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FINAL DELIVERABLE

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Final Design Report

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

PROJECT DESIGN & MANAGEMENT

(CEE:4850:0001)

Rails to Trails

Sac County Hometown Pride Committee, Schaller, Iowa

UNIVERSITY OF IOWA

______________________ Noah Decker, DGN Engineering Project Manager

DGN ENGINEERING

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Section I: Executive Summary

DGN Engineers, a team of three civil engineering students at the University of Iowa, designed a bicycle/pedestrian trail system from Schaller, Iowa to Galva, Iowa, which include a functional trail facility with a parking area located at the community center in Schaller. The main goal is to run the trail from the community center to the end of the decommissioned railroad tracks, and this will be considered the first phase. The secondary goal, or second phase, is to connect the trail at the end of the railroad tracks to the neighboring town, Galva. This project's purpose is to connect two communities, provide a form of exercise, and allow safe travel without having to use busy and high speed roadways. The services involved with this project are being proposed to the Sac County Hometown Pride committee. This committee oversees that the community is an entertaining environment but also safe, by coming up with new ideas for the county, such as projects or events, that will add to both the monetary and social value of the area.

Our design team consists of three civil engineering students at the University of Iowa participating in a senior design course. The team has expertise in the civil engineering field, both through internships and the rigorous school work and education they have completed thus far. The schooling completed has covered many of the major components of civil engineering, including but not limited to: transportation, environmental, structural, and water resources. Internship experience and classwork both provided valuable experience in the online programs needed for this project (AutoCAD, Civil 3D, Microsoft Office Suite, etc.).

This project had some impacts on the community and the environment, and also posed some challenges and constraints. The trail design had to be taken into consideration. If the trail is not funded by federal or state grants, then the trail will take up a portion of the county's budget. The trail must create a safe environment for those who use it. The land that will need to be used is also owned by people of the community. A steep grade hill could potentially be of issue, but nothing major.

There are a few design alternatives that were evaluated for the project. The first major decision that still needs to be made, as the option is being left open, is choosing the material for the trail. Asphalt or concrete with gravel subbases or only a gravel subbase are a few of the options. Both asphalt and concrete will allow the trail to receive grants and get federal funding, but only having just a gravel subbase will not. Also, the tougher the material the less maintenance will have to be completed, saving money. Another option being left open is the steep grade hill. The two alternatives are to tunnel underneath the existing road, or to just add a lot of fill material and create a crosswalk over the road. Another design consideration was the location of the trailhead facility and parking. A few different locations were evaluated, but the final place for both the parking lot and the trail facility was the community center in Schaller. The last design consideration is the sustainability of the trailhead facility. The style of the facility was another consideration. The end decision was to make it have a traditional aesthetic to match the style of the community. This trail facility is a wood framed, stand alone structure with a single restroom. The trail alignment had two major routes to choose from. The first ran from the community center through town using shared roads to the decommissioned railroad tracks. The second alignment went from the community center around the edge of town using the same pavement used throughout the trail to the decommissioned railroad tracks. The second option was chosen, as this was the desire of the client. The trail is 10 feet wide and ended up being just under seven miles long.

There are two design features that each have two alternatives, allowing a decision to be made by the client. One feature is choosing the pavement type, asphalt or concrete, and the other feature is to choose the trail with the designed tunnel or without. There are also two stages. With this, there are eight different main cost estimates. All cost estimates contain the parking lot and trail facility. After examining the outcome of them all, it is recommended that the trail be paved with concrete as it the cheaper option, and to construct the trail with the tunnel, based on the client's desires. For just the first stage only, came to a total of $286,500. The total cost for the entire project that includes both stage 1 and 2 came to $657,000. The client is able to pick and choose which alternatives and which features they desire. Further details and breakdowns of each element of the design can be seen in Section VII.

Section II: Organization Qualifications and Experience

DGN Engineering - Iowa City, Iowa 52240.

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DGN Engineering is a student run civil engineering design team participating in a senior design course at the University of Iowa, College of Engineering. The design team includes:

- **Noah Decker**: Project Manager, Civil and Environmental Practice focus, lead for the trail and parking lot design. Noah Decker has relevant experience through previous internships at Shive-Hattery and the City of Marion Engineering Department. While at Shive-Hattery, Noah has design experience with Civil 3D on site development and transportation engineering projects. Relevant education includes Transportation Design, Design of Concrete Structures, Bridge Engineering, and Foundation Design.

- **Derek Nebergall**: Civil and Environmental Practice focus, lead for the shelter and site layout design. Derek has had experience through an internship with the Cedar County Engineer in Iowa, which gave valuable experience with AutoCAD. Relevant knowledge came from Transportation Design, Bridge Engineering, and Foundation Design. He also has a little bit of experience in architecture and 3D modeling from high school coursework.

- **Xiaoyan Gong**: Civil and Environmental Practice focus, lead for the environmental and hydrologic related design. Xiaoyan learned a lot relevant knowledge through Water Resources Design course and Transportation Design course.

Section III: Design Services

1. Project Scope: A traditional trailhead facility was designed and placed on the site of the existing community center in Schaller. This facility will provide restroom access as well as drinking water access. There was an existing gravel parking lot and the outline of this lot was used as the general size and layout for the paved parking lot that was designed for this project, as well an a paved entrance. The paved trail starts at the north side of the parking lot at the community center and runs along Dean Avenue until it reaches 200th Street, where a left is made. It then runs along 200th Street until it gets to the lagoon where it finally meets up with decommissioned railroad tracks. It runs along the railroad tracks until it reaches the north side of the cemetery. The trail going from the community center is considered the first phase of the trail. In this first phase, a tunnel was designed to go underneath Cory Avenue when running along the railroad tracks towards the cemetery. This design can be utilized, or just running the trail over the crosswalk can be the solution. The second phase, which can be carried out later on, runs from where the trail ended at the cemetery to the west along D15 (200th Street) all the way to the neighboring town of Galva. The trail was designed for both bicyclists and pedestrians and adheres to ADA standards allowing multimodal access from Schaller to Galva.

2. Work Plan: The work plan can be seen in Section Appendix A. The chart represents the tasks that needed to be finished and the start and end date of each task. Each of these tasks were delegated to specific or multiple design team members based on their previous work and related experience. Being the project manager, Noah Decker ensured that each task was completed along the course of the project and acted as the main contact to the client. Noah also was the deciding vote when making design decisions. As the editor, Derek Nebergall oversaw that all reports and deliverables were presented with the highest standards as well as make final formatting decisions. As the technical support, Xiaoyan Gong oversaw the organization of all technical reports and project files. The whole design team helped with the initial research of the site, which included locating utilities, researching relevant codes and standards and the initial set up of essential files. Xiaoyan focused on the environmental and hydrologic impacts and design. Derek led the team in the facility design, with support in trail and parking lot design. Noah led the team in the trail design, parking lot design and the design of the tunnel. The team worked together on any presentation tasks.

Section IV: Constraints, Challenges and Impacts

1. Constraints: A budget was never presented, but a few decisions were made by selecting a known less costly option to keep costs down/reasonable. The beginning of the trail was constrained to the community center and was to run through the decommissioned railroad right of way to the west of town. The trail also needed to be run from Schaller to Galva to ensure another mode of transportation between the two cities. The trail facility was to provide restroom and water access. The aesthetic of the trail facility needed to fit in the with the existing look of both the town and specifically the community center, which the facility was placed in close proximity to. There is a time budget; final designs and presentations must be done by May 3, 2019.

2. Challenges: The designing of the trail posed a few different challenges along the way. One of the biggest challenges was the steep hill approaching Cory Avenue from the east and how to approach the design. The two solutions for this problem were to create a crosswalk across the road by adding fill material, or to construct a tunnel underneath of the road. Potentially placing the trail on land owners not in favor of the trail was also another challenge.

3. Society Impact within the Community: There will be both positive and negative impacts within the Schaller and surrounding community. The proposed trail will inevitably be diverted through land owner property. Gaining easements and rights to property has the potential to negatively impact those landowners. They may want to keep the land instead of receiving compensation for it. The trail design also has to be taken into consideration. If the trail is not funded by federal or state grants, then the trail will take up a portion of the county's budget. The trail must create a safe environment for those who use it. The trail could provide a fun and pleasant way to exercise as well as add a form of transportation that was previously impossible or dangerous. The trail could potentially reduce crime due to high volume travel and proper lighting and could also create a sense of community pride. The trail facility will provide a restroom and water access to those using the trail, but can be used for other functions as well. Placing the facility at the community center will allow the facility to be used during events using the baseball/softball field, and events at the community center that are using the outdoor patio space.

Section V: Alternative Solutions That Were Considered

For the trail design paving material alternatives, there is gravel subbase, asphalt pavement with a gravel subbase, and portland cement concrete pavement with a gravel subbase. If a gravel subbase trail was selected, it was unlikely any federal or state funding would be added to the project's budget. The gravel trail would not follow some ADA and Iowa DOT standards and would limit government funding. A pavement trail would potentially get federal or state funding and increase the project budget. Another design consideration with material selection is erosion and maintenance. Gravel trails tend to erode quicker than paved trails and the increased erosion requires more maintenance. Higher maintenance costs will need to be considered when planning for a sustainable and low cost future. While paved trails would be more expensive upfront in material cost, it could be worth looking into them to reduce maintenance costs and create a longer lasting end product. Both asphalt and concrete pavement with gravel subbases were designed as alternatives and can be selected by the preference of the client.

The trailhead facility had a few different design options, both with the same functionality. The main purpose for the facility was for water and restroom access and the two main options looked at were a modern version and a more traditional version. Both options are shown in Appendix B. The more traditional facility is typically something you would see in a small town and would fit the style of existing buildings in the area. It is also a cheaper option because of the simpler material usage and a very common construction technique. The more modern style will likely attract more attention to the accessory building and make a bold statement to the surrounding area, and this would not be desirable. Ultimately, the more traditional facility style was chosen because of its ability to match the existing the style of the community center where the trailhead will be being placed in close proximity to. It being a lower cost option was also a deciding factor.

Another major design consideration was the location of the trailhead facility and parking area. User connectivity must also be considered when determining the location of the trailhead facility. It will be important for all local and non-local residents to be able to access the trail easily and safely. Both the parking area and the trail facility were chosen to be located the community center in Schaller. The trail facility was chosen to be put next to the community center for a few reasons. The starting point of the trail begins at the community center and it makes the most sense to have this located here. The property is already owned by the city which makes placing it here very simple and saves money by not having to purchase more property. A benefit to choosing this location is that the facility can also be used during any outdoor events at the community center or a game going on at the baseball/softball field. Similarly, the parking area will work best at the community center as it is the start of the trail and there is already an existing gravel parking lot at the community center making it an easy transition to a paved one, rather than starting from scratch. This location was also the main preference of the client.

The alignment of the trail also provided two alternatives. The first alternative called for the trail to start at the dead end of South Hanover Street and then just have a shared road for biking through town all the way to the community center. This option will be less expensive as it will save on a lot of concrete/asphalt material and labor along with it. The second alternative called for continuing the concrete trail along the city property to get to the community center. This option added a lot of cost through a lot more concrete. Also making a lot of pavement markings for allowing the bikes to share the road with the cars would be avoided. The second alternative of continuing the trail along city property was chosen at the discretion of the client.

There are two alternatives for the trail when crossing Cory Avenue adjacent to the cemetery west of Schaller. The reason for there being two options is that there is a steep incline when approaching the road from the east that could pose a problem. The first alternative is to just add fill material to get the trail up and over the road and provide a crosswalk to get to the other side. This option will be a cheaper option, but it allows for a more dangerous trail having to cross a road; even with pavement markings and signs. The second alternative is to construct a tunnel underneath of the road that the trail can follow. This option will be much more pricey and require a lot of work to be completed, but is safer by not having to deal with a road crossing. These two alternatives are both being designed, and the option is being kept open to the preference of the client.

Section VI: Final Design Details

Trail Facility:

The trail facility is a stand-alone structure placed close in proximity to and west of the newly created parking lot. This facility was designed to be large enough to have space for a toilet, urinal, and sink, and to be ADA compliant by meeting the sizing requirements. This structure takes up 70 square feet, has 8' high walls, and has a gable-end roof with a custom truss design. Both the walls and roof are completed using 2x6 wood framing, to create more space for insulation to help stop pipes from freezing. The aesthetic of the building is designed to be able to fit in with the community center. This building was rendered in a popular architectural program, Sketchup. Images of the final design and aesthetic can be seen in Section X. The foundation for this building was designed using Vesic's equation. The final calculated size for the base of the square foundation was 5'-0", with a thickness of 1'-4". The foundation is 5'-0" below ground level, as to be placed underneath the frostline, to prevent heaving. Calculations for the sizing of the foundation are included in Appendix C. Some material selections and material estimations for the building were completed using RS Means Building Construction Costs and RS Means Residential Construction Costs. See Design Sheet 8 for the floor plan, elevations, cross-sections, and truss details, and Design Sheet 4 for the location of the facility. Section IX contains pictures of the finished product.

Parking Lot:

The community center in Schaller already had an existing gravel parking lot and the existing edge was used to size the parking lot. The existing gravel lot will be paved with 6" thick PCC, sized according to SUDAS. The lot will have 47 parking spaces, with 2 of them being ADA compliant. To allow for adequate stormwater drainage, the parking lot follows the slope of the existing gravel parking lot. The north end of the PCC parking lot has been been raised slightly compared to the existing gravel to reduce the slope of the parking lot. The parking lot slope reduced from roughly 5% grade to a 2-3% grade and reduced the amount of time that it takes stormwater to exit the parking lot and prevents ponding from occurring in the grassland area to the north. The parking lot also included a 5' ADA accessible sidewalk that routed from the existing PCC sidewalk to the proposed 7' x 10' restroom facility. The cross slopes of the sidewalk have been designed at a 1.5% slope and the running slopes have been designed to be under 1" per 1'. The 5' sidewalk included a flat turning space where the sidewalk bends 90 degrees. Material selections were complete using RS Means Construction Costs as well as averaged from multiple reliable sources. See Design Sheet 4 for the site development plan and Design sheet 5 for the grading and drainage plan of the parking lot.

Tunnel:

The tunnel was designed as an alternative to cross Cory Avenue on the west side of Schaller. Cory Ave. presented a challenge as there were very steep grades coming off of the road to the existing railroad right of way. There was roughly a 14' drop from the road to the toe of the slope. The tunnel was designed as two PCC cantilever retaining walls with a simply supported PCC slab resting on top. The retaining wall designs took into account overturning factors, sliding friction, and bearing stresses of materials and traffic above the wall and adequate factors of safety were used. Passive stresses were calculated on each side of the retaining walls to account for overturning forces. Resisting forces were calculated using self weights of the retaining wall components and overhead weights of traffic, soil and PCC road. Sliding friction was calculated using the self weights of the retaining wall and overhead forces and took into account the cohesion of the in-situ soil. Bearing capacity was factored in using Vesic's equation and surcharge pressure. Each of these processes is outlined in the ACI Manual and by the Army Corps of Engineers. The simply supported slab takes into the distributed weight of the road, soil and traffic. Calculations for the tunnel can be found in Appendix D.

Trail Design:

The first stage of the trail was designed from the community center in Schaller and attached to the cemetery to the west of town. It ran to the north along Dean Avenue and followed East County Road to the west. Along the roads, there was a 5' buffer designed in to separate the trail from oncoming traffic. This buffer was found in the Iowa DOT Design Manual. The trail reached the lagoons that reside on the north side of Schaller and then utilized the existing railroad right of way till it reached the cemetery. The trail was designed to be ADA compliant and the alternatives were both paved options. The first option was PCC and the second was hot mix asphalt. The options both consisted of a 6" gravel subbase that provided a base for the pavement to sit on. Both pavements provided ADA compliance and long lasting options to make the trail available to the town for most of the year. The details of the first stage of the trail can be found in Design Sheets 10 to 25.

The second stage of the trail was designed from the cemetery to the town of Galva roughly seven miles to west. This section of the trail allowed for safe access from Schaller to Galva and was also designed to be ADA compliant. The two design alternatives were the same, hot mix asphalt and PCC. This allowed for pedestrians and bicyclists to utilize the entire trail most months out of the year. The details of the second stage of the trail can be found in Design Sheet Set A and Design Sheet Set B.

Section VII: Engineer's Cost Estimate

Table 1 contains eight different total costs for this completed project. There are two design features that each have two different alternatives. The first alternative is whether the trail pavement is asphalt or concrete. Four of the options are designed with concrete, and the other four with asphalt. The other alternative is whether the tunnel created underneath the road is to be added or not. Once again, four options include with the tunnel, and four are without it. The second column, under the heading "Stage 1 Only", is the total cost of each different option by only completing stage 1. The third column, under the heading "Both Stages Total" is the total cost that includes both stage 1 and stage 2. All of the costs in this table include the parking lot and trail facility.

Tables 2, 3, 4, and 5 contain the cost breakdown of the tunnel, parking lot, trail facility, and crosswalk respectively. Tables 6 and 7 contain the cost breakdowns of the trail design for stage 1 with asphalt and concrete, respectively. Tables 8 and 9 contain the cost breakdowns of the trail design for just stage 2 with asphalt and concrete, respectively.

Table 1: Design Alternatives Total Cost

Design Alternative Cost Estimate	Total	Including Stage 2
Stage 1 Tunnel - Asphalt	$343,500.00	$773,500.00
Stage 1 Tunnel - Concrete	$359,500.00	$908,500.00
Stage 1 No Tunnel - Asphalt	$252,500.00	$682,500.00
Stage 1 No Tunnel - Concrete	$268,500.00	$817,500.00

Table 2: Underpass Tunnel Total Cost Breakdown

Cost Estimate Underpass Tunnel					
Description of Work	Quantity	Unit	Unit Price	Total Cost $	Found at
Remove PCC Road	1200	SY	$9.50	$11,400.00	RS Means Building Construction
Remove Subbase	25	CY	$2.47	$61.75	RS Means Building Construction
Remove Soil	925	CY	$2.47	$2,284.75	RS Means Building Construction
Reinforced PCC	185	CY	$150.00	$27,750.00	Averaged Between 3 Sites
Backfill	38250	CY	$2.08	$79,560.00	RS Means Building Construction
Subbase	1200	SF	$1.04	$1,248.00	RS Means Building Construction
PCC Road	25	CY	$150.00	$3,750.00	Averaged Between 3 Sites
Total				**$126,000.00**	

Table 3: Parking Lot Total Cost Breakdown

Cost Estimate Parking Lot					
Description of Work	Quantity	Unit	Unit Price $	Total Cost $	Found at
Cut/Fill	305	CY	2.08	$634.40	RS Means Building Construction
6" PCC Lot	350	CY	150	$52,500.00	Averaged Between 3 Sites
6" PCC Curb	10	CY	150	$1,500.00	Averaged Between 3 Sites
4" PCC Sidewalk	3	CY	150	$450.00	Averaged Between 3 Sites
Pavement Markings (Yellow)	1000	LF	0.17	$170.00	Federal Highway Administration
Total				**$55,000.00**	

Table 4: Trail Facility Total Cost Breakdown

Cost Estimate Faciltiy					
Description of Work	Quantity	Unit	Unit Price $	Total Cost $	Found at
Remove soil	40	CY	$2.47	$98.80	RS Means Building Construction
Reinforced PCC foundation	2	CY	$100.00	$200.00	Averaged Between 3 Sites
Backfill	38	CY	$2.08	$79.04	RS Means Building Construction
PCC slab	1.5	CY	$150.00	$225.00	Averaged Between 3 Sites
2x6 wood framing	70	SF	$5.60	$392.00	RS Means Residential Construction
Roof - gable end	70	SF	$6.49	$454.30	RS Means Residential Construction
Roof - finish	70	SF	$3.91	$273.70	RS Means Residential Construction
Drywall	70	SF	$3.11	$217.70	RS Means Residential Construction
Siding	70	SF	$7.43	$520.10	RS Means Residential Construction
Lavatory	1			$2,654	RS Means Residential Construction
Electrical service	1			$1,100	RS Means Residential Construction
Elctrical devices	1			$278	RS Means Residential Construction
Steel door - 3068	1			$465	RS Means Building Construction
Total				**$7,000.00**	

Table 5: Crosswalk - Total Cost Breakdown

Cost Estimate Crosswalk					
Description of Work	Quantity	Unit	Unit Price	Total Cost $	Found at
Stop Sign	2	Each	$50.00	$100.00	Averaged Between 3 Sites
Pavement Markings	60	LF	$0.17	$10.20	RS Means Building Construction
Detectable Warnings (2x5)	4	Each	$450.00	$1,800.00	Averaged Between 3 Sites
Cut/Fill	16000	CY	$2.08	$33,280.00	RS Means Building Construction
Total				**$35,000.00**	

Table 6: Trail with Asphalt Stage 1 Only - Total Cost Breakdown

Cost Estimate Trail Stage 1 - Asphalt					
Description of Work	Quantity	Unit	Unit Price $	Total Cost $	Found at
Cut/Fill	4963	CY	2.08	$10,323.04	RS Means Construction
4" Asphalt	1693	Tons	70	$118,510.00	Averaged Between 3 Sites
6" Subbase	1345	CY	1.04	$1,398.80	RS Means Construction
Clear and Grub	1.53	AC	16500	$25,245.00	RS Means Construction
Total				**$155,500.00**	

Table 7: Trail with Concrete Stage 1 Only - Total Cost Breakdown

Cost Estimate Trail Stage 1 - PCC					
Description of Work	Quantity	Unit	Unit Price $	Total Cost $	Found at
Cut/Fill	4963	CY	2.08	$10,323.04	RS Means Construction
4" PCC	896	CY	150	$134,400.00	Averaged Between 3 Sites
6" Subbase	1345	CY	1.04	$1,398.80	RS Means Construction
Clear and Grub	1.53	AC	16500	$25,245.00	RS Means Construction
Total				**$171,500.00**	

Table 8: Trail with Asphalt Stage 2 Only - Total Cost Breakdown

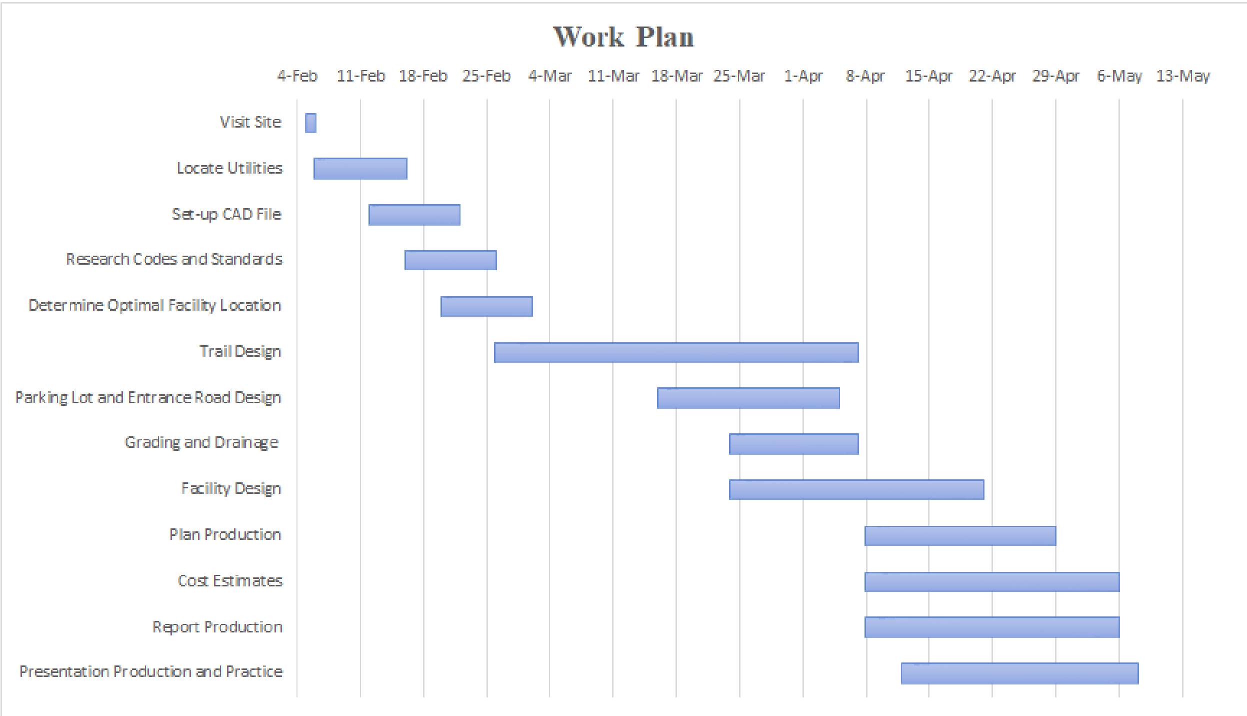
Cost Estimate Trail Stage 2 - Asphalt					
Description of Work	Quantity	Unit	Unit Price $	Total Cost $	Found at
Cut/Fill Sac County	3496	CY	2.08	$7,271.68	RS Means Construction
Cut/Fill Ida County	974	CY	2.08	$2,025.92	RS Means Construction
4" Asphalt Sac	5039	Tons	70	$352,730.00	Averaged Between 3 Sites
4" Asphalt Ida	893	CY	70	$62,510.00	Averaged Between 3 Sites
6" Subbase Sac	4003	CY	1.04	$4,163.12	RS Means Construction
6" Subbase Ida	1341	CY	1.04	$1,394.64	RS Means Construction
Total				**$430,000.00**	

Table 9: Trail with Concrete Stage 2 Only - Total Cost Breakdown

Cost Estimate Trail Stage 2 - PCC					
Description of Work	Quantity	Unit	Unit Price $	Total Cost $	Found at
Cut/Fill Sac County	3496	CY	2.08	$7,271.68	RS Means Construction
Cut/Fill Ida County	974	CY	2.08	$2,025.92	RS Means Construction
4" PCC Sac	2666	CY	150	$399,900.00	Averaged Between 3 Sites
4" PCC Ida	893	CY	150	$133,950.00	Averaged Between 3 Sites
6" Subbase Sac	4003	CY	1.04	$4,163.12	RS Means Construction
6" Subbase Ida	1341	CY	1.04	$1,394.64	RS Means Construction
Total				**$549,000.00**	

Section VIII: Appendices

Appendix A: Work Plan



Appendix B: Trailhead Alternatives

Modern Trailhead Facility

Traditional Trailhead Facility


Melvin Berlin Park
Courtesy of Hitchcock Design Group

Appendix C: Trail Facility Foundation Design Calculations

Foundation Design Calcs for Trail Facility

$\gamma := 125\ \frac{lb}{ft^3}$ $\quad \gamma_{sat} := 135\ \frac{lb}{ft^3}$ $\quad \gamma_{water} := 62.4\ \frac{lb}{ft^3}$ $\quad \gamma_{bf} := 120\ \frac{lb}{ft^3}$

$\gamma_c := 150\ \frac{lb}{ft^3}$ $\quad \mu_s := 0.35$ $\quad FS_q := 3$ $\quad t_f := 16\ in$

$FS_v := 2$ $\quad B_4 := 5\ ft$

$P_4 := 165000\ lb$ $\quad V_4 := 25000\ lb$ $\quad D_f := 4.5\ ft$ $\quad c' := 0\ \frac{lb}{ft^2}$ $\quad t_s := 6\ in$

$\phi' := 30\ deg$

$$P_a := 0.5 \cdot D_f \cdot B_4 \cdot \left(\gamma \cdot D_f \cdot \left(\tan\left(45\ deg - \frac{\phi'}{2}\right)\right)^2 - 2 \cdot c' \cdot \tan\left(45\ deg - \frac{\phi'}{2}\right)\right) = 2109.375\ lb$$

$$V_{slide} := V_4 + P_a = 27109.375\ lb$$

$$w_f := t_f \cdot {B_4}^2 \cdot \gamma_c = 5000\ lb$$

$$V_N := (P_4 + w_f) \cdot \tan(\phi') + 0.5 \cdot \left(0.5 \cdot \left(\tan\left(45\ deg + \frac{\phi'}{2}\right)\right)^2 \cdot \gamma \cdot B_4 \cdot {D_f}^2\right) = 107641.733\ lb$$

$$FS_v := \frac{V_N}{V_{slide}} = 3.971$$

$$A := {B_4}^2 = 25\ ft^2$$

$$q := \frac{P_4}{A} + \gamma_c \cdot t_s + \gamma_{bf} \cdot (D_f - t_f) = 7055\ \frac{lb}{ft^2}$$

$$N_q := e^{(\pi \cdot \tan(\phi'))} \cdot \left(\tan\left(45\ deg + \frac{\phi'}{2}\right)\right)^2 = 18.401$$

$$k := \frac{D_f}{B_4} = 0.9$$

$$N_c := \frac{(N_q - 1)}{\tan(\phi')} = 30.14$$

$$d_\gamma := 1$$

$$d_c := 1 + 0.4 \cdot k = 1.36$$

$$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi') = 22.402$$

$$d_q := 1 + 2 \cdot \tan(\phi') \cdot (1 - \sin(\phi'))^2 \cdot k = 1.26$$

$$m := \frac{2 + \frac{B_4}{B_4}}{1 + \frac{B_4}{B_4}} = 1.5$$

$$i_q := 1 - \left(\frac{V_4}{P_4}\right) = 0.848$$

$$i_c := i_q - \left(\frac{1 - i_q}{N_q - 1}\right) = 0.84$$

$$s_c := 1 + \frac{N_q}{N_c} \cdot \frac{B_4}{B_4} = 1.611$$

$$i_\gamma := 1 - \left(\frac{V_4}{P_4}\right)^{m+1} = 0.991$$

$$s_q := 1 + \frac{B_4}{B_4} \cdot \tan(\phi') = 1.577$$

$$s_\gamma := 1 - 0.4 \cdot \frac{B_4}{B_4} = 0.6$$

$$\sigma_D := \gamma \cdot D_f = 562.5\ \frac{lb}{ft^2}$$

$$q_N := \sigma_D \cdot N_q \cdot s_q \cdot d_q \cdot i_q + 0.5 \cdot \gamma \cdot B_4 \cdot N_\gamma \cdot s_\gamma \cdot d_\gamma \cdot i_\gamma = 21614.855\ \frac{lb}{ft^2}$$

$$FS_q := \frac{q_N}{q} = 3.064$$

The width of this square footing is 5'-0"

Appendix D: Tunnel Design Calculations

Noah Decker
Tunnel Calcs
Senior Design

Define Variables

$H := 9.8333\ ft$ $x_1 := 1\ ft$ $x_2 := 1\ ft$ $x_3 := 5.0\ ft$ $x_4 := 5.0\ ft$

$x_5 := 2\ ft$

$D := \left(\frac{10}{12}\right) ft + x_5 = 2.833\ ft$ $H_{total} := 14\ ft$

$t_{walk} := 4\ in$ $t_{subbase} := 6\ in$ $t_{road} := 6\ in$ $t_{slab} := 8\ in$

$\beta := 0\ deg$ $\gamma_1 := 125\ \frac{lbf}{ft^3}$ $\phi'_1 := 30\ deg$

$\phi'_2 := 20\ deg$ $c_1 := 0\ \frac{lbf}{ft^2}$ $c_2 := 625\ \frac{lbf}{ft^2}$ $\gamma_c := 150\ \frac{lbf}{ft^3}$

$c_a := \frac{c_2}{2} = 312.5\ \frac{lbf}{ft^2}$ $P_p := 0$ $\delta_1 := 0\ deg$ $\delta_2 := \phi'_2 = 20\ deg$

$H_w := x_5 + H = 11.833\ ft$ $\gamma_2 := 125\ \frac{lbf}{ft^3}$

$B := x_2 + x_3 + x_4 = 11\ ft$

Design Calculations

Calculate Passive Stress

$$K_a := \cos(\beta) \cdot \left(\frac{\cos(\beta) - \sqrt[2]{(\cos(\beta))^2 - (\cos(\phi'_1))^2}}{\cos(\beta) + \sqrt[2]{(\cos(\beta))^2 - (\cos(\phi'_1))^2}} \right) = 0.333$$

$z_1 := t_{road} + t_{subbase} = 1\ ft$

$z_2 := z_1 + t_{slab} + 9\ ft = 10.667\ ft$

$P_{a1} := 0.5 \cdot \gamma_1 \cdot {z_1}^2 \cdot K_a = 0.021\ klf$

$P_{a2} := 0.5 \cdot \gamma_1 \cdot {z_2}^2 \cdot K_a = 2.37\ klf$

$P_a := (P_{a1} + P_{a2}) \cdot \frac{(z_2 - z_1)}{2\ ft} = 11.557\ klf$

$z_a := 3.251\ ft$

Calculate Weights and Moment arms

Weight of Soil Behind Retaining Wall

$w_1 := H \cdot x_4 \cdot \gamma_1 = 6.146\ klf$ $X_1 := x_3 + x_2 + \frac{x_4}{2} = 8.5\ ft$

Weight of Concrete Footing

$$w_2 := x_5 \cdot (x_2 + x_3 + x_4) \cdot \gamma_c = 3.3\ klf \qquad X_2 := \frac{x_2 + x_3 + x_4}{2} = 5.5\ ft$$

Weight of Stem

$$w_3 := x_1 \cdot H \cdot \gamma_c = 1.475\ klf \qquad X_3 := x_3 + \left(\frac{x_1}{2}\right) = 5.5\ ft$$

Weight of Subbase and Sidewalk Slab

$$w_4 := t_{subbase} \cdot x_3 \cdot \gamma_1 + t_{walk} \cdot x_3 \cdot \gamma_c = 0.563\ klf \qquad X_4 := \frac{x_3}{2} = 2.5\ ft$$

Weight of Soil Above Tunnel

$$w_5 := \frac{(14\ ft - 9\ ft - t_{slab}) \cdot (x_3 + 2 \cdot x_2) \cdot \gamma_1}{2} = 1.896\ klf$$

Weight of Road and Subbase Above Tunnel

$$w_6 := \frac{t_{slab}\ (x_3 + 2 \cdot x_2) \cdot \gamma_c + t_{subbase} \cdot (x_3 + 2 \cdot x_2) \cdot \gamma_c}{2} = 0.613\ klf$$

Weight of Traffic - 2 Feet of Soil

$$w_7 := \frac{(x_3 + 2 \cdot x_2) \cdot \gamma_1 \cdot 2\ ft}{2} = 0.875\ klf$$

Calculate Factor of Safety for Overturning

$$M_o := P_a \cdot z_a = 37.573\ kip \cdot \frac{ft}{ft}$$

$$M_R := w_1 \cdot X_1 + w_2 \cdot X_2 + w_3 \cdot X_3 + w_4 \cdot X_4 = 79.908\ kip \cdot \frac{ft}{ft}$$

$$FS_o := \frac{M_R}{M_o} = 2.127$$

Needs to be 1.5

Calculate Pp

$$K_p := \tan\left(45\ deg + \frac{\phi'_2}{2}\right)^2 = 2.04$$

$$\sigma_p := K_p \cdot \gamma_2 \cdot x_5 + 2 \cdot c_2 \cdot (K_p)^{0.5} = 2.295\ ksf$$

$$P_P := 0.5 \cdot (\sigma_p) \cdot x_5 = 2.295\ klf$$

Calculate Fmax

$$SumP := w_1 + w_2 + w_3 + w_4 + w_5 + w_6 + w_7 = 14.867\ klf$$

$$F_{max} := SumP + \left(x_2 + x_3 + x_4\right) \cdot 0.5\ c_2 = 18.304\ \mathbf{klf}$$

Calculate Factor of Safety for Sliding

$$FS_v := \frac{F_{max}}{P_a} = 1.6$$

Needs to be 1.5

Check for uplift

$$M_{net} := M_R - M_o = 42.335\ \mathbf{kip} \cdot \frac{\mathbf{ft}}{\mathbf{ft}}$$

$$x_R := \frac{M_{net}}{SumP} = 2.848\ \mathbf{ft}$$

$$e := \frac{x_2 + x_3 + x_4}{2} - x_R = 2.652\ \mathbf{ft} \quad < \quad \frac{x_2 + x_3 + x_4}{6} = 1.833\ \mathbf{ft}$$

Since e is greater than B/6, there is no uplift force

Calculate q toe

$$I := \frac{1}{12} \cdot 1 \cdot \left(x_2 + x_3 + x_4\right)^3 = 110.917\ \frac{\mathbf{ft}^4}{\mathbf{ft}}$$

$$q_{toe} := \frac{SumP}{x_2 + x_3 + x_4} + \frac{SumP \cdot e \cdot \left(\frac{x_2 + x_3 + x_4}{2}\right)}{I} = 3.307\ \mathbf{ksf}$$

$$q_{heel} := \frac{SumP}{x_2 + x_3 + x_4} - \frac{SumP \cdot e \cdot \left(\frac{x_2 + x_3 + x_4}{2}\right)}{I} = -0.604\ \mathbf{ksf}$$

Calculate qn (Effective area method)

$$B' := x_2 + x_3 + x_4 - 2\ (e) = 5.695\ \mathbf{ft}$$

Bearing Capacity Factors

$$N_q := e^{\pi \cdot \tan(\phi'_2)} \cdot \tan\left(45\ \mathbf{deg} + \frac{\phi'_2}{2}\right)^2 = 6.399$$

$$N_c := \frac{\left(N_q - 1\right)}{\tan\left(\phi'_2\right)} = 14.835$$

$$N_\gamma := 2 \cdot (N_q + 1)\ \tan(\phi'_2) = 5.386$$

Depth Factors

$$d_\gamma := 1.0$$

$$k := \frac{D}{B} = 0.258$$

$$d_q := 1.0$$

$$d_c := 1.0 = 1$$

Load Inclination Factors

$$i_q := \left(1 - \left(\frac{P_a}{\frac{F_{max}}{\tan(\phi'_2)}}\right)\right)^2 = 0.593$$

$$i_\gamma := (i_q)^{\left(\frac{3}{2}\right)} = 0.457$$

$$i_c := i_q - \left(\frac{(1 - i_q)}{N_q - 1}\right) = 0.518$$

Shape Factors (continuous footing)

$$s_c := 1.0$$

$$s_q := 1.0$$

$$s_\gamma := 1.0$$

Bearing Pressure

$$\sigma_D := \gamma_1 \cdot H_w = 1.479\ \boldsymbol{ksf}$$

$$q_N := c_2 \cdot N_c \cdot s_c \cdot d_c \cdot i_c + \sigma_D \cdot N_q \cdot s_q \cdot d_q \cdot i_q + 0.5 \cdot \gamma_2 \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot d_\gamma \cdot i_\gamma = 11.292\ \boldsymbol{ksf}$$

Calculate Factor of Safety for Bearing

$$q' := \frac{SumP}{B'} = 2.61\ \boldsymbol{ksf}$$

$$FS_q := \frac{q_N}{q'} = 4.326$$

Needs to be 3.0

Design Summary

$$FS_o := \frac{M_R}{M_o} = 2.127 \qquad FS_v := \frac{F_{max}}{P_a} = 1.584 \qquad FS_q := \frac{q_N}{q'} = 4.326$$

Appendix E: Bibliography

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Section IX: Design Renderings and Models

Trail Facility - Sketchup:

Figure 1: Southeast view of facility

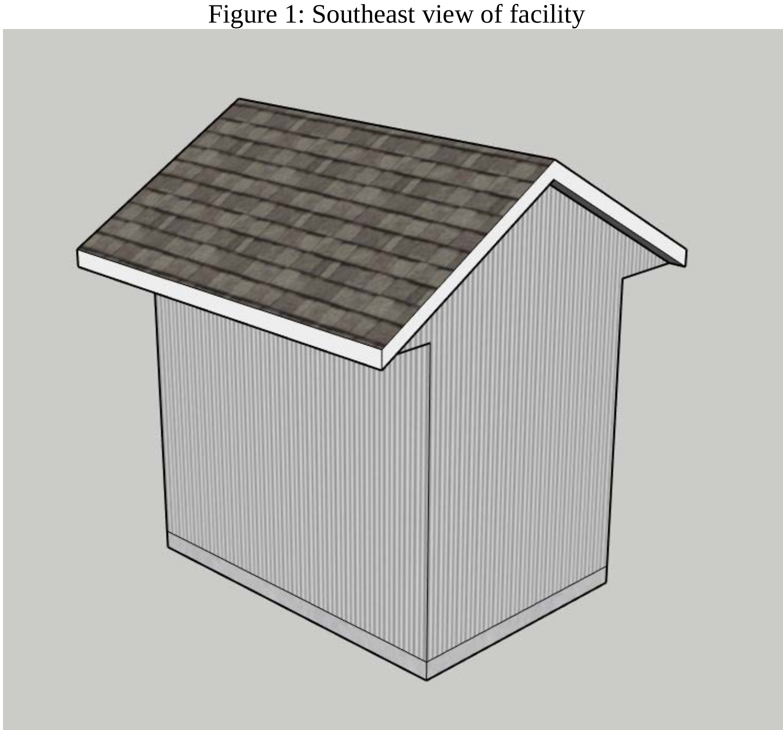

Figure 2: Northwest view of facility

Section X: Design Drawings

Refer to attached plan sheets on separate document.