Red Butte Creek Pedestrian Overpass

Cable Stayed Bridge

Project Report 2023: University of Utah Department of Civil and Environmental Engineering

Project #4910.03.05

In Accordance With:

The University of Utah

The John and Marcia Price Department of Civil and Environmental Engineering\

Prepared for:

Salt Lake City Division of Transportation

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Project Number #4910.03.05

Academic Disclaimer:
The following report is the work of undergraduate engineering students, not that of a professional engineer. This work is for academic purposes only.

Acknowledgments
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Mentors and Supporting Parties:

Parametrix- Adam Birdsall

Applied Geotech- Dave Nordquist

Parsons Engineering- Todd Ude

CONTECH Engineered Solutions- Chad Kitchen

Red Butte Creek Steering Committee

Executive Summary
The following report details the preliminary design work for a pedestrian overpass at Foothill Drive in Salt Lake City, UT. The proposed solution for the area is a Cable Stayed pedestrian bridge that matches the aesthetic of a nearby bridge, Legacy Bridge. The document outlines the statement of need, the stakeholders involved, and the basis of design. The report establishes the need for the project and identifies the challenges to bring the project to its completion. The road in the project study area is near Red Butte Creek, Foothill Drive is a heavily trafficked road. It is classified as a collector road, connecting many people to their final destinations. Foothill drive is currently at max capacity and unable to undergo lane expansion. By implementing a pedestrian crossing in this area, other modes of transportation will be more readily available to residents and commuters in the area. This will enable the area to become a more complete street as people can bike and walk to their destinations more safely and conveniently. People will be safer crossing and less jaywalkers will be spotted trying to cross this dangerous road. The implementation of this project will greatly aid in reduction of traffic among foothill and increase the quality of life for all people in the community. Along with its transportation benefits, the project has an opportunity to aid in supporting sustainability for the community.

This report also explores the technical considerations of the site features including geotechnical, topographic, and hydraulic characteristics. It addresses potential hazards and discusses the basis of design based on ISI Envision Grading Criteria, SLC complete streets ordinance, and other useful tools. The stakeholders will be at the forefront of driving the ultimate project design.

The report aims to illustrate the potential benefits of implementing a pedestrian crossing in this area and discusses how the team chose this design. Attached to the report's body are the engineering drawing sets for the chosen design, a Cable Stayed bridge with a spiral ramp (Figure 8.)

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Project Summary

The following sections define the project needs statement and goals and visions for the project. The design basis for the project was created based on various influential factors and the influence of the stakeholders.

1.1 Project Needs Statement

Heavy traffic is prevalent along Foothill Drive as nearby residents commute to the University of Utah campus and research park. The area can be unsafe for residents to cross due to the high quantity of vehicles on Foothill Drive. This area is extremely important for the commuters and residents in the area and fast accessibility to the surrounding area is important for many. With exponentially increasing population and traffic, the area has become unsafe and challenging to navigate, particularly for pedestrians. There have been previous studies done by the Utah Department of Transportation (UDOT) to explore a potential expansion of the road to help reduce the burden of this heavily trafficked area, but ultimately it has been concluded that an expansion of the road is not favorable due to several factors. These factors include the consideration that the residential areas and property that would be negatively impacted by an expansion. The current situation at Foothill Drive must be addressed in an innovative and technical way. If it is ignored, the increasing population in the area will continue to be an issue, traffic will be worsened, and pedestrian safety will suffer.

A new proposal for a pedestrian overpass bridge is being drafted to help address the issues at hand. Adding a pedestrian overpass will enable pedestrians to walk or bike safely across this busy road and commute to various locations nearby via alternate routes. Additionally, this project's success will aid in reducing the number of cars on foothill drive as residents may find alternative routes other than driving on Foothill Drive to arrive at their final destinations in the area. The overall quality of life for people in this area will improve as people can easily and safely commute from point A to point B. Safety will be improved and the economic growth of the area assisted.

1.2 Project Goals and Vision

On September 28th, 2019, a pedestrian woman was struck while crossing Foothill Drive by an oncoming vehicle that failed to spot her in time, she succumbed to her injuries at the hospital the next day [5], [6]. This incident, as well as multiple others over the course of many years, have laid precedent to the idea that Foothill Drive is incredibly dangerous for pedestrians and cyclists to cross, especially around high volume and high priority areas, such as near the University of Utah. At the University of Utah currently, pedestrian travel has taken a large backseat compared to vehicular travel around most of Foothill Drive, making it much safer for residents near the area to simply drive to campus, rather than walk what should only be a quick trip walking. This not only comes at high long-term cost for the residents near Foothill Drive, but also aggravates the high traffic volumes along Foothill Drive, as it is a major road used for travel to the University of Utah as well as other businesses nearby.

To make pedestrian and cyclist travel safer and more convenient along Foothill Drive, Salt Lake City and the University of Utah are looking into developing a trail that runs parallel to Red Butte Creek, meant for both pedestrian and bicycle use. However, since Red Butte Creek does flow underneath Foothill Drive south of Mario Capecchi Drive, unique action will need to be to implement this trail. To aid in the connection to the future trail, a pedestrian overpass is being proposed in this area. This report details the design process and considerations to implement this solution.

1.3 Project Participants and Organization

For the development of this project, the following staff structure was adopted:

1. Project Lead: Lynn Jacobs, Salt Lake City Department of Transportation
2. Instructional Team: Dr. Doug Schmucker, Dr. Steven Bartlett, HR Clark III
3. Design Group Leader: Karlus Pulley
4. Design Group Members: Benjamin Gerber, Ronnie Kaye, Wona Kim, Sebastian Lopez, Tessa Muir

Within this structure, the Design Group Members would develop various design aspects and report it to the Design Group Leader, Karlus Pulley, who would verify its accuracy before submitting it to the Instructional Team. The Instructional Team would then submit it to the Project Lead, Lynn Jacobs.

1.4 Stakeholders

Project #4910.03.05 has many stakeholders involved that have different goals and priorities that have been kept in mind during the design process. Each stakeholder is incredibly influential in the direction a project may take, due to their heavy investment in the success of the project, both in terms of time and economics. As such, it is paramount to keep their priorities for the project in mind during the design process. Their input has been used to determine the direction the design should go in.

The stakeholders are from various branches within the city and government, such as Salt Lake City Engineering, Salt Lake City Trails, US Army Corps of Engineers, and others (Table 1). In addition, there is also the Sunnyside Neighborhood Community, a group of residents in the nearby neighborhood, who wish for the project to not inhibit the quality of life during construction and improve it after completion of the passageway.

Beyond the Sunnyside Neighborhood Community, there is a clear trend of priorities between most of the stakeholders. The stakeholders of this project want the passageway to not harm the existing ecosystem, which includes Red Butte Creek, the Riparian Corridors, and Sovereign Lands, and to make access to the trail easy for all ability levels for both pedestrians and cyclists. Of course, it is safe to assume that every stakeholder would wish for the project to be as cost effective as possible, so minimizing the budget of the project is also a priority. Table 1 below gives an overview of every stakeholder within the project and their top three priorities for the design.

Table 1: Stakeholder Information

Stakeholder	Priority 1	Priority 2	Priority 3
Salt Lake City Engineering	Integrate usage and purpose, and improve equity and access	Low maintenance and construction	Protect existing Riparian Corridors
Salt Lake City Trails	Accommodate pedestrians and cyclists of any level	Minimize elevation change	Connect to future trails
Sunnyside Neighborhoo Community	Direct passage across Foothill Drive	No unnecessary construction or interruptions	No impact on street parking and passage
US Army Corp of Engineers	Minimize impact to stream banks and channel	N/A	N/A
Salt Lake City Ordinanc Riparian Corridor Overlay District	Preserve and Protect Riparian Corridors	N/A	N/A
Utah Division of Forestry, Fire & State Lands	Protect Sovereign Lands	N/A	N/A
Utah State Engineer's Office	Minimize impact to stream banks and channel	N/A	N/A
Salt Lake County Engineering and Flood Control	No impact within 20 feet of channel bank/flood control facility	N/A	N/A
Salt Lake County Watershed Planning anc Restoration	Zero net impact to downstream systems	N/A	N/A
UDOT	No at-grade pedestrian crossing	No change in street width, volume, and current traffic flow	Preserve existing Right of Way
US Federal Governmen	Preserve existing Right of Way	Ability to secure access points comparable to threat level	N/A
Veterans Association (VA)	No violation of the existing Enhanced Use Lease	Integration into Existing Fort Douglas Parking Structure	Structure must allow for both screening and be locked down independently of VA building

It should be noted that while following the Stakeholder's priorities is ideal, in some cases following all the Stakeholder's priorities will not be possible. In this case, the designer will communicate with the impacted stakeholder and work to find a compromise that works for both parties.

2 Site Description and Analysis

The site for this project proposed unique challenges in implementing a pedestrian bridge solution. These challenges include the property right of way boundaries, geologic and hydraulic traits of the site, and the overall topography of the site.

2.1 Location/General Usage

The project area lies parallel to Red Butte Creek as it flows underneath Foothill Drive, south of Mario Capecchi Drive and north of Wakara Way. Figure 1 below shows an aerial view of the focus area for this project.

Figure 1: Aerial Image of Site from Google Earth Pro

2.2 Geological/Geotechnical Information

For a crossing located between Foothill Dr. and Wakara Way, there are 4 major stakeholders to consider when information on the area is to be collected. These stake holders are UDOT, VA Affairs, Fort Douglas, and the University of Utah. Getting these 4 agencies to collaborate will make this job move along effectively. UDOT, the University, and the V.A are on board with the project and willing to cooperate. Fort Douglas is off limits and limited disturbance should be expected. In the region surrounding this crossing, the soil is an alluvial fan and debris fan deposit with a maximum explored depth of 10 meters.

The borings conducted on this site was conducted utilizing the ravine as a primary test pit. The team will need to conduct 2 borings on the East Side of Foothill Dr. The lane adjacent to the existing culvert must be shut down on the day of testing. The University of Utah and UDOT will need to give permission to work in the area. The team must dig at least 30 feet to provide enough information for a buried bridge option. For a typical pedestrian overpass option, the approximate size of the structure will be 12' wide, 140' long equating to a 4'x15' concrete footing. This ensured proper geotechnical site testing for the design of the cable stayed overpass.

The site consists of 3 soil types converging near the site and Red Butte Creek. The soil types are mostly rocky, with sandy gravel, gravelly sand, silt, and clay. The distribution of these soil types in the site location and their full descriptions can be seen in Appendix III.

The soil characteristics in the area are very rocky and sandy, presenting challenges in the possibility of an underpass as large boulders or rocks may be in the way of the underpass.

To confirm soil and geographic characteristics, a professional geotechnical analysis was performed. As two main alternatives are being investigated, either a pedestrian bridge or underpass, the alternative requiring a deeper boring hole will control the decided boring depth. The recommended boring depths are based off the required footing depth of the pedestrian bridge and the minimum radius of the tunnel plus an additional 10' of free depth. These metrics were decided in collaboration with Dave Nordquist, P.E. from AGEC Applied Geotech. The final boring hole depth recommendation is 30', this can be seen in Appendix II.

2.3 Additional Risks and Hazards:

In addition to the flooding hazard as seen in, there is seismic activity that will need to be accounted for. This project is in the Wasatch fault zone so any solution will need to take into consideration earthquake design constraints. To the north, there is a moderately constrained less than 15,000 years old fault line. To the East and South, there is a moderately constrained less than 130,000 years old fault line. These fault lines require additional consideration according to the Utah earthquake building codes and FEMA building codes.

2.4 Hydrologic/Hydraulic

The stormwater division looked at Red Butte Creek from a larger perspective. The Red Butte Watershed is 11.4 square miles and contains various culverts throughout the research park. This includes a dam at the mouth of the creek. The watershed is the smallest of the 4 major watersheds around downtown Salt Lake City. The others include City Creek, Emigration, and Parleys (the largest at 52 square miles). The creeks 1 percent duration to design for is 46 cubic feet per second. That value stands as the peak flow rate.

The hydraulic considerations that must be followed during this project's design phase are limited for overpass construction. The geotechnical boring conducted on October 27th revealed that there was no groundwater encountered within the first 12 feet. This mitigates design criteria regarding hydraulics. The primary criteria that will be considered are working within a riparian corridor and working within proximity of a stream. This will require a Stream Alteration Permit, and a Riparian Corridor permit to complete construction. Alternatively, the bridge can be designed outside the waterway area to avoid these complications.

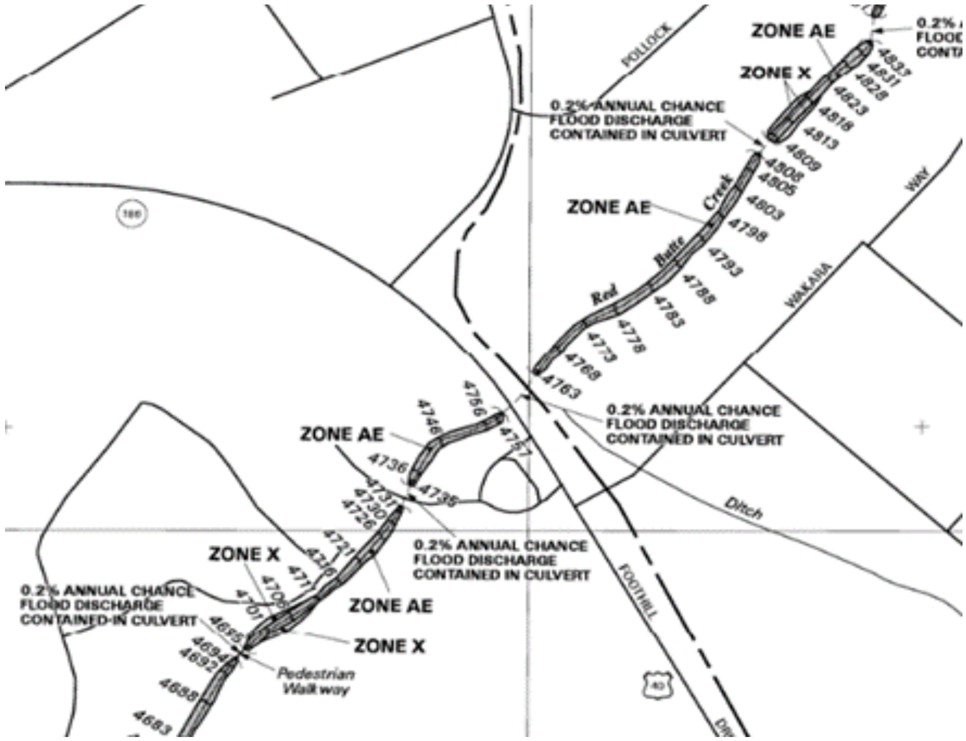

Figure 2: Fema Floodplain

The waterway in the area is more than 6 feet deep and is unlikely to overflow the banks. In contrast, the likelihood of erosion and bank collapse is high, especially in larger rainfall events. This would allow for particles much bigger than normally to be moved by the stream to be washed out. This is one of the reasons for using pile foundations for the main bridge and having redundant foundations for the spiral ramp structure. The average flow for the creek ranges from about 10 cubic feet per second to a minimum 1.5 cubic feet per second (Appendix I). Additionally, the maximum height seen is 3 feet. It may be possible to use this information to model a potential flood and see which parts of the bridge would be impacted. However, the team has decided to ensure the bridge will be designed to withstand flooding. This will ensure a conservative design and an abundance of safety. Additionally, by designing the bridge to withstand flooding, the concern of the 100-year flood in this area is addressed.

2.5 Topographic

Below is the site location with UDOT R.O.W and property lines. Note that foothill spans about 105 feet and there are 7-9 lanes of traffic. Also, a 20-foot clearance box is needed for the overpass achieved in the design plans.

Figure 3:ROW for Site Location

The overall topography of the site and elevation profile can be seen in Appendix IV. This information was used to ensure a viable project design for this project location and unique topography.

3 Summary of Criteria

3.1 Project Criteria

Based on the items detailed above, the highest priority items that the project must adhere to are as follows:

Establish a safe pedestrian crossing at a different grade across Foothill Drive, located near Red Butte Creek

1. Integrate the crossing into existing and planned infrastructure as much as possible and limit the disturbance to existing conditions.
2. Make the crossing accessible to all, including cyclists and those with disabilities.
3. The crossing must be as sustainable as possible, to leave as little of a footprint in the existing nature as possible, especially around Red Butte Creek.

3.2 Basis of Design

The main design criteria that governed the selection of this design are as follows:

-Basis of Design

1. Enable various modes of contact (strollers, pedestrians, bikers)
2. Accessibility to all
3. Aesthetic Appeal
4. Sustainable manufacturing
5. Safe for pedestrians and vehicles.

Also, the ISI Envision Estimate is a large part of the design basis. This estimate scores our bridge's ability to meet various desirable outcomes for the community. This includes improving quality of life, leadership, resource allocation, natural world, and climate resilience.

-*ISI Envision Estimate*

Using the ISI Envision Estimate framework, this project scores an impressive *GOLD STAR* rating. This means this project is above average to improve the city's overall infrastructure and is viable to pursue future planning and design. The largest opportunity the project offers is within the category of "quality of life "as it scored 7/12, the highest of any other category. This is mostly because the improved walkability will enable pedestrians to get around their hometown easier and be safer while doing so. **22/56** is the final score. This yields an impressive **40%** which is an award level of **Gold** by the ISI Envision standard. This shows that this project is above average to improve the city's overall infrastructure and is viable to pursue future planning and design. The detailed scores of all the categories are in Appendix VI.

3.2.1 Integration of Stakeholder Priorities and Values

Ensuring stakeholder priorities and values has been of the upmost importance in the project design. One key element that encompasses many of the values from stakeholders is the complete streets analysis conducted for the project. "Complete Streets" is a term used by Salt Lake City Engineering to describe the goal of the community and area as it pertains to transportation and infrastructure. This also goes hand in hand with the UDOT master plan and its goals which are synchronous with that of Salt Lake City engineering for this Foothill Drive area.

The summary of the conclusions from this analysis can be seen below in table 3.

Table 3: Complete Streets Analysis

Community Context and Connections	The area is near many popular destination sites such as hospitals, schools, trails, parks, businesses, the natural history museum, and Red Butte Stone House. Connection to this area is valuable to residents and commuters.
Street Classification and Function	Currently at *full* capacity according to UDOT. 7-9 lanes of busy traffic. SLC foothill trails master plan details connection of trails in this area.
Master Plans and City Goals	Based on pedestrian, bicycle, trails, and city master plans a common goal is to increase the healthiness of the community and enable an active lifestyle. Air quality improvement is a top priority among many. The future possibility of light rail in the area and walkability to bus stations and future light rail stations are a priority.
Traffic Data and Lane Configuration	Foothill drive is considered a collector road with posted speed of 40 mph. Based on prior studies by UDOT, an additional lane of traffic is not possible for the area. Pedestrian counts and bicycle counts are estimated to be medium-high traffic volumes.
Safety & Crash Data	Average number of vehicle crashes. Pedestrian fatality due to j-walking in the area. Posted speed is 40 mph.
Intersections and Crossings	Current crossings and traffic lights are up to the latest technologies. There should be an easier crossing for pedestrians south of Wahlen Way.

The complete street checklist further illustrates the need for a pedestrian crossing in the area. For further information on the complete streets initiative, see Appendix V.

Construction of a crossing will assist in getting cars off the road and improving air quality. Accessible pedestrian crossings will promote a healthy active lifestyle, a goal of the Sunnyside community and other stakeholders. Safety will be increased for pedestrians and pedestrian fatalities avoided; a major goal stated by UDOT and Salt Lake City Corporation.

3.2.2 Integration of Sustainability

The Red Butte Creek steering committee are important stakeholders in this project. While the project does encroach on the riparian corridor buffer zone, one consideration mentioned by the committee is to use permeable pavers near the creek. This allows for sufficient drainage into the soil and is an environmental consideration the team will implement for pavers that encroach on the creek.

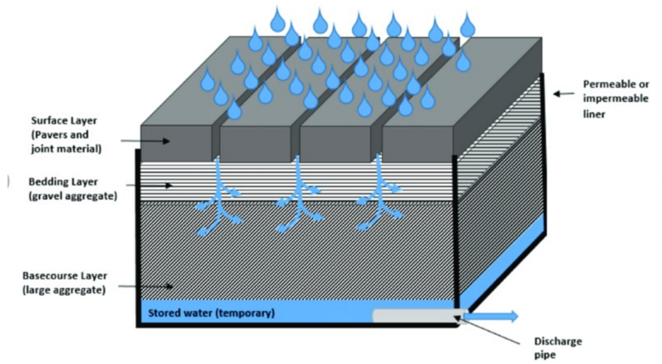

Figure 4:Permeable Paver

The project strives to be as sustainable as possible through its thoughtful design. Sustainability in this context refers to all three pillars of sustainability, environmental, economic, and social. The ISI envision estimate shows the project has great benefit in improving sustainability in the community. This is due to the consideration that the addition of a pedestrian bridge and making the area more pedestrian friendly, the use of public transportation and the decrease of cars on the road. This fits into the SLC (Salt Lake City) master plan and goal to have more "Complete Streets." Along with the possible benefit of reducing CO2 emissions from individual cars which falls into the environmental pillar of sustainability, the project will also be an economic benefit for the entire community. The project will increase the economic value of the area and promote business and development in the area while increasing the availably of affordable transportation options to all. Making transportation accessible and affordable falls into the last pillar of sustainability, ensuring the project is a benefit for all. This project additionally may save lives as it keeps pedestrians safe, another social benefit for the community.

Considering these factors and the ISI envision estimate, the project, if funded, will be a project that increases the sustainability and resiliency of the Salt Lake City community. For more information on sustainability as it pertains to the project, see Appendix VII.

3.2.3 Integration of Equity, Diversity, Inclusion, Access

The safety of not just the pedestrians and cyclists using the overpass, but also the passengers within the vehicles travelling underneath, has been held paramount during the design process. To protect all lives impacted by the overpass as best as possible, there are multiple guidelines that can be followed, such as AASHTO, which requires pedestrian overpasses built across highways to be approximately 15-17 feet above the highway, to allow large vehicles such as semi-trucks and buses to comfortably pass underneath.

Other precautions are being taken using design precedence based on similar projects within the area. Figure 1 below shows Job's Crossing Overpass on University of Utah Campus, which incorporates a large guardrail system to prevent any potential risk of falling to the highway below.

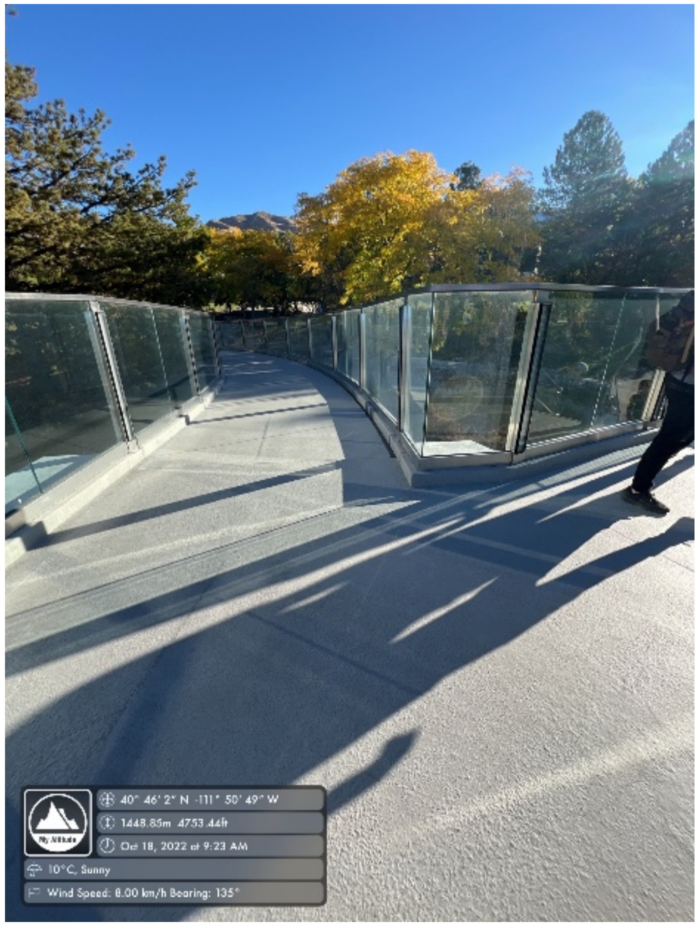

Figure 5: Jobs Crossing Overpass: P.C. Tessa Muir

The guardrails measure to be about 6 feet high, with steel frames around the glass to prevent small forces from breaking the guardrail and rendering it useless. The height of this guardrail helps prevent pedestrians from accidentally falling off. Throughout the entire design process, one main priority when analyzing the feasibility behind implementing the design is how safe it is for all human life. The overpass will be safe, regardless of where pedestrians are positioned in relation to the overpass, or what accessibility level they may be at.

The traffic line-of-site will need to be considered to keep the vehicles traveling below the bridge uncomfortable. This will keep both pedestrians and other vehicles safe and will be important during inclement weather and at night.

The following facilities will be installed for people who use the bridge. This will ensure the bridge design is in alignment with CEPTD strategy which aims to reduce crime on the bridge.

Security Box (Help Box)

The fact that the security box is installed has the effect of suppressing crime, and in the event of an actual crime, the video taken by security box acts as excellent evidence. This allows people to secure relatively safe areas. In addition, a button that reports danger can be installed at regular intervals to further strengthen crime prevention. This is a feature available on legacy bridge. The security box is lit up and has a button to push for help. A similar feature will be useful in creating a safe environment for pedestrians to be at night and avoid aid in emergency help when needed. When pushed, local authorities will be notified, and further action will be taken to assist in the emergency.

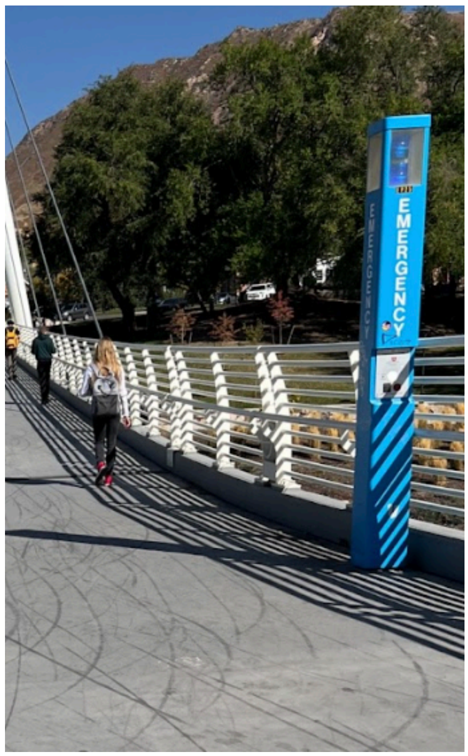

Figure 6:Legacy Bridge Emergency Call Box P.C.: Tessa Muir

-Ample Light

Ample light will be available on the bridge to keep pedestrians visible and safe during the late hours of the night. A good example of this is Legacy Bridge at the University of Utah Campus. Below an example of the lighting required is shown.

Figure 7:Lighting on Legacy Bridge (nowplayingutah.com)

-Elevator

Elevators are installed on both sides of the pedestrian bridge for people who have difficulty with long ramps, or for overpass users who need to move a lot of heavy luggage. It is effective to use elevators in inclement weather, such as when the ramps are slippery due to too much snow or rain. ADA accessible ramps will be installed for their convenience.

-Braille blocks

Install a detectable warning sign on the pedestrian ramp. The sign is embossed with bumps on the surface. So that the visually impaired can know the location or direction by the touch of the sole when walking.

3.3 Decision Criteria

Based on all the items listed above, the Decision Criteria were selected to be as follows:

- Prioritize safety and accessibility more than anything else.
- Whenever possible, apply sustainable engineering practices.
- Use materials and practices to make the design economically focused.
- Focus on creative ways to implement design while avoiding areas of contention, i.e., VA Right-of-Way.
- Design to be aesthetically pleasing, while still sustainable and economic.

3.4 Design Criteria
Based on the Design Basis of the project, the Design Criteria were selected to be as follows:

- Enable Various Modes of Transportation (Cyclists, Pedestrians, Strollers, etc.)
- Accessibility
- Natural Environment Protection
- Aesthetic Appeal
- Sustainable Manufacturing
- Safety

3.5 Concept of Design: 3D Model

As seen below, the bridge design selected by the team and stakeholders for research and preliminary design work mimics the aesthetic of Legacy Bridge (see cover page image). It is a cable stayed bridge with a spiral ramp on the VA end and a straight ramp connecting to the future trailhead. The unique spiral ramp design allows pedestrians and cyclists to use the bridge and connects to the trail and orthopedic center on the opposing side while saving space.

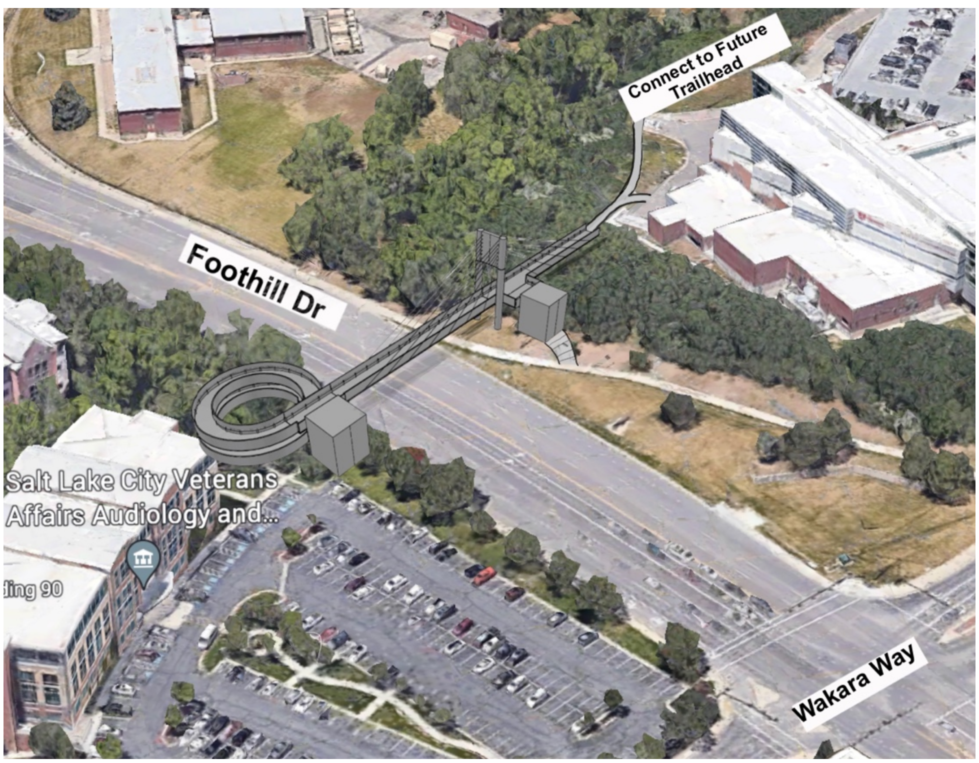

Figure 8: 3D Model Concept: Sebastian Lopez

Additionally, the design fulfills many criteria from the basis of design and could be a viable solution for the current transportation needs in the Foothill area. The following section discusses other alternatives that are possible in the area. While this bridge is certainly a great option, the ultimate decision will depend on a variety of factors including the stakeholders and city planner's ultimate desires for the area.

4 Summaries of Process for Alternative Development, Analysis, and Selection

As alternatives are explored, the Basis of Design will be essential in defining decision criteria. The solution must fit within the land constraints of the site, as well as appease various stake holders. The overpass will enable a higher quality of life for residents and commuters in the area as they can connect to critical areas nearby.

Various load support systems for this overpass are being considered, each with their own variations in how the load is distributed throughout the overpass, and where extra design considerations beyond the passageway are located. Each support system must be able to support both the dead loads of the structural elements of the overpass, as well as the expected live loads from pedestrian and cyclist use. In addition, the support systems must be able to withstand forces from outside sources such as wind, storms, earthquakes, and so on. The following sections break apart each potential support type considered for this project, based on precedence in various bridge and overpass projects in the past.

Arch support structures for overpasses primarily use arc shaped supports that receive and distribute the force among multiple parts of said arcs, which connect to abutments at each end of the overpass that send the force to the foundation underneath them. Arch systems can be built with multiple methods and materials, such as the structural steel seen in the figure above, or arches built out of masonry, concrete, and so on. The effort needed to design this system is relatively low, with the calculations to estimate the load distribution being simple and are often best applied in overpasses with short spans from end to end, which this project falls under.

Truss support systems use a combination of simple vertical and occasionally horizontal beams that are forged together to form simple triangular units. These triangular units take and distribute the load among themselves, the beams either experiencing tension or compression depending on the location of the total point load on the overpass, ultimately balancing the entire truss system out and neutralizing the load if none of the trusses experience a breaking point in load. Truss systems are economically friendly, efficiently using materials and minimizing the need for upkeep, if the truss system was properly designed for the needed load 5 capacity. In addition, trusses are normally built with the system held above the overpass, allowing more clearance space for the vehicles driving along Foothill Drive below the overpass being designed for this project.

Cable stayed support systems implement towers built upon the overpass that have cables spanning down and attaching to other parts of the overpass, using the tower as a foundation to send the force from the tension of the cables developed by the dead and live loads of the overpass to the Earth below. Cable stayed systems are normally implemented in bridges and overpasses with long spans and are easy to design. Like the truss system before, the cables are built above the overpass, leaving plenty of clearance for the vehicles on Foothill Drive below this overpass. In addition, the materials needed for construction are relatively cheap, and there is no falsework (temporary support structures needed during construction) needed for the development of a cable system normally.

Beam support systems are the simplest systems used in the modern day for bridges and overpasses. They work by transferring the dead and live loads of the overpass into the evenly spaced vertical columns or other support structures the overpass sits upon, each with their own foundation they rest upon. Depending on the length and size of the overpass, only two support structures, one on each end of the overpass, may be needed for this project, considerably cutting the cost of the project's support system down. In addition, structures used for beam supports like columns are naturally sturdy due to their shape and material they are usually made of, meaning that the beams themselves will not be easily damaged by common outside forces such as wind or snow, making them highly favorable for areas where these forces are prevalent, including the location of this project.

Multi-span support system is a system that "splits" the overpass into multiple sections, each supported by their own isolated support system. These are most seen in tandem with cable stayed or beam systems as shown above, however it can be used with all other support systems outlined within this section. They are most often used in long and large bridges, to split the loads necessary to support them and their expected live loads evenly along the entire span, lessening the stress and potential damage that can accrue if only a single span is used. Generally, the more spans the overpass is split between, less stress and loads is taken on by each span at any given time, meaning that the damage from said stress and loads is heavily reduced, increasing the overpass' longevity and minimizing the required upkeep that would be needed compared to a single span system.

Precast concrete archways are crossings designed and built at an offsite location. The pieces constructed in these factories are then brought in on semi-truck beds and can be installed in a day. The clear advantages of using this type of overpass are expedited construction, reduced construction costs, and higher-quality concrete components. The prefabricated pieces bear the loads and disburse them into the filled footings. The pieces are constructed in controlled environments with standardized pieces to ensure a high-quality product with an increased life cycle. Constructing these components allows the concrete to achieve its full 28-day strength before it is exposed to adverse conditions and ultimately increases its compressive strength. The only fallback for this option is the aesthetic appeal, it creates a large obstruction to surrounding areas. Yet, this alternative would be the fastest and cheapest option for the Foothill Dr. pedestrian crossing.

5 Design Development Summary

The following sections detail the design process and calculations for this project. It also outlines the predicted maintenance required once the bridge is complete and the permits required to proceed with construction.

5.1 Process

The calculations were to find the components of the bridge and ramp that would work in the field. Meeting the requirements both of space limitations, and desired components. This would be overdesigned because simpler calculation methods were used but establishes an understanding of what would be needed. These calculations neglect earthquakes because of the dynamic finite element model required for this kind of structure. A larger amount of money will be required to ensure this bridge is reasonably safe.

Table 3: Design Dimensions

Bridge Component	Calculation Method	Results
Main Span	Focus on each segment between cables. This structure is designed to be structurally sound without the cables for potential one or two-day installation. *Only requiring Foothill to be closed at night as the concrete and cables are assembled in stages.*	– 20ft spacing between cables. – 4in concrete on 2 in corrugated steel sheet. – W24x68 by W14x26 Beam frame (30ft x 15ft) with bolted connections.
Cables	Match the weight of each segment of the bridge to the sine of the cable length.	– 1.2in, 225,000 psi die drawn cable.
Mast	Legacy bridge as a reference model.	– Two 3ft diameter, 77ft columns. 20ft tall section for cable attachments.
West Main Column	Match footing for the mast.	– Concrete Footing 10ft in diameter. – Pile length/depth of 28ft.
Main Foundations	Legacy bridge as a reference model.	– Concrete Footing 10ft in diameter. – Pile length/depth of 28ft.
Spiral Ramp	Ramp slope below the 8.33% ADA requirement. 50ft space between VA building and ramp. Two layer stacked ramp. 22.5 ft elevation difference from top to bottom. By keeping the inside of the ramp at a slope below 8% on the inside of the ramp the outside 8 feet are below the 5.33% required for an ADA ramp with no landings. *So technically the elevators are not required for ADA compliance.*	– Outside 55ft diameter, length 583ft, slope 3.7%. – Inside 29ft diameter, length 297ft, slope 7.6%.
Spiral Ramp Slab	Find the longest distance between columns and use the L/18 rule of thumb.	– Longest distance 20.3ft. – Thickness of slab 12in, by removing the 1.5in because of redundancy and overdesign.
Spiral Ramp Columns	Redundant small columns to keep the ramp mostly straight between columns. Matching pares on inside and outside to add stability.	– Eight sets of 12in x 18in columns.
Spiral Ramp Foundations	Using soil bearing strength of 2,500psf, and service column load of 46.5kip. Simple concrete footing analysis with grade 80, #5 bar and 4,000psi concrete.	– 4ft4in x 4ft4in square, 12in thick concrete foundation.

An example of the calculations done for a reinforced concrete column supporting the spiral ramp are as follows:

Using a dead load of 155psf for the weight of reinforced concrete, a live load of 100psf, a design wind speed of 120mph, and a Snow Load of 24.3psf. This makes the ultimate design load 418psf on the tributary areas using load combination 4, and the service load 302psf using service load combination 6.

Because the there are eight sets of columns the <u>maximum</u> tributary area for one column is;

$$Area = \frac{1}{8}\pi((26.5')^2 - (20')^2) = 119\ ft^2$$

Which makes the Ultimate Design Load from each ramp level $= 119\ ft^2 \cdot 418\ psf\ =$ $49.6\ kips$

Two levels of spiral ramp are the most any set of columns needs to hold up.

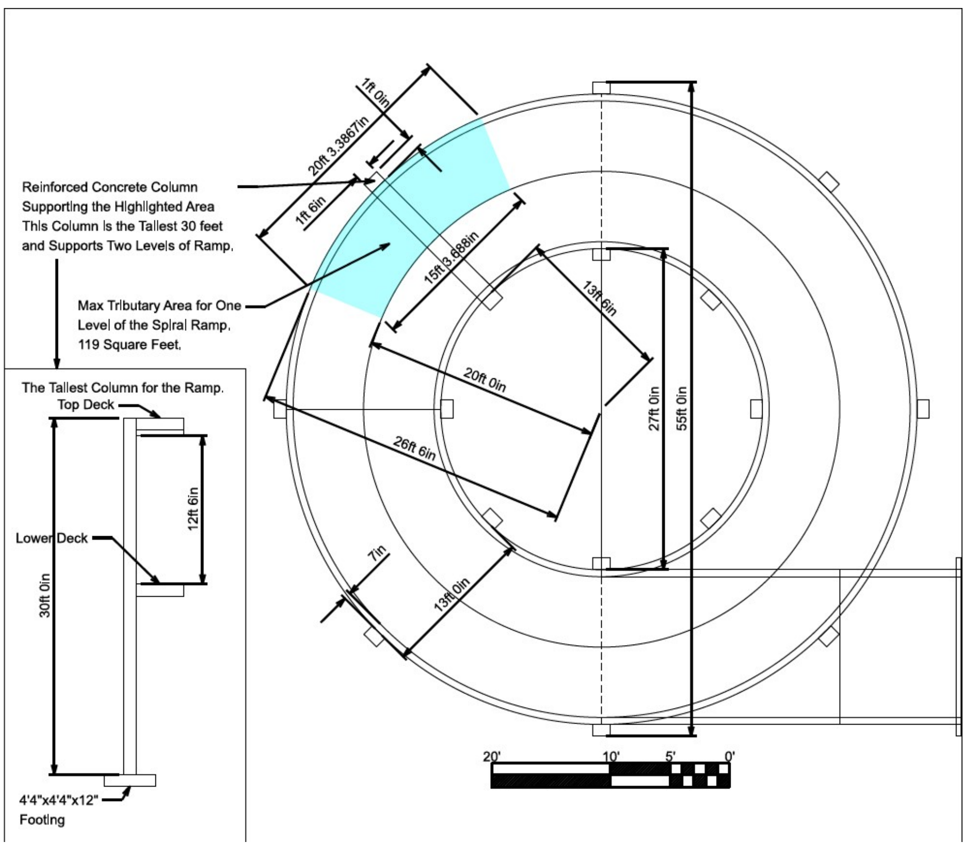

Figure 9: Spiral Ramp Concrete Column Calculation Drawings

Using a column 18" deep and 12" wide, with 4,000 psi concrete, and 80,000psi size #7 rebar. Where the rebar is layered as 3, 2, and 3 bars at 1.5", 6", and 9.5" respectively.

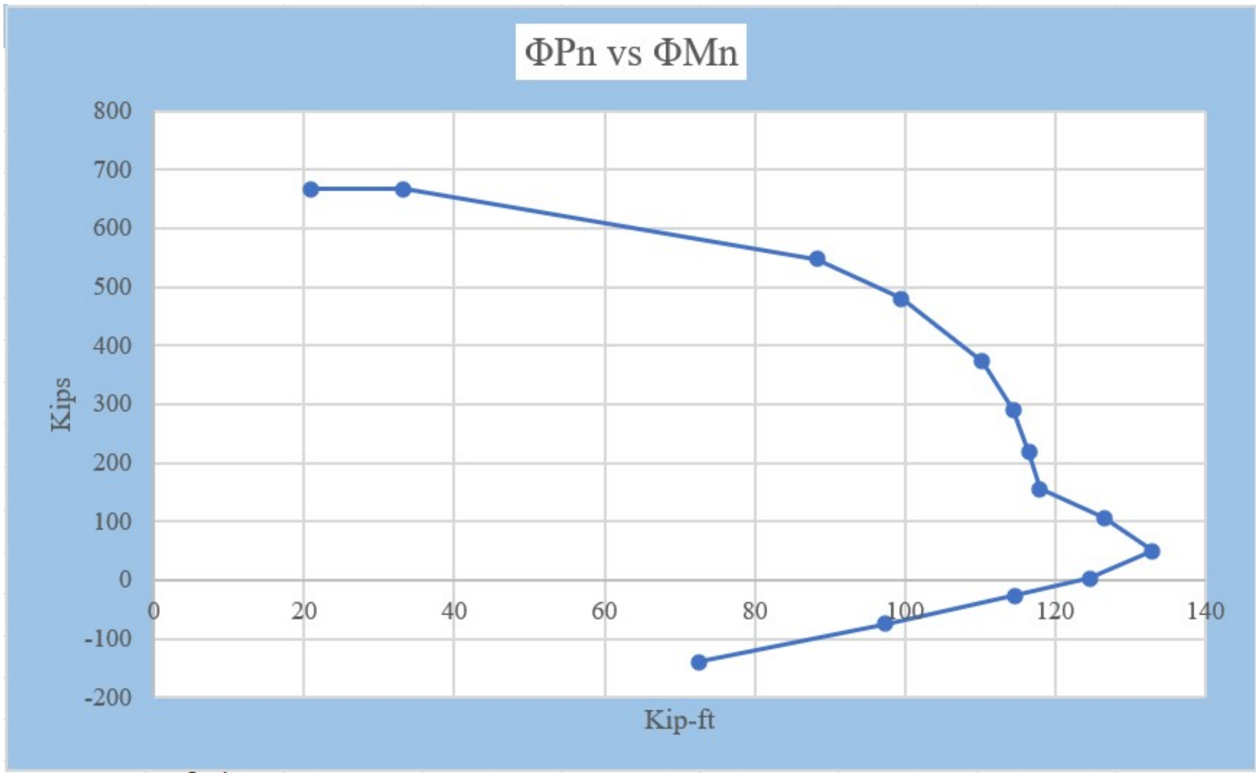

Figure 10: Spiral Ramp Concrete Column Shear Moment Diagram

Additional calculations for the bridge deck are included in appendix VII.

5.2 Design Data and Specification Summary

Table 4: Value for Bridge Dimensions

Main Span (over Foothill Dr)	
Length	150ft
Width	15ft
Thickness	20in *See Materials at the End of Table
Elevator Slab	
Length	30ft
Width	25ft
Thickness	18in
Double Stacked Spiral Ramp on West Side (VA)	
Elevation Gain	22.5ft
Clearance	12.5ft
Inner Diameter	29ft
Outer Diameter	55ft
Width	13ft
Thickness	12in
Length (center of the ramp)	440ft
Cable Ramp on the East Side (Orthopedic Center)	
Length	150ft
Width	15ft
Masts	
Diameter	3ft
Total Height	77ft
Materials	
Concrete Slab Thickness	4in
Steel Frame Below Slab Thickness	16in

5.3 Operations and Maintenance Summary

The Cable stay bridge design will require regular inspections and maintenance of the cable-stay system and foundational pylons every 2 years. These inspections will ensure the bridge is operating in a safe operational state. The main concern in cable-stayed bridge maintenance is the corrosion and anchorage of the cables. Other items that need to be inspected include the damping system, prestressed concrete, foundations, abutments, piers, and bearings. This will stand as a typical inspection. The largest cost and maintenance required will come from cable re-tensioning. This will need to be closely monitored every two years for any abrasions or malfunctions.

The bridge's approximate cable lifespan is approximately 60+ years and with good maintenance there is potential for more. Companies like DYWIDAG provide diverse services to maintain cable stayed bridges. These services include deicing, robotic wire rewrapping, cable corrosion protection, UV Protection, and visual cable inspection.

5.4 Construction Needs and Phasing Summary
Due to the plans to operate within the Riparian Corridor and within the flood plain, the following permits will be needed to proceed with construction.

Table 5: Construction Needs/Permits

Permit	Controlling Entity	Interest
Salt Lake County Flood Plain Permit	Army Corps of Engineers	Required to work in a flood plain area.
Salt Lake City Riparian Permit	RCO and Army Corps of Engineers	Area C (buffer Transition Area): permits are not required as long as the project complies with local city regulations as well as what is permitted in Area A & B. However, certain projects are prohibited such as: Commercial parking lots, detention basins, retention ponds (storm water), and leach fields.
State Stream Alteration Permit	Army Corps of Engineers	Any work that will alter the bed or banks of a natural stream in Utah must obtain written authorization from the State Engineer. Projects may also require additional permitting from the U.S. Army Corps of Engineers.
Salt Lake County Flood Control Permit	Salt Lake City Engineering	Work that occurs within 20 feet (6.1 meters) of the top of the channel bank of any "flood control facility" (which includes most streams in Salt Lake County) will require a Flood Control Permit, per Title 17 of the Salt Lake County Code of Ordinances.

Most of the construction will have to be completed at night to satisfy stakeholder needs. The staging will be compliant with Salt Lake City requirements available on their website. The work completed will also require mitigated noise, and various traffic safety measures including an access management permit to satisfy UDOT requirements. It is assumed that the elevation changes will be mitigated during construction.

Salt Lake City Trails requirements will affect the designing of pedestrian paths along the Red Butte crossing. The design will need to be designed for; pedestrians and cyclists of all ability levels, connections to future trail points, width's necessary to accommodate two-way passage and a bike lane, Cross-slopes, and centerline profiles to accommodate all mobility levels (compliant with ADA), and to maintain the existing riparian Corridor along Red Butte Creek.

It is important to control traffic on construction sites to ensure safety, prevent any accidents that may occur to pedestrians and workers, and reduce any traffic congestion due to construction. The construction will be carried out for about two months. Traffic jams are expected to occur during rush hour because there are many places near the construction site that cause traffic such as hospitals and schools. In addition, this is a heavy traffic road that connects from a residential complex to downtown. The detour considered due to construction takes four minutes longer than the existing road which passes through Hempstead Rd, Pollack Rd, and Wakara Way.

Figure 11: Detour Map

To prevent any accidents, it is necessary to warn pedestrians or drivers before they get close to the site. As shown in the picture above, it is important to inform where the construction is going, where the detour starts, and which road to use. The figure below depicts proposed signage for the detour.

6 Design Summary Effectiveness

To analyze the effectiveness of the selected design, the Design Criteria outlined in Section 3.4 were judged. The results of the analysis can be found in Table 6 below.

Based on the project criteria defined in Table 6, below, the design overall exceeds many of the design criteria.

With respect to the fact that a few of the criteria are not met, careful consideration to determine a compromise for these issues has been undertaken. One being the issue of staying out of the riparian corridor which will not be possible. As discussed previously, alteration permits will be required due to the invasion of the riparian corridor. Additionally, while the materials to build the bridge include common building materials such as steel and concrete which are commonly used building materials, they aren't particularly sustainable materials. However, they will provide a long-standing structure and aid in the overall sustainability of the community when sustainability is viewed through the lens of social, economic, and environmental factors. It is also recommended that where possible at the end of the bridge's life, the concrete, steel, and other materials be recycled. This will improve the overall sustainability in a cradle to grave approach. These materials are also ideal for the structural integrity of the bridge.

Table 6: Analysis of Basis of Design

Basis of Design				
Design Criteria	**Bridge Element**	**Meets Criteria**	**Exceeds Criteria**	**Does Not Meet Criteria**
Enable Various Modes of Transportation (bikers, pedestrians, stollers)	Spiral ramp and east end ramp allow for easy cycling and walking across	x		
	Elevator is in the plans for the VA side. There will also be an elevator near the mast on the orthopedic side.	x		
	Wide path for cyclists and walkers		x	
	Ramp on the orthopedic side is being made less than 5% to allow for accesiblity.	x		
	Lane configuration for bikers and pedestrians		x	
	Connecting to trails on Orthopedic Side		x	
	Elevators are large enough for bikes, wheelchairs, strollers etc.			
Accessibility	Elevator is in the plans for the VA side. There will also be an elevator near the mast on the orthopedic side.	x		
Protect Natural Environment	Floodplain analysis/Riparian Cooridor	x		
	Implement final landscaping plan	x		
	Research of Landscaping plan options	x		
	Uses only environmentally friendly materials			x
	Stays out of 100 ft buffer for Riparian Corridor			x
	Protection of current trees/greenery	x		
Aesthetic Appeal	Preliminary Design work	x		
	Match materials/style to Legacy Bridge		x	
Sustainabile Manufacturing	Research on sustainbile building materials for salt lake	x		
Safe for Pedestrians, vehicles, and all.	Security box		x	
	Graffiti protective coating		x	
	Traffic Plan	x		
	Lighting plan	x		
	Research suicide prevention ideas for bridges	x		
	Safe design	x		
	High hand railing	x		
	ADA accomidations	x		
	Intensive structural analysis	x		
	Seismic Analysis	x		

7 Cost Estimation

Based on preliminary cost estimation, the proposed bridge design will cost approximately $8.4M

Table 7: Cost Estimation- Base Materials

Cost Estimation					
Item	**Unit**	**Dimension**	**QTY**	**Unit Cost**	**Total Cost**
Steel Used Superconstruction					
Railing for East Ramp	F	150	2	$ 43.00	$ 12,900.00
Railing for West Spiral Ramp Inner	F	95	1	$ 43.00	$ 4,085.00
Railing for West Spiral Ramp Outer	F	172	1	$ 43.00	$ 7,396.00
Structural Steel	LB	20000	1	$ 5.00	$ 100,000.00
Masts	S.F	600	2	$ 120.00	$ 144,000.00
Steel Cable	F	3000	28	$ 2.00	$ 168,000.00
Concrete Used Superconstruction					
Concrete Deck	C.Y	200	1	$ 800.00	$ 160,000.00
Concrete Regular Column with Rebar	C.Y.	25	7	$ 800.00	$ 140,000.00
No 7 Rebar for Deck	F	830	2	$ 1.02	$ 1,693.20
Subconstruction					
Elevators	EA		2	$300,000.00	$ 600,000.00
Subtotal					$ 1,338,074.20
Contingency Cost (* see footnote)	50%				$ 669,037.10
Inflation to Project Year	7.7% Annually				$ 923,271.20
Design Fee	12%				$ 240,853.36
Traffic Controls	3%				$ 60,213.34
Construction Managment	5%				$ 100,355.57
Mobilization	8%				$ 160,568.90
Clearing and Grubbing	3%				$ 60,213.34
Survey	1%				$ 20,071.11
	Total				**$ 3,552,587.00**

*Contingency Cost: This accounts for any additional costs for materials and parts that are not included up to this point. For example, it includes any additional small components that will be needed such as joints, deck drains, etc.

An additional $100,000 is estimated for an environmental study due to the proximity to the riparian corridor.

Considerations for the Preliminary Cost Estimate:

The prices listed for materials include manufacturing and installation of each material, although there may be discrepancies once actual vendors are selected. Additional custom parts for the unique design such as the spiral ramp may also be needed and could increase cost. According to the significant inflation in the construction industry after 2021, it is set as 7.7%. It has been calculated by reflecting the price increase of all materials. Therefore, the price was measured higher than the price calculated and adjusted for this estimate.

Cross Referencing for Cost Estimation Accuracy:

To ensure the cost estimation was reasonable, it was referenced with two other cost estimates near the project area. First, the framework provided was used by the UVU pedestrian bridge cost estimate built from 2018 to 2021 for $11 M. The cost estimation for UVU was conducted by R2H Engineering Inc and followed UDOT methodology cost estimation. This estimate aided in some of the unit costs for materials (including labor and installation). The team also used this framework to include line items that will also be in this project (such as traffic control percentages, and construction management percentages).

Additionally, the cost estimation of the Legacy Bridge was used to this preliminary estimate due to its similarities in style, structure, and materials. Legacy Bridge total cost in 2001 was 5M, adjusting for inflation from the Bureau of Labor statistics (approximately 68.5% from 2001 to 2023) this yields a predicted cost of 8.4M for a bridge like Legacy Bridge. The span of our design is slightly larger and includes a spiral ramp, potentially increasing this cost very slightly. Further investigation into cost estimate will be needed to ensure accuracy, but it is predicted that this cost estimate could increase by 5-10% to account for custom design, and the additional length and spiral ramp that Legacy Bridge does not have.

8 Work Summary

The information provided in the document details what would be required to make a cable stay bridge at this site and identifies the challenges for its completion. Specifically, it addresses the basis of design that will be considered when deciding the best project plan for implementing an overpass over foothill drive near Red Butte Creek. The road near Red Butte Creek, Foothill Drive, is a heavily trafficked road and it is classified as an “other principle arterial,” connecting many people from a freeway interchange to major destinations. Foothill drive is currently at max capacity and unable to undergo lane expansion. By implementing a pedestrian crossing in this area, complete access for bicycles and pedestrians to their destinations on either side of Foot more safely and conveniently. People will be safer crossing and fewer jaywalkers will be spotted attempting to cross this dangerous road. Along with its transportation benefits, the project has an opportunity to aid in supporting sustainability for the community and support an active lifestyle. By improving access to the Red Butte Creek Trail, the community will be more engaged in the protection of the Red Butte Creek and Red Butte Canyon watershed. This newfound appreciation for the community will be a benefit to the area.

Attached are the design sheets for the final bridge design. The design is for a two 150ft span cable stay bridge. With a spiral concrete ramp 53ft in diameter. This will be close enough to the creek to require additional permits but will be less affected by the flood plain. The rough cost estimate is that the bridge would cost 3 million dollars. The addition of elevators should make the VA more receptive because of the safe access to public transportation for their patrons. Based on utility maps, power and internet lines would be affected by this bridge's installation. This bridge's construction would necessitate the closure of Foothill Drive on this block for 2 to 4 months, to install and check the main span.

To date, the preliminary design work on the pedestrian cable stayed bridge shows promising results to fulfill the basis of design. The bridge effectively fulfills the design criteria determined by the project's various stakeholders.

Appendix I: Streamflow

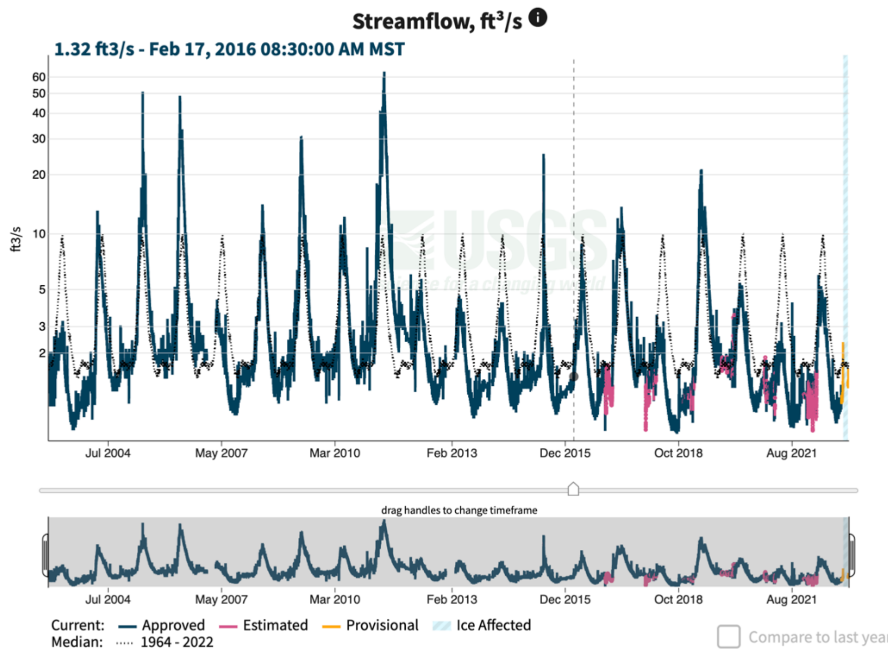

Figure 12:Red Butte Creek Average Flow 2003-Present: Source-USGS

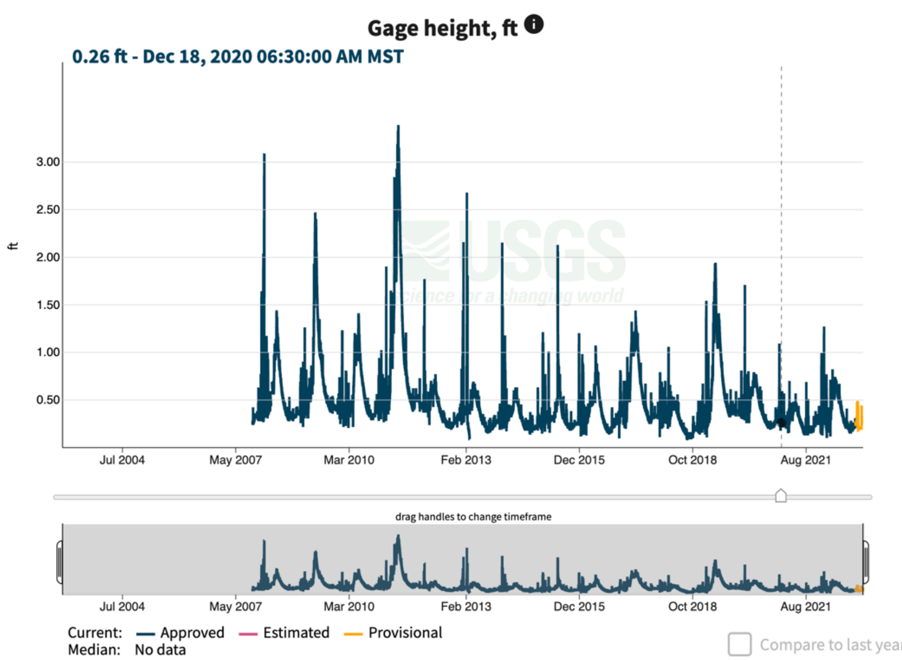

Figure 13:Red Butte Creek Gage Height: Source- USGS

Appendix II- Boring Hole Depth and Location

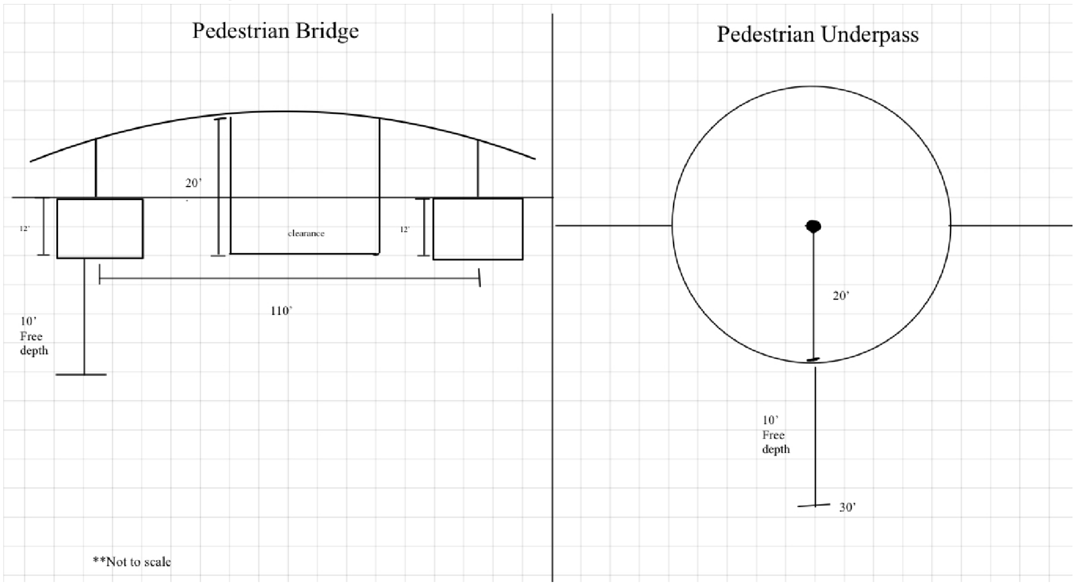

Figure 14: Minimum Boring Depth

The locations recommended for drilling by Dave Nordquist are shown below in figure 7. Both the recommended boring hole location and depths were used when geotechnical site testing was performed on October 20,2020.

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Figure 15: Approximate Boring Hole Locations

Appendix III: Soil Types at Site

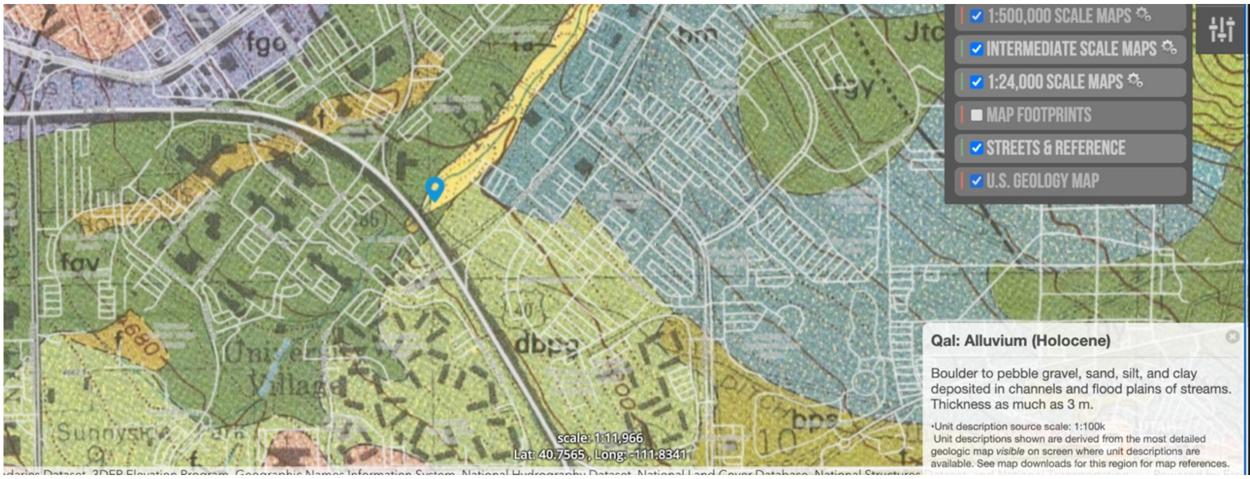

Figure 16:Soil type at Red Butte Creek

Figure 17: Soil type south of Red Butte Creek

Figure 18: Soil type north of Red Butte Creek

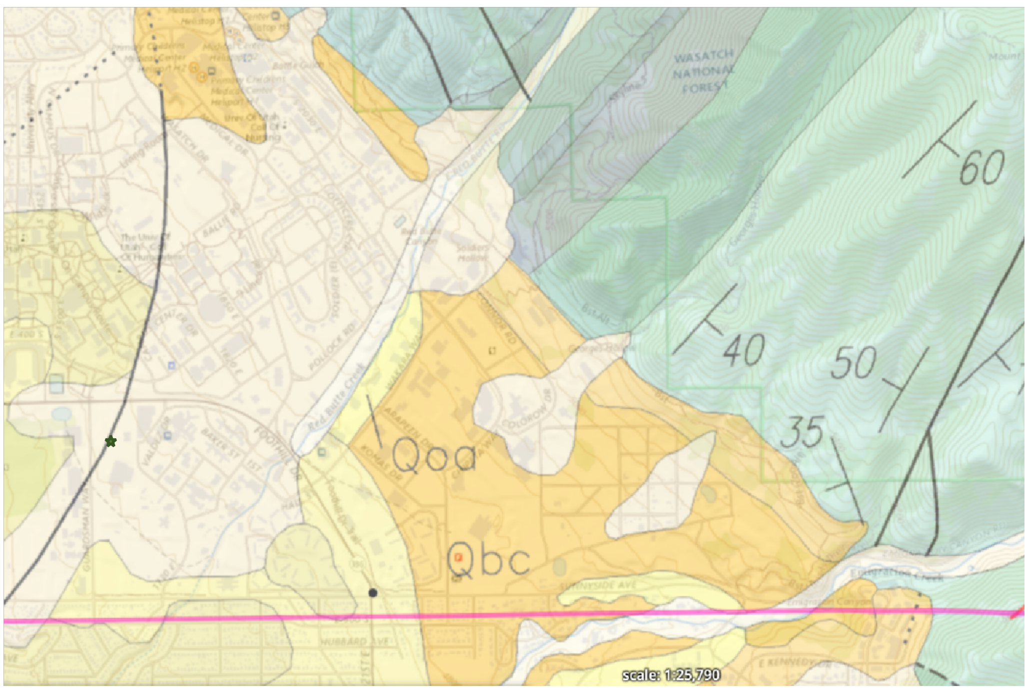

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Figure 19: Geographic Traits of Site- geology.utah.gov

Appendix IV: Topography

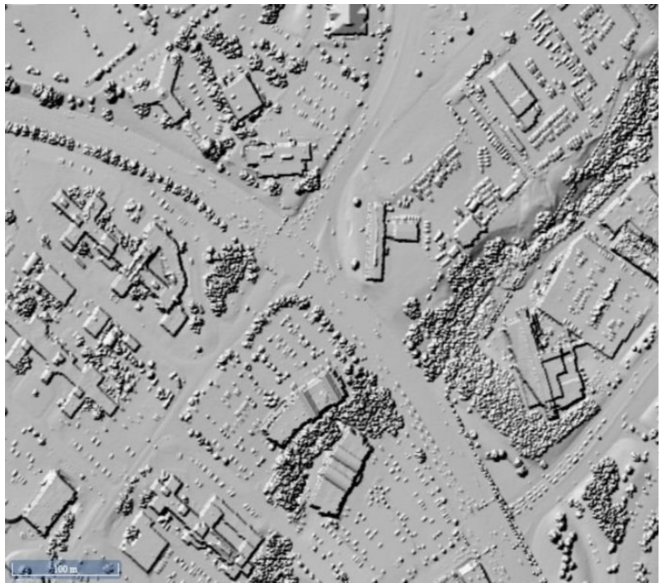

Figure 20: Topographic Map of Site: Open Topography

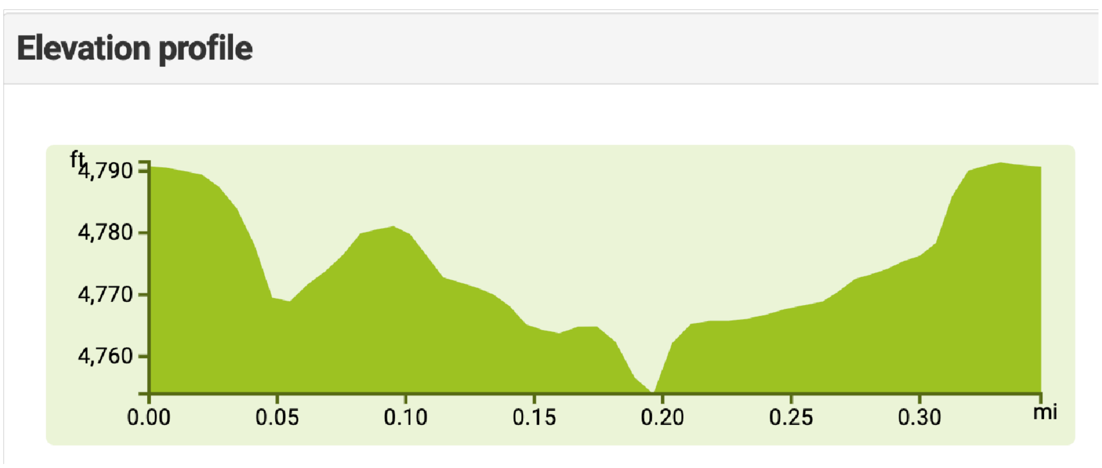

Figure 21: Site Elevation Profile: Streamstats.usgs.org

Appendix V: Complete Streets

The complete streets initiative is a goal from the SLC department of transportation to make pedestrian/people friendly features on all streets.

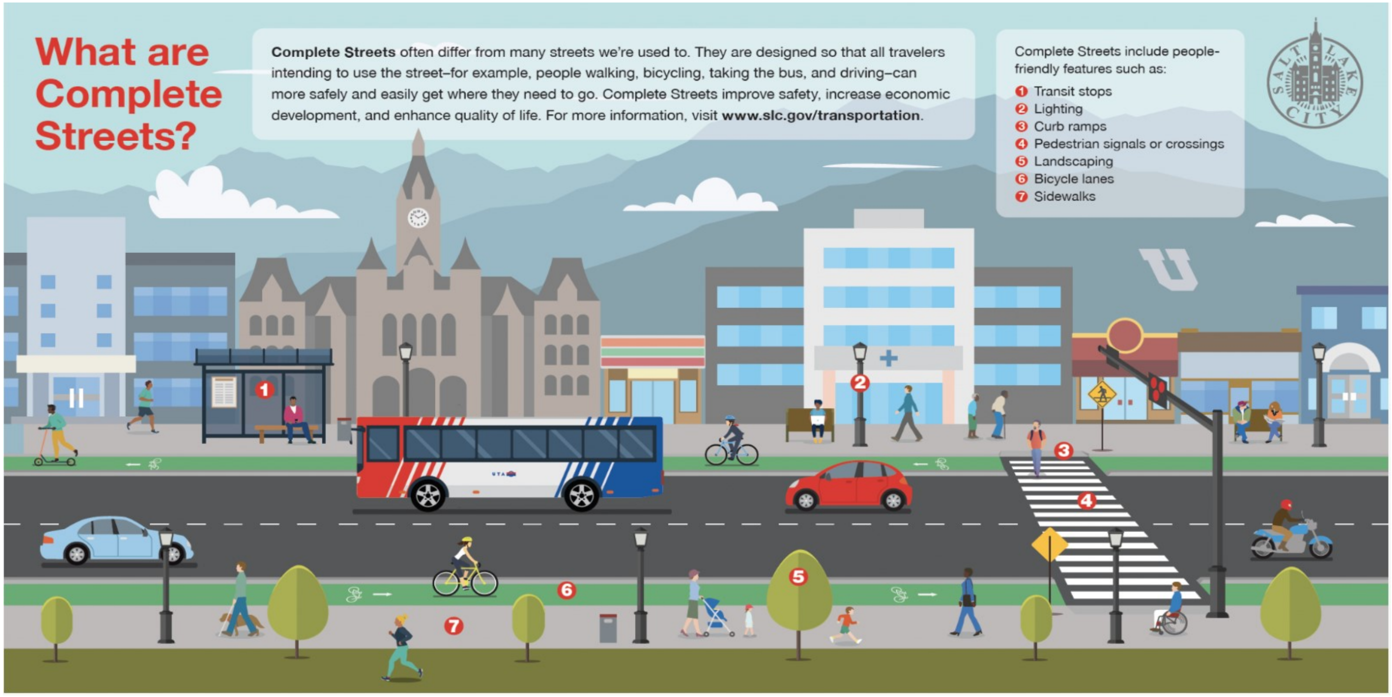

Figure 22: Complete Streets

A complete street is an ordinance for Salt Lake City and aims to provide streets with all the following characteristics.

- Transit Stops
- Lighting
- Curb Ramps
- Pedestrian Signals and Crossings
- Landscaping
- Bicycle lanes
- Side Walks

Appendix VI: ISI Envision Estimate

Name: Pedestrian Crossing at Red Butte Creek and Foothill Drive
Date: 9/12/2022

Ratings Key:

- +0 not applicable or no opportunity
- +1 basic opportunity
- +2 chance to go above and beyond for little cost

Quality of Life
Does the project:

1. Improve health and safety for the broader community? +2
2. Preserve and enhance cultural resources? +1
3. Meet the needs and goals of the community? +1
4. Minimize negative impact on the surrounding community? +1
5. Follow a fair, equitable, and inclusive development process? +1
6. Is the project located near public transportation? +1

Discuss:
Overall, the project is a great opportunity to introduce a better public transportation system for pedestrians and bikers. This will enable residents to enjoy the cultural benefits of the Museum of natural history more effortlessly as they're able to safely cross foothill drive. It will help the community reach its goal of commuting to campus and other businesses nearby. It will reduce the negative impact of pedestrians getting hurt or killed via J-walking. The development will be fair and enable bikers, walkers, and disabled people to safely cross making it more equitable and fairer. This is also located right by a bus stop. Overall score 7/12 which a score of 6/12 indicates a basic opportunity, meaning this opportunity is slightly above basic, and overall, a good opportunity.
SCORE: 7/12

Leadership

1. Are there sustainability commitments from the project developers? +1
2. Is there a sustainability management plan in place? +1
3. Are stakeholders engaged? +1
4. Will the project stimulate economic development? +1
5. Are residents employed on the project? +1
6. Is the project located near public transportation? +1

Discuss:
Sustainability is important to many if not most of the stakeholders including SLC trails, and Salt Lake City engineers. The project could aid in economic development if new businesses decide to come to this area due to its improved walkability for residents. It is likely that residents would be employed. This would be close to the bus stop nearby and, in the future, a potential light rail.

For each question, speculate as to:
+0 not applicable or no opportunity
+1 basic opportunity

+2 chance to go above and beyond for little cost SCORE: 6/12
Resource Allocation 1. Is the project constructed from sustainable materials? +1 2. Does the project manage construction and operational waste? +1 3. Does the project reduce energy consumption and source renewable energy? +1 4. Does the project reduce water consumption and protect water resources? +0 5. Does the project monitor energy and water use? +0 Discuss: The plan is to use a material that is sustainable and manage the waste appropriately. This project would reduce energy consumption as it is predicted more people would choose to walk, take the bus, or bike if it is more easily accessible. The project would not generate any energy or affect water resources significantly. It also would have no effect on monitoring energy or water use. For each question, speculate as to: +0 not applicable or no opportunity +1 basic opportunity +2 chance to go above and beyond for little cost SCORE: 3/10
Natural World Does the project: 1. Avoid sites of high ecological value? +1 2. Protect wetlands and surface water quality? +0 3. Maintain hydrological functions? +0 4. Manage storm water? +0 5. Protect soil health? +0 6. Manage or eliminate invasive species? +0 Discuss: The project would avoid affecting Red Butte creek; however, it does not provide any additional natural world protection. It would not affect any hydrological functions as the design intention is to avoid the river and utilities. The soil health will also be unaffected and species also unaffected. The goal is to have the smallest impact possible. For each question, speculate as to: +0 not applicable or no opportunity +1 basic opportunity +2 chance to go above and beyond for little cost SCORE:1/12
Climate and Resilience Does or is the project:

1. Reduce greenhouse gas emissions? +1 2. Reduce air pollutant emissions? +1 3. Avoid unsuitable sites? +1 4. Reduce climate change vulnerability? +1 5. Resilient and adaptable? +1 Discuss: The project will enable more people to walk, take the bus, or ride a bike which will reduce the number of cars on the road and effectively reduce greenhouse gas emissions, air pollution, and enable people to be safe in transportation. It avoids unsuitable sites as the site is healthy and has no environmental hazards that are known. It will also reduce climate change vulnerability due to its potential to reduce GHG. It will be resilient to weather and climate making it a long-standing solution for the foreseeable future. SCORE: 5/10
Summary: **22/56** is the final score. This yields an impressive **40%** which is an award level of **Gold** by the ISI Envision standard. This shows that this project is above average to improve the city's overall infrastructure and is viable to pursue future planning and design. The biggest opportunity the project offers is within the category of Quality of life as it scored 7/12, the highest of any other category. This is mostly because the improved walkability will enable pedestrians to get around their hometown easier and be safer while doing so.

Appendix VII: Environmental Considerations
There is a strong desire among many of the stakeholders including the Red Butte Steering committee, Salt Lake City Engineering, as well as the residents and commuters in the nearby area that the structure does not interfere with the health of the community. By choosing bridge materials that are environmentally sustainable and electing for an environmentally sustainable design, air quality and water quality in the nearby area can be improved.

The current selection of materials includes steel and concrete. A life cycle assessment of the bridge's materials can show the overall environmental impact of the construction of the project. The life cycle assessment includes where the material may be sourced from, the durability of the material, and other environmental considerations of the design. For this in-depth technical analysis, a software program such as Open LCA may be beneficial in comparing bridge materials to ensure the best materials have been selected. An additional modeling software analysis for environmental components of the bridge may also be beneficial to determine the best design moving forward.

Based on current design plans, the bridge will be approximately 75 feet from the creek. This means permits will be required for construction, and additional environmental care will be needed when operating in this region as the construction will be within both the riparian corridor and FEMA floodplain regions. (See Figure 2). To mitigate risk due to the proximity of floodplains, the team plans to use erosion resistance and salt water resistant concrete. This will ensure the structural integrity of the bridge will not be compromised in the case of flooding. Additionally, foundations and the depth of the mast have been designed with this in mind to ensure project safety and success in the event of flooding.

The riparian corridor buffer can be seen below in Figure 23.

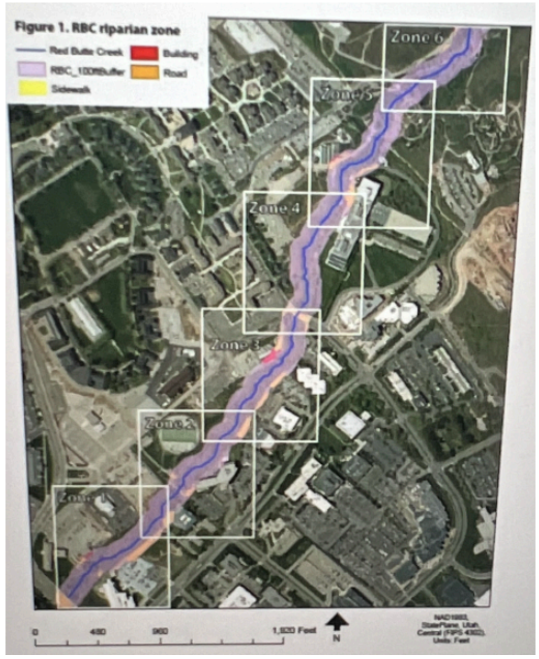

Figure 23:Riparian Corridor- 100ft Buffer from RBC Masterplan

Upon need or request, an environmental impact statement can be produced to ensure this project is as sustainable as possible and will not harm the surrounding area.

Appendix VIII: Bridge Deck Design Calculations

Less material is needed by going with a steel frame with a steel deck instead of using more concrete. Steel as a material can be constructed faster and is more eco-friendly than concrete. It was decided to use a 30ft x 15ft steel frame, supporting a 2inch steel deck with a 4inch concrete thickness.

Certain Assumptions were made throughout the design:

- LRFD design, Load Combination: 1.2DL + 1.6LL
- Dead load (DL): 62.5 psf
- Live Load (LL): 100 psf
- $\gamma_{concrete}$ = 145 pcf (normal weight)
- F'c = 4 Ksi (compressive strength of concrete)
- F_y = 50 Ksi (A992 Steel)
- Partial Beam Composition (requirements, must meet one of these conditions)
    - Beam span not exceeding 30ft.
    - Beams with at least 50% composite action.
    - Beams with minimum ¾ in. stud at in. O/C
- Calculating for deflections, construction live load is 20psf.
- When calculating deflections individually, each must not exceed L/360. Nor L/240 when added together.
- Used AISC (American Institute of Steel Construction) Manual (15th edition)
- Effective slab width of concrete is 30ft.

* For 30ft beam*

1.2DL + 1.6LL = 1.2(62.5) + 1.6(100) = 235 psf = .235ksf

Required Moment Strength: $\frac{W_u L^2}{8} = \frac{(.235ksf)(30ft)(30ft)^2}{8}$ = 793 K-ft

Y2 = Y1 - $\frac{a}{2}$ = 6 - $\frac{4}{2}$ = 4

- Y2 is the location of the compression force from the top of the steel
- Y1 is the total thickness of the deck (6inches)
- a is the thickness of the concrete

*Based on the AISC manual (Table 3-19), try using a W24X68 *

$\phi_b M_p$ = 889 K-ft > M_u = 904 K-ft (ok)

Percent composition: $\frac{251}{1010}$ x 100% = 24.8 % (ok, L is = to 30 ft) (table 3-19)

Check construction bare steel: W_u = Concrete + Steel + Construction live load

Concrete load on beam: $145 \frac{lbs}{ft^3} \times \frac{4}{12}$ ft x 30ft = $1450 \frac{lbs}{ft} \times 1.5 = 2175 \frac{lbs}{ft}$

1.5 is a factor to account for concrete in the ribs

Construction live load: $20 \frac{lbs}{ft^2}$ x 30 ft = $600 \frac{lbs}{ft}$

Steel: $68 \frac{lbs}{ft}$

$W_u = 1.2(2175 \frac{lbs}{ft}) + 1.2(68 \frac{lbs}{ft}) + 1.6\,(600 \frac{lbs}{ft}) = 3652 \frac{lbs}{ft}$

$M_u =: \frac{W_u L^2}{8} = \frac{(3.65\frac{k}{ft})(30ft)^2}{8} = 410$ K-ft < $\emptyset_b M_{p} =$ 664 K-ft (ok) (table 3-19)

Check construction dead load:

$\Delta_{DL} = \frac{5wL^4}{384\,EI} = \frac{5\left(2.24\frac{k}{ft}\right)(30ft)^4(12in)^3}{384(29000ksi)(1830in^4)} = .769$ in. $< \frac{L*12}{360} = \frac{30*12}{360} = 1$ in. (ok)

$I_{lb\ W24x62} = 1830in^4$ (table 3-20)

Check construction live load:

$\Delta_{LL} = \frac{5wL^4}{384\,EI} = \frac{5\left(3\frac{k}{ft}\right)(30ft)^4(12in)^3}{384(29000ksi)(2840in^4)} = .664$ in. $< \frac{L*12}{360} = \frac{30*12}{360} = 1$ in. (ok)

$I_{W24x62} = 2840in^4$ (table 3-20)

Check total deflections:

$\Delta_{LL} + \Delta_{DL} = 1.43$ in $< \frac{L*12}{240} = \frac{30*12}{240} = 1.5$ in. (ok)

Select shear studs:

- use ¾ in. studs
- deck is parallel
- width of rib = 2in W_r
- height of rib = 2 in H_r
- $\frac{Wr}{Hr} = 1$, Q_n =18.3 (table 3-21)

$\frac{\Sigma Q_n}{Q_n} = \frac{251}{18.3} = 13.7$ = 14 studs per ½ length = 28 total

* For 15ft beam*

1.2DL + 1.6LL = 1.2(62.5) + 1.6(100) = 235 psf = .235ksf

Required Moment Strength: $\frac{W_u L^2}{8} = \frac{(.235ksf)(30ft)(15ft)^2}{8}$ = 198 K-ft

Y2 = Y1 - $\frac{a}{2}$ = 6 - $\frac{4}{2}$ = 4

- Y2 is the location of the compression force from the top of the steel
- Y1 is the total thickness of the deck (6inches)
- a is the thickness of the concrete

*Based on the AISC manual (Table 3-19), try using a W14X26 *

$\emptyset_b M_p$ = 216 K-ft > M_u = 198 K-ft (ok)

Percent composition: $\frac{96.1}{385}$ x 100% = 25 % (ok, L < 30 ft) (table 3-19)

Check construction bare steel: W_u = Concrete + Steel + Construction live load

Concrete load on beam: 145 $\frac{lbs}{ft^3}$ x $\frac{4}{12}$ ft x 30ft = 1450 $\frac{lbs}{ft}$ x 1.5 = 2175 $\frac{lbs}{ft}$

1.5 is a factor to account for concrete in the ribs

Construction live load: 20 $\frac{lbs}{ft^2}$ x 30 ft = 600 $\frac{lbs}{ft}$

Steel: 26 $\frac{lbs}{ft}$

W_u = 1.2(2175 $\frac{lbs}{ft}$) +1.2(26 $\frac{lbs}{ft}$) +1.6 (600 $\frac{lbs}{ft}$) = 3601 $\frac{lbs}{ft}$

$M_u = \frac{W_u L^2}{8} = \frac{(3.6\frac{k}{ft})(15ft)^2}{8}$ = 101 K-ft < $\emptyset_b M_p$ = 151 K-ft (ok) (table 3-19)

Check construction dead load:

$\Delta_{DL} = \frac{5wL^4}{384\,EI} = \frac{5\left(2.2\frac{k}{ft}\right)(15ft)^4(12in)^3}{384(29000ksi)(245in^4)}$ = .353 in. < $\frac{L*12}{360} = \frac{15*12}{360}$ = .5 in. (ok)

$I_{lb\ W24x62} = 245in^4$ (table 3-20)

Check construction live load:

$\Delta_{LL} = \frac{5wL^4}{384\,EI} = \frac{5\left(3\frac{k}{ft}\right)(15ft)^4(12in)^3}{384(29000ksi)(429in^4)}$ = .275 in. < $\frac{L*12}{360} = \frac{15*12}{360}$ = .5 in. (ok)

$I_{W14x26} = 429in^4$ (table 3-20)

Check total deflections:

$\Delta_{LL} + \Delta_{DL}$ =.628 in < $\frac{L*12}{240} = \frac{15*12}{240}$ = .75 in. (ok)

Select shear studs:

- use ¾ in. studs
- deck is perpendicular
- 1 stud per rib
- Strong-side
- F'c = 4 Ksi
- $\gamma_{concrete}$ = 145 pcf (normal weight)
- Q_n =21.5 (table 3-21)

$\frac{\Sigma Q_n}{Q_n} = \frac{96.1}{21.5}$ = 4.46 = 5 studs per ½ length = 10 total

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