-14 16.3.1.2b)**
\[ \phi P_{nt} = 129.6 \text{ k} \geq P_{ut} = 0 \text{ k} \]

**Dowel Development (Footing) (ACI 318-14 25.4)**
\[ P_{uc} = 0 \text{ k} \quad \text{(concrete bearing is sufficient: } \phi P_{nc} \geq P_{ub}) \]
\[ \text{ratio} = P_{uc} / P_{nt} = (0 \text{ k}) / (93.6 \text{ k}) = 0.0 \]
\[ l_d = 6 \text{ in} \geq l_{req,dow} = 0 \text{ in} \]

**Compressive Force Transfer (Pedestal) (ACI 318-14 22.8.3.1, 16.3.1.2a)**
\[ \phi P_{nb} = 977.6 \text{ k} \geq P_{ub} = 24.2 \text{ k} \]

**Minimum Steel Across Joint (ACI 318-14 16.3.4.1)**
\[ A_s = 2.4 \text{ in}^2 \geq A_{min} = 2 \text{ in}^2 \]

**Dowel Development (Pedestal) (ACI 318-14 25.4)**
\[ P_{us} = 0.0 \text{ k} \quad \text{(concrete bearing is sufficient: } \phi P_{nc} \geq P_{ub}) \]
\[ \text{ratio} = P_{us} / P_{ns} = (0 \text{ k}) / (93.6 \text{ k}) = 0.0 \]
\[ l_d = 22.5 \text{ in} \geq l_{req,dow} = 0 \text{ in} \]

**Axial/Flexure (ACI 318-14 22.4)**
\[ \phi P_{nmax} = 777.8 \text{ k} \geq P_n = 24.2 \text{ k} \]

**Biaxial Unity**
\[ \frac{M_{nx}}{M_{0x}} + \frac{M_{nz}}{M_{0z}} \left[ \frac{1 - \beta}{1 - \beta} \right] = \left( \frac{0 \text{ in}^2}{1326 \text{ in}^2} \right) + \left( \frac{0 \text{ in}^2}{1326 \text{ in}^2} \right) \left[ \frac{1 - (0.650)}{1 - (0.650)} \right] = 0.0 \]

**Shear Check (ACI 318-14 22.5.6.1, 22.5.1.1, 10.5.1.1c)**
\[ \phi V_c = \phi V_s = \phi V_n = 78.35 \text{ k} \geq V_0 = 0 \text{ k} \]

**Pedestal**

**Axial/Flexure (ACI 318-14 22.4)**
\[ \phi P_{nmax} = 533.3 \text{ k} \geq P_n = 24.2 \text{ k} \]

**Shear Check (ACI 318-14 22.5.6.1, 22.5.1.1, 10.5.1.1c)**
\[ \phi V_c = \phi V_s = \phi V_n = 78.35 \text{ k} \geq V_0 = 0 \text{ k} \]
### Factored Loads

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<thead>
<tr>
<th>Load Type</th>
<th>Value</th>
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<td>Axial Force</td>
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<tr>
<td>Moment Z</td>
<td>0 in·k</td>
</tr>
<tr>
<td>Shear X</td>
<td>0 k</td>
</tr>
<tr>
<td>Shear Z</td>
<td>0 k</td>
</tr>
<tr>
<td>Overburden</td>
<td>0 psf</td>
</tr>
<tr>
<td>Footing Weight</td>
<td>1.89 k</td>
</tr>
<tr>
<td>Pedestal Weight</td>
<td>1.17 k</td>
</tr>
</tbody>
</table>

### Resultant

- Resultant location: (X, Z) = (0 ft, -0 ft)
- Resultant: 11.46 k (factored)
- Max pressure: 1273 psf (includes effects of overburden and footing weight)

### Reinforcement Limits

#### Min Steel Check (ACI 318-14 7.6.1.1)

- A_s = 3.1 in² ≥ A_s min = 0.78 in²  ✔

#### Min Strain Check (ACI 318-14 7.3.3.1)

- ε_t = 0.0055 ≥ ε_s min = 0.0040  ✔

### Footing Flexure

#### Z-Flexure (+X side)

- M_z = R_2 d_2 = (2546 lb)(4 in) = 10.18 in·k
- ε_M = 824.9 in/k ≥ M_z = 10.18 in·k  ✔

#### Z-Flexure (-X side)

- M_z = R_1 d_1 = (2546 lb)(4 in) = 10.18 in·k
- ε_M = 824.9 in/k ≥ M_z = 10.18 in·k  ✔

#### X-Flexure (+Z side)

- M_x = R_1 d_1 = (2546 lb)(4 in) = 10.18 in·k
- ε_M = 720.3 in/k ≥ M_x = 10.18 in·k  ✔

#### X-Flexure (-Z side)

- M_x = R_2 d_2 = (2546 lb)(4 in) = 10.18 in·k
- ε_M = 720.3 in/k ≥ M_x = 10.18 in·k  ✔
**Strength Checks [Load Set: New Load Set Combination: 1.4D] (continued)**

---

**Footing Shear**

**Shear (+X side)**

\[ V_{x2} = R_{x2} = 735.9 \text{ lb} = 0.74 \text{ k} \]

\[ eV_n = 19.42 \text{ k} \geq V_u = 0.74 \text{ k} \]

**Shear (-X side)**

\[ V_{x1} = R_{x1} = 934.8 \text{ lb} = 0.93 \text{ k} \]

\[ eV_n = 17.29 \text{ k} \geq V_u = 0.93 \text{ k} \]

**Shear (+Z side)**

\[ V_{z2} = R_{z2} = 934.8 \text{ lb} = 0.93 \text{ k} \]

\[ eV_n = 17.29 \text{ k} \geq V_u = 0.93 \text{ k} \]

**Shear (-Z side)**

\[ V_{z1} = R_{z1} = 934.8 \text{ lb} = 0.93 \text{ k} \]

\[ eV_n = 17.29 \text{ k} \geq V_u = 0.93 \text{ k} \]

---

**Footing Punching Shear**

**Punching Shear Check (ACI 318-14 8.5.1.1(d), R8.4.4.2.3)**

\[ V_p = \frac{V_{ud} + \gamma_v M_{ux} \theta_x + \gamma_v M_{uz} \theta_z}{b_d d} \]

\[ = \frac{(101.5 \text{ in})(5.38 \text{ in}) + (0.40)(0 \text{ in})(101.5 \text{ in})(12.69 \text{ in}) + (0.40)(0 \text{ in})(101.5 \text{ in})(12.69 \text{ in})}{(39204 \text{ in}^4) + (39204 \text{ in}^4) + (39204 \text{ in}^4)} \]

\[ = 7.1 \text{ psi} \]

\[ \phi V_n = 189.7 \text{ psi} \geq V_u = 7.1 \text{ psi} \]

---
**Strength Checks**

**Interface**

- **Compressive Force Transfer (Footing)** (ACI 318-14 22.8.3.1, 16.3.1.2a)
  \[ \phi P_{nb} = 1685 \text{k} \geq P_{ub} = 9.57 \text{k} \]
- **Tension Force Transfer (ACI 318-14 16.3.1.2b)
  \[ \phi P_{nt} = 129.6 \text{k} \geq P_{ut} = 0 \text{k} \]
- **Dowel Development (Footing)** (ACI 318-14 25.4)
  \[ P_{ub} = 0.0 \text{k} \geq P_{nc} = (0 \text{k})/(93.6 \text{k}) = 0.0 \]
  \[ l_d = 6 \text{ in} \geq l_{req\_dow} = 0 \text{ in} \]

**Pedestal**

- **Compressive Force Transfer (Pedestal)** (ACI 318-14 22.8.3.1, 16.3.1.2a)
  \[ \phi P_{nb} = 977.6 \text{k} \geq P_{ub} = 9.57 \text{k} \]
- **Minimum Steel Across Joint (ACI 318-14 16.3.4.1)**
  \[ A_s = 2.4 \text{ in}^2 \geq A_{min} = 2 \text{ in}^2 \]
- **Dowel Development (Pedestal)** (ACI 318-14 25.4)
  \[ P_{ub} = 0.0 \text{k} \geq P_{ns} = (0 \text{k})/(93.6 \text{k}) = 0.0 \]
  \[ l_d = 22.5 \text{ in} \geq l_{req\_dow} = 0 \text{ in} \]

- **Axial/Flexure (ACI 318-14 22.4)**
  \[ \phi P_{nmax} = 777.8 \text{k} \geq P_{u} = 9.57 \text{k} \]

- **Biaxial Unity (ACI 318-14 10.5.1.1c)**

- **Shear Check (ACI 318-14 22.5.6.1, 22.5.1.1, 10.5.1.1c)**
  \[ \phi V_c = (33.96 \text{k}) + (43.78 \text{k}) = 77.74 \text{k} \]
  \[ \phi V_n = (77.74 \text{k}) \geq V_u = 0 \text{k} \]

**Shear Check (ACI 318-14 22.5.6.1, 22.5.1.1, 10.5.1.1c)**

- **Axial (k)**
  \[ \phi V_c = (33.96 \text{k}) + (43.78 \text{k}) = 77.74 \text{k} \]
  \[ \phi V_n = (77.74 \text{k}) \geq V_u = 0 \text{k} \]
Stability Checks  [Load Set: New Load Set  Combination: 1.0D + 1.0S]

--- Forces ---

Factored Loads

<table>
<thead>
<tr>
<th>Load Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Force</td>
<td>16 k</td>
</tr>
<tr>
<td>Moment X</td>
<td>0 in.k</td>
</tr>
<tr>
<td>Moment Z</td>
<td>0 in.k</td>
</tr>
<tr>
<td>Shear X</td>
<td>0 k</td>
</tr>
<tr>
<td>Shear Z</td>
<td>0 k</td>
</tr>
<tr>
<td>Overburden</td>
<td>0 psf</td>
</tr>
<tr>
<td>Footing Weight</td>
<td>1.35 k</td>
</tr>
<tr>
<td>Pedestal Weight</td>
<td>0.83 k</td>
</tr>
</tbody>
</table>

Resultant location (X,Z) = (0 ft, -0 ft)

Resultant = 18.18 k

Bearing Pressure

\[ q_{allow} \geq q_{gross} \]

\[ q_{allow} = 3000 \text{ psf} \]

\[ q_{gross} = 2020 \text{ psf} \]

Max pressure = 2020 psf

(Gross: Includes effects of footing weight and overburden)

--- Overturning ---

Overturning

\[ W_f = 1.35 \text{ k} \]  (weight of footing)
\[ W_p = 0.83 \text{ k} \]  (weight of pedestal)
\[ F_{ob} = \text{overburden} \cdot (A_{ftg} - A_{pool}) \]
\[ F_{ob} = (0 \text{ psf})(9 \text{ ft}^2 - 2.78 \text{ ft}^2) = 0 \text{ k} \]

F.S. against overturning about X axis is infinite (no applied moment)

F.S. against overturning about Z axis is infinite (no applied moment)

--- Sliding ---

Sliding

\[ W_f = 1.35 \text{ k} \]  (weight of footing)
\[ W_p = 0.83 \text{ k} \]  (weight of pedestal)
\[ F_{ob} = \text{overburden} \cdot (A_{ftg} - A_{pool}) \]
\[ F_{frict} = C_f(W_f + W_p + F_{ob} + P) = (0.40)(1.35 \text{ k} + (0.83 \text{ k}) + (16 \text{ k}) + (7.27 \text{ k}) = 7.27 \text{ k} \]
\[ F_{coh} = c \cdot A_{ftg} \cdot (10 \text{ psf})(9 \text{ ft}^2) = 0 \text{ k} \]
\[ F_{passiveX} = 0 \text{ k} \]
\[ F_{passiveZ} = 0 \text{ k} \]
\[ F_{resistX} = F_{frict} + F_{coh} + F_{passiveX} + F_{add} = (7.27 \text{ k}) + (0 \text{ k}) + (0 \text{ k}) + (0 \text{ k}) = 7.27 \text{ k} \]
\[ F_{resistZ} = F_{frict} + F_{coh} + F_{passiveZ} + F_{add} = (7.27 \text{ k}) + (0 \text{ k}) + (0 \text{ k}) + (0 \text{ k}) = 7.27 \text{ k} \]

F.S. against sliding in X direction is infinite (no applied force)

F.S. against sliding in Z direction is infinite (no applied force)
Stability Checks [Load Set: New Load Set  Combination: 1.0D + 1.0S] (continued)

**Uplift**

![Diagram](image)

- **Uplift**
- \( P = 16 \text{ k} \)
- F.S. against uplift is infinite (axial force is in compression)
Wood Deck Design
Deck Columns

Inner Column (worst case scenario)

\[
DL := 6 \text{ psf}
\]

\[
LL := 100 \text{ psf}
\]

\[
L := 15 \text{ ft}
\]

\[
Load := 6784 \text{ lb}
\]

Red Wood 8X8 N0.2

\[
F_b := 750 \text{ psi}
\]

\[
A := 56.25 \text{ in}^2
\]

\[
C_D := 1.15 \quad \text{Snow load}
\]

\[
C_M := .8 \quad \text{Wet}
\]

\[
C_t := 1 \quad \text{No extreme Heat}
\]

\[
C_F := 1 \quad \text{Not deeper than 12 inches}
\]

\[
C_i := .8 \quad \text{Incised}
\]

\[
C_p := .32 \quad \text{Reference Spreadsheet}
\]

\[
F'_c := F_c \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i \cdot C_p
\]

\[
F'_c = 176.64 \text{ psi}
\]

\[
P_{allowable} := 9936 \text{ lb}
\]

\[
Check := \frac{\text{Load}}{P_{allowable}} = 0.683 \quad \text{OK! 68%}
\]

Use 8x8 Red wood No.2 for all columns
Deck Joist

Red Wood No.2 2x12

\[ F_b := 775 \text{ psi} \]

\[ F_v := 160 \text{ psi} \]

\[ F_{cp} := 425 \text{ psi} \]

\[ E := 1000000 \text{ psi} \]

\[ C_D := 1.15 \quad \text{Snow load} \]

\[ C_M := .85 \quad \text{Wet} \]

\[ C_i := 1 \quad \text{No extreme Heat} \]

\[ C_l := 1 \quad \text{Lateral support} \]

\[ C_F := 1.1 \quad \text{size factor} \]

\[ C_{Fv} := 1 \quad \text{Not using as flat member} \]

\[ C_i := .8 \quad \text{Incised} \]

\[ C_x := 1 \quad \text{Not a repetetive member} \]

\[ C_b := 1 \quad \text{Bearing Area greater than 6"} \]

\[ w := 53 \text{ psf} \]

\[ L := 16 \text{ ft} \]

\[ A := 56.26 \text{ in}^2 \]

\[ l := (96 \text{ in})^4 \]

\[ I := 98.93 \text{ in}^4 \]

\[ W := 17 \text{ plf} \]
Moment

\[ M := 20352 \text{ in} \cdot \text{lb} \]

RXN

\[ R := 848 \text{ lb} \]

\[ S_x := \frac{20352}{725} = 28.072 \]

Use 2x12 Sx=31.64 in^3

Bending

\[ F_b' := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_i \cdot C_F \cdot C_{Fu} \cdot C_r \]

\[ F_b' = 666.655 \text{ psi} \]

\[ fb := \frac{20352}{31.64} \text{ psi} \]

Check := \( \frac{fb}{F_b'} = 0.965 \) OK 96%

Horizontal Shear

\[ F_v' := F_v \cdot C_D \cdot C_M \cdot C_t \cdot C_i \]

\[ F_v' = 125.12 \text{ psi} \]

\[ f_v := 91.64 \text{ psi} \]

Check := \( \frac{f_v}{F_v'} = 0.732 \) OK 73%
Deflection

\[ E' := E \cdot C_M \cdot C_i \cdot C_t \]

\[ E' = (6.8 \cdot 10^5) \text{ psi} \]

Deflection TL

\[ \Delta D := \frac{(5 \cdot W \cdot l)}{384 \cdot E' \cdot I} = 0.023 \text{ in} \]

\[ \Delta D = 0.023 \text{ in} \]

\[ D := \frac{96}{\Delta D} = 4.122 \cdot 10^3 \text{ in} \]

\[ \frac{D}{\Delta D} \leq 360 \text{ and } 240 \]

OK!

Crushing

\[ F_{cP}' := F_{cP} \cdot C_M \cdot C_i \cdot C_t \cdot C_b \]

\[ F_{cP}' = 289 \text{ psi} \]

\[ f_{cp} := 80.76 \text{ psi} \]

\[ \text{Check} := \frac{f_{cp}}{F_{cP}'} = 0.279 \]

OK 27%

Use 2x12 joist 12" O.C.
GuardRail

Using Red Wood Structural Grade

2x4 flat picket design

PLL=200 lbs

\[ P := 200 \text{ lb} \]
\[ L := 42 \text{ in} \]

Forces

\[ M := P \cdot L = 8400 \text{ in} \cdot \text{lb} \]

Per Picket (five Pickets)

\[ p := \frac{M}{5} = 1680 \text{ in} \cdot \text{lb} \]

End reaction per picket

\[ RXN := \frac{P}{5} = 40 \text{ lb} \]

\[ S_x := 1.31 \text{ in}^3 \]
\[ F_b := 1100 \text{ psi} \]
\[ F_v := 160 \text{ psi} \]
\[ F_{cP} := 425 \text{ psi} \]
\[ E := 1000000 \text{ psi} \]
\[ C_D := 1 \quad \text{Live Load 10 Years} \]
\[ C_M := .85 \quad \text{Wet} \]
\[ C_M' := .97 \quad \text{Wet service factor table page 32} \]
\[ C_t := 1 \quad \text{No extreme Heat} \]
\[ C_t := 1 \quad \text{Lateral support} \]
\[ C_F := 1.5 \quad \text{size factor supplement page 32} \]
\[ C_{Fu} := 1.1 \quad \text{Using as flat member} \]
\[ C_i := 1 \quad \text{N/A} \]
\[ C_r := 1 \quad \text{Not a repetitive member} \]

\textbf{Bending:}

\[ F_b' := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_{Fu} \cdot C_i \cdot C_r \]

\[ F_b' = 1542.75 \text{ psi} \]

\[ f_b := \frac{1680}{1.31} = 1282.443 \]

\[ \text{Check} := \frac{f_b \cdot \text{psi}}{F_b'} = 0.831 \quad \text{OK 83\%} \]
Horizontal Shear

\[ F'_v := F_v \cdot C_D \cdot C_M \cdot C_l \cdot C_i \]

\[ F'_v = 155.2 \text{ psi} \]

\[ f_v = 11.42 \text{ psi} \]

\[ \text{Check} := \frac{f_v}{F'_v} = 0.074 \quad \text{OK 7%} \]

use 2x4 Red Wood flat pickets
Deck Beam
Red Wood (2) 3x12 Select Structural

\[ F_b := 1100 \, \text{psi} \]
\[ F_v := 160 \, \text{psi} \]
\[ F_{cp} := 425 \, \text{psi} \]
\[ E := 1100000 \, \text{psi} \]
\[ C_D := 1.15 \quad \text{Snow load} \]
\[ C_M := 0.85 \quad \text{Wet} \]
\[ C_t := 1 \quad \text{No extreme Heat} \]
\[ C_l := 1 \quad \text{Lateral support} \]
\[ C_F := 1.1 \quad \text{size factor} \]
\[ C_{Fu} := 1 \quad \text{Not using as flat member} \]
\[ C_i := 0.8 \quad \text{Incised} \]
\[ C_r := 1 \quad \text{Not a repetetive member} \]
\[ C_b := 1 \quad \text{Bearing Area greater than 6"} \]

\[ w := 53 \, \text{psf} \]
\[ L := 16 \, \text{ft} \]
\[ A := 56.26 \, \text{in}^2 \]
\[ l := (12 \, \text{in} \cdot 8 \, \text{ft})^4 \, \text{in} \]
\[ I := 593.2 \, \text{in}^4 \]
\[ W := \frac{w \cdot 8}{12} \]
\[ M := 40704 \, \text{in} \cdot \text{lb} \]
\( RXN := 1696 \text{ in} \cdot \text{lb} \)

\[ S_x := 45.22 \text{ in}^3 \]

(2) \( 3 \times 12 \times 105.46 \text{ in}^3 \)

**Bending**

\[ F'_b := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_i \cdot C_F \cdot C_{Fw} \cdot C_i \cdot C_r \]

\[ F'_b = 946.22 \text{ psi} \]

\[ \text{Check} := \frac{385.96}{890.56} = 0.433 \quad \text{OK 43%} \]

**Horizontal Shear**

\[ F'_v := F_v \cdot C_D \cdot C_M \cdot C_t \cdot C_i \]

\[ F'_v = 125.12 \text{ psi} \]

\[ f_v = 45.21 \text{ psi} \]

\[ \text{Check} := \frac{f_v}{F'_v} = 0.361 \quad \text{OK 36%} \]

**Deflection**

\[ E' := E \cdot C_M \cdot C_t \cdot C_i \]

\[ E' = (7.48 \times 10^5) \text{ psi} \]

**Deflection TL**

\[ \Delta D := \frac{(5 \cdot W \cdot t)}{384 \cdot E' \cdot I} \]

\[ \Delta D' := 0.088 \]

\[ D := \frac{96}{0.088} = 1.091 \times 10^3 \]
L/1091 < 360 and 240

OK to use

Crushing

\[ F_{cp'} := F_{cp} \cdot C_M \cdot C_I \cdot C_i \cdot C_b \]

\[ F_{cp'} = 289 \text{ psi} \]

\[ f_{cp} := 80.76 \text{ psi} \]

Check: \[ \frac{f_{cp}}{F_{cp'}} = 0.279 \]

Ok 27%
Deck Posts

Using Red Wood Structural Grade

4x4 flat

PLL=250 lbs

\[ P := 250 \text{ lb} \]
\[ L := 40 \text{ in} \]

Forces

\[ M := P \cdot L = 10000 \text{ in} \cdot lb \]

End reaction per picket

\[ RXN := P = 250 \text{ lb} \]

\[ S_x := 7.15 \text{ in}^3 \]
\[ F_b := 1100 \text{ psi} \]
\[ F_e := 160 \text{ psi} \]
\[ F_{cp} := 425 \text{ psi} \]
\[ E := 1100000 \text{ psi} \]
\[ C_D := 1 \text{ Live Load 10 Years} \]
\[ C_M := .85 \text{ Wet} \]
\[ C_t := 1 \text{ No extreme Heat} \]
\[ C_l := 1 \text{ Lateral support} \]
\[ C_F := 1.5 \text{ size factor supplement page 32} \]
\[ C_{Fu} := 1 \text{ N/A} \]
\[ C_i := 1 \text{ N/A} \]
\[ C_r := 1 \text{ Not a repetetive member} \]

Bending
\[ F_b' := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_{Fu} \cdot C_i \cdot C_r \]
\[ F_b' = \left(1.403 \cdot 10^3\right) \text{ psi} \]

\[ fb := \frac{10000}{7.15} = 1.399 \cdot 10^3 \]
\[ Check := \frac{fb \cdot \text{psi}}{F_b'} = 0.997 \text{ OK 99%} \]
Horizontal Shear

\[ F_v' := F_v \cdot C_D \cdot C_M \cdot C_t \cdot C_i \]

\[ F_v' = 136 \text{ psi} \]

\[ f_v := 31 \text{ psi} \]

\[ \text{Check} := \frac{f_v}{F_v'} = 0.228 \quad \text{OK 22%} \]

use 4x4 Red Wood posts

4x4 post Bolt Connection

Moment at base of post = PL

\[ M' := P \cdot L = 10000 \text{ in \cdot lb} \]

Tension at upper bolt

\[ T := \frac{M'}{7.25} = 1379.31 \text{ in \cdot lb} \]

Use Simpson DTT2Z connection
Bolt Connection For GuardRail

Moment = PL

\[ P := 200 \text{ lb} \]

\[ L := 42 \text{ in} + 1.5 \text{ in} + 2 \text{ in} + 5.25 \text{ in} + 2 \text{ in} \]

\[ M := P \cdot L = 10550 \text{ in} \cdot \text{lb} \]

\[ p := \frac{M}{5} = 2110 \text{ in} \cdot \text{lb} \]

We are using 5 pickets

\[ c := 7.25 \text{ in} \]

Tension = \( \frac{M}{c} \)

\[ T := \frac{p}{c} = 291.034 \text{ lb} \]

Using 5/16 in lag screws

\[ G := .37 \text{ NDS Page 87 (specific Gravity)} \]

\[ W := 169 \text{ Withdrawal Value NDS page 77} \]

\[ w := W \cdot 3.5 \text{ lb} \]

\[ C_D := 1 \text{ Live Load 10 Years} \]

\[ C_M := .7 \text{ Wet service factor table page 32} \]

\[ C_t := 1 \text{ No extreme Heat} \]

\[ C_{eg} := 1 \text{ No end grain connection} \]

\[ C_{tn} := 1 \text{ Not a toe nail} \]
\[ W' := w \cdot C_D \cdot C_M \cdot C_t \cdot C_{eg} \cdot C_{tn} \]

\[ W' = 414.05 \text{ lb} \]

\[ \text{Check} := \frac{T}{W'} = 0.703 \quad \text{OK! 70\%} \]

Use 5/16 lag screws
Retaining Wall for Path Design
### Design Detail

Concrete f'c = 3000 psi  
Rebar Fy = 60000 psi  
Unit Weight = 150 lb/ft³

### Check Summary

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Check</th>
<th>Provided</th>
<th>Required</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.660</td>
<td>Overturning</td>
<td>2.27</td>
<td>1.50</td>
<td>1.2D + 1.0H</td>
</tr>
<tr>
<td>0.837</td>
<td>Sliding</td>
<td>1.79</td>
<td>1.50</td>
<td>1.2D + 1.0H</td>
</tr>
<tr>
<td>0.897</td>
<td>Bearing Pressure</td>
<td>3000 psf</td>
<td>2662 psf</td>
<td>1.0D + 1.0H</td>
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<tr>
<td>0.397</td>
<td>Bearing Eccentricity</td>
<td>8.73 in</td>
<td>23 in</td>
<td>1.0D + 1.0H</td>
</tr>
</tbody>
</table>

#### Toe Checks

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Shear</th>
<th>20.4 k/ft</th>
<th>5.73 k/ft</th>
<th>1.2D + 1.6H</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.702</td>
<td>Moment</td>
<td>28.44 ft·k/ft</td>
<td>19.95 ft·k/ft</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.048</td>
<td>Min Strain</td>
<td>0.0838</td>
<td>0.0040</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.000</td>
<td>Min Steel</td>
<td>0.03 in²</td>
<td>0 in²</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.148</td>
<td>Development</td>
<td>81 in</td>
<td>12 in</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.667</td>
<td>S&amp;T Max Spacing</td>
<td>12 in</td>
<td>18 in</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.836</td>
<td>S&amp;T Min Rho</td>
<td>0.0022</td>
<td>0.0018</td>
<td>1.2D + 1.6H</td>
</tr>
</tbody>
</table>

#### Heel Checks

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Shear</th>
<th>21.32 k/ft</th>
<th>14.26 k/ft</th>
<th>1.4D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.733</td>
<td>Moment</td>
<td>41.96 ft·k/ft</td>
<td>30.77 ft·k/ft</td>
<td>1.2D + 1.6H</td>
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<tr>
<td>0.066</td>
<td>Min Strain</td>
<td>0.0609</td>
<td>0.0040</td>
<td>1.2D + 1.6H</td>
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<tr>
<td>0.000</td>
<td>Min Steel</td>
<td>0.04 in²</td>
<td>0 in²</td>
<td>1.2D + 1.6H</td>
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<tr>
<td>0.209</td>
<td>Development</td>
<td>70 in</td>
<td>18.8 in</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.667</td>
<td>S&amp;T Max Spacing</td>
<td>12 in</td>
<td>18 in</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.836</td>
<td>S&amp;T Min Rho</td>
<td>0.0022</td>
<td>0.0018</td>
<td>1.2D + 1.6H</td>
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#### Stem Checks

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Moment</th>
<th>73.88 ft·k/ft</th>
<th>42.78 ft·k/ft</th>
<th>1.2D + 1.6H</th>
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<tbody>
<tr>
<td>0.377</td>
<td>Shear</td>
<td>21.2 k/ft</td>
<td>7.99 k/ft</td>
<td>1.2D + 1.6H</td>
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<tr>
<td>0.123</td>
<td>Max Steel</td>
<td>0.0324</td>
<td>0.0040</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.000</td>
<td>Min Steel</td>
<td>0.07 in²</td>
<td>0 in²</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.424</td>
<td>Base Development</td>
<td>21 in</td>
<td>8.9 in</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.000</td>
<td>Horz Bar Rho</td>
<td>0.0000</td>
<td>0.0000</td>
<td>1.2D + 1.6H</td>
</tr>
<tr>
<td>0.667</td>
<td>Horz Bar Spacing</td>
<td>12 in</td>
<td>18 in</td>
<td>1.2D + 1.6H</td>
</tr>
</tbody>
</table>

### Criteria

- Use basic criteria from common projects: Yes
- Building Code: IBC 2015
- Concrete Load Combs: IBC 2015 (Strength)
- Masonry Load Combs: ASCE 7-16 (ASD)
- Stability Load Combs: IBC Retaining Wall St...
- Apply Sds Factor to Seismic Combination: No
- Restrainted Against Sliding: No
- Neglect Bearing at Heel: Yes
- Use Vert. Comp. for OT: No
- Use Vert. Comp. for Sliding: No
- Use Vert. Comp. for Bearing: Yes
- Use Surcharge for Sliding & OT: Yes
- Use Surcharge for Bearing: Yes
- Neglect Soil Over Toe: No
- Neglect Backfill Wt. for Coulomb: No
- Factor Soil Weight As Dead: Yes
- Use Passive Force for OT: Yes
- Assume Pressure To Top: Yes
- Extend Backfill Pressure To Key Bottom: No
- Use Toe Passive Pressure for Bearing: No
- Required F.S. for OT: 1.50
- Required F.S. for Sliding: 1.50
- Has Different Safety Factors for Seismic: No
- Allowable Bearing Pressure: 3000 psf
- Req’d Bearing Location: Middle third
- Wall Friction Angle: 25°
- Friction Coefficient: 0.35
- Soil Reaction Modulus: 172800 lb/ft³
### Strength Check Results Summary

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Stem M-applied (ft·k/ft)</th>
<th>Stem M-allow (ft·k/ft)</th>
<th>Stem V-applied (k/ft)</th>
<th>Stem V-allow (k/ft)</th>
<th>Stem Min. ld (in)</th>
<th>Stem Actual ld (in)</th>
<th>Stem Min. strain</th>
<th>Stem Actual strain</th>
<th>Stem Min. steel (in²/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2D + 1.6H</td>
<td>42.78</td>
<td>73.68</td>
<td>7.99</td>
<td>21.2</td>
<td>8.9</td>
<td>21</td>
<td>0.0040</td>
<td>0.0324</td>
<td>0</td>
</tr>
<tr>
<td>1.2D + 0.9H</td>
<td>24.06</td>
<td>73.68</td>
<td>4.49</td>
<td>21.2</td>
<td>8</td>
<td>21</td>
<td>0.0040</td>
<td>0.0324</td>
<td>0</td>
</tr>
<tr>
<td>0.9D + 1.6H</td>
<td>42.78</td>
<td>73.68</td>
<td>7.99</td>
<td>21.2</td>
<td>8.9</td>
<td>21</td>
<td>0.0040</td>
<td>0.0324</td>
<td>0</td>
</tr>
<tr>
<td>0.9D + 0.9H</td>
<td>24.06</td>
<td>73.68</td>
<td>4.49</td>
<td>21.2</td>
<td>8</td>
<td>21</td>
<td>0.0040</td>
<td>0.0324</td>
<td>0</td>
</tr>
<tr>
<td>1.4D</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>0.0040</td>
<td>0.0324</td>
<td>0</td>
</tr>
</tbody>
</table>

### Stability Check Results Summary

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Overturning Moment (ft·k/ft)</th>
<th>Overturning F.S.</th>
<th>Sliding Force (lb/in)</th>
<th>Resisting Force (lb/in)</th>
<th>Sliding F.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0D + 1.0H</td>
<td>50.68</td>
<td>1.50</td>
<td>837.9</td>
<td>1.791</td>
<td>1.791</td>
</tr>
</tbody>
</table>

### Loading Options/Assumptions
- Passive pressure neglects top 0 ft of soil.

### Load Combinations
- IBC 2015 (Strength)
- 1.2D + 1.6H
- 1.2D + 0.9H
- 0.9D + 1.6H
- 0.9D + 0.9H
- 1.4D
### Backfill Pressure

#### Lateral Earth Pressure

**Rankine Active Earth Pressure Theory**

\[
K_a = \cos \alpha - \frac{\cos^2 \alpha - \cos^2 \phi}{\cos \alpha + \cos^2 \alpha - \cos^2 \phi} = \cos (20^\circ) - \frac{\cos^2 (20^\circ) - \cos^2 (30^\circ)}{\cos (20^\circ) + \cos^2 (20^\circ) - \cos^2 (30^\circ)} = 0.4142
\]

- \( \gamma = 100 \text{ lb/ft}^3 \)
- \( \phi = 30^\circ \)
- \( c = 0 \text{ psf} \)

\[\sigma_a = \gamma H K_a - 2 c = (100 \text{ lb/ft}^3)(19.82 \text{ ft})(0.4142) - 2 \text{ (0 psf)}(0.4142) = 620.9 \text{ psf} \]

\( \alpha_P = \alpha = 20^\circ \) (resultant force angle with horizontal)

#### Lateral Earth Pressure (stem only)

\[\sigma_a = \gamma H K_a - 2 c = (100 \text{ lb/ft}^3)(16 \text{ ft})(0.4142) - 2 \text{ (0 psf)}(0.4142) = 662.7 \text{ psf} \]

\( \alpha_P = \alpha = 20^\circ \) (resultant force angle with horizontal)
### Passive Pressure

![Diagram of passive pressure](image1)

#### Lateral Earth Pressure

Rankine Passive Earth Pressure Theory

\[
K_p = \tan^2 \left( 45^\circ + \frac{\phi}{2} \right) = \tan^2 \left[ 45^\circ + \frac{30^\circ}{2} \right] = 3.0
\]

\[
\sigma_p = \gamma H K_p + 2 c K_p = (100 \text{ lb/ft}^3)(7 \text{ ft})(3.0) + 2(0 \text{ psf})\sqrt{3.0} = 2100 \text{ psf}
\]

### Manually Specified Lateral Stem Pressure

![Diagram of manually specified lateral stem pressure](image2)

-10 psf
## Wall/Soil Weights

<table>
<thead>
<tr>
<th>Weight Type</th>
<th>Value</th>
<th>Location</th>
<th>Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill Pressure</td>
<td>-231.88 lb/in</td>
<td>11 ft</td>
<td></td>
</tr>
<tr>
<td>Manual Lateral Pressure</td>
<td>-0 lb/in</td>
<td></td>
<td>-18.5 ft</td>
</tr>
<tr>
<td>Footing Weight</td>
<td>-275 lb/in</td>
<td>5.5 ft</td>
<td>0 lb/in</td>
</tr>
<tr>
<td>Stem Weight</td>
<td>-425 lb/in</td>
<td>5 ft</td>
<td>0 lb/in</td>
</tr>
<tr>
<td>Key Weight</td>
<td>-43.75 lb/in</td>
<td>8.5 ft</td>
<td>0 lb/in</td>
</tr>
<tr>
<td>Backfill Weight</td>
<td>-37.91 lb/in</td>
<td>9.33 ft</td>
<td>0 lb/in</td>
</tr>
<tr>
<td>Soil over toe Weight</td>
<td>-66.67 lb/in</td>
<td>2 ft</td>
<td>0 lb/in</td>
</tr>
</tbody>
</table>

## Bearing Pressure Calculation

### Friction

\[ F = \mu R = (0.350)(1515 \text{ lb/in}) = 530.2 \text{ lb/in} \]

### Bearing Pressure Calculation

<table>
<thead>
<tr>
<th>Contributing Forces</th>
<th>Vert Force</th>
<th>Vert Offset</th>
<th>Horz Force</th>
<th>Horz Offset</th>
<th>OT Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill Pressure</td>
<td>-231.88 lb/in</td>
<td>11 ft</td>
<td>-637.08 lb/in</td>
<td>6.61 ft</td>
<td>238791 in·lb/ft</td>
</tr>
<tr>
<td>Manual Lateral Pressure</td>
<td>-0 lb/in</td>
<td>-</td>
<td>-0.83 lb/in</td>
<td>18.5 ft</td>
<td>2220 in·lb/ft</td>
</tr>
<tr>
<td>Footing Weight</td>
<td>-275 lb/in</td>
<td>5.5 ft</td>
<td>0 lb/in</td>
<td>-</td>
<td>-217800 in·lb/ft</td>
</tr>
<tr>
<td>Stem Weight</td>
<td>-425 lb/in</td>
<td>5 ft</td>
<td>0 lb/in</td>
<td>-</td>
<td>-306000 in·lb/ft</td>
</tr>
<tr>
<td>Key Weight</td>
<td>-43.75 lb/in</td>
<td>8.5 ft</td>
<td>0 lb/in</td>
<td>-</td>
<td>-315000 in·lb/ft</td>
</tr>
<tr>
<td>Backfill Weight</td>
<td>-37.91 lb/in</td>
<td>9.33 ft</td>
<td>0 lb/in</td>
<td>-</td>
<td>-50955.83 in·lb/ft</td>
</tr>
<tr>
<td>Soil over toe Weight</td>
<td>-66.67 lb/in</td>
<td>2 ft</td>
<td>0 lb/in</td>
<td>-</td>
<td>-19200 in·lb/ft</td>
</tr>
</tbody>
</table>

\[ -\frac{1200444.57 \text{ in·lb/ft}}{1746.87 \text{ lb/in}} = 4.77 \text{ ft} \]

Note: Bearing resultant used for friction calcs is 1515 lb/in - reduced per user options (for sliding check).
Stability Checks [1.0D + 1.0H]

### Overturning Check

#### Overturning Moments

<table>
<thead>
<tr>
<th>Force Distance Moment</th>
<th>Force Distance Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill pressure (horz)</td>
<td>637.1 lb/in 6.61 ft 606084 in·lb/ft</td>
</tr>
<tr>
<td>Manual lateral pressure</td>
<td>0.83 lb/in 18.5 ft 2220 in·lb/ft</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>608304 in·lb/ft</strong></td>
</tr>
</tbody>
</table>

#### Resisting Moments

<table>
<thead>
<tr>
<th>Force Distance Moment</th>
<th>Force Distance Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive pressure @ toe</td>
<td>612.5 lb/in -0.67 ft -58800 in·lb/ft</td>
</tr>
<tr>
<td>Footing Weight</td>
<td>-275 lb/in 5.5 ft 217800 in·lb/ft</td>
</tr>
<tr>
<td>Key Weight</td>
<td>-43.75 lb/in 5 ft 31500 in·lb/ft</td>
</tr>
<tr>
<td>Backfill Weight</td>
<td>-866.67 lb/in 8.5 ft 81800 in·lb/ft</td>
</tr>
<tr>
<td>Stem Weight</td>
<td>-37.91 lb/in 9.33 ft 50960 in·lb/ft</td>
</tr>
<tr>
<td>Soil over toe Weight</td>
<td>-66.67 lb/in 2 ft 19200 in·lb/ft</td>
</tr>
</tbody>
</table>

**Total:** 1382656 in·lb/ft

\[
\text{F.S.} = \frac{\text{RM}}{\text{OTM}} = \frac{1382656\text{ in·lb/ft}}{608304\text{ in·lb/ft}} = 2.273 > 1.50 \text{ (OK)}
\]

### Sliding Check

#### Sliding Force(s)

<table>
<thead>
<tr>
<th>Force Distance Moment</th>
<th>Force Distance Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill pressure</td>
<td>637.1 lb/in</td>
</tr>
<tr>
<td>Manual lateral pressure</td>
<td>0.83 lb/in</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>637.1 lb/in</strong></td>
</tr>
</tbody>
</table>

#### Resisting Force(s)

<table>
<thead>
<tr>
<th>Force Distance Moment</th>
<th>Force Distance Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive pressure @ toe</td>
<td>612.5 lb/in</td>
</tr>
<tr>
<td>Friction</td>
<td>530.2 lb/in</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>1143 lb/in</strong></td>
</tr>
</tbody>
</table>

\[
\text{F.S.} = \frac{\text{RF}}{\text{SF}} = \frac{1143\text{ lb in}}{637.1\text{ lb in}} = 1.791 > 1.50 \text{ (OK)}
\]

### Bearing Capacity Check

Bearing pressure < allowable (2662 psf < 3000 psf) - OK
Bearing resultant eccentricity < allowable (8.73 in < 22 in) - OK

### Wall Top Displacement

(based on unfactored service loads)

<table>
<thead>
<tr>
<th>Force Distance Moment</th>
<th>Force Distance Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection due to stem flexural displacement</td>
<td>0.059 in</td>
</tr>
<tr>
<td>Deflection due to rotation from settlement</td>
<td>0.162 in</td>
</tr>
<tr>
<td><strong>Total deflection at top of wall (positive towards toe)</strong></td>
<td><strong>0.222 in</strong></td>
</tr>
</tbody>
</table>

QuickRWall 5.0 (iesweb.com) C:\Users\17205\Desktop\Path walls.rwd Page 6 of 21 Thursday 03/04/21 12:05 PM
Stem Flexural Capacity

Capacity (ACI 318-14 11.5.2.2, »22.3, »22.2) @ 0 ft from base [Negative bending]
\[
a = \frac{A_s f_y}{0.85 f_C} = \frac{0.07 \text{ in}^2/\text{in}(60000 \text{ psi})}{0.85(3000 \text{ psi})} = 1.55 \text{ in}
\]
\[
\varphi M_n = \varphi A_s f_y (d - a/2) = (0.90)(0.07 \text{ in}^2/\text{in}(60000 \text{ psi})[[21.5 \text{ in}]-\{1.55 \text{ in}\}/2] = 73.68 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, »22.3, »22.2) @ 0 ft from base [Positive bending]
\[
a = \frac{A_s f_y}{0.85 f_C} = \frac{0.05 \text{ in}^2/\text{in}(60000 \text{ psi})}{0.85(3000 \text{ psi})} = 1.18 \text{ in}
\]
\[
\varphi M_n = \varphi A_s f_y (d - a/2) = (0.90)(0.05 \text{ in}^2/\text{in}(60000 \text{ psi})[[21.56 \text{ in}]-\{1.18 \text{ in}\}/2] = 56.63 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, »22.3, »22.2) @ 14.26 ft from base [Negative bending]
\[
a = \frac{A_s f_y}{0.85 f_C} = \frac{0.07 \text{ in}^2/\text{in}(60000 \text{ psi})}{0.85(3000 \text{ psi})} = 1.55 \text{ in}
\]
\[
\varphi M_n = \varphi A_s f_y (d - a/2) = (0.90)(0.07 \text{ in}^2/\text{in}(60000 \text{ psi})[[21.5 \text{ in}]-\{1.55 \text{ in}\}/2] = 73.68 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, »22.3, »22.2) @ 14.6 ft from base [Positive bending]
\[
a = \frac{A_s f_y}{0.85 f_C} = \frac{0.05 \text{ in}^2/\text{in}(60000 \text{ psi})}{0.85(3000 \text{ psi})} = 1.18 \text{ in}
\]
\[
\varphi M_n = \varphi A_s f_y (d - a/2) = (0.90)(0.05 \text{ in}^2/\text{in}(60000 \text{ psi})[[21.56 \text{ in}]-\{1.18 \text{ in}\}/2] = 56.63 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, »22.3, »22.2) @ 17 ft from base [Negative bending]
\[
a = \frac{A_s f_y}{0.85 f_C} = \frac{0.07 \text{ in}^2/\text{in}(60000 \text{ psi})}{0.85(3000 \text{ psi})} = 0 \text{ in}
\]
\[
\varphi M_n = \varphi A_s f_y (d - a/2) = (0.90)(0.07 \text{ in}^2/\text{in}(60000 \text{ psi})[[21.5 \text{ in}]-\{0 \text{ in}\}/2] = 0 \text{ ft·k/ft}
\]

Capacity (ACI 318-14 11.5.2.2, »22.3, »22.2) @ 17 ft from base [Positive bending]
\[
a = \frac{A_s f_y}{0.85 f_C} = \frac{0.05 \text{ in}^2/\text{in}(60000 \text{ psi})}{0.85(3000 \text{ psi})} = 0 \text{ in}
\]
\[
\varphi M_n = \varphi A_s f_y (d - a/2) = (0.90)(0.05 \text{ in}^2/\text{in}(60000 \text{ psi})[[21.56 \text{ in}]-\{0 \text{ in}\}/2] = 0 \text{ ft·k/ft}
\]
Stem Shear Capacity

Shear Capacity (ACI 318-14 11.5.5.1, 22.5.1.1, 22.5.5.1) @ 0 ft from base  [Positive shear]
\[ \lambda = 1.0 \quad \text{(normal weight concrete)} \]
\[ V_c = 2 \lambda \sqrt{f'_{c}} d = 2 (1.0) \sqrt{3000 \text{ psi}} (21.5 \text{ in}) = 28.26 \text{ k/ft} \]
\[ \psi V_n = \psi V_c = (0.750)(28.26 \text{ k/ft}) = 21.2 \text{ k/ft} \]

Shear Capacity (ACI 318-14 11.5.5.1, 22.5.1.1, 22.5.5.1) @ 0 ft from base  [Negative shear]
\[ \lambda = 1.0 \quad \text{(normal weight concrete)} \]
\[ V_c = 2 \lambda \sqrt{f'_{c}} d = 2 (1.0) \sqrt{3000 \text{ psi}} (21.5 \text{ in}) = 28.26 \text{ k/ft} \]
\[ \psi V_n = \psi V_c = (0.750)(28.26 \text{ k/ft}) = 21.2 \text{ k/ft} \]

Shear Capacity (ACI 318-14 11.5.5.1, 22.5.1.1, 22.5.5.1) @ 17 ft from base  [Positive shear]
\[ \lambda = 1.0 \quad \text{(normal weight concrete)} \]
\[ V_c = 2 \lambda \sqrt{f'_{c}} d = 2 (1.0) \sqrt{3000 \text{ psi}} (21.5 \text{ in}) = 28.26 \text{ k/ft} \]
\[ \psi V_n = \psi V_c = (0.750)(28.26 \text{ k/ft}) = 21.2 \text{ k/ft} \]

Shear Capacity (ACI 318-14 11.5.5.1, 22.5.1.1, 22.5.5.1) @ 17 ft from base  [Negative shear]
\[ \lambda = 1.0 \quad \text{(normal weight concrete)} \]
\[ V_c = 2 \lambda \sqrt{f'_{c}} d = 2 (1.0) \sqrt{3000 \text{ psi}} (21.5 \text{ in}) = 28.26 \text{ k/ft} \]
\[ \psi V_n = \psi V_c = (0.750)(28.26 \text{ k/ft}) = 21.2 \text{ k/ft} \]
Main vertical stem bars (bottom end) - Development Length Calculation (ACI 318-14 11.7.1.2, 25.4.2.3, 25.4.3)

\( \nu_e = 1.0 \)  (uncoated hooked bars)
\( \nu_C = 0.70 \)  (based on side cover and extension cover)
\( \nu_f = 1.0 \)  (no confining reinforcement)
\( \lambda = 1.0 \)  (normal weight concrete)

\[
I_{db} = \left( \frac{\lambda}{50} \right) \frac{\nu_e \nu_C \nu_f}{\nu_f} \left( \frac{F'_{c}}{F_c} \right) = \left( \frac{60000 \text{ psi}}{(1.0)(0.70)(1.0)} \right) \left( \frac{1 \text{ in}}{50} \right) = 15.34 \text{ in}
\]

8 \( d_b = 8 \text{ in} < 8.0 \text{ in} \)  (minimum limit, does not control)

Main vertical stem bars (top end) - Development Length Calculation (ACI 318-14 11.7.1.2, 25.4.2.3, 25.4.3)

\( \nu_t = 1.0 \)  (bars are not horizontal)
\( \nu_e = 1.0 \)  (bar not epoxy coated)
\( \nu_s = 1.0 \)  (bars are #7 or larger)
\( \lambda = 1.0 \)  (normal weight concrete)
\( s/2 = (12 \text{ in})/2 = 6 \text{ in} \)
\( c_b = 2.5 \text{ in} \)  (lesser of half spacing, ctr to surface)
\( K_{tr} = 0.0 \)  (no transverse reinforcement)

\[
\frac{c_b}{d_b} = \left( \frac{2.5 \text{ in}}{1 \text{ in}} \right) = 2.50
\]

\[
I_d = \left( \frac{3}{40} \right) \frac{\nu_t \nu_e \nu_s}{\lambda} \left( \frac{F'_{c}}{F_c} \right) = \left( \frac{3}{40} \right) \frac{(60000 \text{ psi})(1.0)(1.0)(1.0)}{(1.0)(3000 \text{ psi})} \left( \frac{2.5 \text{ in}}{1 \text{ in}} \right) = 32.86 \text{ in}
\]

2nd curtain vertical bars (top end) - Development Length Calculation (ACI 318-14 11.7.1.2, 25.4.2.3, 25.4.3)

\( \nu_t = 1.0 \)  (bars are not horizontal)
\( \nu_e = 1.0 \)  (bar not epoxy coated)
\( \nu_s = 1.0 \)  (bars are #7 or larger)
\( \lambda = 1.0 \)  (normal weight concrete)
\( s/2 = (12 \text{ in})/2 = 6 \text{ in} \)
\( c_b = 0.88 \text{ in} \)  (lesser of half spacing, ctr to surface)
\( K_{tr} = 0.0 \)  (no transverse reinforcement)

\[
\frac{c_b}{d_b} = \left( \frac{0.88 \text{ in}}{1 \text{ in}} \right) = 2.7857
\]

\[
I_d = \left( \frac{3}{40} \right) \frac{\nu_t \nu_e \nu_s}{\lambda} \left( \frac{F'_{c}}{F_c} \right) = \left( \frac{3}{40} \right) \frac{(60000 \text{ psi})(1.0)(1.0)(1.0)}{(1.0)(3000 \text{ psi})} \left( \frac{0.88 \text{ in}}{1 \text{ in}} \right) = 28.76 \text{ in}
\]
Toe Checks [1.2D + 1.6H]

### Controlling Moment

Design moment $M_o$ for toe need not exceed moment at stem base:

- $M_{oe} = 19.95 \text{ ft k f} < M_{beam} = 42.76 \text{ ft k f}$
- $M_o = 19.95 \text{ ft k f}$ (stem moment does not control)

### Flexure Check (ACI 318-14 13.3.2.1, 7.5.2.1, =22.3, =22.2, 7.5.1.1a)

- $a = \frac{A_p}{0.05 F_c} = \frac{0.03 \text{ in}^2 / \text{ in}}{0.05 (3000 \text{ psi})} = 0.61 \text{ in}$
- $M_o = A_p f_y (d - a / 2) = (0.90)(0.03 \text{ in}^2 / \text{ in})(60000 \text{ psi})(20.69 \text{ in} - 0.61 \text{ in} / 2) = 28.44 \text{ ft k f}$
- $M_o = 28.44 \text{ ft k f} / f \geq M_o = 19.95 \text{ ft k f}$ ✓

### Shear Check (ACI 318-14 13.3.2.1, 7.5.3.1, »22.5.1, »22.5.5, 7.5.1.1b)

- $\lambda = 1.0$ (normal weight concrete)
- $V_C = 2 \cdot \frac{\lambda}{\sqrt{F_c}} \cdot d = 2 (1.0)(0.03)(20.69 \text{ in}) = 27.19 \text{ k f / ft}$
- $V_t = A_p f_y / (0.750) = 27.19 \text{ k f / ft} = 20.4 \text{ k f / ft}$
- $V_{et} = 20.4 \text{ k f / ft} \geq V_C = 5.73 \text{ k f / ft}$ ✓

### Minimum Strain Check (ACI 318-14 13.3.2.1, 7.3.3.1)

- $\beta_t = 0.850$ ($F_c \leq 4000 \text{ psi}$)
- $a = \frac{A_p}{0.05 F_c} = \frac{0.03 \text{ in}^2 / \text{ in}}{0.05 (3000 \text{ psi})} = 0.61 \text{ in}$
- $\varepsilon = 0.003 \left(\frac{a}{d} - 1\right) = 0.003 \left(\frac{20.69 \text{ in}}{0.61 \text{ in}} - 1\right) = 0.0838$
- $\varepsilon = 0.0838 \geq 0.004$ ✓

### Minimum Steel Check (ACI 318-14 13.3.2.1, 6.6.1)

- $M_o = 28.44 \text{ ft k f} / f \geq (4 / 3)M_o = (4 / 3)(19.95 \text{ ft k f}) = 26.6 \text{ ft k f}$
- Check is waived per ACI 9.6.3.1

### Shrinkage and Temperature Steel (ACI 318-14 13.2.8.1, 7.6.4.1, 24.4.3.2, 24.4.3.3)

- $P_{ST, prov} = \frac{A_{ST}}{t_{ST}} = \frac{0.62 \text{ in}^2 / \text{ in}}{(24 \text{ in})(12 \text{ in})} = 0.0022$
- $P_{ST, prov} = 0.0022 \geq P_{ST, min} = 0.0008$ ✓

18 inch limit governs

- $s_{ST, max} = 18 \text{ in}$
- $s_{ST} = 12 \text{ in} \leq s_{ST, max} = 18 \text{ in}$ ✓

### Development Check (ACI 318-14 13.2.8.1, 25.4.2.3, 25.4.10)

- $M_o \geq M_{ae} = \frac{19.95 \text{ ft k f}}{28.44 \text{ ft k f}} = 0.7016$ (ratio to represent excess reinforcement)
- $\varepsilon = 1.0$ (12 inches or less cast below - 3.00 inches)
- $\varepsilon = 1.0$ (bar not epoxy/centd)
- $\varepsilon = 0.80$ (bars are #6 or smaller)
- $\lambda = 1.0$ (normal weight concrete)
- $s / 2 = (12 \text{ in}) / 2 \text{ in} = 6 \text{ in}$
- $d_o = (3 \text{ in}) + 0.63 \text{ in} / 2 = 3.31 \text{ in}$
- $c_o = 3.31 \text{ in}$ (lesser of half spacing, ctr to surface)
- $K_o = 0.0$ (no transverse reinforcement)
- $K_o + K_d = (3.31 \text{ in}) + 0.00 = 5.30$

### Factoring $I_d$ by the excess reinforcement ratio (0.7016) per 25.4.10: $I_d = 11.53$ in

12 inch minimum controls

- $I_d, prov = 81 \text{ in} \geq I_d = 12 \text{ in}$ ✓
Heel Checks: [1.2D + 1.6H]

**Controlling Moment**
Design moment $M$ for heel need not exceed moment at stem base:

$$M_{\text{heel}} = 30.77 \text{ ft} \cdot \text{k} / \text{ft} < M_{\text{max}} = 42.78 \text{ ft} \cdot \text{k} / \text{ft}$$
$$M_{d} = 30.77 \text{ ft} \cdot \text{k} / \text{ft}$$
(stem moment does not control)

**Flexure Check (ACI 318-14 13.3.2.1, 7.5.1.1, >22.3, >22.2, 7.5.1.1a)**

$$a = \frac{A_{s} f_{y}}{0.85 f_{c}'} = \frac{(0.04 \text{ in}^{2} / \text{in})(60000 \text{ psi})}{0.85 (3000 \text{ psi})} = 0.86 \text{ in}$$
$$\delta M_{b} = \frac{a A_{s} f_{y}}{d - a / 2} = \frac{(0.90)(0.04 \text{ in}^{2} / \text{in})(60000 \text{ psi})[(21.63 \text{ in}) - (0.86 \text{ in}) / 2]}{41.96 \text{ ft} \cdot \text{k} / \text{ft}}$$
$$\delta M_{b} = 41.96 \text{ ft} \cdot \text{k} / \text{ft} \geq M_{d} = 30.77 \text{ ft} \cdot \text{k} / \text{ft}$$

**Shear Check (ACI 318-14 13.3.2.1, 7.5.1.1, >22.5.1, >22.5.5, 7.5.1.1b)**

$$\lambda = 1.0$$
(normal weight concrete)

$$V_{c} = 2 \lambda \frac{f_{c}'}{d} = 2 (1.0) \frac{3000 \text{ psi}}{21.63 \text{ in}} = 28.43 \text{ k} / \text{ft}$$
$$\phi V_{n} = \psi V_{c} = (0.750)(28.43 \text{ k} / \text{ft}) = 21.32 \text{ k} / \text{ft}$$
$$\phi V_{n} = 21.32 \text{ k} / \text{ft} \geq V_{d} = 12.22 \text{ k} / \text{ft}$$

**Minimum Strain Check (ACI 318-14 13.3.2.1, 7.3.3.1)**

$$\beta = 0.850$$
$$a = \frac{A_{s} f_{y}}{0.85 f_{c}'} = \frac{(0.04 \text{ in}^{2} / \text{in})(60000 \text{ psi})}{0.85 (3000 \text{ psi})} = 0.86 \text{ in}$$
$$\phi \xi = 0.003 \left( \frac{d}{a} - 1 \right) = 0.003 \left( \frac{(21.32 \text{ in}) - (0.86 \text{ in}) / 2}{(0.86 \text{ in}) / 2} \right) = 0.0609$$
$$\phi \xi = 0.0609 \geq 0.004$$

**Minimum Steel Check (ACI 318-14 13.3.2.1, 9.6.1)**

$$\delta M_{b} = 41.96 \text{ ft} \cdot \text{k} / \text{ft} \geq \left( \frac{1}{4} / 3 \right) M_{b} = \left( \frac{1}{4} / 3 \right) (41.96 \text{ ft} \cdot \text{k} / \text{ft}) = 41.03 \text{ ft} \cdot \text{k} / \text{ft}$$
Check is waived per ACI 9.6.1.3

**Shrinkage and Temperature Steel (ACI 318-14 13.2.8.1, 7.6.4.1, 24.4.3.2, 24.4.3.3)**

$$\rho_{ST} \text{ prov} = \frac{A_{ST}}{l_{ST}} = \frac{(0.62 \text{ in}^{2} / \text{in})(24 \text{ in})}{(24 \text{ in})(12 \text{ in})} = 0.0022$$
$$\rho_{ST} \text{ prov} = \frac{A_{ST}}{l_{ST}} = \frac{(0.62 \text{ in}^{2} / \text{in})(24 \text{ in})}{(24 \text{ in})(12 \text{ in})} = 0.0022$$
$$0.0018 (60000) = 0.0018 (60000) = 0.0018$$
$$l_{ST} = 0.0018$$
$$\rho_{ST} \text{ prov} = 0.0022 \geq \rho_{ST} \text{ min} = 0.0018$$

18 inch limit governs
$$s_{ST} \text{ max} = 18 \text{ in}$$
$$s_{ST} = 12 \text{ in} \\ s_{ST} \text{ min} = 18 \text{ in}$$

**Development Check (ACI 318-14 13.2.8.1, 25.4.2.3, 25.4.10)**

$$M_{d} = (30.77 \text{ ft} \cdot \text{k} / \text{ft}) (42.78 \text{ ft} \cdot \text{k} / \text{ft}) = 0.7334$$
(ratio to represent excess reinforcement)

$$\nu_{1} = 1.30$$
(more than 12 inches cast below - 21.25 inches)

$$\nu_{3} = 1.0$$
(bar not epoxied coated)

$$\nu_{3} = 0.80$$
(bars are #6 or smaller)

$$\lambda = 1.0$$
(normal weight concrete)

$$s / 2 = (12 \text{ in}) / 2 = 6 \text{ in}$$

cover + $d_{b} / 2 = (2 \text{ in}) + (0.75 \text{ in}) / 2 = 2.38 \text{ in}$$

$\phi_{c} = 2.38 \text{ in}$
(lesser of half spacing, ctr to surface)

$K_{c} = 0.0$  
(no transverse reinforcement)

$$K_{c} + K_{c} = (2.38 \text{ in}) + (0.0) = 3.1667$$

$$l_{y} = \frac{3}{40} \frac{A_{s} f_{y}}{l_{c} f_{c}'} + \frac{0.62 \text{ in}^{2} / \text{in}}{2.5} \frac{d_{b}}{0.75 \text{ in}}$$
$$l_{y} = \frac{3}{40} \frac{(60000 \text{ psi}) (1.0)(1.0)(0.80)}{2.5} \left( \frac{0.75 \text{ in}}{2.5} \right) = 25.63 \text{ in}$$

Factoring $l_{y}$ by the excess reinforcement ratio (0.7334) per 25.4.10: $l_{y} = 18.8 \text{ in}$

$\rho_{ST} \text{ prov} = 70 \text{ in} \geq l_{y} = 18.8 \text{ in}$
**Stem Forces [1.2D + 1.6H]**

- **Stem Internal Forces**
  - -16 psf
  - 7.99 k/ft
  - -996.42 psf
  - -42.78 ft·k/ft

- **Stem Internal Forces**
  - 17
  - 14.88
  - 12.75
  - 10.63
  - 8.5
  - 6.38
  - 4.25
  - 2.13

- **Stem Joint Force Transfer**
  - **Location**
    - @ stem base
  - **Force**
    - 7.99 k/ft

**Stem Internal Forces**

- -16 psf
- -996.42 psf
Stem Moment Checks \([1.2D + 1.6H]\)

\[
\begin{align*}
\text{Check (ACI 318-14 11.5.5.1b) @ 0 ft from base} \\
\phi M_n &= 73.68 \text{ ft·k/ft} \quad M_u = 42.78 \text{ ft·k/ft} \quad \checkmark
\end{align*}
\]

\[
\begin{align*}
\text{Check (ACI 318-14 11.5.5.1b) @ 14.26 ft from base} \\
\phi M_n &= 73.68 \text{ ft·k/ft} \quad M_u = 0.09 \text{ ft·k/ft} \quad \checkmark
\end{align*}
\]

\[
\begin{align*}
\text{Check (ACI 318-14 11.5.5.1b) @ 14.42 ft from base} \\
\phi M_n &= 69.3 \text{ ft·k/ft} \quad M_u = 0.07 \text{ ft·k/ft} \quad \checkmark
\end{align*}
\]
Stem Shear Checks \([1.2D + 1.6H]\)

Shear Check (ACI 318-14 11.5.5.1c) @ 0 ft from base

\[ \phi V_n = 21.2 \text{ k/ft} \geq V_u = 7.99 \text{ k/ft} \]

\( \checkmark \)
Stem Miscellaneous Checks [1.2D + 1.6H]

Minimum Steel Check (ACI 318-14 9.6.1.3) @ 0 ft from base [Stem in negative flexure]
\[ \frac{M_n}{M_u} = \left( \frac{4}{3} \right) \frac{M_n}{M_u} = \frac{42.78 \text{ ft·k ft}}{73.68 \text{ ft·k ft}} = 0.5806 \]
Check is waived per ACI 9.6.1.3 ✔

Minimum Steel Check (ACI 318-14 9.6.1.3) @ 17 ft from base [Stem in negative flexure]
\[ \frac{M_n}{M_u} = \left( \frac{4}{3} \right) \frac{M_n}{M_u} = \frac{0 \text{ ft·k ft}}{0 \text{ ft·k ft}} = 0 \text{ ft·k ft} \]
Check is waived per ACI 9.6.1.3 ✔

Maximum Steel Check (ACI 318-14 9.3.3.1) @ 0 ft from base [Stem in negative flexure]
\[ \beta_t = 1.0 \quad \chi_c = 0.70 \quad \chi_r = 1.0 \]
\[ a = \frac{A_{s'}}{0.85 \frac{F'_c}{\Delta}} = \frac{0.07 \text{ in}^2}{(60000 \text{ psi})} = 1.55 \text{ in} \]
\[ q_i = 0.033 \left( \frac{d}{a} - 1 \right) = 0.033 \left( \frac{21.5}{1.55} - 1 \right) = 0.0324 \]
\[ q_i = 0.0324 \geq 0.004 \quad \checkmark \]

Maximum Steel Check (ACI 318-14 9.3.3.1) @ 17 ft from base [Stem in negative flexure]
\[ \beta_t = 1.0 \quad \chi_c = 0.70 \quad \chi_r = 1.0 \]
\[ a = \frac{A_{s'}}{0.85 \frac{F'_c}{\Delta}} = \frac{0.07 \text{ in}^2}{(60000 \text{ psi})} = 1.55 \text{ in} \]
\[ q_i = 0.033 \left( \frac{d}{a} - 1 \right) = 0.033 \left( \frac{21.5}{1.55} - 1 \right) = 0.0324 \]
\[ q_i = 0.0324 \geq 0.004 \quad \checkmark \]

Wall Horizontal Steel (ACI 318-14 11.6.1, 11.7.3)
\[ \rho = \frac{A_{s' \text{ horz}}}{\frac{3}{12} \text{ in} (24 \text{ in})} = 0.0022 \]
\[ \rho_{\text{min}} = 0.0020 \quad \rho_{\text{min}} \geq 0.0020 \quad \checkmark \]
3 h = 3 (24 in) = 72 in
18 inch limit governs
\[ s_{\text{horz}} = 12 \text{ in} \leq s_{\text{horz max}} = 18 \text{ in} \quad \checkmark \]

Development Check (ACI 318-14 11.7.1.2, 25.4.2.3, 25.4.10)
\[ \frac{M_d}{M_{\text{Mn}}} = \frac{42.78 \text{ ft·k ft}}{73.68 \text{ ft·k ft}} = 0.5806 \quad \text{ratio to represent excess reinforcement} \]
\[ \psi_a = 1.0 \quad \text{(uncoated hooked bars)} \]
\[ \psi_c = 0.70 \quad \text{(based on side cover and extension cover)} \]
\[ \psi_r = 1.0 \quad \text{(no confining reinforcement)} \]
\[ \lambda = 1.0 \quad \text{(normal weight concrete)} \]
\[ \lambda_{dh} = \frac{d_f \lambda \psi_a \psi_c}{50 \lambda \psi_c} = \frac{(60000 \text{ psi})(1.0)(0.70)(1.0)}{50 (1.0)(3000 \text{ psi})} = 15.34 \text{ in} \]
Factoring \( \lambda_{dh} \) by the excess reinforcement ratio (0.5806) per 25.4.10: \( \lambda_{dh} = 8.9 \text{ in} \)
8 \( d_f = 8 \text{ (1 in)} = 8.0 \text{ (minimum limit, does not control)} \)
\[ \lambda_{dh, \text{prov}} = 21 \text{ in} \geq \lambda_{dh} = 8.9 \text{ in} \quad \checkmark \]
**Toe Checks [1.4D]**

### Controlling Moment

Design moment $M_{0e}$ for toe need not exceed moment at stem base:

$$M_{0e} = 18.36 \text{ ft} \cdot \text{k/ft} \geq M_{\text{sum}} = \frac{0.85 \text{ ft} \cdot \text{k}}{\text{ft}}$$

$$M_{0e} = 0 \text{ ft} \cdot \text{k} / \text{ft}$$

Shear Check (ACI 318-14 13.3.2.1, 7.5.3.1, 22.5.1, 22.5.5, 7.5.1.1b)

$$a = \frac{A_s \theta}{0.05 F_c} = \frac{0.03 \text{ in}^2 / \text{in}(60000 \text{ psi})}{0.61 \text{ in}} = 0.12 \text{ in}$$

$$\phi M_{\text{u}} = \theta (d-a/2) = (0.90)(0.05 \text{ in}^2 / \text{in})(0.61 \text{ in})$$

$$(20.69 \text{ in}) - (0.61 \text{ in}) / 2 = 28.44 \text{ ft} \cdot \text{k/ft}$$

$$(20.69 \text{ in}) - (0.61 \text{ in}) / 2 = 28.44 \text{ ft} \cdot \text{k/ft}$$

### Minimum Strain Check (ACI 318-14 13.3.2.1, 7.3.3.1)

$$\lambda_t = 0.850$$

$$a = \frac{A_s \theta}{0.05 F_c} = \frac{0.03 \text{ in}^2 / \text{in}(60000 \text{ psi})}{0.61 \text{ in}} = 0.12 \text{ in}$$

$$\phi V_{\text{u}} = \phi V_{\text{c}} = (0.750)(27.19 \text{ k/ft}) = 20.4 \text{ k/ft}$$

$$\phi V_{\text{u}} = 20.4 \text{ k/ft} \geq V_{\text{c}} = 5.28 \text{ k/ft}$$

### Minimum Steel Check (ACI 318-14 13.3.2.1, 9.6.1)

$$(a = (4 / 3)M_{\text{u}} = (4 / 3)(0.003 \text{ ft} \cdot \text{k/ft}) = 0 \text{ ft} \cdot \text{k/ft}$$

Check is waived per ACI 9.6.1.3

### Shrinkage and Temperature Steel (ACI 318-14 13.2.8.1, 7.6.4.1, 24.4.3.2, 24.4.3.3)

$$\rho_{\text{ST}} = \frac{\rho_{\text{ST}}}{(60000 \text{ psi})} = 0.0022$$

$$\rho_{\text{ST}} = \frac{\rho_{\text{ST}}}{(60000 \text{ psi})} = 0.0022$$

$$\rho_{\text{ST}} = \frac{0.0018}{60000 \text{ psi}} = 0.0018$$

$$\rho_{\text{ST}} = 0.0018$$

18 inch limit governs

$s_{\text{ST max}} = 18 \text{ in}$

$s_{\text{ST}} = 12 \text{ in} \geq s_{\text{ST max}} = 18 \text{ in}$

### Development Check (ACI 318-14 13.2.8.1, 25.4.2.3, 25.4.10)

$$M_{\text{u}} = \frac{-0.0 \text{ ft} \cdot \text{k/ft}}{28.44 \text{ ft} \cdot \text{k/ft} / \text{ft}} = \frac{0.0 \text{ ft} \cdot \text{k/ft}}{28.44 \text{ ft} \cdot \text{k/ft} / \text{ft}}$$

$$v_1 = 1.0 \text{ (12 inches or less cast below 3.00 inches)}$$

$$v_2 = 1.0 \text{ (bar not epoxy coated)}$$

$$v_3 = 0.80 \text{ (bars are #6 or smaller)}$$

$$\lambda = 1.0 \text{ (normal weight concrete)}$$

$$n = \frac{28.44 \text{ ft} \cdot \text{k/ft}}{28.44 \text{ ft} \cdot \text{k/ft} / \text{ft}} = 6 \text{ in}$$

$$c = 3.31 \text{ in} \text{ (lesser of half spacing, c/t to surface)}$$

$$K_{d} = 0.0 \text{ (no transverse reinforcement)}$$

$$G = (0.31 \text{ in} + 0.0) / 0.63 \text{ in} = 5.30$$

$$l_2 = \frac{3.0 \times 0.018}{1.0 \times 0.63 \text{ in}} = 25.41 \text{ in}$$

Factoring $l_2$ by the excess reinforcement ratio $(0.0000)$ per 25.4.10: $l_2 = 0 \text{ in}$

12 inch minimum controls

$l_2_{\text{prov}} = 81 \text{ in} \geq l_2 = 12 \text{ in}$
Heel Checks [1.4D]

Controlling Moment

Design moment $M_{	ext{hole}}$ for heel need not exceed moment at stem base:

$M_{	ext{hole}} = 35.9 \text{ ft·k ft} / \text{ft} > M_{\text{stem max}} = -0 \text{ ft·k ft} / \text{ft}$

$M_{\text{hole}} = -0 \text{ ft·k ft} / \text{ft}$ (stem base moment controls)

Flexure Check (ACI 318-14 13.3.2.1, 7.5.2.1, 22.3, 22.2, 7.5.1.1a)

\[ a = \frac{A_s f_y}{f'_c} = 0.04 \text{ in}^2 / \text{in} (60000 \text{ psi}) = 0.86 \text{ in} \]

\[ \phi M_s = a A_s f_y (d - a / 2) = (0.90)(0.04 \text{ in}^2 / \text{in} (60000 \text{ psi}))(21.63 \text{ in} - 0.86 \text{ in} / 2) = 41.96 \text{ ft·k ft} \]

\[ M_s = 41.96 \text{ ft·k ft} / \text{ft} \geq M_{\text{hole}} = 0 \text{ ft·k ft} / \text{ft} \checkmark \]

Shear Check (ACI 318-14 13.3.2.1, 7.5.3.1, 22.5.1, 22.5.5, 7.5.1.1b)

\[ \lambda = 1.0 \]

(normal weight concrete)

\[ V_C = 2 \lambda \sqrt{f'_c} d = 2(1.0)0.003(21.63 \text{ in}) = 28.43 \text{ k} / \text{ft} \]

\[ \phi V_C = \phi V_n = (0.750)(28.43 \text{ k} / \text{ft}) = 21.32 \text{ k} / \text{ft} \]

\[ \phi V_n = 21.32 \text{ k} / \text{ft} > V_u = 14.26 \text{ k} / \text{ft} \checkmark \]

Minimum Strain Check (ACI 318-14 13.3.2.1, 7.3.3.1)

\[ \beta_1 = 0.850 \]

$\phi = 0.003 \left( \frac{d}{0.75 \text{ in}} - 1 \right) = 0.003 \left( \frac{21.63 \text{ in}}{0.0022 \text{ in}} - 1 \right) = 0.0069 \]

\[ \alpha = 0.0069 \geq 0.004 \checkmark \]

Minimum Steel Check (ACI 318-14 13.3.2.1, 9.6.1)

\[ M_s = 41.96 \text{ ft·k ft} / \text{ft} \geq \left( \frac{4}{1.3} \right) M_{\text{hole}} = \left( \frac{4}{1.3} \right) (-0 \text{ ft·k ft} / \text{ft}) = -0 \text{ ft·k ft} / \text{ft} \]

Check is waived per ACI 9.6.1.3

Shrinkage and Temperature Steel (ACI 318-14 13.2.1, 7.6.4.1, 24.4.3.2, 24.4.3.3)

\[ \rho_\text{st} = \frac{A_{\text{st max}}}{l s_{\text{st}}} = \frac{(0.62 \text{ in}^2 / \text{in})(24 \text{ in})}{12 \text{ in}} = 0.0022 \]

\[ \rho_\text{st} = \frac{A_{\text{st max}}}{l s_{\text{st}}} = \frac{(0.62 \text{ in}^2 / \text{in})(24 \text{ in})}{12 \text{ in}} = 0.0022 \]

\[ \rho_\text{st} = \frac{A_{\text{st max}}}{l s_{\text{st}}} = \frac{0.0018(60000)}{(60000 \text{ psi})} = 0.0018 \]

\[ \rho_\text{st max} = 0.0018 \]

\[ \rho_\text{st} = 0.0022 \geq \rho_\text{st max} = 0.0018 \checkmark \]

18 inch limit governs

\[ s_{\text{st max}} = 18 \text{ in} \]

\[ s_{\text{st}} = 12 \text{ in} \leq s_{\text{st max}} = 18 \text{ in} \checkmark \]

Development Check (ACI 318-14 13.2.1, 25.4.2.3, 25.4.10)

\[ M_s = (-0 \text{ ft·k ft} / \text{ft}) / (41.96 \text{ ft·k ft} / \text{ft}) = -0.0 \]

(ratio to represent excess reinforcement)

\[ v_n = 1.30 \]

More than 12 inches cast below 21.25 inches

\[ v_n = 1.0 \]

(bar not epoxy coated)

\[ v_n = 0.80 \]

(bars are #6 or smaller)

\[ \lambda = 1.0 \]

(normal weight concrete)

\[ s / 2 = (12 \text{ in}) / 2 = 6 \text{ in} \]

cover + $d_n / 2 = (2 \text{ in}) + (0.75 \text{ in}) / 2 = 2.38 \text{ in} \]

\[ c_n = 2.38 \text{ in} \]

(lesser of half spacing, ctz to surface)

\[ K_n = 0.0 \]

(no transverse reinforcement)

\[ c_n + d_n = (2.38 \text{ in}) + (0.0) = 2.38 \text{ in} \]

\[ c_n + d_n = (2.38 \text{ in}) + (0.0) = 2.38 \text{ in} \]

\[ c_n + d_n = (2.38 \text{ in}) + (0.0) = 2.38 \text{ in} \]

\[ l_d = \left( \frac{3}{4} \right) \frac{v_n v_d}{f'_c} s_{\text{avg}} = 2.5 \]

\[ d_n = \left( \frac{3}{4} \right) \frac{(60000 \text{ psi})(1.30)(1.0)(0.80)}{2.5} \]

\[ d_n = 25.63 \text{ in} \]

Factoring $l_d$ by the excess reinforcement ratio (0.0000) per 25.4.10: $l_d = 0 \text{ in}$

12 inch minimum controls

\[ l_d = 70 \text{ in} \geq l_d = 12 \text{ in} \checkmark \]
Stem Forces [1.4D]

Stem Internal Forces

-0 k/ft

0 k/ft

Stem Internal Forces

Moment

Shear

Stem Joint Force Transfer

Location

@ stem base

Force

0 k/ft

Stem Internal Forces
Stem Moment Checks [1.4D]
Stem Shear Checks [1.4D]

![Graph showing shear checks](image)
Cantilever Wall 1

Stem Miscellaneous Checks [1.4D]

Minimum Steel Check (ACI 318-14 9.6.1) @ 0 ft from base [Stem in negative flexure]

\[ \frac{M_t}{M_n} = \frac{37.68}{73.68} = 0.51 \]

Check is waived per ACI 9.6.1.3

Minimum Steel Check (ACI 318-14 9.6.1) @ 17 ft from base [Stem in negative flexure]

\[ \frac{M_t}{M_n} = \frac{0}{73.68} = 0 \]

Check is waived per ACI 9.6.1.3

Maximum Steel Check (ACI 318-14 9.3.3.1) @ 0 ft from base [Stem in negative flexure]

\[ \frac{M_u}{M_n} = \frac{73.68}{73.68} = 1 \]

Maximum Steel Check (ACI 318-14 9.3.3.1) @ 17 ft from base [Stem in negative flexure]

\[ \frac{M_u}{M_n} = \frac{0}{73.68} = 0 \]

Wall Horizontal Steel (ACI 318-14 11.6.1, 11.7.3)

\[ \rho_t = \frac{A_{s_{\text{horz}}}}{h_{\text{horz}}} = \frac{0.62}{24} = 0.026 \]

\[ \rho_{\text{min}} = 0.0020 \]

3 h = 3 (24 in) = 72 in

18 inch limit governs

Development Check (ACI 318-14 11.7.1.2, 25.4.2.3, 25.4.10)

\[ \frac{M_u}{M_{\text{min}}} = \frac{73.68}{73.68} = 1 \]

\( f_y = 60 \text{ ksi} \) (uncoated hooked bars)

\( f_{\text{c}} = 3000 \text{ psi} \) (based on side cover and extension cover)

\( \lambda = 1.0 \) (no confining reinforcement)

\[ l_{\text{dh}} = \left( \frac{f_y}{f_{\text{c}}} \frac{h_{\text{horz}}}{b} \right) d_b = \left( \frac{60000 \text{ psi}}{3000 \text{ psi}} \frac{2}{b} \right) d_b = 15.34 \text{ in} \]

Factoring \( l_{\text{dh}} \) by the excess reinforcement ratio (0.0000) per 25.4.10: \( l_{\text{dh}} = 0 \) in

8 \( d_b = 8 \) (1 in) = 8.0

8 \( d_b \) minimum controls

\( l_{\text{dh}} = 21 \text{ in} \geq 18 \text{ in} \)

QuickRWall 5.0 (iesweb.com) C:\Users\17205\Desktop\Path walls.rwd Page 21 of 21 Thursday 03/04/21 12:05 PM
# Cut/Fill Report

**Generated:** 2021-04-17 09:03:22  
**By user:** Justin

![Path to the drawing](C:\Users\Justin\OneDrive - The University of Colorado Denver\CU DENVER\!!Spring 2021\Senior Design\AUTO_CAD\C:\Users\Justin\OneDrive - The University of Colorado Denver\CU DENVER\!!Spring 2021\Senior Design\AUTO_CAD\Topo_Map_2.17 Corrected path.dwg)

## Volume Summary

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<th>Fill Factor</th>
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<th>Fill (Cu. Yd.)</th>
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* Value adjusted by cut or fill factor other than 1.0
Exhibit 5: Sketches/Diagrams/Plans/Drawings
PRODUCED BY AN AUTODESK STUDENT VERSION
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Detail Section of Path and Parkway

- Existing downhill roadway with two 12' lanes
- Centerline of roadway
- Existing shoulder used for recreation path
- Smaller shoulder created by moving concrete barrier
- Maintain 2% slope from roadway into recreation path

Asphalt trail surface
- Subgrade
- Aggregate base course

Total width of path
- Asphalt shoulder
- 6" 4"

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Figure 21-First rest area location traveling up the Parkway

Figure 20-Second location

Figure 23-Third location

Figure 22-Fourth location at the top before connecting to the tunnel
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Exhibit 6: Copy of Referenced Materials
Table 6 - Applicability of Hydrologic Methods

<table>
<thead>
<tr>
<th>Watershed Size (acres)</th>
<th>Is the Rational Method Applicable?</th>
<th>Is CUHP Applicable?</th>
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<tr>
<td>0 to 90</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>90 to 160</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>160 to 3,000</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Greater than 3,000</td>
<td>No</td>
<td>Yes (subdividing into smaller catchments required)¹</td>
</tr>
</tbody>
</table>

¹ Subdividing into smaller subcatchments and routing the resultant hydrographs using SWMM may be needed to accurately model a catchment with areas of different soil types or percentages of imperviousness.

Table 7 Street Classification

Table 6.2.8.3A

<table>
<thead>
<tr>
<th>TRAFFIC CLASSIFICATION</th>
<th>DRAINAGE CLASSIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Local (&lt;2,000 vehicles per day)</td>
<td>A</td>
</tr>
<tr>
<td>Rural Local (&lt;2,000 vehicles per day)</td>
<td>A</td>
</tr>
<tr>
<td>Urban Collector (2,000-12,000 vehicles per day)</td>
<td>B</td>
</tr>
<tr>
<td>Rural Collector (2,000-12,000 vehicles per day)</td>
<td>B</td>
</tr>
</tbody>
</table>

Table 8 Allowable Encroachment

Table 6.2.8.3B

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>MINOR STORM</th>
<th>MAJOR STORM</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Urban – Flow may spread to crown.</td>
<td>Urban – Flow must not encroach ROW.</td>
</tr>
<tr>
<td></td>
<td>Rural – Flow must not encroach shoulder.</td>
<td>Rural – Flow must not encroach structures at ground line.</td>
</tr>
<tr>
<td>B</td>
<td>Urban – Flow must leave no 10' drive lane free of inundation w/ no curb overtopping.</td>
<td>Urban – Flow must not encroach ROW.</td>
</tr>
<tr>
<td></td>
<td>Rural – Flow must not encroach shoulder.</td>
<td>Rural – Flow must not encroach structures at ground line.</td>
</tr>
</tbody>
</table>
Table 9 - Atlas 14 Precipitation Frequency Table

<table>
<thead>
<tr>
<th>Duration</th>
<th>Average recurrence interval (years)</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>250</th>
<th>500</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-mm</td>
<td>(0.186) (0.146-0.241)</td>
<td>0.227</td>
<td>0.225</td>
<td>0.295</td>
<td>0.327</td>
<td>0.393</td>
<td>0.433</td>
<td>0.496</td>
<td>0.560</td>
<td>0.625</td>
<td>0.714</td>
</tr>
<tr>
<td>10-mm</td>
<td>(0.273) (0.210-0.354)</td>
<td>0.229</td>
<td>0.227</td>
<td>0.297</td>
<td>0.329</td>
<td>0.394</td>
<td>0.433</td>
<td>0.496</td>
<td>0.560</td>
<td>0.625</td>
<td>0.714</td>
</tr>
<tr>
<td>15-mm</td>
<td>(0.332) (0.256-0.431)</td>
<td>0.226</td>
<td>0.224</td>
<td>0.296</td>
<td>0.328</td>
<td>0.393</td>
<td>0.432</td>
<td>0.495</td>
<td>0.559</td>
<td>0.624</td>
<td>0.713</td>
</tr>
<tr>
<td>30-mm</td>
<td>(0.347) (0.250-0.430)</td>
<td>0.224</td>
<td>0.222</td>
<td>0.294</td>
<td>0.326</td>
<td>0.391</td>
<td>0.430</td>
<td>0.493</td>
<td>0.557</td>
<td>0.622</td>
<td>0.711</td>
</tr>
<tr>
<td>60-mm</td>
<td>(0.372) (0.269-0.474)</td>
<td>0.222</td>
<td>0.220</td>
<td>0.292</td>
<td>0.324</td>
<td>0.389</td>
<td>0.429</td>
<td>0.492</td>
<td>0.556</td>
<td>0.620</td>
<td>0.709</td>
</tr>
<tr>
<td>2-h</td>
<td>(0.696) (0.543-0.895)</td>
<td>0.828</td>
<td>0.826</td>
<td>0.897</td>
<td>0.937</td>
<td>1.014</td>
<td>1.065</td>
<td>1.131</td>
<td>1.215</td>
<td>1.310</td>
<td>1.415</td>
</tr>
<tr>
<td>3-h</td>
<td>(0.784) (0.641-1.10)</td>
<td>0.822</td>
<td>0.820</td>
<td>0.892</td>
<td>0.932</td>
<td>1.010</td>
<td>1.059</td>
<td>1.125</td>
<td>1.210</td>
<td>1.305</td>
<td>1.410</td>
</tr>
<tr>
<td>4-h</td>
<td>(0.875) (0.771-1.24)</td>
<td>1.12</td>
<td>1.11</td>
<td>1.18</td>
<td>1.24</td>
<td>1.31</td>
<td>1.38</td>
<td>1.46</td>
<td>1.54</td>
<td>1.63</td>
<td>1.73</td>
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<tr>
<td>12-h</td>
<td>(1.21) (1.11-1.58)</td>
<td>1.09</td>
<td>1.08</td>
<td>1.15</td>
<td>1.22</td>
<td>1.30</td>
<td>1.38</td>
<td>1.47</td>
<td>1.57</td>
<td>1.67</td>
<td>1.77</td>
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<tr>
<td>24-h</td>
<td>(1.50) (1.41-2.17)</td>
<td>1.09</td>
<td>1.08</td>
<td>1.15</td>
<td>1.22</td>
<td>1.30</td>
<td>1.38</td>
<td>1.47</td>
<td>1.57</td>
<td>1.67</td>
<td>1.77</td>
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<tr>
<td>1-day</td>
<td>(1.86) (1.66-2.51)</td>
<td>2.03</td>
<td>2.02</td>
<td>2.24</td>
<td>2.30</td>
<td>2.43</td>
<td>2.50</td>
<td>2.60</td>
<td>2.71</td>
<td>2.83</td>
<td>2.96</td>
</tr>
<tr>
<td>3-day</td>
<td>(2.37) (2.02-2.62)</td>
<td>2.16</td>
<td>2.15</td>
<td>2.27</td>
<td>2.33</td>
<td>2.46</td>
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<td>2.74</td>
<td>2.87</td>
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<tr>
<td>4-day</td>
<td>(2.67) (2.15-2.92)</td>
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<td>2.11</td>
<td>2.23</td>
<td>2.29</td>
<td>2.42</td>
<td>2.48</td>
<td>2.59</td>
<td>2.70</td>
<td>2.83</td>
<td>2.95</td>
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<tr>
<td>1-week</td>
<td>(3.19) (2.58-3.39)</td>
<td>2.00</td>
<td>1.99</td>
<td>2.08</td>
<td>2.15</td>
<td>2.27</td>
<td>2.33</td>
<td>2.44</td>
<td>2.55</td>
<td>2.67</td>
<td>2.79</td>
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<tr>
<td>2-week</td>
<td>(3.73) (3.03-3.61)</td>
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<td>1.96</td>
<td>2.06</td>
<td>2.13</td>
<td>2.25</td>
<td>2.31</td>
<td>2.42</td>
<td>2.53</td>
<td>2.66</td>
<td>2.79</td>
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<tr>
<td>1-month</td>
<td>(3.78) (3.05-3.97)</td>
<td>1.81</td>
<td>1.79</td>
<td>1.89</td>
<td>1.97</td>
<td>2.09</td>
<td>2.16</td>
<td>2.28</td>
<td>2.40</td>
<td>2.53</td>
<td>2.66</td>
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<tr>
<td>2-month</td>
<td>(3.79) (3.06-3.98)</td>
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<td>1.68</td>
<td>1.78</td>
<td>1.86</td>
<td>1.98</td>
<td>2.05</td>
<td>2.17</td>
<td>2.30</td>
<td>2.43</td>
<td>2.56</td>
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<tr>
<td>3-month</td>
<td>(3.77) (3.04-3.97)</td>
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<td>1.58</td>
<td>1.68</td>
<td>1.76</td>
<td>1.88</td>
<td>1.95</td>
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1 Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).
Numbers in parentheses are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates for a given duration and average recurrence interval will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.
Table 6.3. Recommended percentage imperviousness values

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<th>Land Use or Surface Characteristics</th>
<th>Percentage Imperviousness (%)</th>
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<td><strong>Business:</strong></td>
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<td>Downtown Areas</td>
<td>95</td>
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<tr>
<td>Suburban Areas</td>
<td>75</td>
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<tr>
<td><strong>Residential lots (lot area only):</strong></td>
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<tr>
<td>Single-family</td>
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<tr>
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<tr>
<td>0.75 – 2.5 acres</td>
<td>20</td>
</tr>
<tr>
<td>0.25 – 0.75 acres</td>
<td>30</td>
</tr>
<tr>
<td>0.25 acres or less</td>
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<tr>
<td>Apartments</td>
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<td><strong>Industrial:</strong></td>
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<td>Light areas</td>
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<tr>
<td>Heavy areas</td>
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<td>Parks, cemeteries</td>
<td>10</td>
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<tr>
<td>Playgrounds</td>
<td>25</td>
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<td>Schools</td>
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<td>Railroad yard areas</td>
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<td>Greenbelts, agricultural</td>
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<td>Paved</td>
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<td>Gravel (packed)</td>
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<td>Drive and walks</td>
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<tr>
<td>Roofs</td>
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<td>Lawns, sandy soil</td>
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<tr>
<td>Lawns, clayey soil</td>
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Figure 29-Warning Sign and Plaques and Object Markers for Bicycle Facilities
Table 11 - Minimum Curve Radius from CDOT Roadway Design Guide Chapter 14

The AASHTO Bicycle Guide provides an alternative method for calculating minimum radii which in some cases yields a smaller required radius. It is based upon the lean angle of a bicycle.

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<th>R (feet) for Design Speed (mph)</th>
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</tr>
<tr>
<td>5.2</td>
<td>11</td>
</tr>
<tr>
<td>5.4</td>
<td>11</td>
</tr>
<tr>
<td>5.6</td>
<td>11</td>
</tr>
<tr>
<td>5.8</td>
<td>11</td>
</tr>
<tr>
<td>6.0</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 14-7 Minimum Radii and Superelevation for Bicycle Only Paths
### Table 3.3 Recommended $a_1$ Values for the Base Layer Coefficients

<table>
<thead>
<tr>
<th>Component</th>
<th>Design $M_R$ (psi)</th>
<th>Design Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% RAP with R-value $\geq$ 90</td>
<td>48,675</td>
<td>0.19</td>
</tr>
<tr>
<td>100% RAP with 78 $\leq$ R-value $&lt; 90$</td>
<td>32,883</td>
<td>0.15</td>
</tr>
<tr>
<td>Aggregate Base Course (Class 6) with R-value $\geq$ 78</td>
<td>32,883</td>
<td>0.15</td>
</tr>
<tr>
<td>Aggregate Base with R-value $\geq$ 83</td>
<td>38,721</td>
<td>0.14</td>
</tr>
<tr>
<td>Aggregate Base with 77 $\leq$ R-value $&lt; 83$</td>
<td>31,826</td>
<td>0.12</td>
</tr>
<tr>
<td>Aggregate Base with 69 $\leq$ R-value $&lt; 77$</td>
<td>24,503</td>
<td>0.11</td>
</tr>
<tr>
<td>Aggregate Base with 59 $\leq$ R-value $&lt; 69$</td>
<td>21,500</td>
<td>0.10</td>
</tr>
</tbody>
</table>

### Table 3.5 Minimum Total Pavement Thicknesses for Flexible Pavement Structures

<table>
<thead>
<tr>
<th>Traffic, 18k ESALs</th>
<th>HMA Thickness</th>
<th>ABC Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq$ 150,000</td>
<td>2.0”</td>
<td>4”</td>
</tr>
<tr>
<td>150,001 to 500,000</td>
<td>2.5”</td>
<td>4”</td>
</tr>
<tr>
<td>500,001 to 2,000,000</td>
<td>3.0”</td>
<td>6”</td>
</tr>
<tr>
<td>$&gt; 2,000,000$</td>
<td>4.0”</td>
<td>6”</td>
</tr>
</tbody>
</table>
Figure 14-37 Conditions where barriers to embankments are recommended

Figure 30-Railing Height from CDOT Roadway Design Guide
Exhibit 7: Photo Simulations
Figure 31—An Illustration of Typical Signage Location

Figure 32—Directional Signage Examples
Figure 33-An Illustration of the First Rest Area Location

Figure 34-A 3d Model of the proposed path design
Figure 35-A 3d image of the proposed path with retaining walls and guardrails
Exhibit 8: Team Member Resumes
Justin Gaumond E.I.

5303 W. Oberlin Dr. Denver, CO 80235, (720) 203-3097, jgaumond@gmail.com

EDUCATION

Expected Graduation 05/2021

Bachelor of Science: Civil Engineering
University of Colorado Denver – Denver, CO


06/2007 Bachelor of Arts: Theatre
University of Denver – Denver, CO

ACADEMIC PROJECTS

Central City Recreation Trail Design for senior project Central City, CO. (In progress)
- Vertical and horizontal alignment of the trail running parallel to the parkway. Pavement design and drainage calculations using local standards from CDOT and MHFD. Safety considerations for traffic and bikers.

Martin Luther King Jr. Boulevard highway expansion design and proposal. Denver, CO.
- Vertical and horizontal alignments, road classifications, design speed, design vehicle and grade

Design of an intersection using Hot Mix Asphalt and Portland Cement Concrete
- Designed pavement thickness using AASHTO and CDOT standards

EMPLOYMENT EXPERIENCE

05/2020 – 08/2020 Engineering Intern
Weaver Consultants Group – Greenwood Village, CO
-QA for landfill construction, QA for drilling gas extraction wells, QA for compaction and moisture content of constructed lifts for landfill berms, QA document editing

05/2016 – 08/2016 Engineering Intern
Jefferson County Road and Bridge – Golden, CO
- Inspected and mapped stormwater system, documented problem drainage locations, input, and corrected data on county maps regarding the stormwater system

06/2016 - 07/2019 Figure Skating Instructor
South Suburban Parks and Recreation
- Taught private and group lessons to kids and adults

11/2011 – 04/2016 Principal Pair Skater
Royal Caribbean and other professional ice-show companies
- Performed around the world as a pair skater lifting my skating partner while skating
- Wardrobe manager, washed and repaired the cast's costumes

CERTIFICATIONS

E.I.* License will be obtained upon graduation. F.E. Exam Passed.
Portable Nuclear Gauge Safety and U.S.D.O.T Hazmat Certified
Active Member of the ASCE student chapter

COMPUTER SKILLS

AutoCAD Civil 3D, Microsoft Word, Excel, PowerPoint, Teams, ArcGIS
OBJECTIVE: To work for a Structural Engineering Firm under a licensed PE to obtain licensure

EDUCATION:
Bachelor's of Science, Civil Engineering, Emphasis in Structural Engineering

May 2021, Expected

Structural Relevant Courses
- Timber Structure Design
- Structural Steel Design
- Deep and Shallow Foundation Design
- Reinforced Concrete Design
- Structural Analysis
- Senior Design
- AutoCAD
- Pipe and Waste Water Network Design

EXPERIENCE

Project Engineer Intern, CATAMOUNT CONSTRUCTORS INC. JULY 2019 – PRESENT

- Provide onsite administrative support to the project team consisting of the Project Manager, and Superintendent.
- Solid knowledge base for reading plans, understanding scopes of work performed by subcontractors, proficient use of software (Procore, Microsoft office), as well as a general understanding of the risks and approaches to bidding work in different markets

Lead Teller Operations Manager, JP MORGAN CHASE JULY 2014 – JULY 2019

- Assist the Branch manager and tellers to ensure transactions are completes accurately and efficiently
- Reduced risk by ensuring team members knew and followed policy and procedures
- Provide all tools necessary for team members to succeed and be prepared for the day

Guest service Manager, TARGET MARCH 2012- JULY 2014

- Lead a team to success by motivating them to reach a team goal
- Focused on reducing wait time for customers and still maintain a friendly interaction
- Reduced risk by training team to understand and acknowledge loss prevention
- Plan daily sales goals and communicate goals to team

CERTIFICATIONS
- FE Civil Exam (Passed, January 2021)
- OSHA 10

TECHNICAL SKILLS
- Fluent in Spanish (Speaking and writing)
- Proficient in Microsoft Office
- MATLAB Programming language
- Proficient in AutoCAD
MIR ZABIHULLAH QURESHI, E.I.
Aurora, CO 80016 1-720-501-9429 – zabihquraishi@yahoo.com

EDUCATION:
University of Colorado Denver, Denver, Colorado Anticipated Graduation: May 2021
Bachelor of Science, Civil Engineering
Community College of Aurora, Aurora, Colorado
Associate of General Studies Graduation: May 2018
Kabul University, Kabul City, Kabul
Bachelor of Economics Graduation: Not Completed

Academic Projects:
Steel design of a two-story moment frame for an office building in Denver, Colorado.
• The columns, girders and beams were designed per AISC specification.
Martin Luther King Jr. Boulevard highway expansion design and proposal. Denver, Colorado.
• Vertical & horizontal alignments, road classification, design speed, design vehicle, and grade
Potable water supply and distribution design to Castle Oaks community Castle Rock, Colorado.
• Analysis of water use by area served storage tanks, pumps, transmission, and treatment.
Layout and Design of a new bicycle/pedestrian path that connects downtown Central City to Idaho Springs.
• Pavement Design, Bridge Design, Tunnel Design, Alignments and Excavations were included.

Employment:
Wal-Mart Stores, Inc, Aurora, Colorado April of 2017 – August of 2019
• My work at Wal-Mart Stores, Inc. taught and prepared me on how to interact with customers.
• Daily responsibilities at Wal-Mart Stores, Inc. included helping customers with products related questions, offering money services to the customers, helping customers with items checkout and meeting with managers and co-workers regarding sales and customer service.

Alkhair Hospital, Kabul City, Kabul May of 2014 – August of 2015
• Daily responsibilities at Alkhair Hospital included answering phone calls, helping patients with questions regarding formalities and hospital paperwork and admitting patients to the specialist unit.

Certifications: FE Civil Exam (Passed, March 2021)

Software Knowledge: In addition to being familiar with PCs, tablets, and most Android devices, my academic projects have introduced me to all Microsoft Office products, AutoCAD Civil 3D, Revit, Risa, Primavera P6 and MATLAB programming language.
Tai Anh Le
8091 Bryant St, Westminster, CO 80031    (720) 397-1360    atai.le70@gmail.com

SUMMARY
An ambitious student pursuing a Bachelor of Science in Civil Engineering degree eager to developed real-world knowledge, skills, and experience in working in a professional setting. Adaptable and driven with a strong work ethic and the ability to thrive in team-based or individually motivated settings.

EDUCATION
Bachelor of Science in Civil Engineering  May 2021 (Expected Date)
FE Exam  Date of Spring 2021
University of Colorado Denver, Denver, CO

Associate of Science  Graduated May 2017
Community College of Denver (CCD), Denver, CO.

TECHNICAL SKILLS
• Software Skills: AutoCAD Civil 3D, Revit, Microsoft Office Excel, Word and PowerPoint.
• Fluent in written and verbal Vietnamese.

WORK EXPERIENCE
Residential Plumbing Construction, Westminster, CO.  March 2014-Present
• Assisted plumbers and pipe fitters in performing residential construction.
  o Activities included remodeling bathrooms and kitchens in single-family homes
  o Skills included: planning, quantity takeoffs, estimating and problem-solving, preparing substrate, measuring and cutting, and placing ceramic and porcelain tile and brick masonry; cutting, hanging and mudding drywall; mixing and placing concrete, installing soldered copper pipe and threaded steel pipe for pressure water and gas applications.

Computer Lab and Tutoring at CCD, Denver, CO.  May 2016-Present
• Provided customer support to students and answered the phone.
• Assisted faculty and students with using computers software and hardware.

Manager, Faifo Pho & Grill, Westminster, CO.  May 2016-Present
• Scheduling and Managed front-end team of servers, food runners, bussers, and hostesses to ensure acceptable restaurant operations and provide exceptional customer service.
• Worked closely with the owner, chef and cooks to determine menu plans for special events or occasions.
• Monitored and enforced sanitary standards required by the Public Health Regulations.

EXTRACURRICULAR ACTIVITIES
UP2US COACH Across America, Westminster, CO.  August 2015-September 2017
• Provided group tennis lessons about 20 students aged 10 years old and younger.
• Improved physical stamina and dexterity, fostered sportsmanship, and encouraged positive self-esteem.
• Maintained a positive and motivational atmosphere to encourage students to have fun and improve learning.

CERTIFICATES AND TRAINING
United States Professional Tennis Association (USPTA) certified Instructor 2015 to 2017
Karla Sanchez
720.276.9720 | karla.virisanchez@gmail.com | www.linkedin.com/in/karlavsanchez

SKILLS
• ArcGIS
• AutoCAD Civil 3D
• Revit
• RISA 3D
• OSHA 10 Certified
• Building Information Modeling
• EPANET

EDUCATION
University of Colorado Denver
Bachelor of Science in Civil Engineering
Anticipated Graduation May 2021

Emily Griffith Technical College
Completed Water Quality Management courses:
• Wastewater Treatment
• Water Treatment

RESEARCH AND PROJECTS
One World One Water, Metropolitan State University
Research Assistant
Researched hydrologic benefits of Acequia irrigation system. Studied the water rights in the San Luis Valley

National Oceanic and Atmospheric Association
Subcontractor
• Managed black carbon data for four Arctic sites
• Organized, extrapolated, and disseminated black carbon data gathered from four aethalometers and four nephelometer in the Artic
• Prepared, interpreted, and analyzed instrument reliability and validity to characterize aerosol chemistry and microstructure present in atmosphere

National Science Foundation, Red Rocks Community College
Designed a 3D printed water filtration system as part of the National Science Foundation community college innovation challenge.

ACADEMIC INVOLVEMENT
American Society of Civil Engineers
Vice President of External Affairs since 2020 Member since 2018

Society of Hispanic Engineers
Member since 2017

Society of Women Engineers
Member since 2019

UC Denver Steel Bridge Team
Collaborated in design and fabrication of a small-scale bridge for AISC Student Steel Bridge Competition

RELEVANT COURSE WORK
• Water Supply and Distribution Systems
• Fluid Mechanics
• Hydraulic Engineering Systems
• Geotechnical Engineering
• Plane Surveying
• Structural Analysis

WORK EXPERIENCE
Merrick & Company
Engineering Intern III (Oct 2020- Present)
• Analyzed data, developed GIS models, CAD drawings and design reports for water and wastewater master plans
• Assisted in preparing preliminary and final design reports for wastewater treatment facilities

Ready Foods
• Developed and implemented new safety Lockout Tagout programs in accordance with OSHA standards for four processing plants
• Developed technical safety procedures in Spanish and English
• Trained over 100 employees on appropriate Lockout Tagout procedures

AK Design
• Calculated estimates for customer inquiry, managed inventory of materials necessary for gutter installment
• Installed and repaired gutters, flashing, downspouts and surfaces.
• Assisted in caulking pipe joints, measuring and cutting

BD Vending
Owner (Jan. 2010- Dec. 2016)
• Developed relationships with businesses and established new vending machine locations
• Managed 20 vending machines, maintained weekly inventory for products, waste reports, product movement and machine functionality
• Troubleshoot malfunctioning machines and implemented proper repairs

COMMUNITY INVOLVEMENT
Inspiring Connections Outdoors
• Volunteer organizer and instructor for youth rafting and skiing trips

Together Colorado
• Presented research report on immigration reform in front of 600 people including US Senator Michael Bennet
• Testified for instate tuition for the Democratic caucus

Rights For All People
• Presented “Know Your Rights Trainings” to over 100 youth and women in Colorado
ABDULLAH ALFAILAKAWI
Miami, FL | +1 (305) 934-8252 | abdullah.alfailakawi@outlook.com

SUMMARY OF QUALIFICATIONS

- Civil Engineer student, great with problem solving, organizational and communication skills
- Well experienced with Microsoft Excel, Mathcad and AutoCAD (engineering drawings)
- Resourceful planner, managerial practice with previous fundraiser, competitive team worker
- Very innovative when it comes to designing in engineering

EDUCATION

University of Colorado, Denver, CO

Bachelor of Science in Civil Engineering

- Certificate from Kuwait Cultural Office Washington DC
- Certificate from Global first year at FIU
- Certificate from the United States Embassy in Kuwait

EXPERIENCE

National Union of Kuwaiti Students, Miami, FL January 2016 – January 2018

Member of Organizational volunteers

- Helped Kuwaiti students with their college applications all around the United States
- Organized events for students in Miami like barbeques and soccer tournaments
- Gained skills from this work experience which are public relations

Zombie Run, Kuwait City, Kuwait March 2015

Co-owner

- Fundraiser event in Kuwait, money collected was donated to Syria
- Associated with different sponsors like, United States Embassy in Kuwait, Rawda & Hawally Co-op, Heal, Layan and Amideast.

AWARDS AND ACKNOWLEDGEMENTS

SKILLS

AutoCAD, Python, Mathcad and Microsoft (Word, Power Point and Excel)

Languages: Fluent in English and Arabic (read, write and speak)