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IMPROVING THE ACCESSIBILITY AND SUSTAINABILITY OF THE LA MARTA WILDLIFE REFUGE

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This report in the product of an education program and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

Sustainability
Accessibility
Costa Rica

Abstract

The La Marta Wildlife refuge is a nonprofit educational and tourist facility. There are approximately nine miles of trials at La Marta as well as several pavilions and an historical attraction. Since they have little money, maintenance is difficult to perform and most improvements are donations-based. The project team had two goals: (1) Design sustainable trails for the refuge, (2) Design a transport system to allow mobility impaired persons to cross the Gato River and enjoy the historical attraction. The trails were designed using surveying techniques along with soil erosion and runoff analyses. The car transport was designed using safety and stress analysis, material and component selection, and Pro-E solid modeling software. Our deliverables to La Marta are a cost analysis and plans for creating sustainable trails and building the transport system.

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Capstone Design Statement

It is necessary to complete a capstone design for the Major Qualifying Project. Students must combine the skills and knowledge acquired in previous course work and consider practical engineering constraints. These constraints include, “economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political[1].” To meet these requirements our project included economic, environmental, sustainability, manufacturability, ethical, health and safety, social and political considerations and constraints.

Economic

The La Marta Wildlife Refuge is the ownership of UMCA and has a limited budget. They charge a small fee to enter the Refuge but currently do not make a profit. They would like to increase tourism and financial security by investing in new attractions and refurbishing trails. However, the current budget would not sustain any large scale improvements. They depend on private donations for most construction efforts. With this in mind it is imperative to maintain a reasonable cost for construction and limit maintenance.

Environmental

Environmental impacts have become an increasing concern in the last few decades. Costa Rica is on the forefront of environmental protection. Protection of the environment is an especially high priority in the La Marta Wildlife Refuge. We will limit destruction of the existing

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[1] ABET. 6 Apr. 2009 <http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2007-08%20EAC%20Criteria%2011-15-06.pdf>.

wildlife, vegetation and their habitat by using tree fall and local soil material. Steel, concrete and rebar can often be manufactured from recycled material. Whenever possible we will use these materials.

Sustainability

Sustainability can be defined as, “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[2]” We focused on creating designs that limit the need for maintenance. The final design was completed after analyzing the lifetime expectancy of the materials. Through these constraints we limited any negative environmental impacts. Using existing local materials will also promote sustainable practices in the La Marta Wildlife Refuge.

Constructability

Constructability is essential for any final design. Ease of construction, cost, labor, and material availability was considered. We will investigate several locations to confirm that the soil material and vegetation will support the final designs. We will also determine the effects of the construction process on the area.

Ethical

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[2] "Sustainability | US EPA." U.S. Environmental Protection Agency. 13 Jan. 2009 <http://www.epa.gov/Sustainability/>.

We used the engineering principles learned through our coursework to effectively create a final design that is appropriate for the La Marta Wildlife Refuge. It must be economic and sustainable, while maintaining the proper safety constraints. All designs will abide by the civil and mechanical engineering code of ethics as follows:

Engineers uphold and advance the integrity, honor and dignity of the engineering profession by:

Using their knowledge and skill for the enhancement of human welfare

Being honest and impartial, and serving with fidelity their clients (including their employers) and the public; and striving to increase the competence and prestige of the engineering profession[3].

Health and Safety

The most important constraint when redesigning trails and designing a river crossing is safety. The health and safety of the patrons that visit La Marta is of the utmost concern and will not be compromised due to economics, sustainability, or any other variable. Every design will included a proven factor of safety and follow US design specifications.

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[3] "Ethics." National Society of Professional Engineers 6 Apr. 2009 <http://www.nspe.org/ETHICS/codeofethics/index.html>.

Executive Summary

Environmental sustainability is an issue of great importance across the globe. In Costa Rica, one of the main economic focuses, eco-tourism, provides many possible opportunities to create a more usable, sustainable environment for every person to enjoy. The project involved the design of an all-persons accessible, sustainable trail system at the La Marta Wildlife Refuge in Talamanca, Costa Rica.

The project site is located in a historic agricultural area in Costa Rica that is going through a major environmental regeneration project. The site covers over 1,500 hectares of tropical rainforest and includes a wealth of biodiversity with varying altitudes and a river system running through the reserve[4]. The La Marta Wildlife refuge is currently used as a nonprofit educational and tourist facility.

The project sponsor, the Universidad Metropolitana Castro Carazo (UMCA), owns and manages the La Marta Wildlife Refuge. The university takes its students to the refuge to conduct zoological and botanical research and also opens the site to tourists that can visit the refuge for a small fee. Throughout the project the students worked with personnel at the university as well as the park rangers at the reserve.

Since UMCA has a small budget for the upkeep of the refuge, maintenance is difficult to perform and most improvements are funded through donations. Currently, UMCA has been working on publicizing the refuge to tourist groups and is looking into improvements to make the site more tourist-friendly.

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[4] La Marta, 2004

For our project, the project team defined Sustainable Trails as those that are safe, aesthetically pleasing, and long lasting; while using environmentally friendly methods and materials. The project team defined All-Persons Accessible Trails as trails which are designed to allow mobility-impaired persons the ability to enjoy them without assistance.

Working with the sponsors, the project team formulated the scope of the project which included three main goals:

(1) Design a sustainable trail leading up a mountain to an observation tower

(2) Design a transport system to allow mobility-impaired persons to cross the Gato River, making the historic area of the site accessible

(3) Design all-persons accessible trails and features to allow mobility-impaired persons to enjoy the historic site

Achieving these three goals will allow mobility-impaired persons to enjoy the historic area and make La Marta more attractive to tourists overall.

The sustainable trails were designed using surveying techniques, trail building knowledge, material selection comparisons, and soil erosion and runoff analyses. The transport system was designed using material selection comparisons, structural analysis, ergonomics, and safety analysis. Pro-Engineer software was used to model the final design. Within the historic site, Forest Service Trails Accessibility Guidelines (FSTAG) were used to develop sustainable trails with all-persons accessibility in mind.

From our results, the project team was able to provide La Marta with a set of plans that they can use to improve the visitor experience at the refuge in years to come. The deliverables the project team provided were:

(1) Plans for a sustainable trail leading up a mountain to an observation tower

(2) Plans for building a transport system for accessible river crossing

(3) Plans for all-persons accessible, sustainable trails within the historic site

(4) A cost analysis of each set of plans.

The implementation of these plans will create a better experience for all tourists and will allow mobility-impaired persons to access the historic site which is currently a main attraction of La Marta.

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1.0 Introduction

Environmental sustainability is of great importance around the world. Since ecotourism is one of Costa Rica's main economic focuses, there were many possible opportunities to create more usable, sustainable trails environment for everyone to enjoy.

The project involved the design of a trail system at the La Marta Wildlife Refuge in Talamanca, Costa Rica. The site is located in an old agricultural area in Costa Rica that is going through a major governmental regeneration project. It is an area that is over 1,500 hectares in size, and of which 60% was the target of the regeneration effort. The area is in a tropical rainforest and includes a wealth of biodiversity from the varying altitudes and a river system running through the reserve[5].

Through the main sponsor, the National Cleaner Production Center (CNP+L), the MQP students worked with officials managing the reserve from the Costa Rica Ministry of Energy and the Environment (MINAE).

The Civil Engineering side of the project focused on the design of the trail system. Some of the facets of the project included mitigating water runoff, soil erosion prevention, current growth/necessary plantings, rain storm issues, as well as material selection for the trail. All these considerations were used to analyze trails and locations of interest. These locations were found and presented using GPS, Google Earth Pro, and Civil 3D. The design was done with sustainability in mind and Life Cycle Analysis was used to evaluate trail material decisions.

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[5] "La Marta." La Marta. Ed. ULACIT. 2004. ULACIT. 15 Jan. 2009 <http://www.lamarta.com/>.

The project team also looked at making a portion of the trail system handicapped accessible. The Mechanical Engineering majors designed structures that were accessible and easy to maintain. These structures, which will be situated on jungle trails, were designed to be durable, lightweight and mechanically operated. Commercially available all-persons accessible equipment could not have been used do to its high cost, lack of outdoor aesthetics, and inability to withstand the elements. In addition to the design aspects, several analyses were necessary to ensure the quality of the final design. These analyses included, but weren't limited to; cable stretch, weld failure, wheelchair safety, and ergonomic pull force. A cost analysis was necessary to assure that the customer's requirements were met.

2.0 Background

2.1 An Introduction to Sustainability

Sustainability has been best defined by the Brundtland Commision and recognized by the Environmental Protection Agency as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”[6] Many of the world’s leading scientists, including the majority of living Nobel Laureates, have agreed upon a warning: “Human beings and the natural world are on a collision course.”[7] Every day, millions of tons of carbon are released into the air, hundreds of square miles of rainforest are cleared, and scores of species are decimated. At the same time, a quarter million people are added to the already tipping scale. Unfortunately, our efforts are quickly becoming a game of catch-up. In some ways our damage to the environment and its species is irreversible. But it is important that the public and its governments remain optimistic. The only way to coexist with our worldly counterparts is to adapt a sustainable lifestyle.[8]

Costa Rica is an advocate for sustainability. Costa Rica is blessed with a dense rainforest that fosters an abundance of biodiversity. For many years though, Costa Rica’s northern regions were bulldozed for grazing lands. Deforestation was rampant and natural resources were mined without regulation. Many of the vehicles ran on leaded gasoline like most throughout the world.

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[6] "Sustainability | US EPA." U.S. Environmental Protection Agency. 13 Jan. 2009 <http://www.epa.gov/Sustainability/>.

[7] McConnell, Robert L., and Daniel C. Abel. Environmental Issues : An Introduction to Sustainability. 3rd ed. Upper Saddle River: Prentice Hall, 2007.

[8] McConnell, Robert L., and Daniel C. Abel. Environmental Issues : An Introduction to Sustainability. 3rd ed. Upper Saddle River: Prentice Hall, 2007.

But in the early 1990s the government made a commitment to change. The government enacted a tax on gasoline and diesel to lower emissions. Public health improved and a portion of the gas tax money was used to plant tens of thousands of trees in the northern regions that had been cleared for cattle. In order to ensure a lasting sustainable mindset, Costa Rica extended the school year so that the curriculum would include sustainability.[9]

Costa Rica has also become an international destination for ecotourism. Ecotourism is defined as "responsible travel to natural areas that conserves the environment and improves the well-being of local people."[10] It is a way to celebrate the natural environment without negatively impacting it. Eco-tourism began in the late 1980s in accordance with the international outcry for increased environmental protection and regulation. It is arguably the fastest growing subsection of tourism with an annual growth of 10-15%. Ecotourism empowers the local people with financial support. It also enlightens travelers to social and political climates that otherwise would go overlooked.[11] For our project, we are defining Sustainable Trails as those that are safe, aesthetically pleasing, and long lasting; while using environmentally friendly methods and materials.

2.2 An Introduction to Accessibility

Accessible or "all-person's" trails are trails which are designed to allow those with disabilities to enjoy them. For this project, three main sources were referenced, which are governing bodies that regulate accessible trails: The Americans with Disabilities Act (ADA),

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[9] UNDP. 12 Jan. 2009 <http://www.capacity.undp.org/index.cfm?module=Projects&page=Project&ProjID=725>.

[10] "The International Ecotourism Society." 13 Jan. 2009 <http://www.ecotourism.org/webmodules/webarticlesnet/templates/eco_template.aspx?articleid=95&zoneid=2>

[11] Randall, A. (1987). *Resource economics, Second Edition*. New York, USA: John Wiley and Sons

Forest Service Trail Accessibility Guidelines (FSTAG), and the Federal Register (Part II, Architectural and Transportation Barriers Compliance Board).

Many of the primary features of accessible trail design are consistent throughout the documents, meaning each specification is both present and equivalent in each document. Accessible trail design components include: trail grade and cross slope, resting intervals, surface, clear tread width, passing spaces and signs.

Each source lists several specifications of the requirements for an accessible trail. These are primarily metrics such as a "trail grade of up to 1:20 (5%) is permitted for any distance".[12] There are several requirements that explicitly control the maximum length of trail inclines and orientation of trail components. Each document provides several exceptions to the rules when complying with them would significantly alter the nature experience. According to the FSTAG it is acceptable to waive rules "where compliance would be impractical due to terrain or prevailing construction practices".[13] These places, where it is permissible to ignore the regulations, are referred to as conditions of departure.

All the regulations try not to affect the natural environment in any significant way. Thus, creating accessible trails becomes an art form where the trail must be practically navigable without disturbing the natural elements.

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[12] US Forest Service - Caring for the land and serving people. 3 Dec. 2008 <http://www.fs.fed.us/recreation/programs/accessibility/FSORAG.pdf>.

[13] FSTAG, 2008

2.3 Trail Material

2.3.1 Clay

Clay is a very fine textured trail material with a particle size of 0.002 mm. The material acts as a strong binder. The material is extremely hard and resistant to erosion when compacted and dry, but slippery when wet.[14] The material also has a high compactibility.[15]

2.3.2 Silt

Silt is a fine to medium textured trail material on the order of around 0.002 mm to 0.05 mm. The material acts as a strong binder. The material is smooth and solid when compacted and dry, but slippery when wet. The material is more susceptible to erosion than clay.[16] The material also has a medium compactibility.[17]

2.3.3 Sand

Sand is coarsely textured trail material due to it consisting of broken rock on the order of around 0.05 mm to 2.0 mm. The material drains water from it very well. The material is very susceptible to erosion but can work well with other materials adding drainage characteristics.[18] The material also has a low compactibility.[19]

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[14] Parker, Troy S. Natural Surface Trails by Design. Boulder: Natureshape, 2004.

[15] Webber, Peter. Trail Solutions: IMBA's Guide to Building Sweet Singletrack. Ed. Peter Webber. New York: International Mountain Bicycling Association, 2004.

[16] Parker, 2004

[17] Webber, 2004

[18] Parker, 2004

[19] Webber, 2004

2.3.4 Loam

Loam is a mixed textured trail material consisting of sand, silt, and clay on the order of around 0.002 mm to 2.0 mm. The characteristics depend on the proportion of sand, silt, and clay and in some situations can work better than any of its components used alone.[20]

2.3.5 Gravel

Gravel is a very coarsely textured trail material consisting of broken rock on the order of around 2.0 mm to 3”. The material is very susceptible to erosion, but drains very well. The addition of smaller particles can help to fill in spaces between stones and provide binding properties, preventing erosion.[21]

2.3.6 Cobbles and Stones

Cobbles and Stones are pieces of rock from 3” to 24”. They are used for the armoring purposes discussed in Section 2.4.1.

2.3.7 Crushed Stone

Crushed Stone is a trail material consisting of mechanically crushed rock which size varies. Depending on the stone that it comes from, the characteristics can vary greatly and as a result the performance varies when used on trails. The material can be dusty and loose, and can be eroded by any type of fast moving water.[22]

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[20] Parker, 2004

[21] Parker, 2004

[22] Parker, 2004

2.4 Trail Types

2.4.1 Armoring

Armoring is a method of placing stones or erosion resistant material onto a trail tread in order to give it protection. It is a very effective method of preventing erosion in high use areas as well as in wet or soft terrain conditions. It can be useful for locations such as stream crossings, muddy terrain, sandy terrain, high traffic sections, steep slopes, and in climates that receive a high level of rainfall.

2.4.2 Flagstone Paving

Flagstone paving works by placing a large rock perpendicular to the trail to serve as a keystone or anchoring stone. The largest and most even face of the paving stones are placed face up along the trail. There is another anchoring stone placed every six feet to hold the paving in place. [23]

2.4.3 Stone Pitching

Stone pitching is very similar to flagstone paving except that the paving stones are set up on end and this method can also be used to elevate a trail in extremely muddy conditions. It also can be more efficient depending on the type of stone available.

2.4.4 Raised Tread

In consistently wet or soft conditions a raised tread is desirable. This is achieved by laying large rocks down as a foundation. Then medium rocks are placed and locked into position.

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[23] Webber, 2004

The final layer is made up of aggregate consisting of stone between an inch in diameter to stone dust.[24]

2.4.5 Boulder Causeway

When very large rock slabs or boulders are available in the area they can be used to create a paved trail. It is essentially a larger version of the flagstone paving method.[25]

2.4.6 Natural Rock Outcropping

If possible, routing a trail over a natural outcropping of rock will create a sustainable trail section with very little labor and maintenance.[26]

2.4.7 Appalachian Armoring

Appalachian armoring is a method that uses logs placed perpendicular to the trail to keep stones or pieces of broken concrete in place. The logs are placed every four feet on steep trails or every 5-6 feet on less steep trail sections.[27] The logs are anchored in place by rebar stakes driven into the ground and are partially buried as well.

2.4.8 Rock/Log Turnpike

This is labor and material intensive process. The result is an elevated trail tread that will allow a trail to be built through an often wet, saturated, or boggy environment. To build a rock turnpike two parallel ditches must be dug 36 inches apart for hiking trails or 48 inches apart for equestrian use. Then, rocks are placed tightly in the ditches so that two-thirds of the stone is underground. Gravel or crushed stone is used to fill in between the two rock walls with a layer of

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[24] Webber, 2004
[25] Webber, 2004
[26] Webber, 2004
[27] Webber, 2004

soil on the top to shed water.[28] Culverts can be installed as well to allow for drainage under the trail. Culverts should be built first and then the turnpike over the top. Log stringers can also be placed in ditches instead of stones but must be over 10 inches in diameter. In addition, in considerably wet areas sills can be placed under the logs to prevent movement.[29]

2.5 Wetland Considerations

Wetlands are a very important part of an ecosystem because they retain runoff, purify water, and regulate water flow. Wetlands are also host to many diverse species of plants and animals.[30] It is best to avoid wetlands in a trail design but sometimes it is not practical. Our project will utilize a raised tread trail in wetland conditions because it limits the effect on the natural surroundings. A raised tread design creates an elevated plane that will shed water because of the crowned trail surface. The water runoff will collect in the wetland area and support the natural habitat.

2.6 Accessible Structures

If an outdoor trail system contains a structure of any kind, it must conform to ADA regulations in order for the trail to be considered all-persons accessible. There are various types of structures used in outdoor recreation areas such as ramps, boardwalks, platforms, etc. The United States Access Board publishes subsets of the ADA, each of which summarizes accessibility guidelines for various recreation facilities.

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[28] Birkby, Robert C., Peter Lucchetti, and Jenny Tempest. Lightly on the Land : The SCA Trail Building and Maintenance Manual. New York: Mountaineers Books, The, 2006.

[29] Birkby, 2006

[30] Webber, 2004

2.6.1 Boating Facilities

One of these ADA subsets focuses on accessible boating facilities. The structures involved in accessible boating facilities provide a valuable insight that will allow us to design accessible trail structures.

The first issue this document addresses is accessible routes. The ADAAG requires that at least one accessible route connect accessible buildings, facilities, elements, and spaces on a site.[31] There are various technical specifications for these accessible routes. For example, a route must be a minimum of 36 inches wide, and the slope must be a maximum of 1:12 or 8.33%. A boating facility ramp or "gangway" is shown in Figure 1.

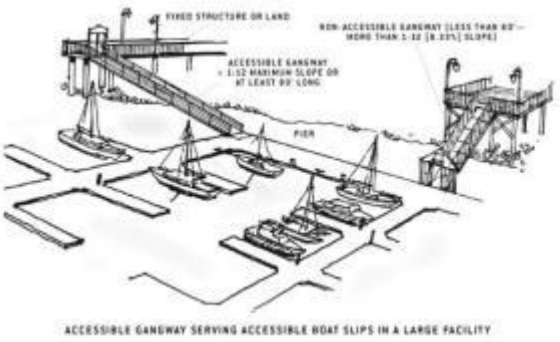

Figure 1 - Boating Facility Ramp[32]

Transition plates are another important aspect of accessible boating facilities and can certainly be applied to trail design. A transition plate is a sloping pedestrian walking surface located at the end of a ramp. The transition plate, shown in Figure 2, allows a wheelchair to

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[31] "Boating facilities." United States Access Board. 3 Dec. 2008 <http://www.access-board.gov/recreation/guides/boating.htm>.

[32] Boating Facilities. 2008

move smoothly from a ramp to a landing. If the slope of the transition plate is greater than 1:20 or 5%, the transition plate must have a landing at the non-gangway end of the transition plate.[33]

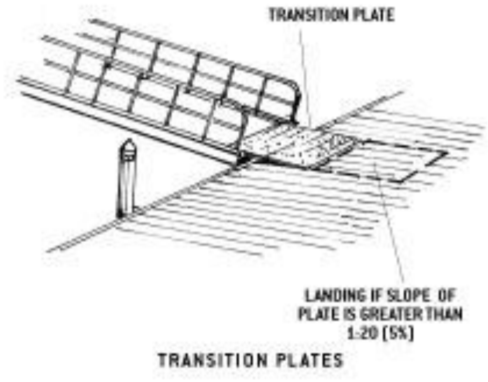

Figure 2 - Transition Plate[34]

The final aspect of this document that applies to trail structure design is edge protection. Boating facility structures are raised platforms with water underneath, therefore preventative measures must be taken to keep wheel chair users from rolling off the platform. These edges are designed to be 4 inches high and 2 inches deep. A diagram of an edge protected structure is shown in Figure 3.

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[33] Boating Facilities, 2008

[34] Boating Facilities, 2008

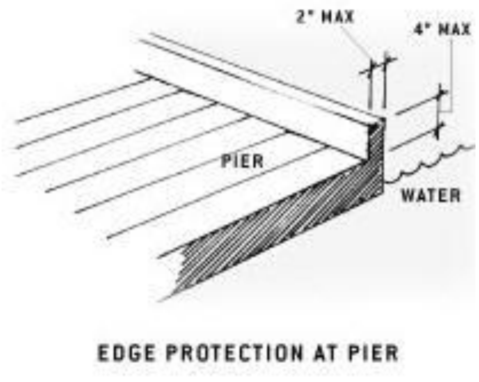

Figure 3 - Edge Protection[35]

2.6.2 Fishing Piers and Platforms

Another subset of the ADA focused on outdoor recreation structures is Fishing Piers and Platforms. Many of the requirements for fishing platforms concur with those for boating facilities, with few exceptions. The bulk of this document discusses the use of hand rails to aid wheelchair users.

Handrails can be used for many reasons such as safety, resting, or to aid the elderly. In the case of fishing platforms, the handrails must not prevent wheelchair users from being able to fish. Thus, at least 25 percent of the length of the railing must be 34 inches or less in height above the ground or deck so a person using a wheelchair or other mobility device has the opportunity to fish.[36] The space between vertical rails is also important to prevent a wheelchair from being caught in the handrail structure. The ADA states that open guards shall have balusters

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[35] Boating Facilities, 2008

[36] "Fishing piers and platforms." United States Access Board. 3 Dec. 2008 <http://www.access-board.gov/recreation/guides/fishing.htm>.

or ornamental patterns such that a 4 inch diameter sphere cannot pass through any opening up to a height of 34 inches. From a height of 34 to 42 inches above the adjacent walking surfaces, a sphere 8 inches in diameter shall not pass.[37] Figure 4 below shows a diagram of railing heights and clearance spaces.

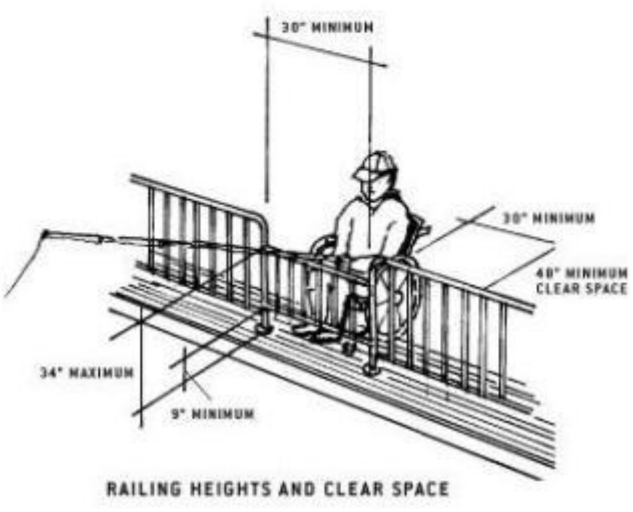

Figure 4 - Railing Heights and Clearances[38]

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[37] Fishing Piers and Platforms, 2008
[38] Fishing Piers and Platforms, 2008

2.7 Case Studies

2.7.1 Natick

The Broadmoor Wildlife Refuge in Natick, Massachusetts, provided our team with useful information that would help make our trail more sustainable. This trail system is not classified as sustainable however we were able to highlight regions that would be considered sustainable and areas that would not. For instance, a portion of the trail was cut through an open field. There were visible markings of machine use to cut back the vegetation (See Figure 5).

Figure 5 – Cut Back Vegetation

The need to have a maintenance crew regularly maintain the trail would not be considered sustainable. In another location, the trail followed very tightly to a wetlands area. The wetlands was encroaching on the trail so much that a section of the trail was actually in the marsh. This forced trail users to push back the brush on the opposite side of the trail to continue. The trail system also highlights very sustainable portions. Throughout a long stretch of the trail either fallen trees or rocks were used. This technique provides support for the trail. During wet conditions the trail material can begin to erode. But this method kept the material on the trail (See Figure 6).

Figure 6 - Erosion Prevention

Another consideration was made for water runoff control that has practical applications for our project. The Natick trail used a riprap section perpendicular to the trail so that a seasonal stream would be directed away from the more vulnerable sections of the trail. Riprap is usually one foot minus stone that is stacked directly on top of the virgin soil. It is primarily used for stabilizing slopes and erosion control. For some applications concrete, wire mesh, or geotechnical fabric is used to further stabilize the rock. This situation, however, maintained simplicity and sustainability.

2.7.2 Puerto Viejo

We visited another site in Puerto Viejo on the Caribbean coast of Costa Rica. This trail was designed with a technique called skirting. Skirting is when a trail parallels a natural site like a tree line or in this case the beach.[39] This trail specifically follows the edge of the beach on both sides because a portion of the trail actually crosses onto the beach and then tucks away again into the tree line. In Figure 7, the trail is within the tree line with the edge of the beach on the left.

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[39] Parker, 2004.

This trail also includes the contrast between light and shade. This is called edge crossing. Similar to the crossing between tree line and beach, the trail crosses from shade to light. “Much of the feeling of a trail comes from how it relates to the site edges. Each type of relationship has its own feel. The most engaging trails have sequences of many or all of these edges.”[40]

Figure 7 – Puerto Viejo Trail

Both sites we visited utilized a vast array of bridge and boardwalk structures. The Puerto Viejo trail used very simple board bridges to span minimal gaps (See Figure 8).

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[40] Parker, 2004

Figure 8 - Plank Bridge

It is a very cost efficient and simple solution for this particular situation. This bridge is sufficient for pedestrians and bicycles but is not a viable option for all-persons accessibility. The Broadmoor Wildlife Refuge had a combination of all-persons accessible and inaccessible bridges and boardwalks.

2.8 Trail Design Factors and Trail Science

2.8.1 The Half Rule

The Half Rule is a basic trail building guideline that states that the angle of the trail cannot be more than half of the angle of the upslope side of the trail. Trails that violate this rule tend to have water flow from upslope runoff run down the trail causing major erosion instead of crossing over the trail.[41]

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[41] Webber, 2004

2.8.2 The Ten Percent Average Guideline

This guideline states that a sustainable trail should maintain an average grade that is less than 10%.[42]

2.8.3 Waterbars

Waterbars are a method of diverting water off of a trails surface. A waterbar consists of a log or rocks that are embedded a few inches higher than the trail and placed at a 45 degree angle as shown in Figure 9. There is also an apron which is a five foot section of trail leading to the waterbar that is shaped to help the waterbar direct the flow of water off of the trail and into outlet ditch, usually lined with rocks to disperse and slow water leaving the trail tread.

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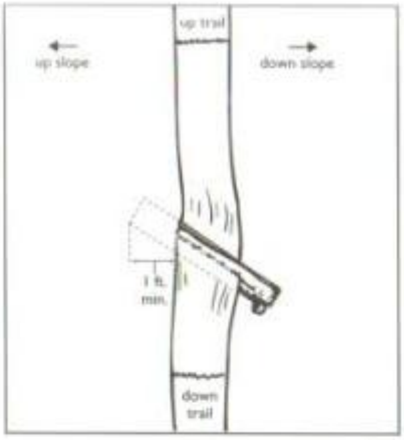
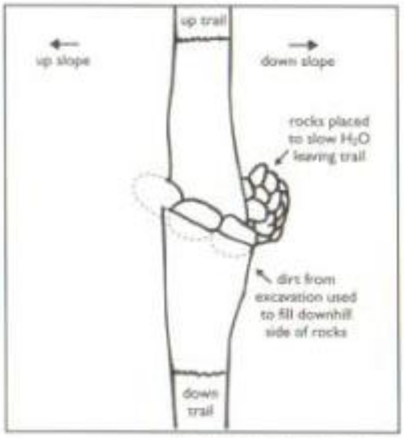
[42] Webber, 2004



A bird's-eye view of a wooden water bar



A bird's-eye view of a rock water bar

Figure 9 - Waterbars[43]

2.8.4 Culverts

Culverts are a method of allowing water to cross a trail's path by directing the flow underneath the trail surface. This method keeps water from crossing over the trail tread, minimizing erosion.[44]An example of a culvert made from rock is shown below in Figure 10.

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[43] Birkby, 2005
[44] Birkby, 2005

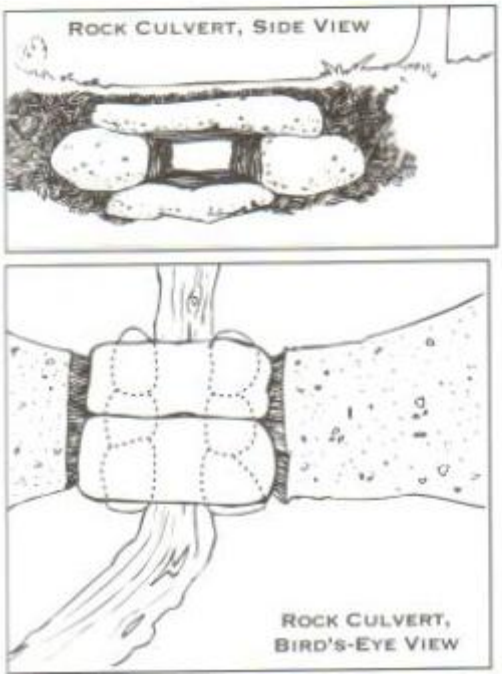

Figure 10 - Culverts[45]

The size of the culvert depends on the amount of water that will need to pass through it. The minimum opening of the culvert should be large enough for a shovel to pass through so that maintenance is easy to perform.[46] If using rock as a material, the bottom of the culvert should be lined with stone and large, sturdy stones should be used to form the walls of the culvert. Large flat stones should span the top which the can be covered by the trail tread. When using wood, the bottom of the culvert should be again lined with stone and sides made with 4”X12” lumber or logs of similar size. The wood should be spiked into place by rebar or other material to help the

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[45] Birkby, 2005

[46] Birkby, 2005

culvert stay in place. The top of the culvert can be covered by 4”X12” planks or split logs and then covering the culvert with the trail tread material.[47]

2.8.5 Grade Reversals

A grade reversal is a method for allowing water to run off of the trail tread. The section is usually between 10-50 feet long and the grade dips down and then rises in order to shed water off the side of the trail.[48]

2.8.6 Outslope

The outslope refers to the method of tilting a trail tread slightly downward and away from the upslope side of the trail. This method allows water to sheet across and off of the trail tread.[49]

2.8.7 Maximum Sustainable Grade

The maximum sustainable grade is dependent on the soil composition of the tread and geographic location of the trail. The maximum grade usually ranges between 5%-15%.[50]

2.9 Accessibility Design Factors

2.9.1 Trail Grade

The purpose of regulating trail grade for accessibility is to allow people in wheelchairs or with mobility limitations access to the trail. The FSTAG defines trail grade as the consistent vertical distance of ascent or descent of a trail expressed as a percentage of its length, commonly

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[47] Birkby, 2005
[48] Webber, 2004
[49] Webber, 2004
[50] Webber, 2004

measures as a ratio of rise to length.[51] The trail grade is the slope in the direction of travel, and is sometimes referred to as the "running slope". A steep hill has a much higher grade than small hill or a flat surface. The regulations for accessible trail grades are expressed in terms of the trail segment length. This is done to ensure that a wheelchair user will have enough rest time throughout his or her use of the trail. For example, the largest grade a trail designer may use for an accessible trail is 1:7; however the length of that trail segment may not exceed 10 feet. Table 1 contains the FSTAG guidelines for accessible trail grades, and the corresponding maximum allowable segment length. It is important to note that any trail grade less than or equal to 1:20 is allowed, regardless of segment length. Similarly, no grade steeper than 1:7 is allowed.

Table 1 - Trail Grade Guidelines[52]

Trail Grade (Rise:Length)	Trail Grade (Percentage)	Allowable Segment Length
Up to 1:20	Up to 5.0	Any Length
1:20 to 1:12	5.0 to 8.3	200 Feet
1:12 to 1:10	8.3 to 10.0	30 Feet
1:10 to 1:8	10.0 to 12.5	10 Feet
1:8 to 1:7	12.5 to 14.3	5 Feet
1:7 and Higher	14.3 and Higher	Not Permitted

2.9.2 Cross Slope

Cross Slope is the percentage of rise to length when measuring the trail tread from edge to edge perpendicular to the direction of travel.[53] The cross slope of a trail must be regulated for

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[51] FSTAG, 2008

[52] FSTAG. 2008

[53] FSTAG, 2008

accessibility in order to provide safety to disabled travelers. A severe cross slope could cause a wheelchair to tip over on its side, and the visually impaired or elderly could lose footing. An accessible trails' cross slope may not exceed 1:20 at any given location, with the exception of drainage sites. The cross slope may be adjusted to a maximum of 1:10 as long as the width of that trail segment is at least 42 inches.

2.9.3 Resting Intervals

Resting intervals are mandated to ensure that a disabled trail user is not overly fatigued to the point where it becomes a safety issue. There are three technical aspects of resting intervals specified; length, slope, and frequency. The length of a resting interval must be 60 inches and the slope must not exceed 1:20 in all directions. The frequency of the resting intervals is based on the trail grade. Steeper trails require shorter distances between resting intervals. A resting interval is required at the end of each allowable segment length. For example, a trail segment with a grade of 1:12 may not exceed 30 feet in length, as discussed in section 2.9.1. Similarly, when a trail grade lies between 1:12 and 1:10, resting intervals must be placed at distances no more than every 30 feet along that trail segment.[54]

2.9.4 Surface

A trail's surface is the material that forms the portion of a trail that people travel on. Gravel and wood are two examples of a trail surface, although surface materials can range from loose dirt to asphalt. There are many considerations to be taken when selecting a trail surface,

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[54] FSTAG, 2008

especially when designing an accessible trail. The FSTAG requires a trail surface to be both firm and stable to allow a disabled person to travel on the trail safely and easily.

2.9.5 Firmness and Stability

The two most important aspects of accessible trails are firmness and stability. Firmness is a measure of compression stress for the surface. A surface such as sand has a low level of firmness while asphalt has a high level of firmness. Stability is a measure of shear stress for a surface. Surfaces with low stability allow lateral or rotational movement. Sand has a low level of stability while wood has a high level of stability.

Firmness and stability are measured by penetration tests using a rotational penetrometer. A rotational penetrometer is inserted into the ground, taking a measurement of how far a probe is able to penetrate the surface under a pre-determined force. The probe is then rotated around and penetrates the surface further. The first measurement gives the firmness while the second measurement gives the stability.[55] High levels of firmness and stability are necessary for accessible trails because they allow easier movement for persons with disabilities. Surfaces with low values of firmness and stability can cause the wheels of a chair or the ends of crutches or canes to sink or slip. The ANSI/ RESNA Standards for Firmness and Stability are shown below in Table 2. The data are expressed in inches of penetration, caused by the force being exerted on the rotational penetrometer.

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[55] "Trail Surfaces: What Do I Need to Know Now? |." National Center on Accessibility. 3 Dec. 2008 <http://www.ncaonline.org/index.php?q=node/332>.

Table 2 - ANSI/ RESNA Standards for Firmness and Stability[56]

	Very Firm / Stable	Moderately Firm / Stable	Not Firm / Stable
Firmness	0.3 inches or less	0.3 to 0.5 inches	Greater than 0.5 inches
Stability	0.5 inches or less	0.5 to 1.0 inches	Greater than 1.0 inch

2.9.6 Surface Types

There are many surface types for a trail designer to choose from, depending on the geographical location of the trail. The factors that go into choosing a trail surface include climate, intended use, budget, primary user group, and in this case, accessibility. As discussed in the previous section, an accessible trail surface must be both firm and stable. Therefore, materials must be selected that meet these requirements. The most commonly used surface for accessibility is asphalt because it does not give way under compressive or shear forces. Asphalt, however does not maintain the outdoor aesthetics of a trail location, and would not be ideal in a rainforest setting.

Engineered wood fiber is a mulch-like surface composed of hardwood chips. It is safe for playground use and can cushion a fall of up to ten feet. However, since the chips are loose, it does not provide the necessary levels of stability and firmness for an accessible trail. The USDA Forest Service created a derivative of engineered wood fiber called stabilized engineered wood

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[56] "Standards for Accessible Ground and Floor Surfaces." American Trails - your national resource for trails and greenways. 3 Dec. 2008 <http://www.americantrails.org/resources/accessible/ADAsurfaceMtg.html>.

fiber which provides the necessary levels of stability and firmness. The stabilized engineered wood fiber uses stabilizing binders to create a thin layer on top of the engineered wood fiber that allows for a smooth surface which can be easily navigated by those with motion impairments. A wood chip surface costs $9/ft^2, and costs significantly less than surfaces of similar use. For example, bonded rubber surfaces cost $20/sq. ft.[57] Engineered wood fiber can be seen below in Figure 11.

Figure 11 - Engineered Wood Fiber[58]

Another option would be to use tightly packed pea gravel, a common choice for US accessible trail surfaces. Pea gravel is nearly as firm as asphalt, but lacks in stability.[59] It is also less expensive than any material suggested thus far at $1/ft^2. Other benefits of pea gravel include better drainage characteristics, aesthetics, and availability. Pea gravel however is the least sustainable of the materials being questioned. It does not occur naturally in the environment of

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[57] Trail Surfaces, 2008

[58] "Playground Surfacing, Playground Mulch, and Engineered Wood Fiber in Massachusetts :: Maryland Materials." Commercial Playground Equipment, Playground Parts, Commercial Playgrounds :: Maryland Materials. 8 Dec. 2008 <http://www.mdmaterials.com/playgroundsurfacing_woodfiber_massachusetts.html>.

[59] Trail Surfaces, 2008

the trail, and lends itself to being washed away by rain, and removed from the trail surface by users. Pea gravel is shown below in Figure 12.

Figure 12 - Pea Gravel[60]

In addition to pea gravel, there are many other rock-based materials that can be used to provide a firm and stable trail. Due to the large number of rock-based options, the FSTAG provides trail designers with a list of various rock-based surfaces that they recommend, as shown below:

Crushed Rock

Rock with broken faces

Rock mixture containing a full spectrum of sizes

Hard rock

Rock that passes through a 13mm screen[61]

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[60] "Lounsbury Landscaping." We'll grow on you!. 13 Dec. 2008 <http://www.lounsburylandscaping.com/gpage1.html>.

[61] Trail Surfaces, 2008

2.9.7 Clear Tread Width

Clear tread width is the length of the trail perpendicular to the direction of travel. The standard clear tread width is 36 inches but may be reduced to 32 inches or less depending on conditions of departure.[62] The purpose of this trail component is to allow wheelchair users free travel along the accessible trail. The width of an average wheelchair's wheelbase is 26 inches, but can vary depending on the size of the user.[63] If the trail width is less than the width of the wheelchair, it may be impassible for the user. Thus, wherever possible, the trail must be at least 36 inches in clear tread width.

2.9.8 Passing Spaces

Passing spaces are used when the clear tread width of a trail is less than 60 inches. Passing spaces are designed for wheelchair users traveling in opposite directions and allow for them to pass each other. If a trail width is greater than 60 inches, wheelchair users and other trail users can pass each other without the use of passing spaces. When the trail is narrower than 60 inches passing spaces become necessary. These passing spaces must be no more than 1000 feet apart to allow for reasonable passing for wheelchair users.[64]

2.9.9 Signage

Signs are required at the trailhead of all accessible trails. These signs must provide the name and length of the trail as well as the typical and maximum trail grade, cross slope and tread width. They must also provide the surface type, firmness and stability and any obstacles present on the trail.

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[62] FSTAG, 2008

[63] "Dimensions of Adult-Sized Wheelchairs." ADA Home Page - ada.gov - Information and Technical Assistance on the Americans with Disabilities Act. Dec. & Jan. 2009 <http://www.ada.gov/descript/reg3a/figA3ds.htm>.

[64] FSTAG, 2008

2.9.10 Level of Difficulty

The various technical requirements for designing an accessible trail provide designers with *minimum* requirements. This means that a trail designed to meet the requirements of the provided legislation poses the highest level of difficulty to disabled trail users. The Virginia Department of Conversation and Recreation has taken the FSTAG requirements, and created two additional levels of difficulty, shown in Table 3 below. These specifications are stricter than those required by the FSTAG and are used as guidelines rather than legislation.

Table 3 - Level of Difficulty[65]

	Easy	Moderate
Width	48 inches	36 inches
Passing Spaces	200-foot maximum interval	300-foot maximum interval
Maximum Grade	1:12 slope	1:10 slope
Average Trail Grade	1:20 maximum	1:20 maximum
Distance allowed at maximum trail grade	30 feet maximum	50 feet maximum
Cross Slope	1:33 maximum	1:33 maximum
Clear Head space	80 inches	80 inches
Resting Intervals	400-foot maximum interval	900-foot maximum interval
Edge Protection	4 inch high on downhill side	4 inch high at dangerous locations
Handrails	34”-38” high at dangerous locations and bridges	34”-38” high at dangerous locations and bridges
Level Changes	2 inch maximum	2 inch maximum
Surface	Hard, skid resistant	Very firm

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[65] FSTAG, 2008

2.10 Platforms

The first step in building a deck is to assign the critical dimensions; the perimeter and height of the deck. A common form of decking is the post beam support system. This design connects vertical posts with horizontal joists (Figure 13). First, pour concrete footings to support the columns. The columns can be connected to the footings by post anchors which are installed while the cement is still wet and fastened to the wood column. The builder will need to know the expected maximum load on the deck in order to determine the number and size of the footings. The joists are then fastened to the posts with decking screws or lag bolts. Once the frame has been laid out with the posts and the joists, the rafters can be laid on top of the joists and fastened with screws or nails[66].

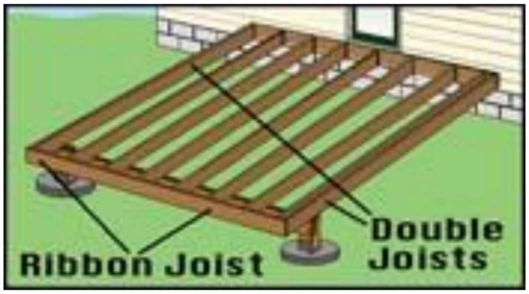

Figure 13 - Joist Connections[67]

The next step in this design is to install railing posts (Figure 14). These posts should be secured to the side of the outside joists. The railing design will change due to local building codes. It is important to find the maximum distance allowed between railing posts, required railing height, maximum height allowed for the bottom rail, maximum distance allowed between

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[66] "How to Design, Plan and Build a Deck." Lowe's Home Improvement. 15 Apr. 2009 <http://www.lowes.com/lowes/lkn?action=howTo&p=Build/BldDck.html>.

[67] "How to Design, Plan, and Build a Deck", 2009

rail pickets and bumper height. Implement these particular variables and use a railing cap to secure the vertical members (Figure 14)[68].

Figure 14 - Deck Railings and Foundation[69]

One of the most important decisions before building a deck or platform is the material selection. If the structure experiences wet conditions, contact with insects and sun damage then pressure treated wood should be considered. This will extend the lifetime expectancy of the deck or platform. Also, consider rust in the hardware. Using galvanized screws and bolts will minimize the corrosion of the hardware.[70]

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[68] How to Design, Plan, and Build a Deck, 2009
[69] How to Design, Plan, and Build a Deck, 2009
[70] How to Design, Plan, and Build a Deck, 2009

3.0 Accessibility Design Process

The first step of the design process is to assess the needs of the customer. Once the needs have been assessed, it is then necessary to produce a series of preliminary design concepts, and then to investigate which of the concepts will best suit the customer's needs. When the final design has been selected, the engineer undergoes a series of analyses that finalize the various components of the design.

3.1 Needs Assessment

The La Marta Wildlife Refuge would like to increase the rate of visitation by tourists. The main attraction at La Marta is their historic site, containing 200-year-old ruins of an agricultural site. Access to the historic site from the parking lot requires the traversal of the 100-foot, 30 meter wide Gato River. The following map (See Figure 15) shows the parking lot, historic site, and Gato River.

Figure 15 - Map of La Marta[71]

Currently, the parking lot and the historic site are connected by a 10-year-old wooden-plank suspension bridge (see Figure 16). This suspension bridge serves its purpose of allowing transportation across the river, but is not an acceptable means of transporting strollers, small children, and most notably, persons confined to a wheelchair. This is due to its narrow design and tendency to sag in the middle.

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[71] Llubere, 2009

Figure 16 - Existing Bridge at La Marta

The solution is to create a new means of crossing the river that meets the following customer specifications:

Low Cost: UMCA, the university that owns La Marta, does not allocate funds to the refuge. The only means of acquiring funding for renovations to the refuge are through donations and grants, thus, the cost of the project must be kept as low as possible to increase UMCA's chances of acquiring the necessary funding in grants and donations.

Sustainability: Costa Rica as a country has taken strides in the past 5 years to develop a more sustainable economy. The proposed solution must be approached from a sustainable standpoint.

Aesthetics: La Marta is a wildlife sanctuary that is used primarily to study its vast selection of plants and animals. It is crucial that the new means of crossing the river maintains the outdoor aesthetics of the refuge.

3.2 Selection

3.2.1 Performance Specifications

The first step in our design process was to determine performance specifications for our design. These design specifications serve as a series of guidelines for the design. Our performance specifications provide quantitative targets for the physical design parameters. The main categories considered were Physical, Functional, Safety and Economic. Physical specifications dictate the dimensions of our design as well as the functional load capacity. Functional Specifications apply to ergonomic considerations for use of the design. Safety specifications cover all safety issues such as pinch points and friction coefficients on ramps. Economics specifications provide cost limits on construction, maintenance and operating costs. The following Table 4 shows the performance specifications.

Table 4 - Performance Specifications

Performance Specifications		
Physical[72]		
	Railing Height	34 inches
	Passing Width	36 inches
	Transition Plate	< 1:20
	Ramp Slope	< 1:12
	Cross Slope	< 1:20
	Bumper Height	4 inches
	Load Capacity	800 lbs
Functional[73]		
	Max Arm Force (Vertical Push)	315 N
	Max Arm Force (Vertical Pull)	226 N
	Max Arm Force (Horizontal Push)	328 N
	Max Arm Force (Horizontal Pull)	233 N
Safety		
	Pinch Points	All Must be Guarded
	Coefficient of Friction[74]	.8 Ramps
		.6 Flat Surfaces
Economic		
	Construction Cost	Less than $2000
	Maintenance Cost	Less than $200/year

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[72] ADA, 2009

[73] Ergonomics consultants. Ergonomic workplace & product design. 10 Feb. 2009 <http://www.humanics-es.com/strength2a.pdf>.

[74] ADA, 2009

3.2.2 Design Concepts

We created eight designs to transport a wheelchair across the river. The designs are briefly described below and are: Gravity Driven Cable Car, Pull Car, Counter-Balanced Dual Cable Car, Rider Crank, Water Power, Wooden Truss Bridge, Steel Truss Bridge and Suspension Bridge.

Cable Cars

The basic cable car concept is a car that rides on steel wire rope between two platforms on opposite sides of the Gato River. The car is made of steel bars welded together and has a carrying capacity of two people.

Gravity Feed: This design includes a "T"-shaped cable support structure on each side of the river. The top beam of the structure is sloped in a direction parallel to the river, creating both a low side and a high side. The top center height of the two structures would be at the same elevation. The high side of the structure would be oriented upstream on one side of the river, while the high side of the opposing structure would be oriented downstream. Two cables would span the river between the upstream and downstream ends of the structure, for traversal in opposite directions across the river. This would cause the car to travel from the high side of one structure to the low side of the other. After the passengers disembark the car, a mechanism would be used to lift the car from the low side to the high side of the structure before returning to the opposite side of the river. Figure 17 shows the gravity feed design.

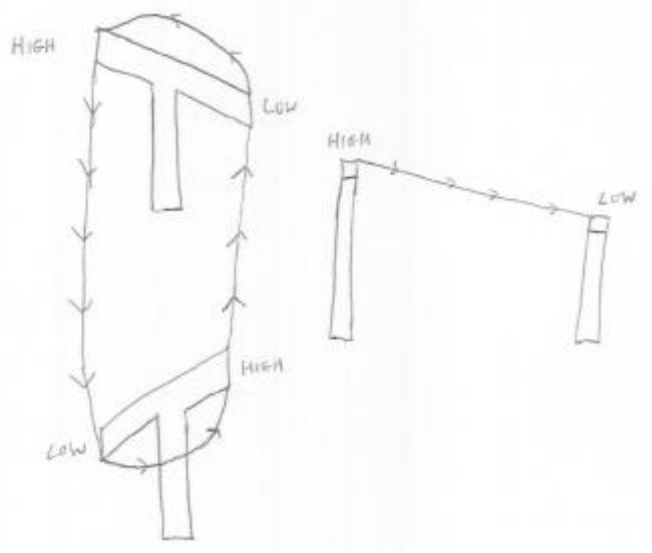

Figure 17 - Gravity Feed

Pull Car: This design is a car suspended from a cable. A rope runs parallel to the cable at an ergonomic height so that it can easily be pulled manually by the passenger across the river. This design has two steel cables, one on each side of the car, to prevent rotation of the car. Figure 18 shows a pull car concept.

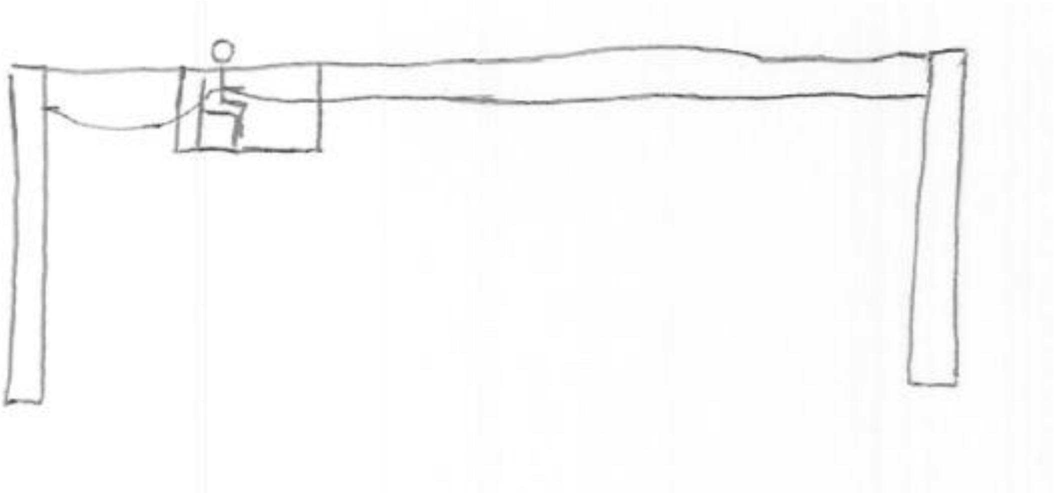

Figure 18 - Pull Car Concept

Counter-Balanced Dual Cable Car: This design has a structure on the ruins side of the river at a higher elevation than the structure on the parking lot side. There are two cars which act as counter balances to each other which provide most of the work needed to pull the car across.

The rest of the work is made up by a crank. Figure 19 shows a Counter-Balanced Dual Cable Car.

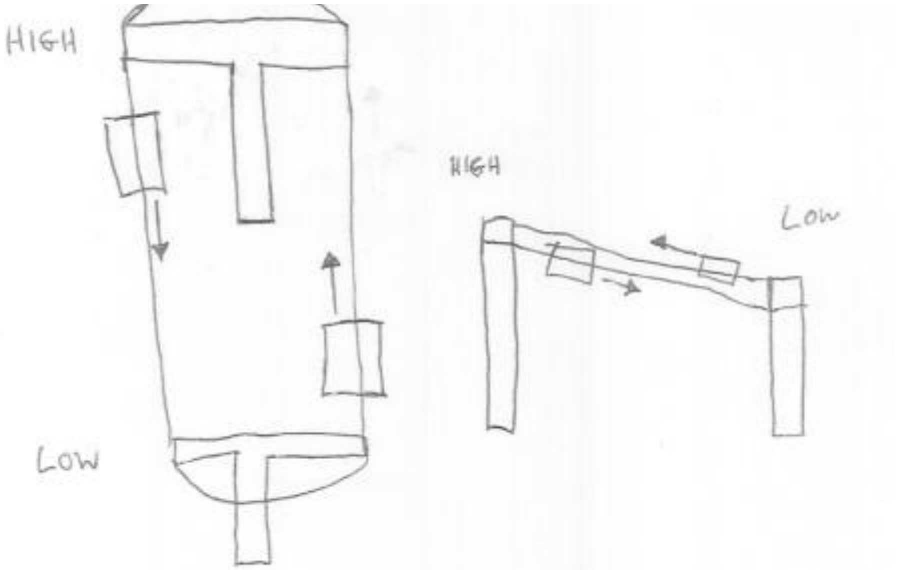

Figure 19 - Counter-Balanced Dual Cable Car

Rider Crank: There is a crank in the car that a user turns to move the car across a stationary steel cable. This design has only one steel cable and the car hangs from it. Figure 20 shows a Rider Crank.

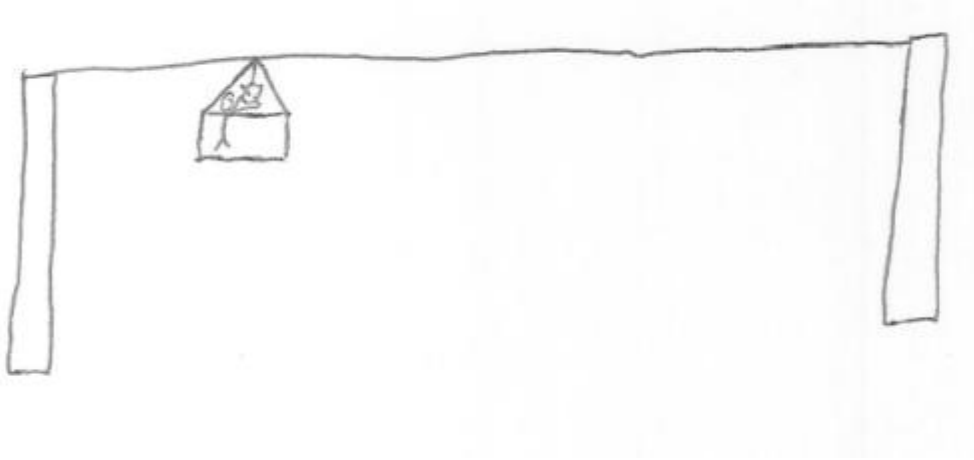

Figure 20 - Rider Crank

Water Powered: A waterwheel harnesses energy from the river to turn gears. These gears can be connected to a mechanism to pull the cable through a clutch. The car is permanently attached to the steel cable like a ski lift so that only the cable must be moved. This is the only design with a dynamic cable. The car must be attached to the cable at one point. This design also requires a double length of cable. Figure 21 shows a Water Powered design concept.

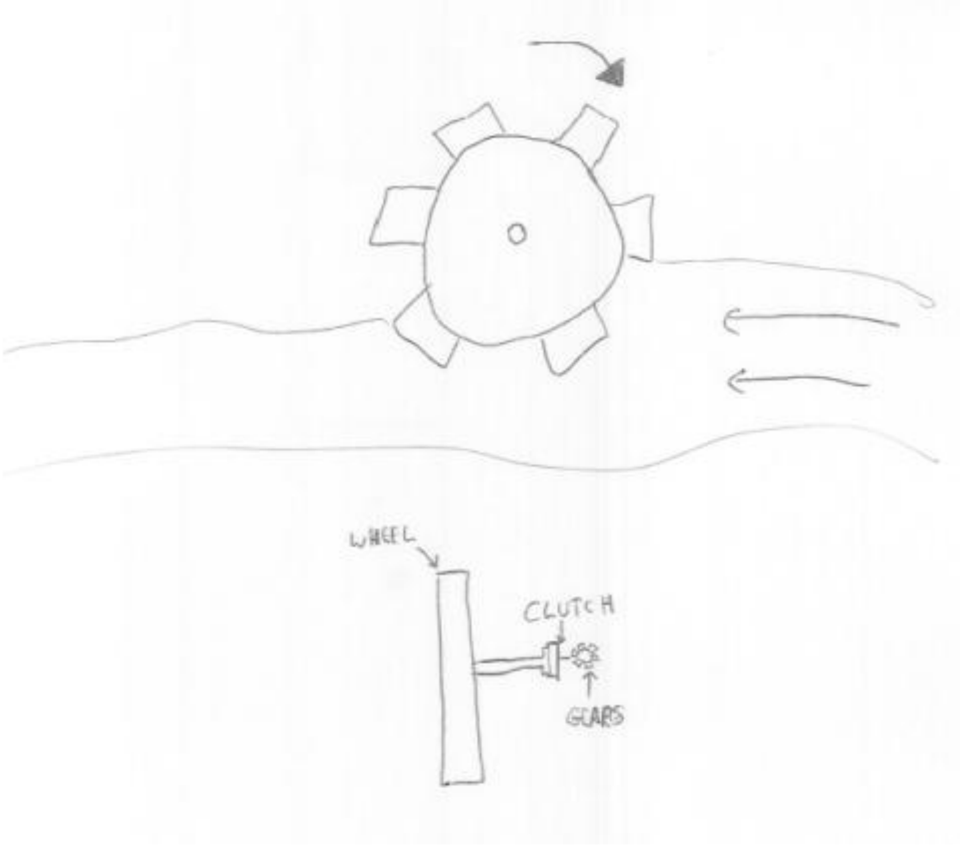

Figure 21 - Water Powered Design Concept

Bridges

The basic bridge concept is to design a bridge across the river that would allow all-persons and specifically mobility impaired persons to cross.

Truss Bridge (Wooden): A truss bridge made out of wood.

Truss Bridge (Steel): A truss bridge made out of steel. Figure 22 shows a truss bridge.

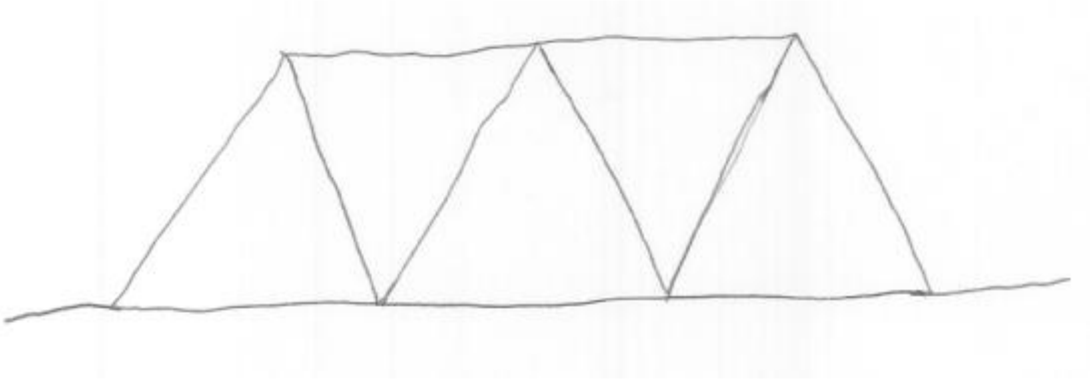

Figure 22 - Truss Bridge

Suspension Bridge: Bridge using suspended steel cables with wooden planks. Figure 23 shows a suspension bridge.

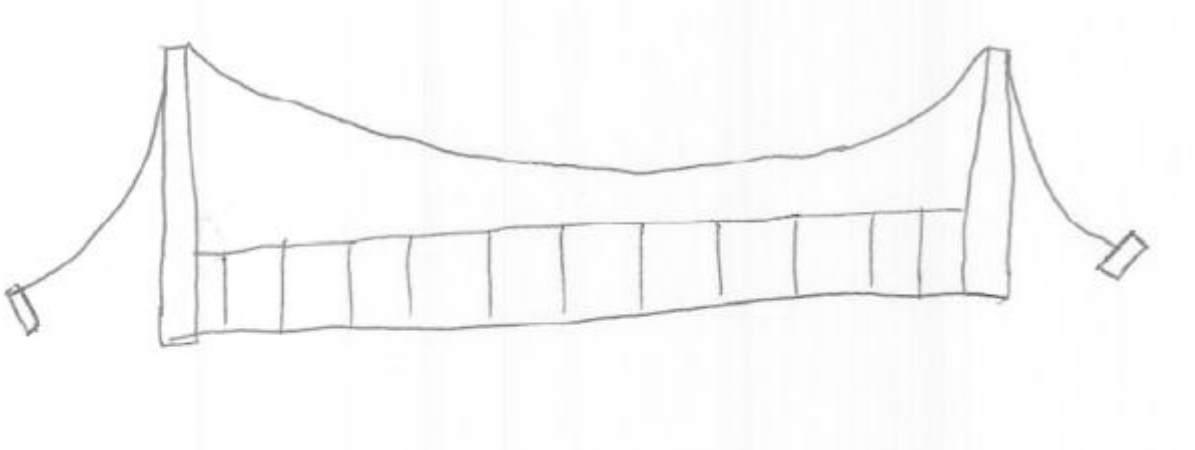

Figure 23 - Suspension Bridge

3.2.3 Weighing Importance of Design Factors

The pairwise reasoning and the decision matrix used to reach our final design concept selection are explained in Appendix E. The results of these processes indicate that four of our preliminary designs fall within ten percent of the highest design value. The highest value is Suspension Bridge at 57.5. This means that any score of at least 51.75 falls within the ten percent tolerance range. The other three designs are Wooden Truss Bridge (56), Pull Car (54.5), and Steel Truss Bridge (53). At this point we approached Sergio Llubere, the La Marta representative, with our four possible designs. He said that La Marta already has a wooden suspension bridge and would like some other mode of transport to make the historical area all-person accessible. After some discussion, we decided the sponsor wanted the Pull Car Design.

3.3 Cable Car Design Description

The final design consists of a passenger car suspended on steel cables that extend between two platforms on opposite sides of the river. The cables are anchored at each end in such a way that the cableway is level. A platform is located at each end of the cable, to facilitate loading and unloading of passengers and to compensate for differences in ground height at either side of the river. The design of the platform and the cableway anchor will be explained further in a later section. Figure 24 illustrates the placement of the cableways and platforms.

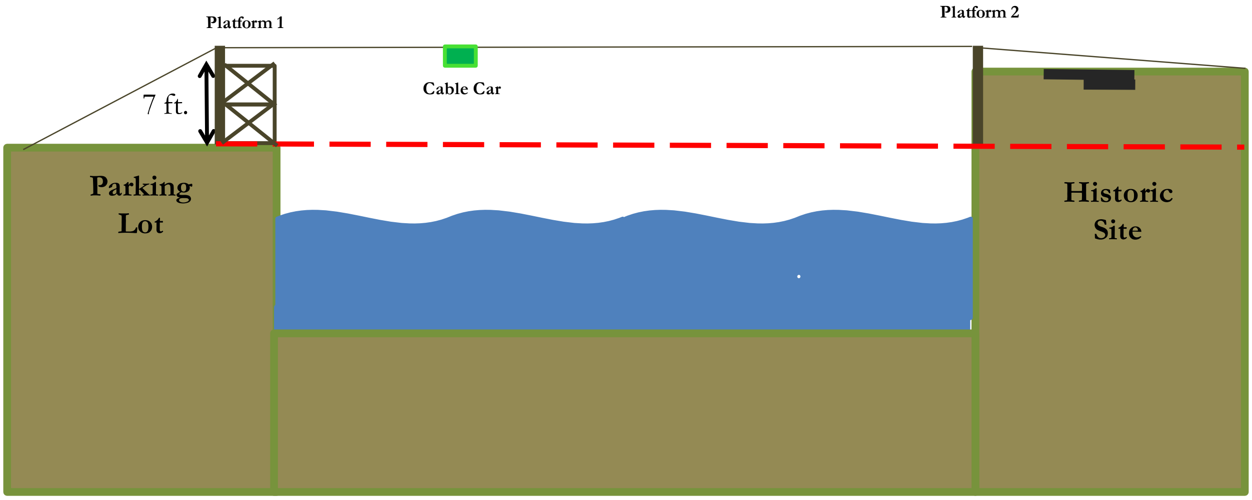

Figure 24 - Platform and Cable Placement

The tram-like car is built from segments of steel square tubing. Figure 25 shows a segment of steel square tubing. The dimensions of the car were chosen based on safety and accessibility. As stated in the background chapter, the minimum passing space for a wheelchair is 36 inches, thus the chosen width of the car was 40 inches to allow clearance for railings. The length of the car was chosen to be 78 inches. This was chosen by placing a rectangle of tape on the floor 40 inches wide and 78 inches long. The members of the project team then placed chairs within the rectangle and assessed the chosen dimensions for comfort. The spacing of the frame members were chosen based on the existing cable car at La Marta.

The material chosen for the car is ASTM A36 structural carbon steel square tubing. Steel was chosen over other metals due to its strength and resistivity to corrosion caused by moisture. A36 steel was chosen based on cost, application, and availability. Costa Rica imports steel products from five major companies. Based on quotations from these five companies, A36 is the least expensive that meets our strength, weight, and environmental requirements. A36, unlike some steels, is able to be welded using fillet welds. The chemical composition of this steel is indicated in Table 5 below.

Table 5 - Chemical Composition of ASTM A36 Carbon Steel[75]

Chemical	Percent
Carbon	0.26
Phosphorous	0.04
Sulfur	0.05
Copper	0.20

The frame of the car will be welded together and features a hinged gate on either end for loading and unloading at each platform. Each gate will also be equipped with a hinged, flip-

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[75] "Properties of Steel." Online Steel Suppliers. 28 Mar. 2009 <http://www.suppliersonline.com/propertypages/A36A.asp>.

down seat, fastened by ball-lock pins. The seats are hinged to allow the user to operate the car either from a wheel chair, or from the seat. Figures 26 – 27 illustrate the car, the gate, and the seat assembly. Figure 28 shows the ball-lock setup that allows the seat to either lock in place, or flip down.

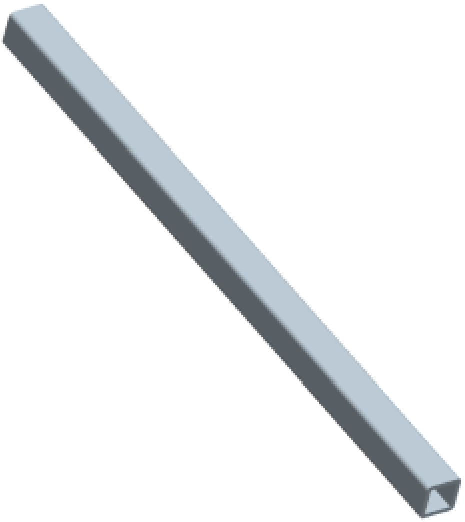

Figure 25 - Steel Square Tubing

Figure 26 - Zip Car

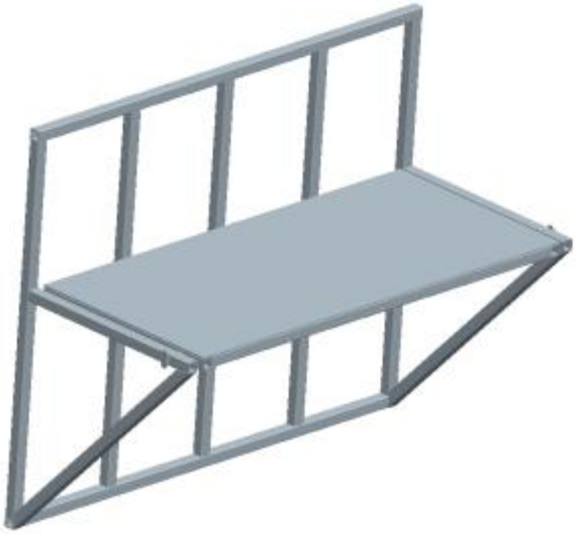

Figure 27 - Gate Assembly

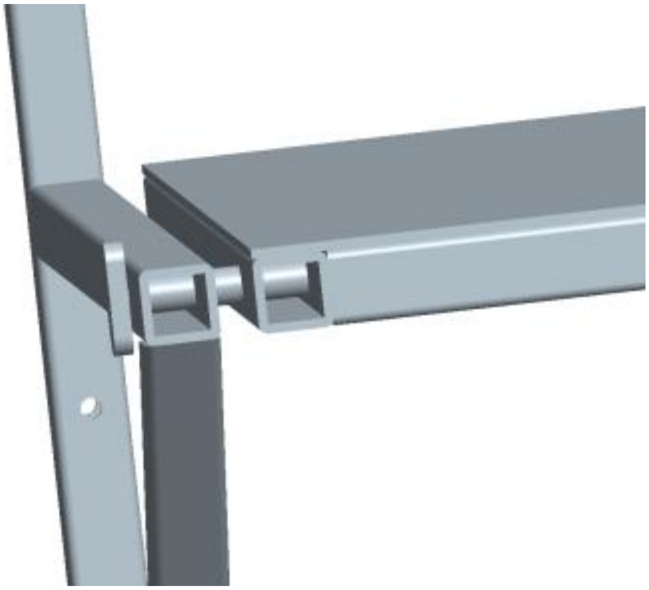

Figure 28 - Seat Assembly

3.3.1 Bearings

The car rolls along the steel wire rope cableway via mast-guide roller bearings shown below in Figures 29 and 30. The bearing selected is a mast guide roller bearing. A mast guide bearing is grooved to accept a rope, or in this case, steel wire rope. The steel wire rope fits into the groove of the mast-guide bearing and allows the car to roll along the cableway with minimal frictional resistance. As shown, there are four bearings located at each corner of the car. Each corner is equipped with an extra pair of bearings for added safety. The lower bearings are placed directly below the top bearings to prevent the steel wire rope from exiting the mast-guide channel.

Figure 29 - Mast Guide Bearing

Figure 30 - Mast Guide Bearing Assembly

3.3.2 Floor

The floor of the car is perforated to reduce weight while maintaining strength. The floor of the car also features a slot to accommodate excess fabric rope slack. Figure 31 shows the floor surface sheet. The walls of the car are covered in plastic coated chain link fencing to comply with the ADA standard for railing spacing. Figure 32 shows an exploded view of the zip car assembly.

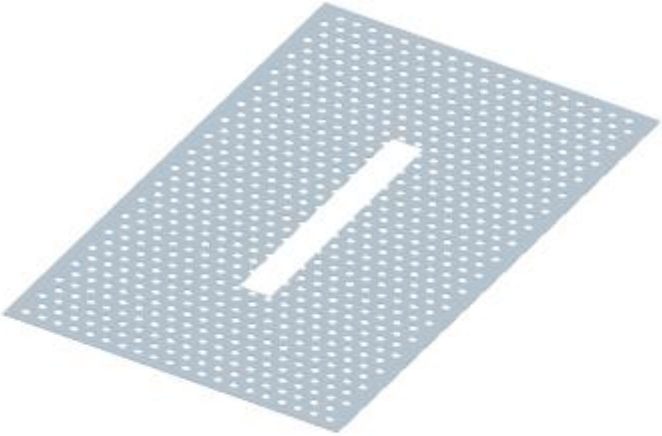

Figure 31 - Perforated Floor Surface

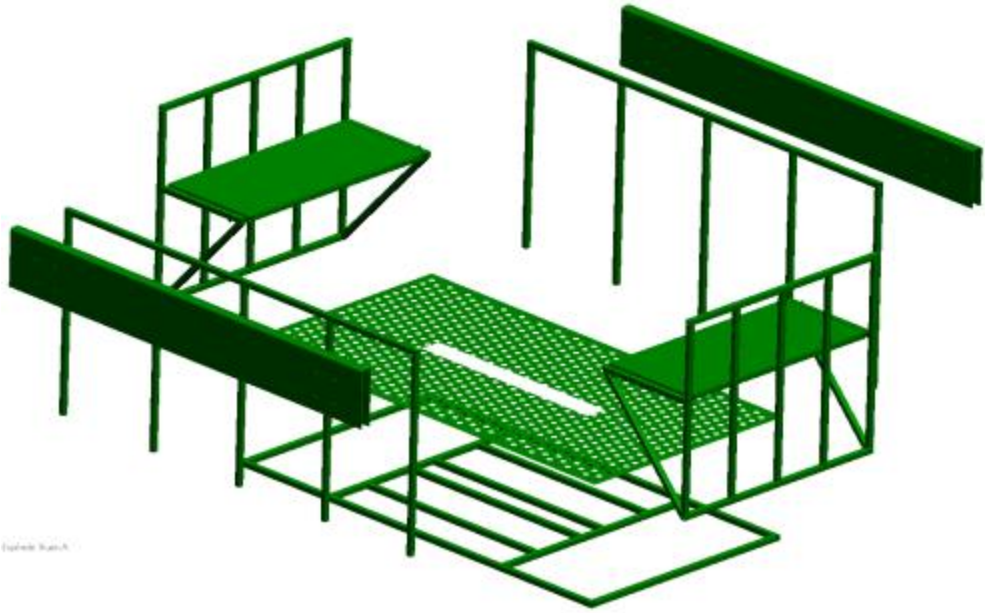

Figure 32 - Zip Car Exploded View

3.3.3 Wheelchair Tiedowns

Our design incorporates the use of wheelchair tiedowns. Wheelchair tiedowns secure the wheelchair to our car design limiting the movement of the chair. Without wheelchair tiedowns, when a person in a wheelchair pulls on the rope to propel the car the wheelchair moves also. We chose ratcheting tiedowns for their low cost, light weight and ease of use. Figure 33 shows an example of wheelchair tiedowns.

Figure 33 - Wheelchair Tiedowns[76]

The hooks on each end of the tiedown attach to the floor of the car. The tiedown strap of the tiedown is threaded through each spoke of the wheelchair in order to prevent the wheelchair from rolling. The wheelchair tiedowns are ratcheting straps which can be used to tighten the tiedown strap to an appropriate tautness.

3.3.4 Bearing Covers

We designed bearing covers to prevent injury due to pinch points. The bearing covers are made of steel and cover the bearings for the entire length of the car.

3.4 Load Calculations

Prior to analyzing the safety of the design, it was necessary to determine the maximum weight of the design. This is the sum of the weight of the car, and the maximum weight of the

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[76] "Ratchet Tie Downs, Ratchet Straps, Ratchet Cargo control lashing - China Manufacturer, Supplier." Ratchet Tie Downs. 25 Feb. 2009 <http://www.liftingrigging.com/Ratchet-Tie-Down/Ratchet-Tie-Down-European-market.htm>.

passengers allowed, including wheelchairs. The weight of the car is equal to 1334 N, determined using Pro/Engineer by PTC. The maximum capacity of the car will be posted as 200 kg, or 1962 N. Additionally, our calculations account for two manual wheel chairs, contributing a total of 222 N. This is based on the American Disabilities Act average weight of a manual wheelchair, 15-25 lbs. For our purposes the higher figure value of 25 lbs was used. By adding the weight of the car, passengers, and wheelchairs, we yield a total weight of 3518 N.

3.5 Refinement and Analysis

3.5.1 Steel Wire Rope

Selection

The cables used to suspend the car over the river are called steel wire rope. Steel wire rope was chosen based on its durability, availability, cost, and ability to withstand moisture. The cost of steel wire rope is significantly less than the alternative of building a rigid track across the river.

The type of steel wire rope chosen is 7 X 19 galvanized. This is the most common type of steel wire rope used in zip-line type applications. It is made of seven large strands of steel, and each large strand is made of 19 smaller strands. Figure 34 illustrates the makeup of 7 X 19 steel wire rope.

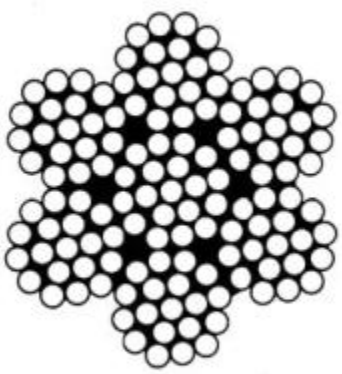

Figure 34 - 7 X 19 Steel Wire Rope[77]

This type of steel wire rope is sold by a leading manufacturer, Loos and Company Steel Wire. Their steel wire rope conforms to military standard MIL-DTL-83420 – wire rope

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[77] Stainless Steel Marine Fixings & Fasteners. 30 Mar. 2009 <http://www.stainlessmarinefixings.com>.

specifications. It is sold in diameters ranging from 1/16 to 1 inch. The selection of steel wire rope diameter is based on its weight per unit length, and coinciding minimum break strength. Table 6 shows three diameter choices, with their corresponding weights and break strengths.

Table 6 - Steel Wire Rope Options[78]

Weight (N/m)	Minimum Break Strength (N)	Diameter (in)
0.423	8,896	1/8
1.605	31,138	1/4
3.546	62,275	3/8

The diameter selected was chosen based on the maximum load exerted on the rope. This load, calculated in the ergonomics section, is 3,518 N. Based on this value, and a factor of safety of three, the 3/8 inch diameter steel wire rope was selected.

Stretch Analysis

In order to determine the magnitude of force required to pull the car along the cableway, it is necessary to calculate the distance the steel wire rope will stretch under the load of the car at full capacity. The first step to completing this calculation is to determine the magnitude of force applied to the steel wire rope, causing it to stretch. It is important to note that this calculation will be a worst-case scenario situation. This means that the amount of stretch will be calculated for the case of the cable car being at the very end of its cycle across the river, thus causing maximum stretch, and the corresponding maximum force needed to pull the car. Note that the platform is

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[78] Exerfelx Pro Fitness cable is Black Custom Colors to match your equipment are available. 3 Apr. 2009 <http://www.loosandcompany.com/loos/pomfretcatalog.pdf>. pg. 32

placed such that the cable car completes its traversal 2.13m from the cable support structure. Figure 35 shows the free body diagram for this situation.

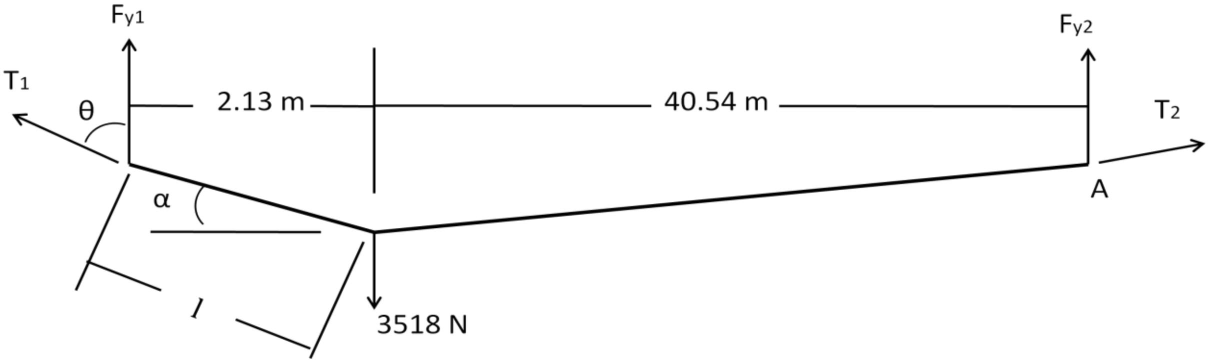

Figure 35 - Cable Stretch Free Body Diagram

It is first necessary to identify the two equations needed to determine the amount of stretch in the cable, as well as its resulting angle alpha. The first equation is based on the geometry of the system, used to calculate the stretched length, l, of the short segment.

$$l_a(\alpha) := \frac{l_0}{\cos(\alpha)}$$

where l_a represents the stretched length as a function of the angle alpha, and l_0 represents the original length (2.13 m). The second equation used is the cable stretch calculation.[79]

$$E(\alpha) := \left(\frac{T_{.1}(\alpha)}{D^2}\right)\cdot C$$

---

[79] Exerfelx, 2001

Where E represents the cable's percent change in length as a function of angle alpha, T_1 represents the tension in the cable, D represents the diameter of the cable, and G is a factor given by the cable manufacturer based on the specifications of the steel wire rope. The values of these variables are as follows:

$$D := .009525m$$

$$G := 0.000014\frac{m^2}{N}$$

The tension, T_1 can be expressed in terms of the vertical component of force at the left contact, and as a function f angle alpha:

$$T_1(\alpha) := \frac{F_{y1}}{\sin(\alpha)}$$

F_{y1} is calculated by taking a moment around point A, this gives the equation:

$$F_{y1} := \frac{|l_1| \cdot |F_w|}{|l_1 + l_0|}$$

Thus,

$$F_{y1} = 3.342 \times 10^3 N$$

Next, the equation for E can be expressed in terms of the original length, l_o and the new length, by realizing that

$$E := \frac{l_0 + l_b(\alpha)}{l_0}$$

Thus,

$$l_b(\alpha) := l_0 \cdot (E(\alpha) - 1)$$

It is important to note that l_a and l_b are both equations for l, the final stretched length. It is necessary to use two different equations for l because the next step is to set them equal to one another and solve for the angle alpha.

$$l_a(\alpha) = l_b(\alpha)$$

The two equations are plotted (Figure 36) to find the intersection of the lines, thus finding the resulting angle α.

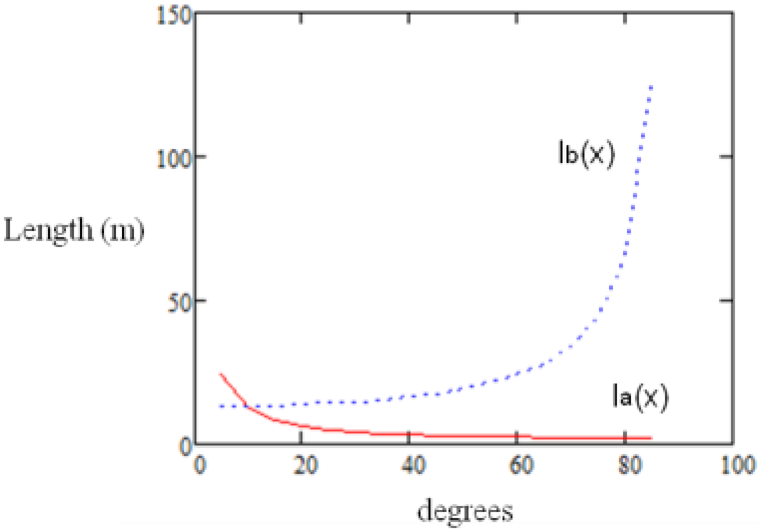

Figure 36 - Length (meters) vs. Angle (degrees)

The resulting α is:

$$\alpha = 9.243deg$$

This represents the maximum, worst case steepest incline of the cable that the user will have to overcome to pull the car along the cable, at the very end of the cycle across the river. The resulting maximum cable tension caused by this angle is:

$$T_1(\alpha) = 3.386\times 10^3 \, N$$

3.5.2 Ergonomics

The car being designed for this project will be operated by the individual traveling in the car across the river. The person operating the car will be required to pull a fabric rope that will provide the force needed to propel the car's bearings along the surface of the steel wire rope. This requires our team to first calculate the force required to move the car, and then to compare that value with published ergonomic data. The force required to pull the car is based on the free body diagram shown in Figure 37.

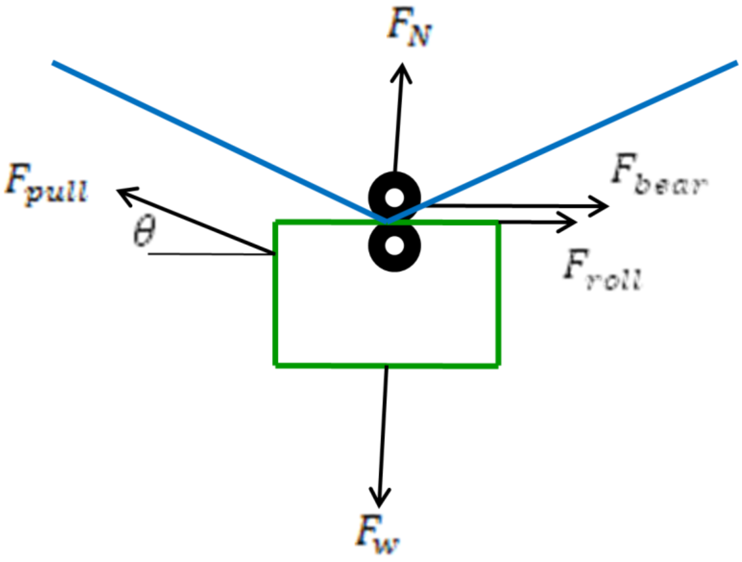

Figure 37 - Pulling Force Free Body Diagram

As shown, the force required to pull the car is resisted by two frictional forces. The first force caused by friction is rolling friction. The two surfaces making contact with one another are the steel bearing outer surface, and the steel wire rope. The second friction force is sliding friction within the bearing, at the axle.

In order to calculate the pulling force, each of the forces shown in Figure 37 must be calculated, and then summed in their respective x and y directions. Once all forces are known, the system is solved for the unknown pulling force, F_{pull}.

The first force to determine is the weight. This refers to the maximum possible capacity of the car plus the weight of the car. This magnitude was calculated and explained in the Load Calculation section.

$$F_W := 3518N$$

F_N represents the normal force, which in this case is equivalent to the weight, $F_{W.}$

$$F_N := F_W$$

The next force calculated is the force due to rolling friction, F_{roll}. This is done by first calculating to coefficient of rolling friction, and multiplying it by the normal force. The coefficient of rolling friction is calculated using the following equation from Mark's Standard Handbook for Mechanical Engineers[80].

$$\mu_{roll} := \frac{P}{F_W}$$

where μ_{roll} is the coefficient of rolling friction, F_W is the load, and P is the frictional resistance of the rolling cylinder.[81]Frictional resistance, P, is calculated using the following equation:

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[80] Avallone, Eugene A., Theodore Baumeister, and Ali Sadegh. Marks' Standard Handbook for Mechanical Engineers 11th Edition. New York: McGraw-Hill Professional, 2006.

[81] Avallone, Eugene A., Theodore Baumeister, and Ali Sadegh. Marks' Standard Handbook for Mechanical Engineers 11th Edition. New York: McGraw-Hill Professional, 2006. pg. 3-28

$$P := \left(\frac{k}{r_{bear}}\right) \cdot F_W$$

Where r_{bear} is the radius of the bearing and k is an experimental unit based on the two surfaces in contact. The k value given for steel on steel, measured in meters, is 5.08 x 10^{-5}. This gives:

$$P = 3.518N$$

We are now able to calculate the coefficient of rolling friction, as well as the force due to rolling friction:

$$\mu_{roll} = 1 \times 10^{-3}$$

$$F_{roll} := \mu_{roll} \cdot F_N$$

$$F_{roll} = 3.518N$$

Next, we calculate the force due to sliding friction in the bearing, F_{bear}. This is done by first calculating the coefficient of sliding friction, and multiplying it by the normal force.

$$F_{bear} := \mu_{bear} \cdot F_N$$

The coefficient of sliding friction was chosen based on data from a large bearing manufacturer. The type of bearing chosen is a deep groove ball bearing. NTN bearing corporation publishes technical articles that aid engineers in the bearing selection process. One of these articles lists the ranges of friction coefficients for the various types of ball bearings they sell. The coefficients for deep groove ball bearings range from 1.0 x 10^{-3} to 1.5 x 10^{-3}. For our purposes the higher value of 1.5 x 10^{-3} was chosen.[82]

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[82] NTN BEARING CORPORATION OF AMERICA. 3 Feb. 2009 <http://www.ntnamerica.com/pdf/2200/frictemp.pdf>.

$$\mu_{bear} := 1.5\,10^{-3}$$

$$F_{bear} := \mu_{bear} \cdot F_{N}$$

$$F_{bear} = 5.277N$$

Now that the values of F_{bear} and F_{roll} are known, we are able to calculate the force required to pull the car, F_{pull}. This is done by first summing the forces in the x-direction:

$$\sum F_x = F_{pullx} - F_{bear} - F_{roll} = 0$$

$$F_{pullx} := F_{bear} + F_{rol}$$

$$F_{pullx} = 8.795N$$

With F_{pullx} known we are able to calculate the total pulling force required using the geometry of the system. As shown previously in Figure 37, the angle between F_{pull} and the horizontal is denoted θ. This represents the worst case situation for angle of incline caused by cable stretch.

$$\theta := 5.20deg$$

The magnitude of F_{pull} is then calculated using the geometry shown in Figure 38 and basic trigonometry.

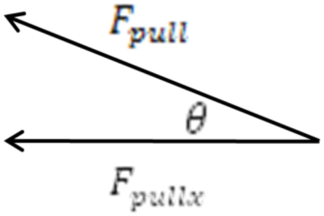

Figure 38 - Pull Force Trigonometry

$$F_{pull} := \frac{F_{pullx}}{\cos(\theta)}$$

$$F_{pull} = 8.831N$$

The resulting force needed to pull the car is 8.831 N or 1.985 lbs. This represents the maximum force required to pull the car at any point throughout the cycle.

It is now necessary to determine the number of pulls needed for the user to travel from one platform to the other. The total number of pulls needed to complete the cycle is determined by estimating the distance achieved by one pull, and dividing the total cable span by that estimate. This estimate was determined by using Ergonomics Design Handbook by Karl Kroemer, which states that the overall horizontal reach envelope of the hands while seated is about .50 m.[83]

The total span of the cableway is 42.672 m. Thus, the resulting number of pulls needed to complete a cycle is 93.3. To further ensure ease of operation an estimate of 100 pulls will be used. Given the maximum force of one pull, and the number of pulls, we must now compare to published ergonomic data to ensure that our design will be easily operated by the user.

The type of grasp the user will undergo is called a power grasp. A power grasp is defined when the total inner hand surface is grasping a cylindrical object which protrudes through both sides of the hand.[84]

The ergonomic data chosen will be that of an average adult man in the fifth percentile. The data for the arm strengths exerted by this class were also taken from Kroemer's handbook. The force values vary based on the angle of the user's elbow, and are shown below in Table 7.

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[83] Kroemer, K. H. E. Ergonomics how to design for ease and efficiency. Englewood Cliffs, NJ: Prentice Hall, 1994.
[84] Kroemer et al, 1994

Table 7 - Sitting Arm Strength[85]

Degree of elbow flexation (deg)	Pull (N)	
	Left Arm	Right Arm
180	222	231
150	187	249
120	151	187
90	142	165
60	116	107

From these data we conclude that the 5th percentile adult male is capable of pulling a range of 107-249 N. To ensure that the user is able to make use of their full arm span, we will use the 107 N value, which coincides with a 60 degree elbow angle. At this angle the rope will nearly be in contact with the user's chest, forcing him/her to extend their arm, and begin a new pull. This force is over 13 times greater than the maximum force required to pull the car along the cableway.

3.5.3 Weld Analysis

It is necessary to assess the strength of the car's welds to ensure the safety its users. The statically indeterminate system that the welds create requires a finite element analysis and the project team was unable to perform this analysis due to time restrictions. An elementary calculation was done to suggest the type of welds and weld material. However, it is

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[85] Kroemer et al, 1994

recommended that the manufacturer seeks the advice of a professional engineer prior to welding the car.

3.6 Safety

3.6.1 Factor of Safety

We chose to use a factor of safety of 3 in our design. This is a typical factor of safety “for less tried materials or for brittle materials under average conditions of environment, load and stress[86].” The steel we are using has not been specifically tested by us, but there is data available, so we categorized it at a less tried material to provide an extra margin of safety.

A factor of safety is the ratio between the design load and the maximum applied load. For the cable, the maximum expected load is 3518 N, as explained in the ergonomics section. The factor of safety is:

$$FoS = \frac{F_{Design}}{F_{MaxApplied}}$$

$$F_{Design} = FoS * F_{MaxApplied}$$

$$F_{Design} = 3 * 3518\, N$$

$$F_{Design} = 10554\, N$$

Thus our design load for the cable is 10554 N. This means that our calculations will use a force of 10554 N to ensure safety.

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[86] "Factors of Safety." RoyMech Index page. 25 Feb. 2009 <http://www.roymech.co.uk/Useful_Tables/ARM/Safety_Factors.html>.

3.7 Cable Car Platforms and Anchoring

Due to a seven foot change in elevation from one side of the Gato River to the other, it was necessary to build loading and unloading platforms for the cable car. The heights of the platforms were strategically chosen to make each of the platforms level with one another, thus creating a horizontal cableway. The first step in designing the platforms was to survey the area. This includes the end of the service road and the area between the canal, concrete slab and the existing bridge structure (Figure 39). To survey this area we used the level site, wooden rod to maintain a consistent height, and a measuring rod. Since there was no control point in the area we assigned one with an arbitrary elevation of 100 ft above sea level. The first control point (CP1) was located in the middle of the parking lot, which would be the site of Platform 1. To determine the next control point we established a turning point ½ of the distance between control point 2 (CP 2) in order to minimize the error reading. CP 2 was located at the furthest point on the plateau before the steep decent to the river, and in line with the location of Platform 2. CP 3 was taken in the ruins area near the canal. CP 4 was taken at the existing structure of the destroyed suspension bridge. CP 5 was taken on the large rock by the side of the river at the location of the other existing structure.

Two points of interest (POI) were taken to learn the elevation of the potential area of Platform 2 (POI 1) and to check the clearance needed for the large rock (POI 2). We used the known relative elevation of CP 3 to determine the elevation POI 1. Then we used the known elevation of CP 2 to determine the elevation of POI 2. These elevations determine the necessary height considerations in order to create a horizontal cable car.

Along with the elevation readings we measured the distance of the river using the 100 ft tape measure. This measurement was imperative to assign a length of cable needed and the distance between Platform 1 and Platform 2.

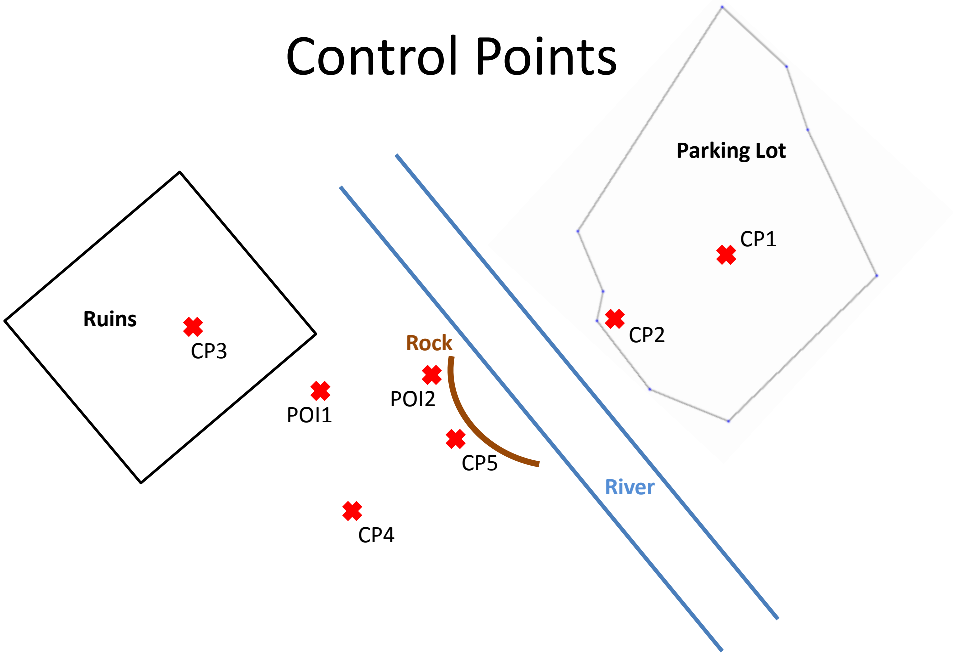

Figure 39 - Control Points

3.7.1 Platform 1 Foundation

To determine the foundation design for Platform 1 we used the Terzaghi formula to calculate the foundation area needed. We first had to investigate the soil characteristics in the potential area. We discovered by using previous techniques, that the soil at the end of the service road was sand consistently throughout. We also assume that the sandy material is completely saturated because of the proximity to the Rio Gato and the annual rainfall amount exceeding 140 inch/yr. This information gives our team the c[87] value as well as the γ[88].

$$c = 0$$

$$\gamma = 130\, lb/ft^3$$

For a sandy soil c is negligible.

The soil type also led us to the determination of the “N” values. These values will take into account internal shearing of the soil for the footing type. For a smooth concrete the equation for the angle of shearing of dense sand is as follows:

$$0.70\Phi_f$$

For dense sand:

$$\Phi_f = 42°$$

Thus Φ_f for dense sand[89]:

$$\Phi_f = 29.4° \approx 30°$$

We now use $\Phi_f = 30°$[90] to find:

$$N_c = 30.10$$

$$N_q = 18.40$$

$$N_\gamma = 18.08$$

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[87] Myslivec, Alois. Bearing capacity of building foundations. Amsterdam: Elsevier Scientific Pub. Co., distributed in the USA and Canada by Elsevier/North-Holland, 1978.

[88] Myslivec, 1978

[89] Myslivec, 1978

[90] Myslivec, 1978

Next we need to find the maximum load q_m that the platform will support. To do that we analyzed the particular column that would support the most load. This column will be required to support a maximum weight of 5800 lbs. This is a combination of the live load and dead load. The live load includes 5 individuals, 3 wheel chairs and 1 cable car. The dead load includes the wood plank, wood column, and concrete. We decided that the footings will penetrate the earth two feet (D) and rise 6 inches above the soil. This will prevent the wood column from making contact with the soil preventing rot.

To solve for q we used the following equation because the soil in this location is completely saturated.[91]

$$q = \gamma D + p$$

$$p = 0$$

In this instance $p = 0$ because the footing protrudes through the surface of the ground. With all of these variables accounted for, the Terzaghi Formula will provide the area required.

$$B = \frac{q_m - \left(\gamma \times D \times N_q\right) - cN_c}{.5 \times \gamma \times N_\gamma}$$

$$B = 0.86\, ft^2$$

This column will require a surface area of at least 0.86 ft^2.

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[91] Myslivec, 1978

3.7.2 Platform 2 Foundation

We used the same method to determine the appropriate size for Platform 2. However, the soil makeup in the location of Platform two is clay and the entire structure will be made of concrete.

This information gives our team the c value as well as the γ.

$$c = 25$$ [92]

$$\gamma = 127\ lb/ft^3$$ [93]

The soil type also led us to the determination of the “N” values. These values will take into account internal shearing of the soil for the footing type. For a smooth concrete the equation for the angle of shearing of dense sand is as follows:

$$0.70\Phi_f$$

For clay:

$$\Phi_f = 18 \approx 20$$

Thus Φ_f for clay[94]:

$$\Phi_f = 20°$$

We now use $\Phi_f = 0°$ and to find[95]:

$$N_c = 3.54$$

$$N_q = 6.40$$

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[92] Myslivec, 1978
[93] Myslivec, 1978
[94] Myslivec, 1978
[95] Myslivec, 1978

$$N_\gamma = 14.83$$

Next we need to find the maximum load $q_m$that the platform will support. The maximum weight includes the dead load (concrete) which equals 6000 lbs and the live load (5 people, 3 wheel chairs) which equals 2355 lbs. Using a factor of safety of 3 we found that:

$$q_m = 25{,}065\ lbs$$

To solve for q we used the following equation because the soil in this location is completely saturated.[96] The concrete slab will also sit on the surface of the soil.

$$q = \gamma D + p$$

$$p = 0$$

$$D = 0$$

With all of these variables accounted for, the Terzaghi Formula will provide the area required.

$$B = \frac{q_m - (\gamma \times D \times N_q) - cN_c}{.5 \times \gamma \times N_\gamma}$$

$$B = 27\ ft^2$$

Using a concrete slab that is 4 ft X 15 ft will provide adequate surface area to support this weight. The proposed concrete slab will have 60 ft^2 of surface area.

3.7.3 Platform 1 Structure

To determine the maximum force on a particular beam we located the beam that would experience the highest load. This beam supports a maximum dead load of 200 lbs and a maximum live load of 1230 lbs. Use a factor of safety of 3 for both the dead load and the live

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[96] Myslivec, 1978

load. These loads are expressed in Figure 40. The following solution will determine the maximum force for any of the 32 columns. All of the columns will be designed to carry this load.

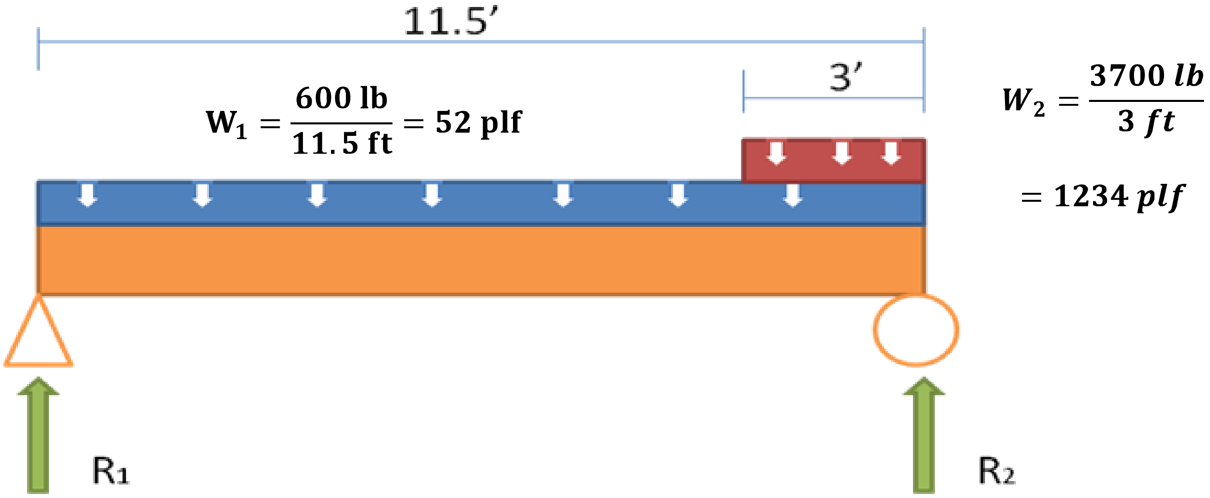


Figure 40 - Platform Free Body Diagram

To solve for R_2 take the moment around R_1.

$$\Sigma M_{R_1} = 0 = 600\ lbs\left(\frac{11.5'}{2}\right) + (3700\text{ lbs})(10') - R_2(11.5)$$

$$R_2 = 3518\ lbs$$

Sum the forces in the y direction to determine R_1.

$$\Sigma F_y = 0 = 600lbs + 3700lbs - R_1 - 3518lbs$$

$$R_1 = 782\ lbs$$

The force in the x direction is negligible on any ramp section and $x = 0$ for a horizontal section.

Column Design for Minimum Eccentricity

Now that we have determined the maximum load on a particular column we can check to see whether our material selection is appropriate for this design. Try 4 X 4 Central American Pine (Same properties as Southern Pine) (No. 2).

$$D + L = P_{TL}$$

$$P_{TL} = 3518\, lbs$$

For this problem the following load duration factor will apply:

$$C_D = 1.15$$

This design has the following design values:

$$F_c = 825\, psi$$

$$F_b = 1850\, psi$$

$$E_{x\,min} = 620{,}000$$

Section properties:

$$b = 3.5\, in$$

$$d = 3.5\, in$$

$$A = 12.25\, in^2$$

$$S_x = 7.146\, in^3$$

$$S_y = 7.146\, in^3$$

Axial:

$$f_c = \frac{P}{A} = \frac{3518\, lbs}{12.25\, in^2} = 288\, psi$$

$$\left(\frac{l_e}{d}\right)_x = \frac{7.15\, ft \times 12\, in/ft}{3.5\, in} = 24.5$$

$$\left(\frac{l_e}{d}\right)_y = \frac{7.15\ \ ft \times 12\, in/ft}{3.5\, in} = 24.5$$

The larger slenderness ratio will be the critical axis.

$$E'_{min} = E_{min}(C_M)(C_t) = 620{,}000(1.0)(1.0) = 620{,}000\, psi$$

For visually graded sawn lumber:

$$c = 0.8$$

$$F_{cE} = \frac{0.822E'_{min}}{\left[\left(\frac{l_e}{d}\right)_{max}\right]^2} = \frac{0.822(620{,}000)}{24.5^2} = 849\, psi$$

Since this column is a trial size it falls into the B&S size category. Accordingly, the size factor for compression parallel to the grain is:

$$F_c^* = F_c(C_D)(C_M)(C_t)(C_F)$$

$$F_c^* = 825(1.15)(1.0)(1.0)(1.0) = 949\, psi$$

$$\frac{F_{cE}}{F_c^*} = \frac{849}{949} = 0.895$$

$$\frac{1 + \frac{F_{cE}}{F_c^*}}{2c} = \frac{1 + 0.895}{2(0.8)} = 1.18$$

$$C_P = \frac{1 + \frac{F_{cE}}{F_c^*}}{2c} - \sqrt{\left(\left(\frac{1 + \frac{F_{cE}}{F_c^*}}{2c}\right)^2 - \frac{1 + \frac{F_{cE}}{F_c^*}}{c}\right)}$$

$$C_P = 1.18 - \sqrt{(1.18^2) - 1.12} = 0.658$$

$$F'_c = F_c(C_D)(C_M)(C_t)(C_P)$$

$$F_c' = 825(1.15)(1.0)(1.0)(0.658)$$

$$F_c' = 625\,psi > 288\,psi \qquad OK$$

Alternatively, the axial stress ratio should be less than 1.0

$$\frac{f_c}{F_c'} = \frac{288}{625} = 0.46 < 1.0$$

The member is the appropriate size for the axial load.

Eccentric Load about Strong Axis

Axial: The axial stress is unchanged for this scenario.

Bending: The only bending stress is caused by the eccentric column force.

$$e_x = 0.1d = 0.1(3.5) = 0.35\,in$$

$$f_{bx} = \frac{Pe_x}{S_x} = f_c\frac{6e_x}{d_x} = 288(.6) = 173\,psi$$

$$C_F = \left(\frac{12}{d}\right)^{\frac{1}{9}} = 1.15$$

Lateral Stability

To prevent lateral torsional buckling determine l_e:

$$l_e = (7.15\,ft \times 12\,in/ft) - 3 \times 3.5 = 75.3\,in$$

$$R_B = \sqrt{\frac{l_e d}{b^2}} = 21.5$$

$$F_{bE} = \frac{1.20E'_{y\,min}}{R_B^2} = \frac{1.20(620{,}000)}{21.5^2} = 1687\,psi$$

$$F_b^* = F_b(C_D)(C_M)(C_t)(C_F)$$

$$F_b^* = 1850(1.15)(1.0)(1.0)(1.15) = 2447\,psi$$

$$\frac{F_{bE}}{F_b^*} = \frac{1687}{2447} = 0.689$$

$$\frac{1 + \frac{F_{bE}}{F_b^*}}{1.9} = 0.889$$

$$C_L = \frac{1 + \frac{F_{bE}}{F_b^*}}{1.9} - \sqrt{\left(\left(\frac{1 + \frac{F_{bE}}{F_b^*}}{1.9}\right)^2 - \frac{\frac{F_{bE}}{F_b^*}}{0.95}\right)}$$

$$C_L = 0.889 - \sqrt{\left((0.889)^2 - \frac{0.689}{0.95}\right)} = 0.634$$

$$F'_{bx} = F_b C_D C_M C_t C_l C_F C_r$$

$$F'_{bx} = 1850(1.15)(1.0)(1.0)(0.634)(1.0)(1.0)$$

$$F'_{bx} = 1368\, psi \ > 173\, psi \qquad OK$$

Now we use the amplification factor for eccentric bending stress, which was found earlier.

$$\left(\frac{l_e}{d}\right)_x = \frac{7.15\, ft \times 12\, in/ft}{3.5\, in} = 24.5$$

Also the Euler elastic buckling stress:

$$F_{cEx} = F_{cE} = 849\, psi$$

$$\frac{f_c}{F_{cEx}} = \frac{288}{849} = 0.339$$

$$(Amp\ Fac)_{ecc} = 1 + 0.234\left(\frac{f_c}{F_{cEx}}\right) = 1 + 0.234(0.339) = 1.08$$

$$Amp\ Fac = \frac{1}{1 - \frac{f_c}{F_{cEx}}} = \frac{1}{1 - \frac{288}{849}} = 1.51$$

$$\left(\frac{f_c}{F_c'}\right)^2 + \left(\frac{1}{1 - f_c/F_{cEx}}\right)\frac{f_b + f_c(6e_x/d_x)\left[1 + 0.234\left(\frac{f_c}{F_{cEx}}\right)\right]}{F_{bx}'}$$

$$= (0.212) + 1.51\left[\frac{0 + 172.8(0.0793)}{173}\right]$$

$$= 0.332 < 1.0 \quad OK$$

Eccentric Load about Weak Axis

Axial: The axial stress test will remain the same.

Bending: The eccentric column force will be the only bending stress.

$$e_y = 0.1d = 0.1(3.5) = 0.35\, in < 1.0\, in$$

$$\therefore\, e_y = 1.0\, in$$

$$Ecc. f_{by} = \frac{Pe_y}{S_y} = f_c\frac{6y}{d_y} = 288\frac{(6)}{(3.5)} = 493\, psi$$

Now we determine the adjusted bending design value for the y axis.

$$F_{by}' = F_b C_D C_M C_t C_F$$

$$= 1850(1.15)(1.0)(1.0)(1.15)$$

$$= 2447\, psi > 493\, psi \qquad OK$$

Combined Stresses

The following equations display the amplification factor for eccentric bending stress:

$$\left(\frac{l_e}{d}\right)_y = 24.5$$

$$F_{cEy} = \frac{0.822E_{min}'}{\left[\left(\frac{l_e}{d}\right)_y\right]^2} = \frac{0.822(620{,}000)}{(24.5)^2} = 850\, psi$$

$$\left(\frac{f_c}{F_c'}\right)^2 + \frac{f_{by} + f_c(\frac{6e_y}{d_y})[1 + 0.234(f_c/F_{cEy})]}{F_{by}'\left[1 - \frac{f_c}{F_{cEy}} - (f_{bx}/F_{cEx})^2\right]}$$

$$(0.212) + \frac{0 + 288(1.71)\left[1 + 0.234\left(\frac{288}{850}\right)\right]}{2447\left[1 - \left(\frac{288}{850}\right) - (0)^2\right]}$$

$$0.540 < 1.0 \quad OK$$

These calculations prove that a 4 X 4 Central American Pine will support the maximum load on the platform.

3.7.4 Platform Hardware

The sections will be connected by 3/4 inch bolts. As shown in Figure X, these bolts will support a maximum proof load of 55,000 psi when using the Grade 2 ¾ inch bolt. A proof load is defined as, "An axial tensile load which the product must withstand without evidence of any permanent set[97]." Use six of these bolts to connect each ramp section to the adjacent section. To connect the platform sections to the columns, use ¾ inch lag bolts. Each connection requires two Grade 2 lag bolts. Then cross brace the columns using the 2 X 6 planks and ¾ inch lag bolts. Using the same bolts will allow UMCA to order in large quantities, which will minimize the cost and simplify repairs.

---

[97] "Bolt Depot - Bolt Grade Markings and Strength Chart." Bolt Depot - Nuts and Bolts, Screws and Fasteners online. 19 Apr. 2009 <http://www.boltdepot.com/fastener-information/Materials-and-Grades/Bolt-Grade-Chart.aspx>.

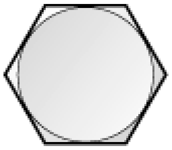
Head Marking	Grade and Material	Nominal Size Range (inches)	Mechanical Properties		
			Proof Load (psi)	Min. Yield Strength (psi)	Min. Tensile Strength (psi)
US Bolts					
 No Markings	**Grade 2** Low or medium carbon steel	1/4 thru 3/4	55,000	57,000	74,000
		Over 3/4 thru 1-1/2	33,000	36,000	60,000

Table 8 Bolt Table[98]

Column/Foundation Connections

The 4 X 4 Central American Pine columns will be connected to the concrete foundations using steels plate connectors. These plate connections will be secured in the concrete using a central bolt. Then the vertical portions of the plate will be secured to the wood columns with carpentry nails, decking screws or similar and bolts (figure 41).

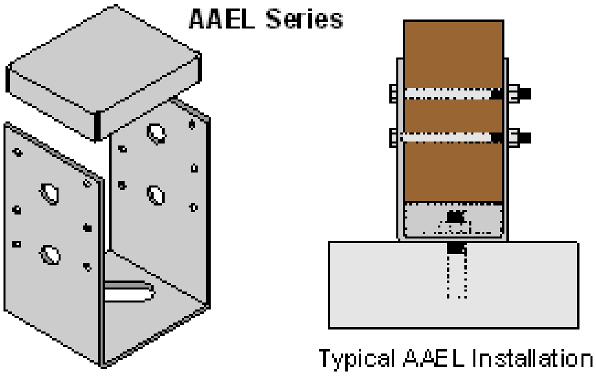


Figure 41 - Steel Plate Connector[99]

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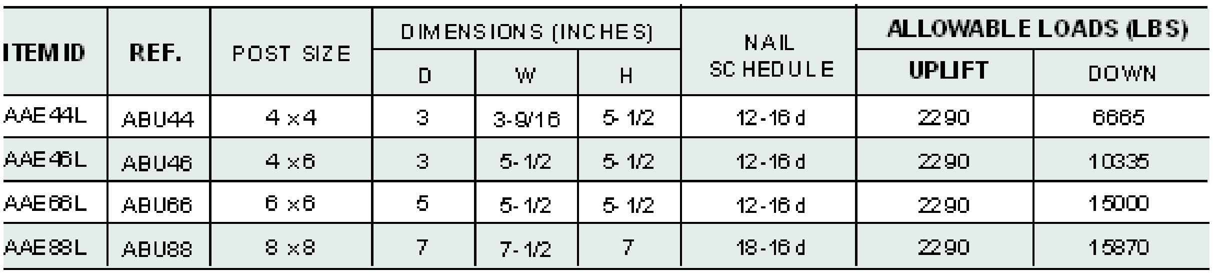
[98] Bolt Depot, 2009

Figure 42 shows that the plate for the 4 X 4 post will support the maximum weight on a particular column.



ITEM ID	REF.	POST SIZE	DIMENSIONS (INCHES)			NAIL SCHEDULE	ALLOWABLE LOADS (LBS)	
			D	W	H		UPLIFT	DOWN
AAE44L	ABU44	4 x 4	3	3-9/16	5-1/2	12-16 d	2290	6665
AAE46L	ABU46	4 x 6	3	5-1/2	5-1/2	12-16 d	2290	10335
AAE66L	ABU66	6 x 6	5	5-1/2	5-1/2	12-16 d	2290	15000
AAE88L	ABU88	8 x 8	7	7-1/2	7	18-16 d	2290	15870

Figure 42 - Steel Plate Connector Allowable Load[100]

3.7.5 Concrete Anchor

To find the required size of each of the four anchors we determined the tension in the cable first. The total tension in the cable, which includes a factor of safety of 3 equals:

$$T_t = 3386\,N * 3 = 10158\text{ N} = 2284\,lbf$$

Using the following free body diagram (Figure 43) we notice that the angle at which the cable connects to the anchor is 45°.

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[99] "Post Anchors." Tamlyn.com. 9 Apr. 2009 <http://www.tamlyn.com/index_files/PostAnchors.htm>.

[100] Post Anchors, 2009

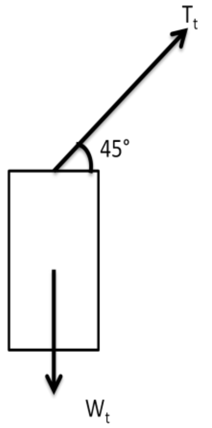

Figure 43 - Anchor Free Body Diagram

Thus:

$$W_t = (\cos(45)) * 2284 \text{ lbf}$$

$$W_t = 1616 \text{ lbf}$$

With the knowledge that concrete has a mass of 150 lb/ft^3 we can interpolate the amount of concrete needed:

$$\frac{1616 \text{ lbf}}{150 \frac{lb}{ft^3}} = 10.77 \text{ ft}^3$$

We recommend using 12 ft^3 so that the anchor dimensions are 2 ft X 2 ft X 3 ft. This will simplify the concrete form process.

3.7.6 Material and Parts Selection

Sustainable Material Selection

The materials chosen for all aspects of this design will be chosen with sustainability in mind. In engineering, the ease of a product to be recycled or reused is based on the variety of materials used in the design. The project team has made every effort to build the product out of similar materials without sacrificing cost, safety, and other design constraints.

Cable and Platform Hardware

It is important to specify the materials of the hardware. Since the majority of the car is fastened by welds, the only hardware necessary is in the gate hinge, the seat hinge, and the seat's ball lock pins. The hinges require bolts, nuts, and washers. The recommended material for this hardware is galvanized steel, due to the high levels of humidity and moisture exposure. The ball lock pins will be sliding in and out of the seat frame holes; therefore a stainless steel ball lock pin will be used.

Anchor

The cable anchor used at each platform is chosen based on strength, resistance to weather, and ability to hold in concrete. The chosen material for this application is ASTM A36 Galvanized steel; in the shape of an I-beam. This is further explained in the Cable Anchoring Section.

Wood

The Material that will be used for platform 1 is pressure treated Central American Pine. It has the same properties as Eastern White Pine, and is plentiful in Costa Rica.

4.0 Sustainable Trail Design Process

We have defined Sustainable Trail design as the process of engineering trails that are safe, aesthetically pleasing, and long lasting; while using environmentally friendly methods and materials. In order to accomplish sustainability in trail design, several core elements were considered. A sustainable trail needed to protect the environment, meet the needs and expectations of the user, and require little maintenance. The Mountaintop Vista at the top of the La Mina trail in La Marta was a location that the UMCA requested we investigate. It is a main attraction at La Marta because of the panoramic view from the pavilion at the top of the ascent.

4.1 Mapping the Area

We mapped the area by using a Garmin GPS device. After GPS coordinates were taken, they were uploaded into Google Earth Pro to show the trail system visually. This information helped the project team and sponsors locate and define the desired locations for improvement.

4.2 Distance and Elevation Measurements

We used a standard 100’ tape to take distance measurements in the field. We used a CST/Berger Sight/Surface Level and a 72” measuring stick to take elevation measurements along the trail (figure 44 to 45). We started from the observation tower on the top of the Mountaintop Ascent Trail. We took elevation readings every 20-25ft depending on the slope of the trail. We also measured the distance between each elevation reading with the 100’ tape measure. This method allows our team to simulate the relative elevation for the Mountaintop Ascent Trail.

Figure 44 - Taking Elevation Measurements

Figure 45 - Taking Elevation Measurements

4.3 Evaluating Existing Soil Composition

An important step in the evaluation of the trails at La Marta was the analysis of the soil composition. Soil samples were taken at five sections of different soil type along the Mountaintop Ascent Trail. We also took soil samples at points of interest at the end of the parking lot and the opposite side of the river. We used the following techniques to test the soil.

The first technique used in the field was the soil permeability test. This test gave us information on how quickly the soil allowed water to drain. We first hammered 6 inch long, 4 inch diameter PVC pipe 1 inch into the soil. We checked for level using a 10 inch level and then added ½" of water into the pipe (figure 46). At the moment of contact we began the stop watch and allowed the water to sink through the soil. When the water completely drained, we stopped the time and compared it to the table in figure 47[101].

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[101] CASFS - Welcome. 15 Feb. 2009 <http://casfs.ucsc.edu/education/instruction/tofg/download/unit_2.1a_soil_physical.pdf>.

Figure 46 - Soil Permeability Test

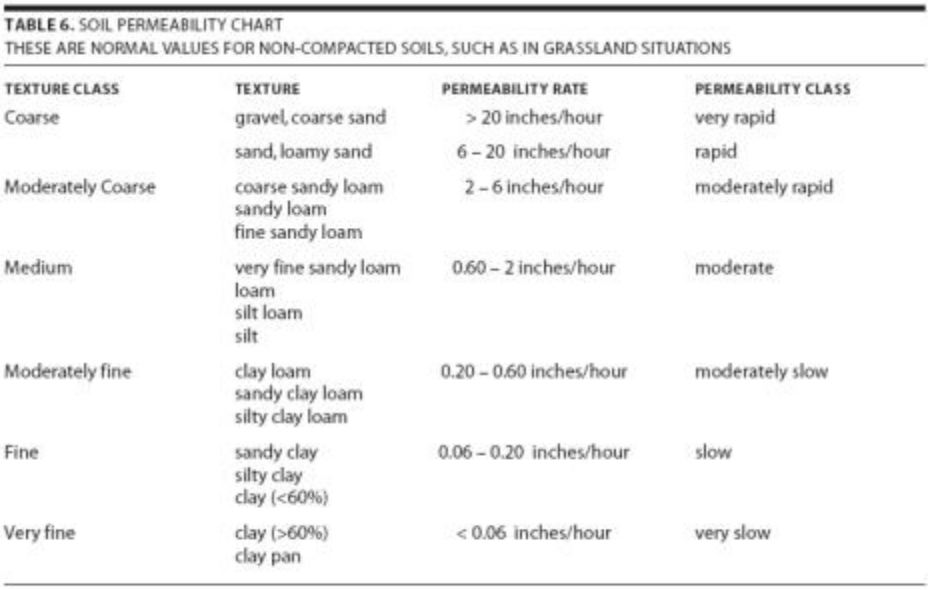

TABLE 6. SOIL PERMEABILITY CHART
THESE ARE NORMAL VALUES FOR NON-COMPACTED SOILS, SUCH AS IN GRASSLAND SITUATIONS

TEXTURE CLASS	TEXTURE	PERMEABILITY RATE	PERMEABILITY CLASS
Coarse	gravel, coarse sand	> 20 inches/hour	very rapid
	sand, loamy sand	6 – 20 inches/hour	rapid
Moderately Coarse	coarse sandy loam sandy loam fine sandy loam	2 – 6 inches/hour	moderately rapid
Medium	very fine sandy loam loam silt loam silt	0.60 – 2 inches/hour	moderate
Moderately fine	clay loam sandy clay loam silty clay loam	0.20 – 0.60 inches/hour	moderately slow
Fine	sandy clay silty clay clay (<60%)	0.06 – 0.20 inches/hour	slow
Very fine	clay (>60%) clay pan	< 0.06 inches/hour	very slow

Figure 47 - Soil Permeability Chart[102]

While this test was running we collected a soil sample from the same sections as the permeability test. We took these samples from every location that we did a permeability test so to compare data for a more precise soil composition reading. In figure 48 there is an example of a soil sample being taken from the area just in front of the permeability test location. We brought these samples back to San Jose to conduct a soil composition test.

The soil composition test required one cylindrical jar for each sample. The jar was filled 1/3 full with the soil specimen. Then water was added to fill the jar. Each specimen was marked for its particular location. The jar was then vigorously shaken until the soil was completely

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[102] CASFS – Welcome, 2009

mixed with the water. The jar was then placed aside and left until the water in the jar was clear.[103]

Once the water was clear, layers were distinguishable in the jar. The top layer was clay, the middle layer was silt and the bottom layer was sand (Figure 48). These layers were measured individually and then divided by the total height of soil in the jar to determine a percentage. Once the percentages were calculated, the data was compared to the Soil Triangle in Figure 49 to determine a soil type[104].

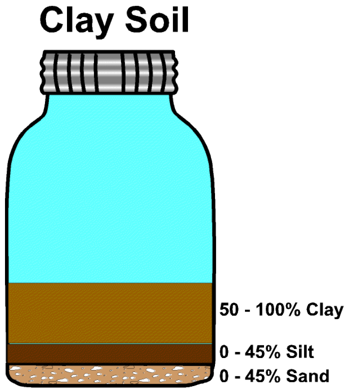

Figure 48 - Soil Composition Test[105]

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[103] CASFS – Welcome, 2009
[104] CASFS – Welcome, 2009
[105] CASFS – Welcome, 2009

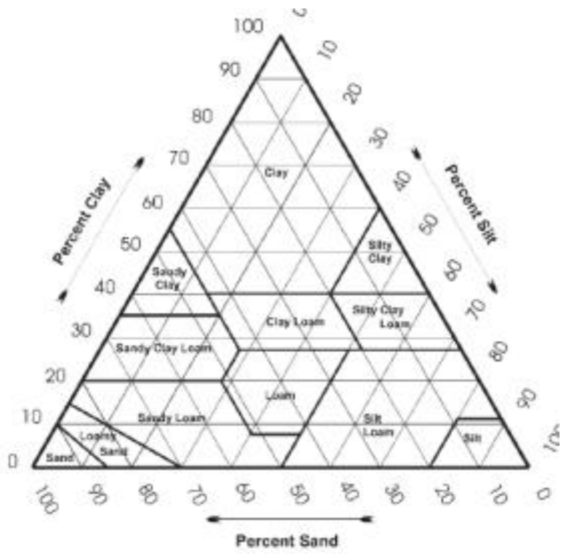

Figure 49 - Soil Triangle[106]

4.4 Erosion Analysis

4.4.1 Universal Soil Loss Equation

The project team used the Universal Soil Loss Equation to evaluate the erosion prevention due to the designed trail improvements. The Universal Soil Loss Equation is a method that gives an annual soil loss amount based on a number of factors including rainfall, soil erodability, slope, and plant cover. The equation looks like[107]:

$$A = R * K * S * C$$

A= Soil Loss, Tons per Acre per Year

R= Rainfall Erosion Index

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[106] CASFS – Welcome, 2009
[107] Marsh, 2004

K= Soil Erodibility Factor

S= Slope Factor

C= Plant Cover Factor

Each factor is found through the use of soil samples and observations taken on site coupled with tables of known values. The following Tables 9-10 and Figures 50-51 below show how the different factors are chosen:

Table 9 - Plant Cover Factors[108]

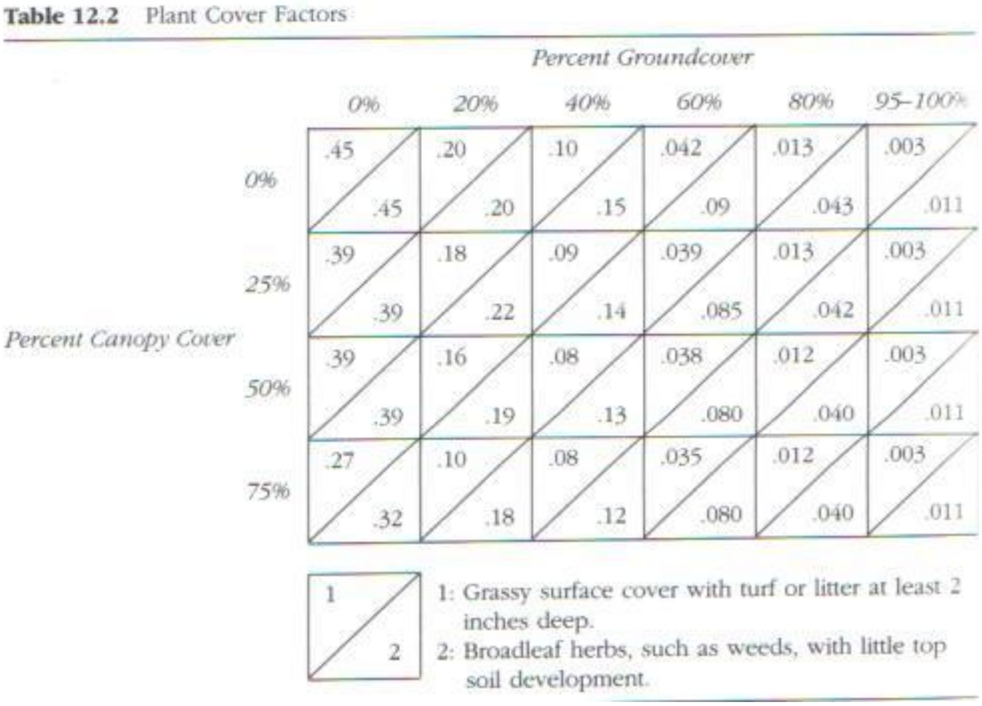

Table 12.2 Plant Cover Factors

		Percent Groundcover					
		0%	20%	40%	60%	80%	95–100%
Percent Canopy Cover	0%	.45 .45	.20 .20	.10 .15	.042 .09	.013 .043	.003 .011
	25%	.39 .39	.18 .22	.09 .14	.039 .085	.013 .042	.003 .011
	50%	.39 .39	.16 .19	.08 .13	.038 .080	.012 .040	.003 .011
	75%	.27 .32	.10 .18	.08 .12	.035 .080	.012 .040	.003 .011

1 2	1: Grassy surface cover with turf or litter at least 2 inches deep. 2: Broadleaf herbs, such as weeds, with little top soil development.

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[108] Marsh, 2004

Table 10 - Slope Geometry Factor[109]

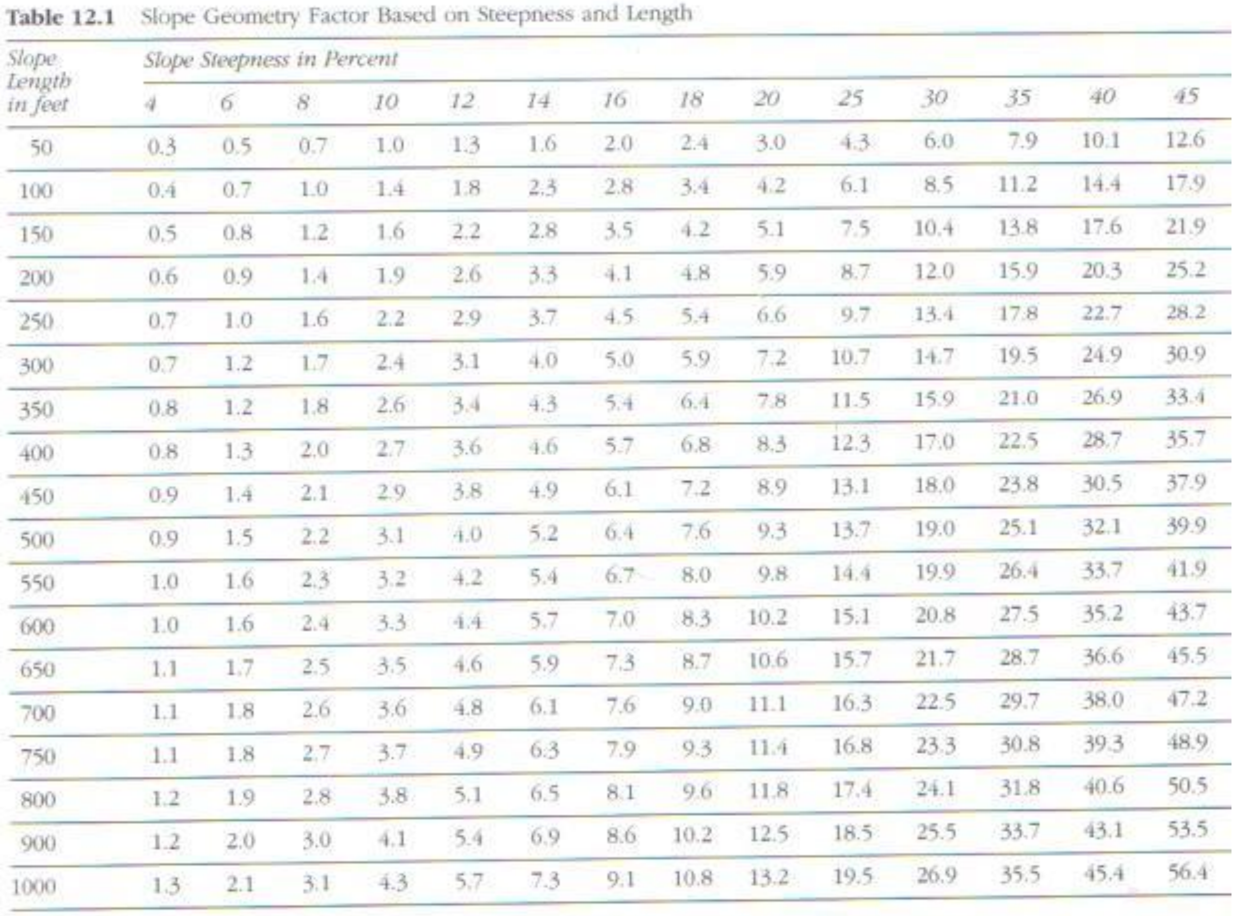

Table 12.1 Slope Geometry Factor Based on Steepness and Length

Slope Length in feet	*Slope Steepness in Percent*													
	4	*6*	*8*	*10*	*12*	*14*	*16*	*18*	*20*	*25*	*30*	*35*	*40*	*45*
50	0.3	0.5	0.7	1.0	1.3	1.6	2.0	2.4	3.0	4.3	6.0	7.9	10.1	12.6
100	0.4	0.7	1.0	1.4	1.8	2.3	2.8	3.4	4.2	6.1	8.5	11.2	14.4	17.9
150	0.5	0.8	1.2	1.6	2.2	2.8	3.5	4.2	5.1	7.5	10.4	13.8	17.6	21.9
200	0.6	0.9	1.4	1.9	2.6	3.3	4.1	4.8	5.9	8.7	12.0	15.9	20.3	25.2
250	0.7	1.0	1.6	2.2	2.9	3.7	4.5	5.4	6.6	9.7	13.4	17.8	22.7	28.2
300	0.7	1.2	1.7	2.4	3.1	4.0	5.0	5.9	7.2	10.7	14.7	19.5	24.9	30.9
350	0.8	1.2	1.8	2.6	3.4	4.3	5.4	6.4	7.8	11.5	15.9	21.0	26.9	33.4
400	0.8	1.3	2.0	2.7	3.6	4.6	5.7	6.8	8.3	12.3	17.0	22.5	28.7	35.7
450	0.9	1.4	2.1	2.9	3.8	4.9	6.1	7.2	8.9	13.1	18.0	23.8	30.5	37.9
500	0.9	1.5	2.2	3.1	4.0	5.2	6.4	7.6	9.3	13.7	19.0	25.1	32.1	39.9
550	1.0	1.6	2.3	3.2	4.2	5.4	6.7	8.0	9.8	14.4	19.9	26.4	33.7	41.9
600	1.0	1.6	2.4	3.3	4.4	5.7	7.0	8.3	10.2	15.1	20.8	27.5	35.2	43.7
650	1.1	1.7	2.5	3.5	4.6	5.9	7.3	8.7	10.6	15.7	21.7	28.7	36.6	45.5
700	1.1	1.8	2.6	3.6	4.8	6.1	7.6	9.0	11.1	16.3	22.5	29.7	38.0	47.2
750	1.1	1.8	2.7	3.7	4.9	6.3	7.9	9.3	11.4	16.8	23.3	30.8	39.3	48.9
800	1.2	1.9	2.8	3.8	5.1	6.5	8.1	9.6	11.8	17.4	24.1	31.8	40.6	50.5
900	1.2	2.0	3.0	4.1	5.4	6.9	8.6	10.2	12.5	18.5	25.5	33.7	43.1	53.5
1000	1.3	2.1	3.1	4.3	5.7	7.3	9.1	10.8	13.2	19.5	26.9	35.5	45.4	56.4

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[109] Marsh, 2004

Fig. 12.7 Rainfall erosion index for the United States east of the Rocky Mountains. In the West, index values are less reliable and best calculated from local rainfall records.

Figure 50 - Rainfall Erosion Index[110]

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[110] Marsh, 2004

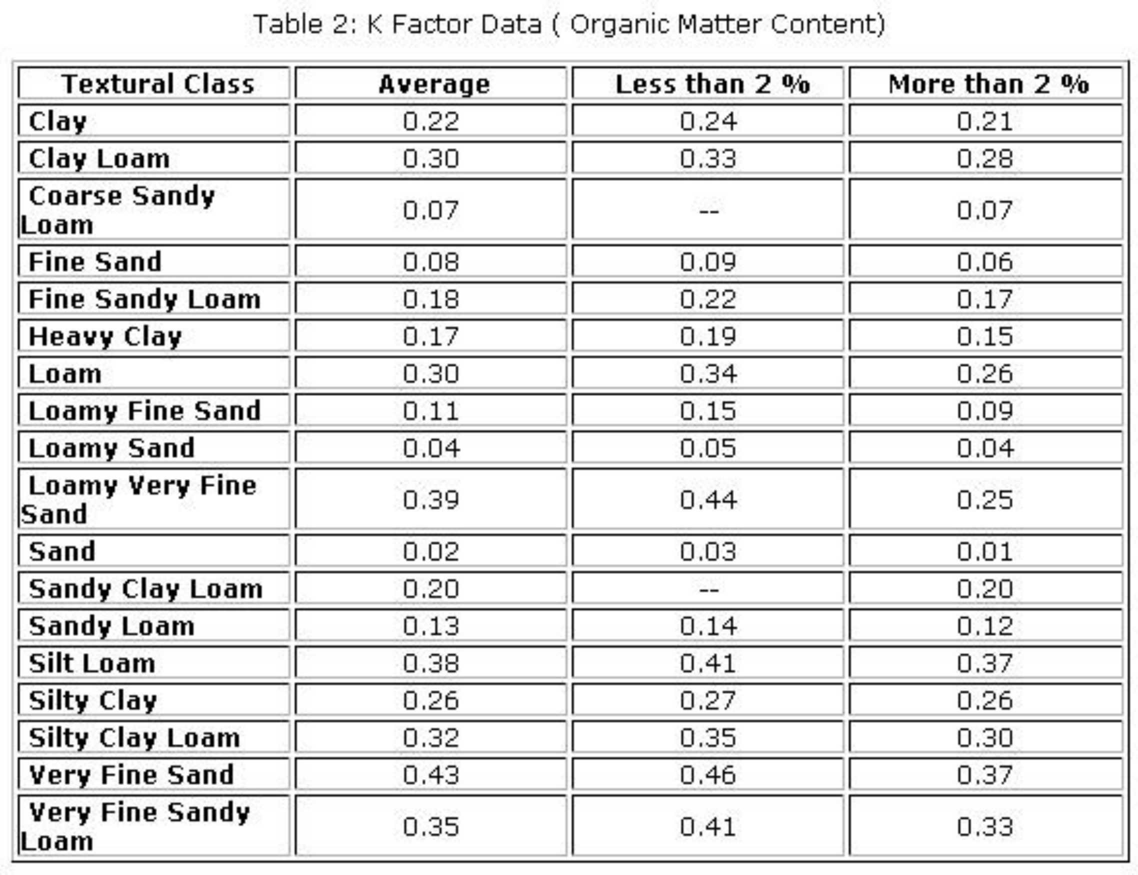

Table 2: K Factor Data (Organic Matter Content)

Textural Class	Average	Less than 2 %	More than 2 %
Clay	0.22	0.24	0.21
Clay Loam	0.30	0.33	0.28
Coarse Sandy Loam	0.07	--	0.07
Fine Sand	0.08	0.09	0.06
Fine Sandy Loam	0.18	0.22	0.17
Heavy Clay	0.17	0.19	0.15
Loam	0.30	0.34	0.26
Loamy Fine Sand	0.11	0.15	0.09
Loamy Sand	0.04	0.05	0.04
Loamy Very Fine Sand	0.39	0.44	0.25
Sand	0.02	0.03	0.01
Sandy Clay Loam	0.20	--	0.20
Sandy Loam	0.13	0.14	0.12
Silt Loam	0.38	0.41	0.37
Silty Clay	0.26	0.27	0.26
Silty Clay Loam	0.32	0.35	0.30
Very Fine Sand	0.43	0.46	0.37
Very Fine Sandy Loam	0.35	0.41	0.33

Figure 51 - K Factor Data[111]

4.5 Runoff Analysis

4.5.1 Runoff Mapping

The project team used topographic information in order to locate the watershed area affecting the trails that were to be improved. An example of this method is shown below in Figure 52.

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[111] "Universal Soil Loss Equation (USLE)." Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) Home Page. 28 Apr. 2009 <http://www.omafra.gov.on.ca/english/engineer/facts/00-001.htm>.

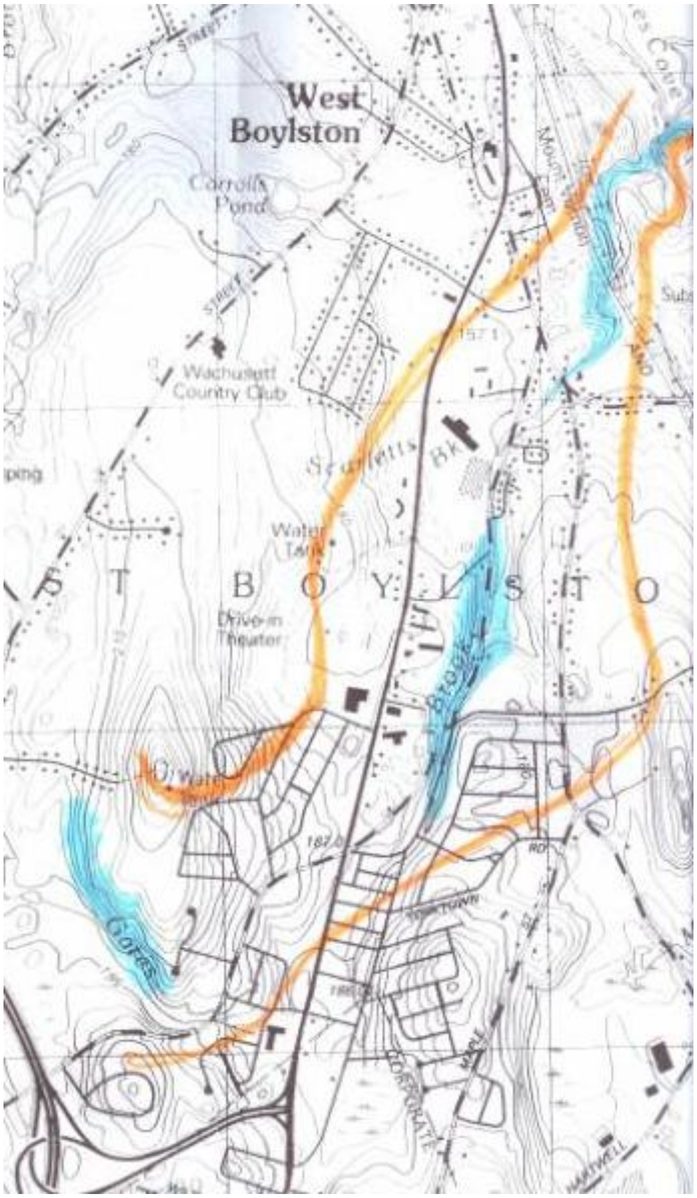

Figure 52 - Example of Runoff Mapping[112]

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[112] Gilday, Andrew, Hydrographic Topographic Map of West Boylston, Massachusetts, CE3074, Professor Mathisen, Worcester Polytechnic Institute, 2007.

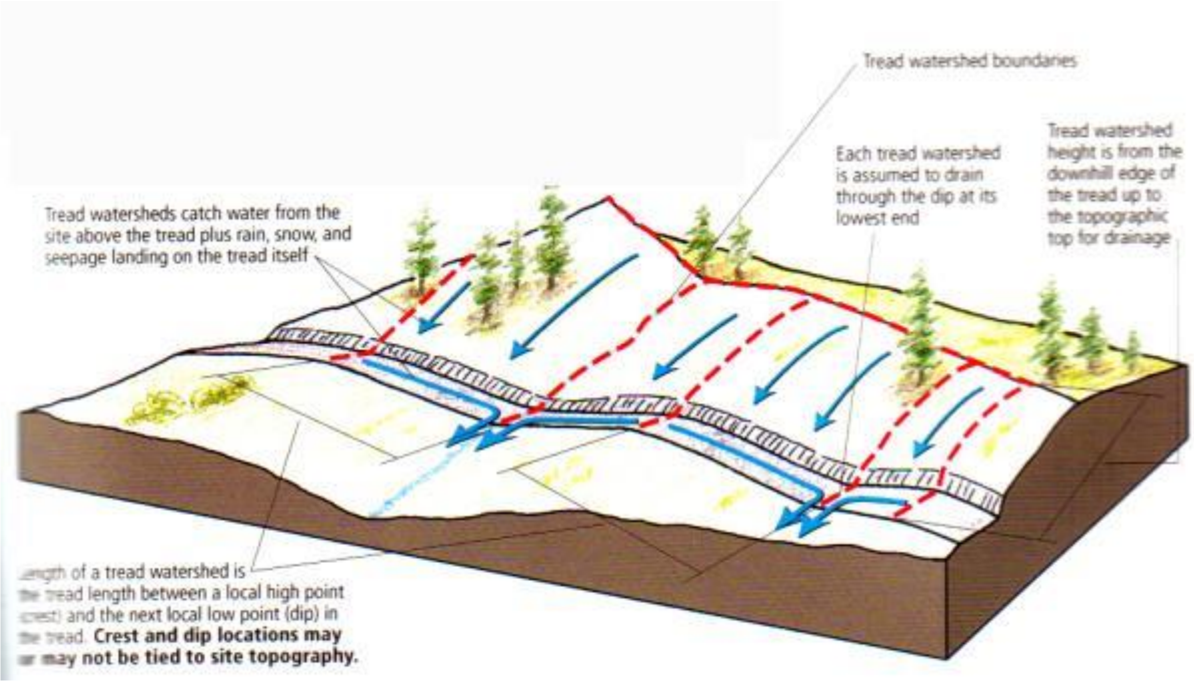

Figure 53 - Runoff[113]

Rainfall Data

The project team used as a worst case scenario the highest amount of storm rainfall in the United States based on 10-year storm rainfall data obtained from a rainfall frequency atlas prepared by the U.S. Department of Agriculture. This rainfall information is shown below in Figure 54.

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[113] Parker, 2004

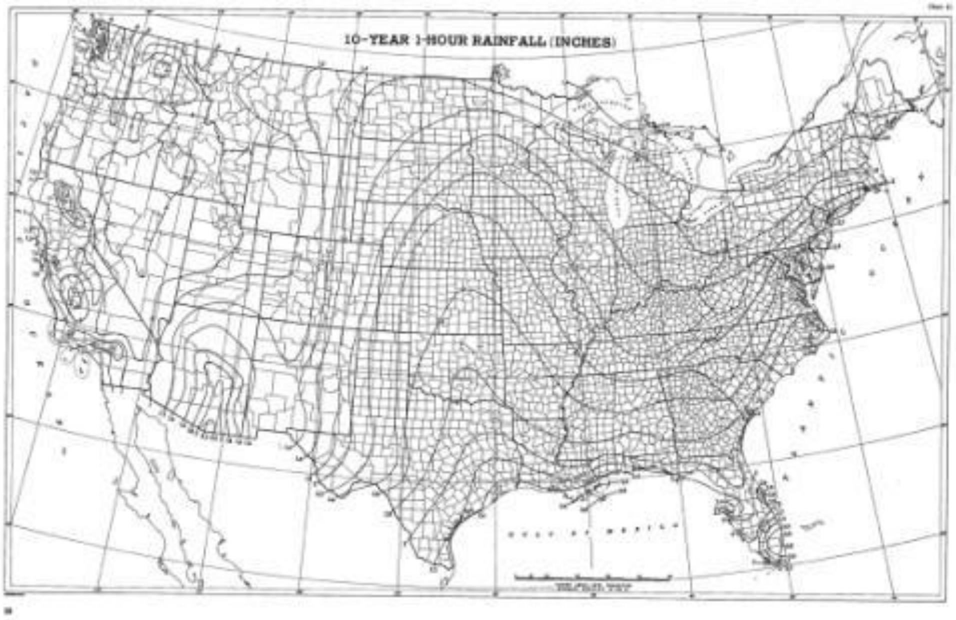

Figure 54 - 10 Year Storm Chart[114]

Rational Method

The project team used the Rational Method to calculate the amount of water flow due to runoff that the trail would need to be designed for. The equation is[115]:

$$Q = C * I * A$$

Q= Flow Rate (cfs)

C= Runoff Coefficient

I= Maximum Rainfall (in./hr.)

A= Area (sq. ft.)

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[114] Hershfield 1961

[115] Marsh, William M. Landscape Planning : Environmental Applications. New York: John Wiley & Sons, Incorporated, 2005.

Using this equation the project team was able to evaluate the water flow affecting the trail during a rainstorm. This information was used to design trail features that work to divert water off or across the trail.

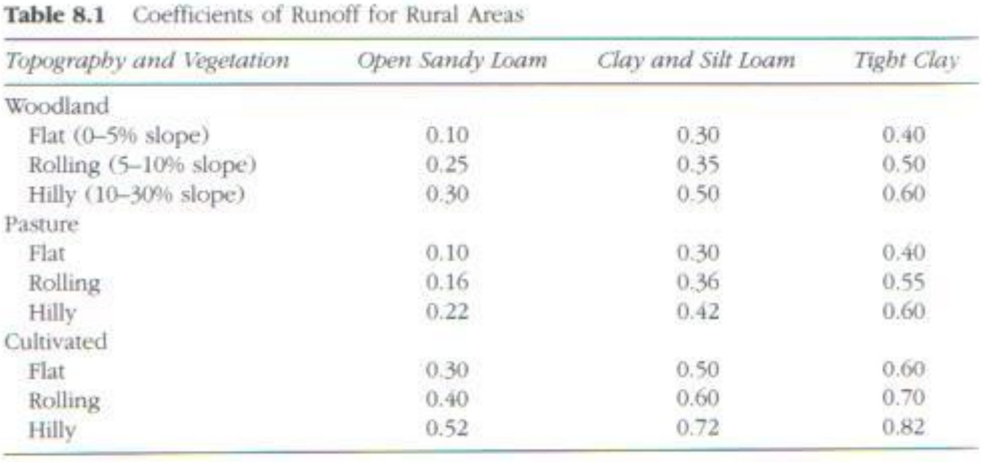

Table 8.1 Coefficients of Runoff for Rural Areas

Topography and Vegetation	*Open Sandy Loam*	*Clay and Silt Loam*	*Tight Clay*
Woodland			
Flat (0–5% slope)	0.10	0.30	0.40
Rolling (5–10% slope)	0.25	0.35	0.50
Hilly (10–30% slope)	0.30	0.50	0.60
Pasture			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
Cultivated			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.82

Figure 55 - Coefficients of Runoff[116]

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[116] Marsh, 2004

5.0 Results

5.1 Creating All Persons Access to the Historic Site

5.1.1 Final Car Design

Mechanical Drawings were created to aid the sponsor in manufacturing of our design. These drawings were created in Pro/Engineer, and detail the dimensions and assembly of each assembly component. These drawings can be seen in Appendix B. The drawings are accompanied by a Bill of Materials shown in Appendix C.

5.1.2 Platform Design

AutoCAD renderings are shown to provide the manufacturer with all necessary dimensions of the platforms and their corresponding foundations. These renderings can be seen in Figures 56-59.

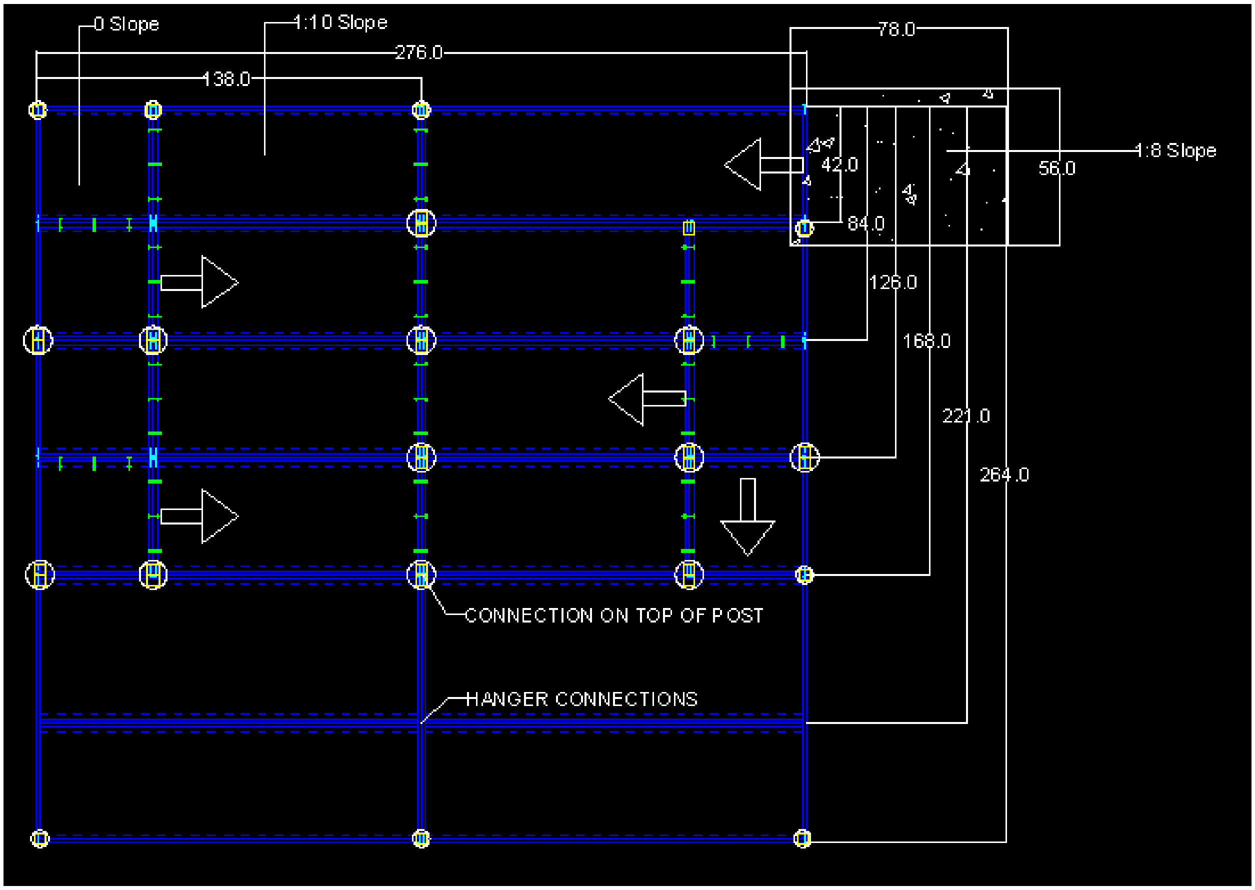


Figure 56 - Platform 1

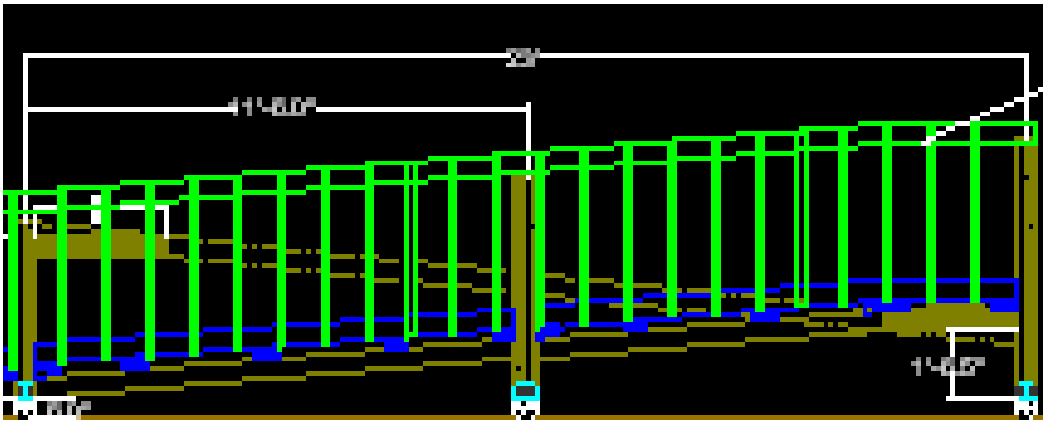


Figure 57 - Platform Railings

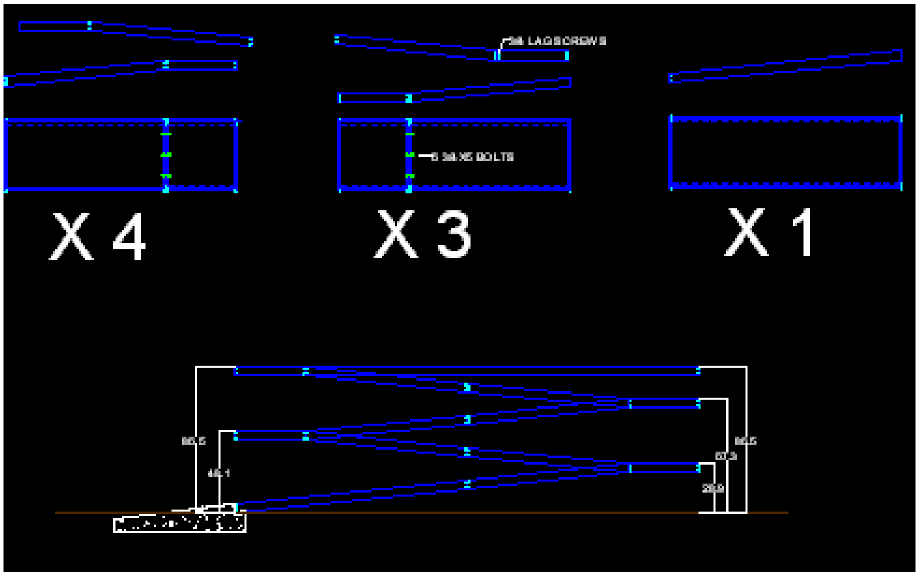


Figure 58 - Manufacturing Assembly Plan

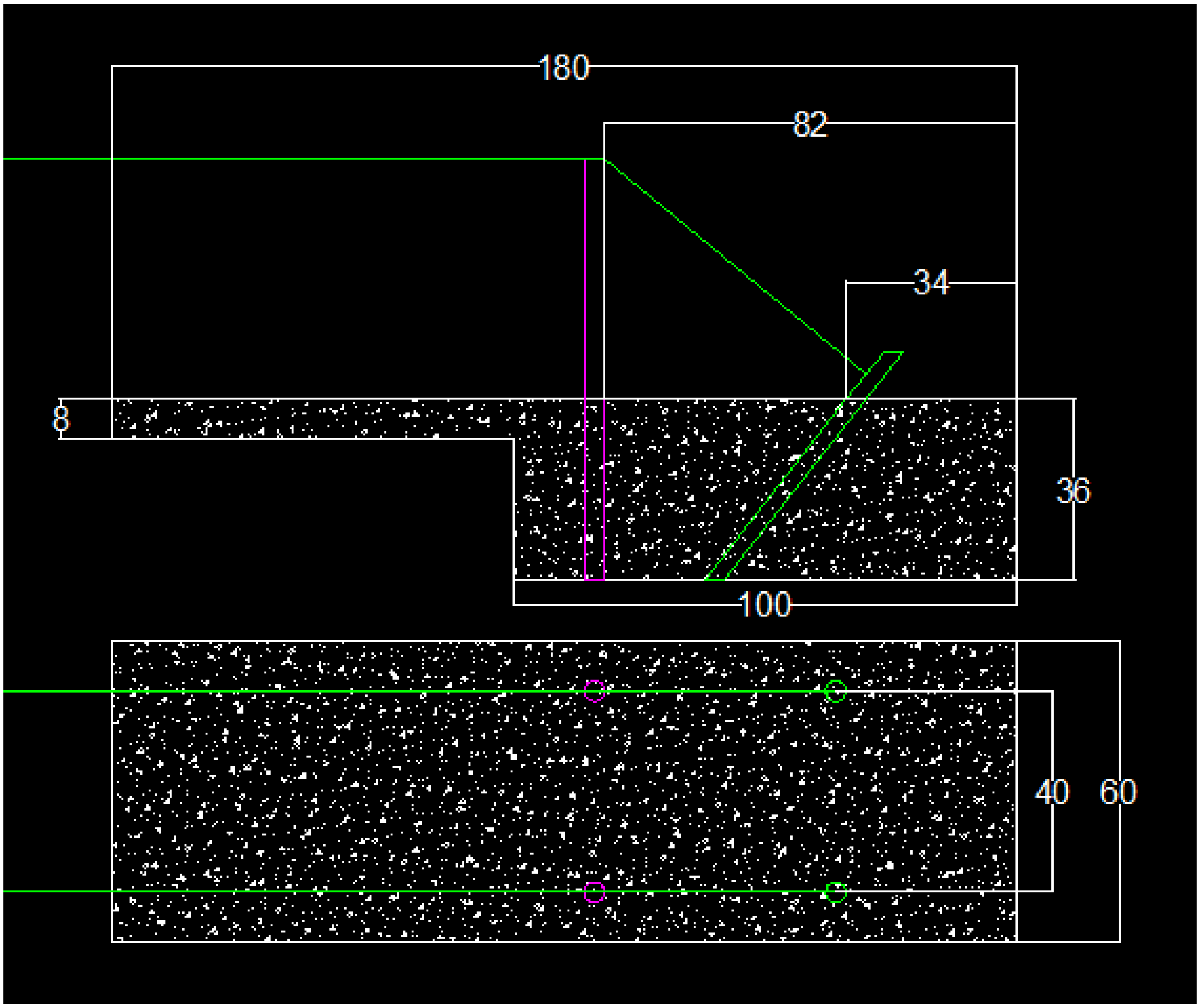


Figure 59 - Platform 2

5.2 Sustainable Trail Design

5.2.1 Mountaintop Ascent Trail

The vista at the end of the Mountaintop Ascent Trail is one of the main attractions of the La Marta Wildlife Refuge. The trail travels up a mountain that was once an old mine which gives it its name, La Mina. The trail is 150 meters in length and it is a very difficult climb to the summit. Currently, most of the trail is unsafe to hike because of the soil composition, grades, and slippery, unsafe corduroy trail tread. The trail experiences rain several times a day typically and was constantly moist even though the project team was on-site during the dry season. Erosion is a major problem on the trail as well. Table 11 shows the field data from the mountaintop ascent trail.

Table 11 - Trail Field Work

Field Data 2/12/08

CONTROL POINT	DISTANCE	HEIGHT	SOIL SAMPLE	EXISTING TRAIL TYPE
1	0.00	58.00		MOUNTAINTOP
2	178.00	39.00	X	MOUNTAINTOP
3	270.50	37.00		NATURAL
4	226.00	12.00		NATURAL
5	160.00	34.00		NATURAL
6	125.00	24.00		NATURAL
7	291.00	11.00		NATURAL
8	191.00	17.00		NATURAL
9	188.00	3.00		NATURAL
10	149.00	4.50		NATURAL
11	120.00	13.50		NATURAL
12	90.00	15.00		NATURAL
13	105.50	9.00		NATURAL
14	99.00	10.00		NATURAL
15	107.00	4.00	X	NATURAL
16	116.00	8.00		NATURAL
17	111.00	23.00		NATURAL
18	100.50	5.50		NATURAL
19	147.00	10.00		NATURAL
20	153.00	6.00		NATURAL
21	265.50	26.00		NATURAL
22	395.00	38.50	X	MUD
23	411.00	50.00		MUD
24	339.00	52.50		MUD
25	396.00	53.00		MUD
26	221.50	60.00		MUD
27	159.50	21.00		MUD
28	255.00	56.00		CORDUROY
29	335.00	99.50		CORDUROY
30	411.00	92.00		CORDUROY
31	292.00	102.00		CORDUROY
32	361.00	56.13	X	CORDUROY

The green areas in Sections 1, 5, 6, 8, and 9 will involve a raised tread design due to the amount of water on the trails creating a wetlands-similar environment. The blue areas in Sections 2, 3, 4, and 7 represent the locations where stairs will be included in the design. These sections of trail were of a grade higher than the maximum sustainable grade of 15%. All of the details for the 9 trail sections are provided in the Figure 60 and Table 12.

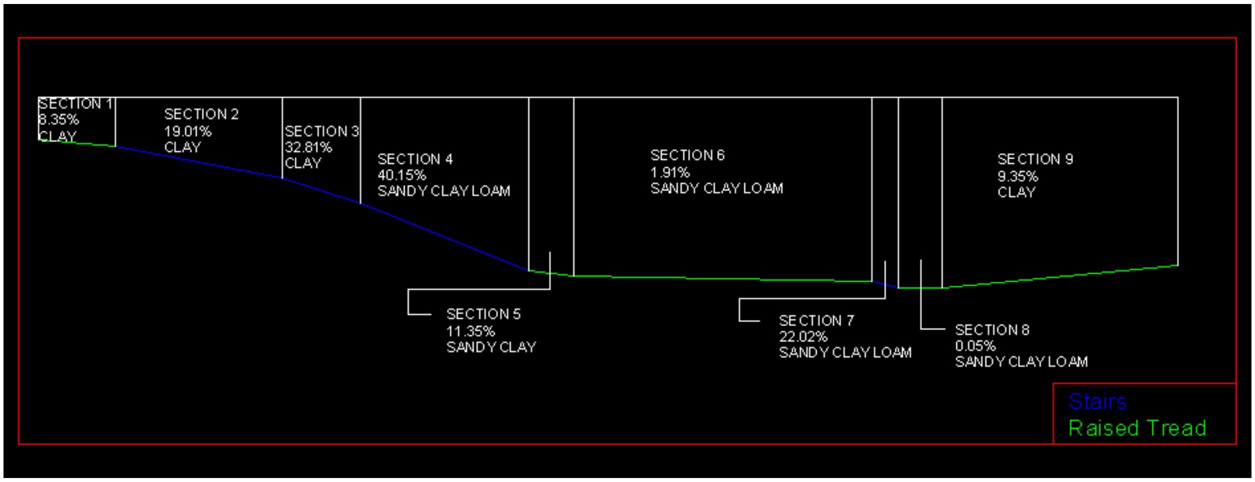


Figure 60 - Profile View of Trail

Table 12 - Trail Distances and Elevations

Mountaintop Ascent Trail

TRAIL SECTION	DISTANCE (ft.)	Accum. Distance	Grade (H/D)	Hieght	Elevation
0	0.00	0.00	0.00%	0.00	3300.00
1	37.38	37.38	8.35%	3.12	3296.88
2	82.75	120.13	19.01%	15.73	3281.15
3	38.08	158.21	32.81%	12.49	3268.66
4	83.17	241.38	40.15%	33.39	3235.26
5	22.13	263.50	11.35%	2.51	3232.75
6	146.88	410.38	1.91%	2.81	3229.94
7	13.29	423.67	22.02%	2.93	3227.02
8	21.25	444.92	0.05%	0.01	3227.01
9	116.58	561.50	9.35%	10.90	3237.90

5.2.2 Section Design

Sections 1, 5, 6, 8, and 9

In these sections of the mountaintop ascent trail a raised tread trail design will be implemented. The raised tread design was chosen to the environment being constantly wet and very similar to a wetlands condition. The raised tread will use a naturally rot and insect resistant wood, achiotillo, that the park rangers collect regularly.

The trail is made by spacing 10”or greater diameter logs 3’ apart to line the trail and give support to the raised tread. Gravel or sand is place between the logs to serve as a base layer and to help the drainage of water of the trail. The tread is crowned with a mix of mostly clay to help shed water and for stability and some sand or travel for traction when wet. Figures 61 and 62 below show the top and side views of the raised tread trail respectively.

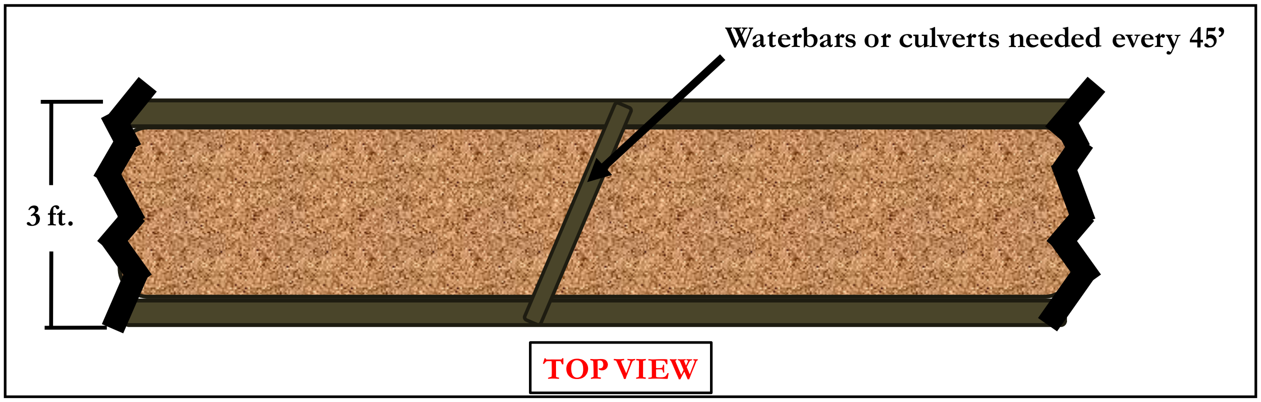


Figure 61 - Trail Top View

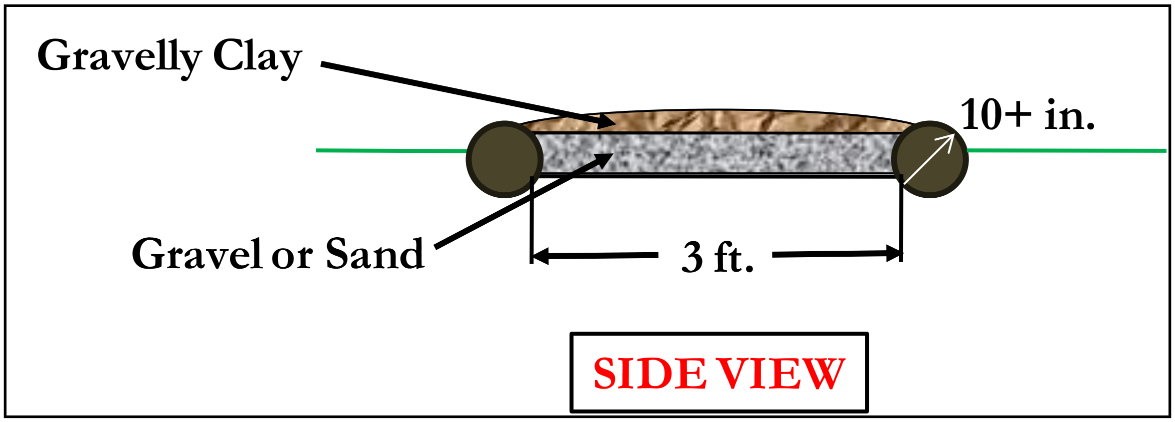


Figure 62 - Trail Side View

These trail sections also incorporate water bars and culverts in the design. The water bars are made by burying an achiotillo log diagonally across the trail so that about 2 inches is above the trail tread. The end of the water bar has a rock apron that will slow and disperse water leaving the trail. Water bars are necessary at least every 45’ due to the amount of runoff on the trail. The design of a water bar is shown below in Figure 63.

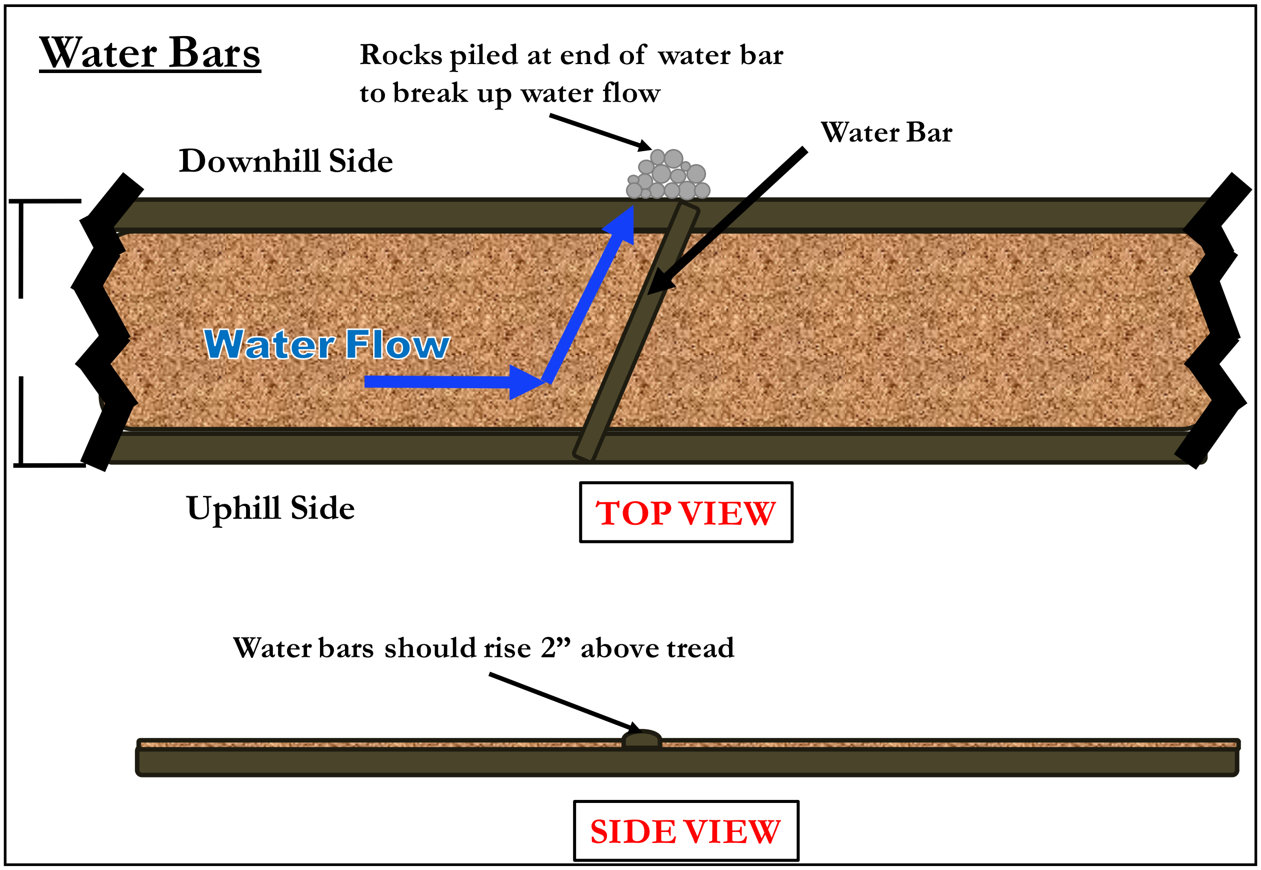


Figure 63 - Water Bars

The project team also designed culverts which allow runoff moving downhill to pass beneath the trail rather than building up and running over the top of the trail, eroding the trail tread. The runoff analysis concluded that at least 4 culverts are needed over the whole trail. The project team recommends one culvert be built in each of the five sections. The culvert includes a 12 inch by 18 inch opening. The bottom of the culvert is lined with rock so as to slow water moving through the culvert and to prevent the culvert floor from washing out. Achiotillo logs are again used in this construction. Large logs are staked into place forming the walls and smaller (around 3 inches) logs run parallel with the tread providing support for the trail tread running over the culvert. The design of the culvert is pictured in Figure 64 below.

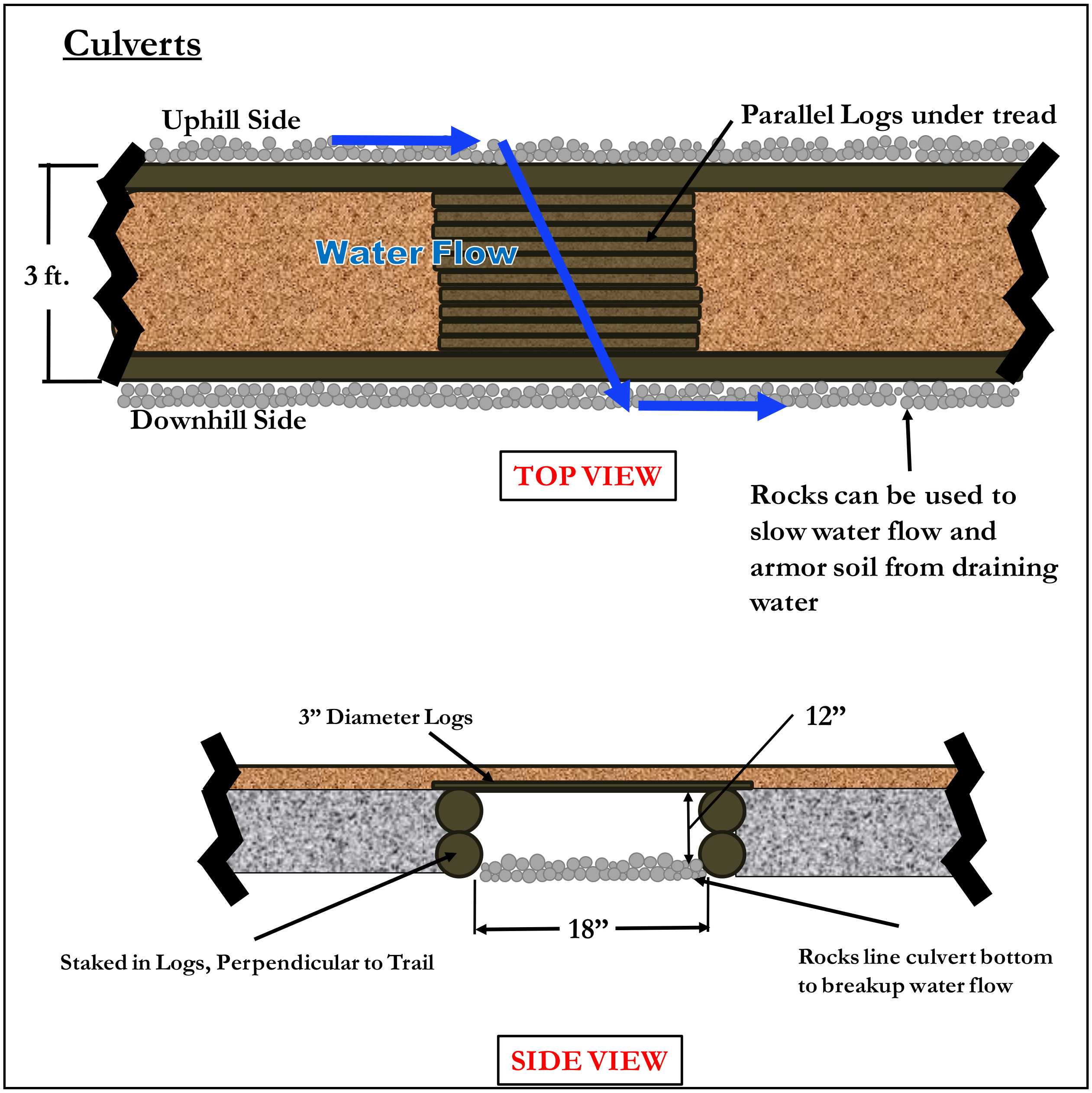


Figure 64 - Culverts

Section 2

In this section of the mountaintop ascent a stair design will be implemented. The slope in this section is 19.01% and the length is 82.75 ft. Twenty-four steps will be needed in this section.

The length of 42 inches for the step was chosen because it is a comfortable distance for a stair that requires two paces as tested by the project team. The elevation of each step is 8 inches. This figure will remain consistent for all step designs used for the mountaintop ascent trail.

The current material in this section is clay. Clay is a good base for the stair design but will become very slippery when wet. With an annual rainfall of over 140 inches and daily rain showers the steps will not dry. To improve traction a 2 inch layer of sand should be compacted and mixed into the top layer of clay.

The planks will be cut to match the width of the trail in a particular location and found from the tree fall as long as the width is approximately 8 inches. Achiotillo is a good choice of material because it is durable and resistant to rot. Both species of wood and soil material are found onsite at the La Marta Refuge so that no additional material expense will incur.

There are two recommendations for fastening the planks in their location. The first would include bending steel bars in u-shapes around the wood planks (Figure 65). Once hammered in these planks would be securely positioned by a material that will not rot, bend, or crack. A similar design is used throughout other areas in the La Marta Wildlife Refuge. The second recommendation requires two wooden spikes per step. The spikes should be 36” in length and placed at least 6” inside the end of each step as shown in Figure 66. Secure the spikes with 3 inch decking screws if using rectangular planks achiotillo or with metal wire for cylindrical planks (bamboo, achiotillo).

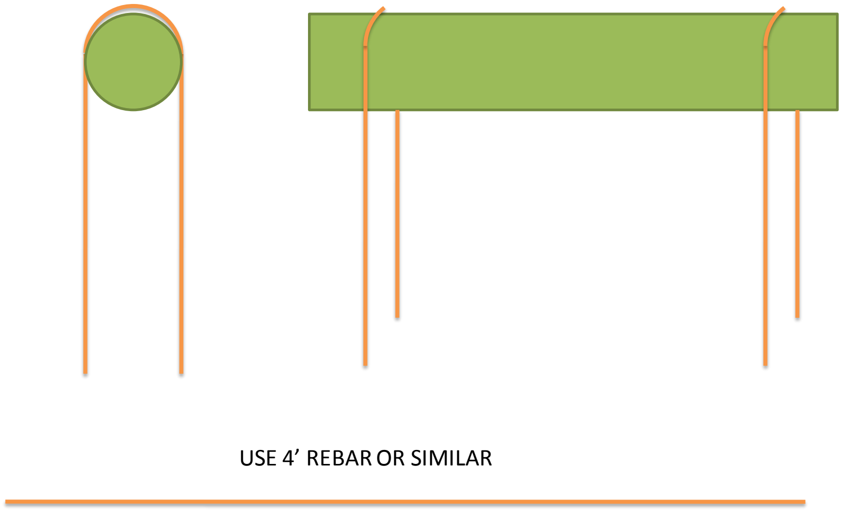


Figure 65 - Staking

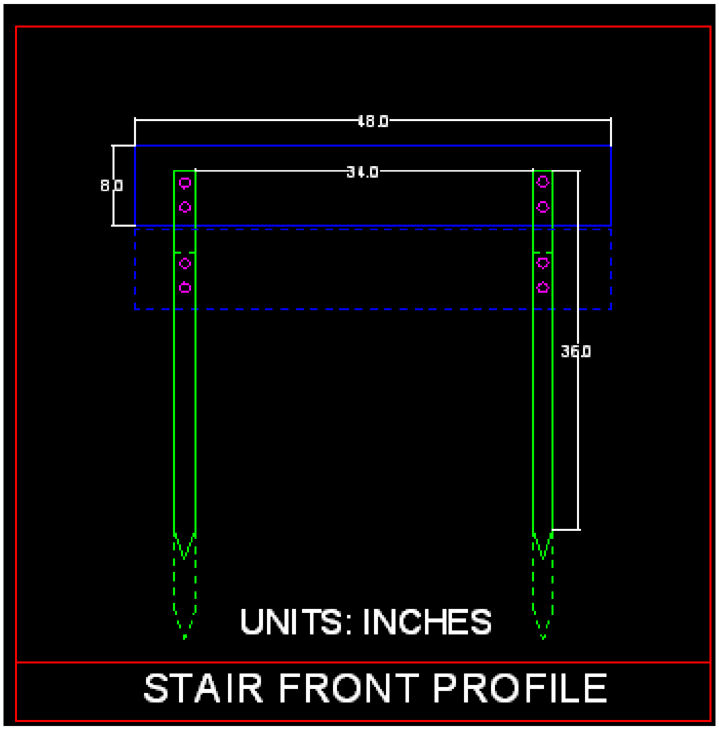


Figure 66 - Stair Front View

Section 3

Section 3 is 38.08 ft long and has a slope of 32.81%. The step will be 24 inches long and a vertical step of 8 inches, remaining consistent with the previous step height (figure 67). This location will require 19 steps. Similar to Section 2 the soil composition is clay. The structural design, plank selection and soil composition will be the same as Section 2.

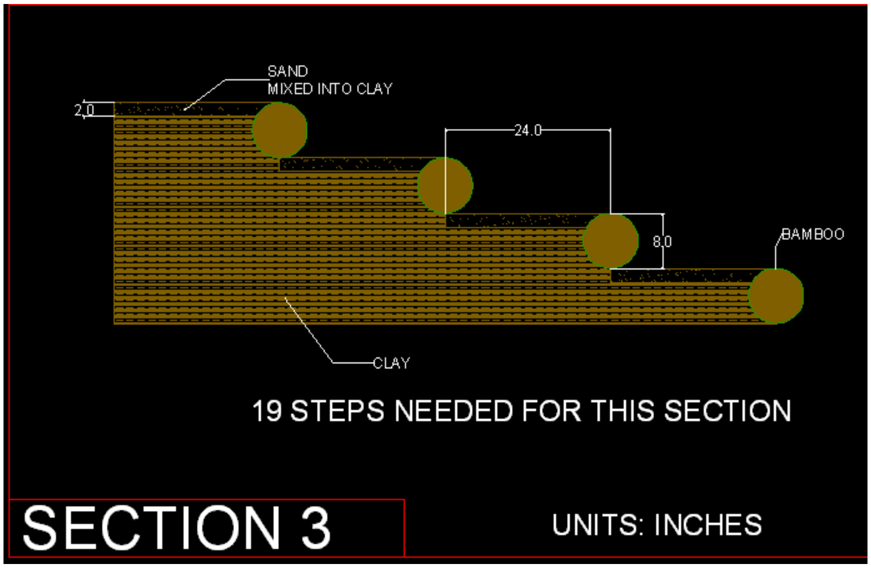


Figure 67 - Section 3 Design

Section 4

Section 4 is 83.17 ft long and has a slope of 40.15%. This section has the highest slope of any other section along this trail. The design will call for 50 steps at 20 inches in length and 8 inches in step height. The structural design and plank selection will remain the same as Section 2 and 3. However, since the soil makeup of this area is sandy clay loam an added component will be included in this design to increase stability and decrease erosion. This design is called reed-trench terracing as seen in figure 68. (Donald H Gray) The placement of reed grass or palm tree branches will disperse the water laterally through capillary action off the trail. The materials will be found onsite and incur no addition cost.

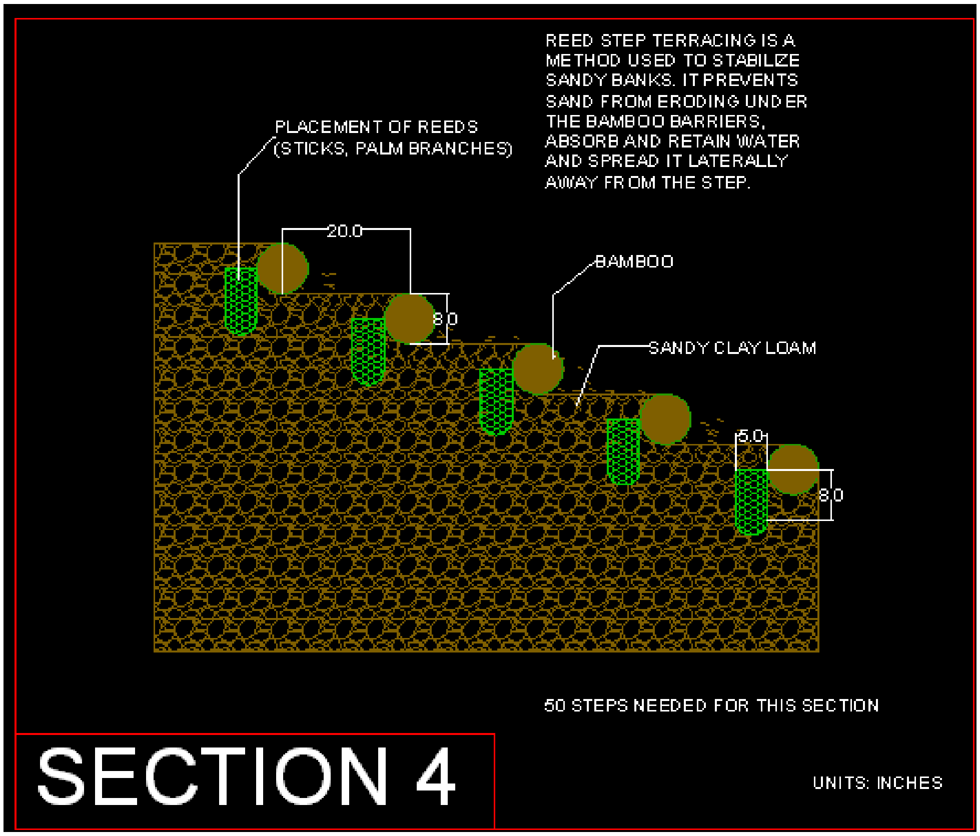


Figure 68 - Section 4 Design

Section 7

Section 7 is 13.29 ft long and has a slope of 22.02%. This short section of trail will require 5 steps at a length of 36 inches and a vertical step of 8 inches (figure 69). The soil composition in this location is clay. Thus, the structural design, plank selection and soil composition will be the same as Section 2 and 3.

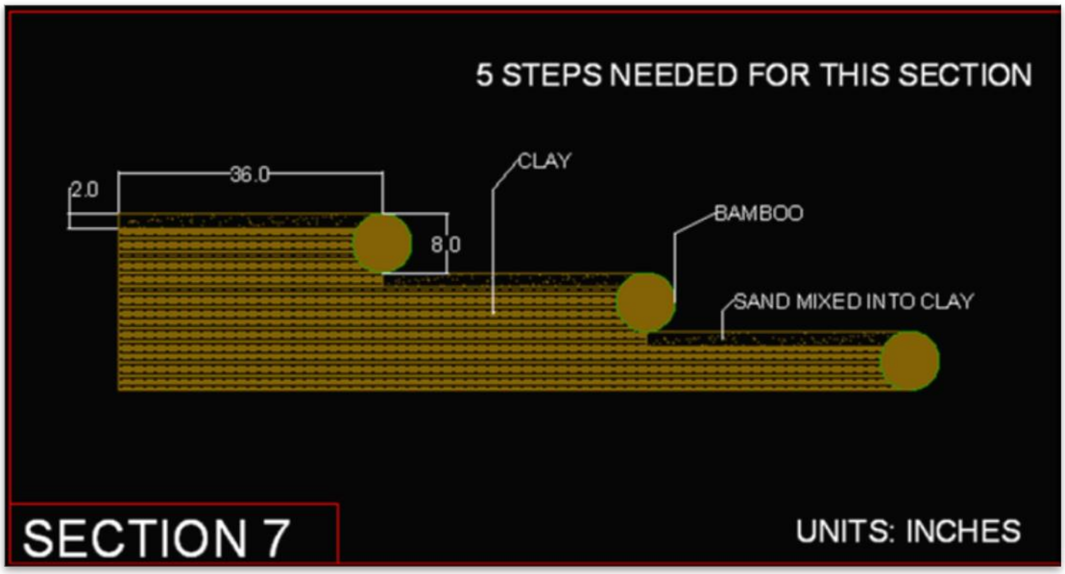


Figure 69 - Section 7 Design

5.2.3 Historic Area All-Persons Accessible Trails

The project team also looked into the trail system around the historic site at La Marta. All of the current trails around the historic site met FSTAG requirements for grade. The only improvements needed were to make sure the trails are all at least 3 feet wide on all sections. In Figure 70 below, all of the historic area trails are outlined in green. There is also a yellow box on the figure that denotes a flat area where a accessible bathroom facility could be placed in the future. The entrances to the coffee processing area have a 12 inch wall that will need a ramp for a wheelchair to navigate. The ramps will need to be at a slope of no more than 1:8 and will need to be at least 3 feet wide with bumpers for safety.

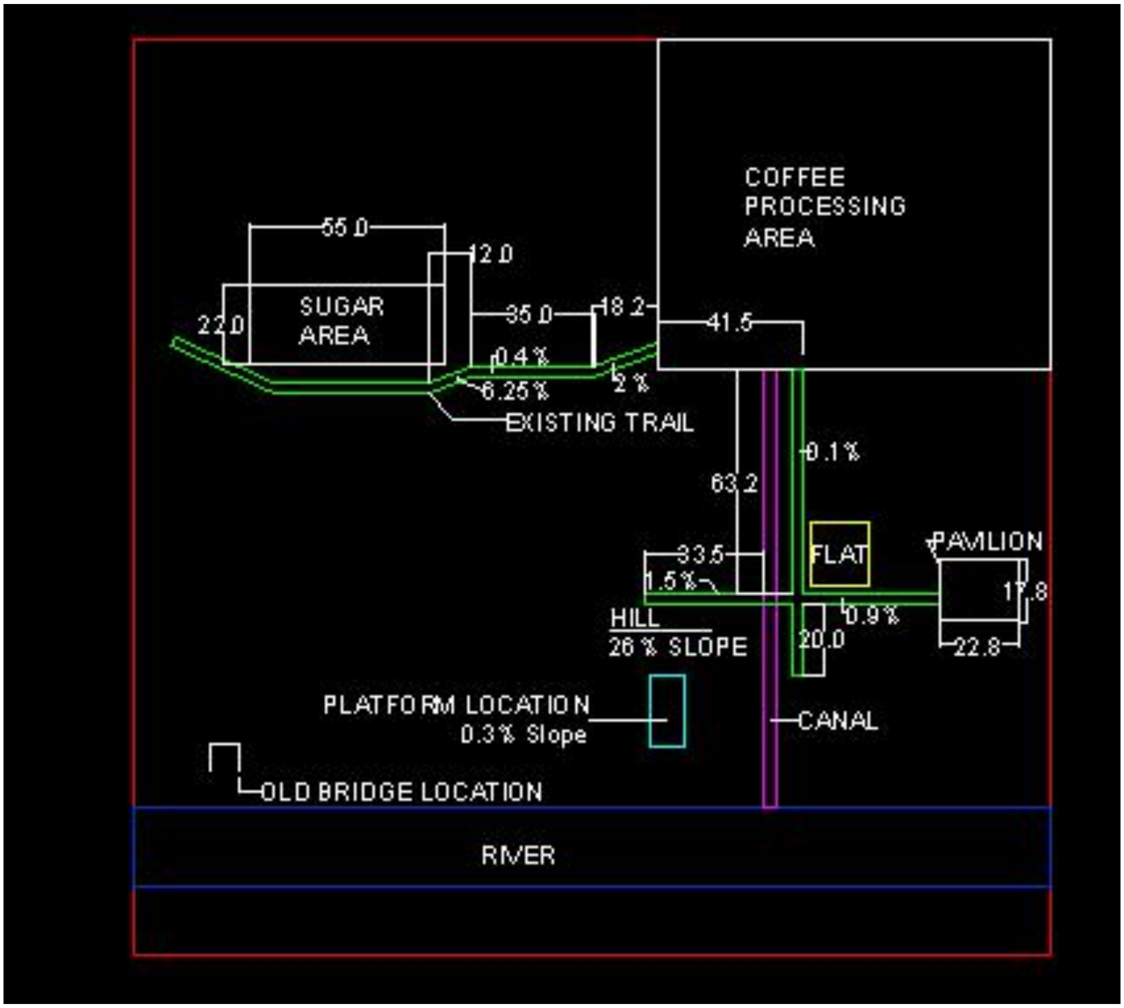


Figure 70 - Historic Area Map

5.2.4 Erosion Analysis

The project team the Universal Soil Loss Equation (USLE) to evaluate the erosion prevention due to the designed trail improvements. The USLE is shown below:

$$A = R * K * S * C$$[117]

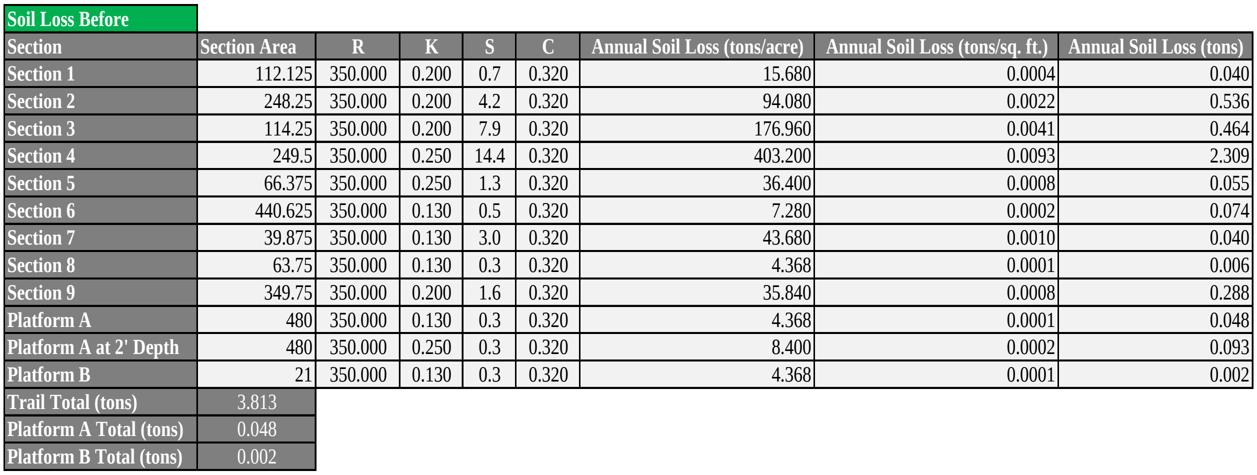
---

[117] Marsh, 2004

For example, in Trail Section 1 had a rainfall erosion index value of 250, a Soil Erodibility Factor of 0.200, a Slope Factor of 0.7, and a Plant Cover Factor of 0.320, giving the equation:

$$A = 250 \ast 0.200 \ast 0.7 \ast 0.320$$

This gave an amount of 15.680 tons per acre. That amount was multiplied by 2.29568411 × 10^{-5} to show in the result in tons/sq.ft., a value of 0.0004. This value was then multiplied by the Trail Section 1 area, 112.5 square feet, which gave a result in tons of 0.040. This method was repeated for each section and the tons of each section were added together to give a total amount of soil loss in tons due to erosion per year. The results of those calculations are shown below in Figure 71.

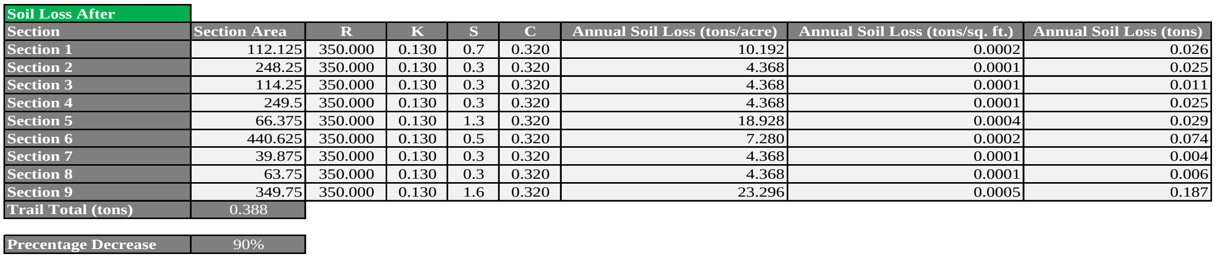


Soil Loss Before

Section	Section Area	R	K	S	C	Annual Soil Loss (tons/acre)	Annual Soil Loss (tons/sq. ft.)	Annual Soil Loss (tons)
Section 1	112.125	350.000	0.200	0.7	0.320	15.680	0.0004	0.040
Section 2	248.25	350.000	0.200	4.2	0.320	94.080	0.0022	0.536
Section 3	114.25	350.000	0.200	7.9	0.320	176.960	0.0041	0.464
Section 4	249.5	350.000	0.250	14.4	0.320	403.200	0.0093	2.309
Section 5	66.375	350.000	0.250	1.3	0.320	36.400	0.0008	0.055
Section 6	440.625	350.000	0.130	0.5	0.320	7.280	0.0002	0.074
Section 7	39.875	350.000	0.130	3.0	0.320	43.680	0.0010	0.040
Section 8	63.75	350.000	0.130	0.3	0.320	4.368	0.0001	0.006
Section 9	349.75	350.000	0.200	1.6	0.320	35.840	0.0008	0.288
Platform A	480	350.000	0.130	0.3	0.320	4.368	0.0001	0.048
Platform A at 2' Depth	480	350.000	0.250	0.3	0.320	8.400	0.0002	0.093
Platform B	21	350.000	0.130	0.3	0.320	4.368	0.0001	0.002
Trail Total (tons)	3.813							
Platform A Total (tons)	0.048							
Platform B Total (tons)	0.002							

Figure 71 - Soil Loss Before

Through the same set of calculations, the amount of soil loss was calculated for the trails in a scenario where the improvements had been implemented. The resulting difference in soil loss was a 90% decrease as shown in the numbers below in Figure 72.



Soil Loss After

Section	Section Area	R	K	S	C	Annual Soil Loss (tons/acre)	Annual Soil Loss (tons/sq. ft.)	Annual Soil Loss (tons)
Section 1	112.125	350.000	0.130	0.7	0.320	10.192	0.0002	0.026
Section 2	248.25	350.000	0.130	0.3	0.320	4.368	0.0001	0.025
Section 3	114.25	350.000	0.130	0.3	0.320	4.368	0.0001	0.011
Section 4	249.5	350.000	0.130	0.3	0.320	4.368	0.0001	0.025
Section 5	66.375	350.000	0.130	1.3	0.320	18.928	0.0004	0.029
Section 6	440.625	350.000	0.130	0.5	0.320	7.280	0.0002	0.074
Section 7	39.875	350.000	0.130	0.3	0.320	4.368	0.0001	0.004
Section 8	63.75	350.000	0.130	0.3	0.320	4.368	0.0001	0.006
Section 9	349.75	350.000	0.130	1.6	0.320	23.296	0.0005	0.187
Trail Total (tons)	0.388							

Precentage Decrease	90%

Figure 72 - Soil Loss After

5.2.5 Runoff Analysis

Runoff Mapping

The project team used a topographic map to locate the watershed affecting the trail. The green lines denote the boundary of the refuge and the blue lines show existing trails. The La Mina trail is shown below in red in Figure 73.

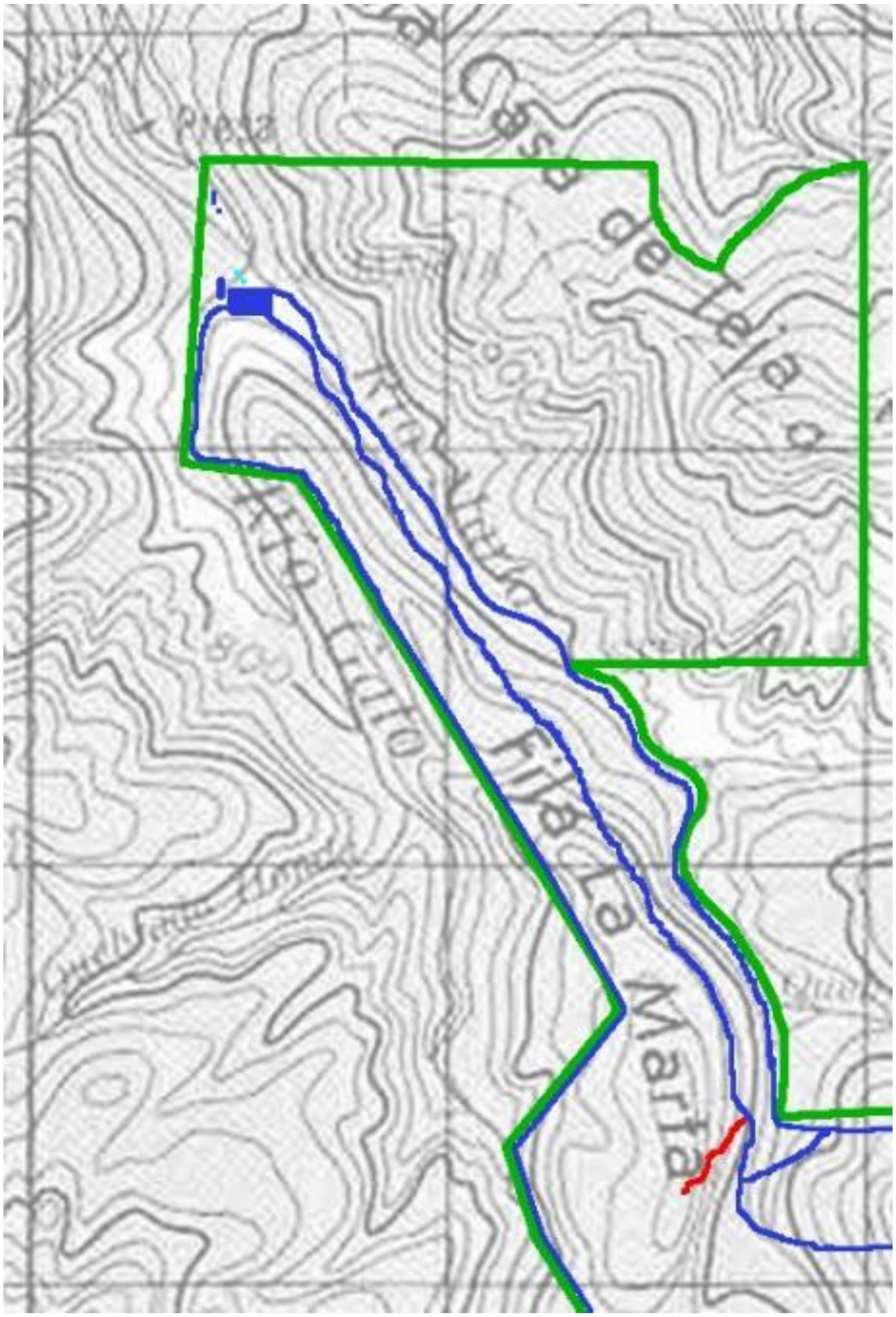


Figure 73 - Topographic Map of La Marta Wildlife Refuge

From this map the area of the watershed could be calculated. Since the trail sections cross diagonally across the contour lines, the entire west of the trail is upslope and the entire east side of the trail is down slope. This creates a triangular watershed as the rainstorm runoff moves downhill as shown below in Figure 74.

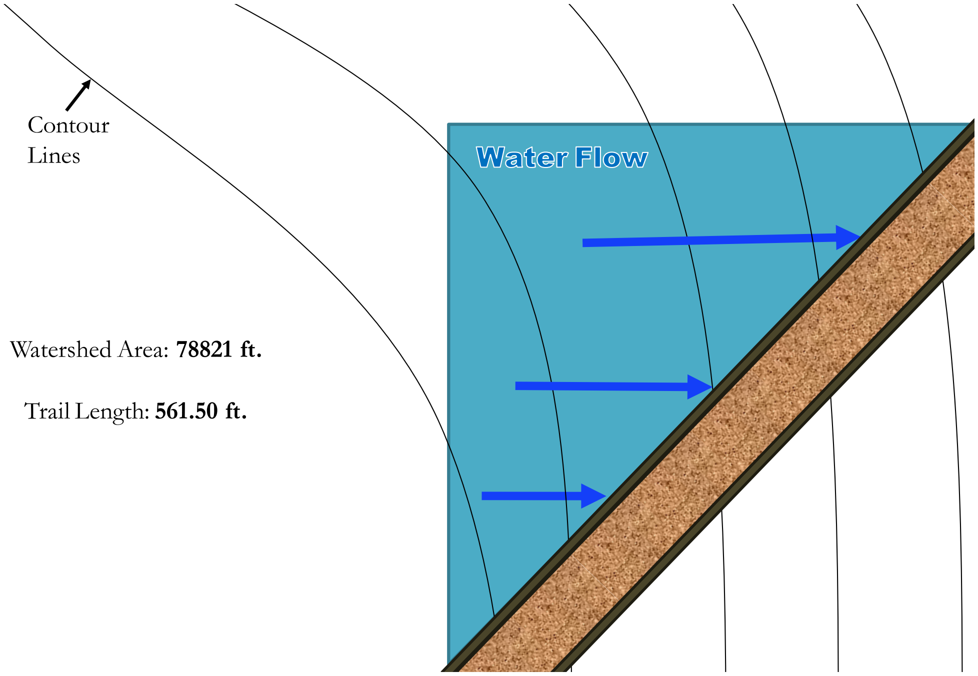


Figure 74 - Watershed Area

After finding the watershed area, the Rational Method was used to find the amount of water in cubic feet per second that the trail would have to cope with due to runoff[118].

$$Q = C * I * A$$

This was done by finding a runoff coefficient of 0.5 from the table in Figure 56.

$$Q = 0.5 * I * A$$

---

[118] Marsh 2004

This coefficient was multiplied by the amount of rain in a typical rainstorm 0.20 inches/hour[119], and in a worst case scenario calculation the 10-year storm number of 3.8 inches/hour.

$$Q = 0.5 * 0.20 * A$$

Those two factors were multiplied by the final factor, A, the watershed area which was 78821 square feet.

$$Q = 0.5 * 0.20 * 78821$$

The results from the Rational Method calculation for an average rainstorm and 10-year storm calculation are shown below in Figure 75 and 76.

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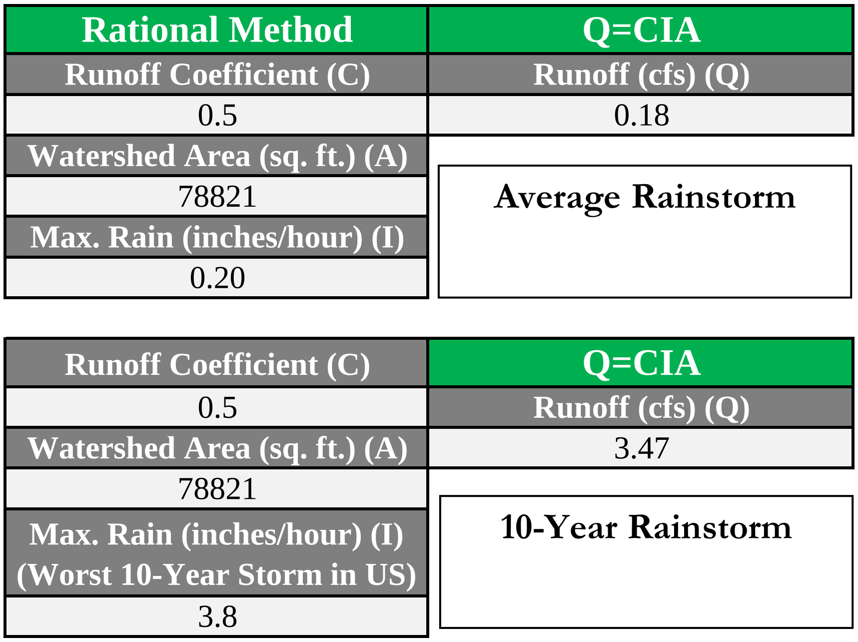
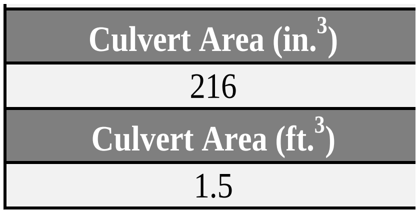
[119] Llubere, 2009



Rational Method	Q=CIA
Runoff Coefficient (C)	Runoff (cfs) (Q)
0.5	0.18
Watershed Area (sq. ft.) (A)	
78821	Average Rainstorm
Max. Rain (inches/hour) (I)	
0.20	

Runoff Coefficient (C)	Q=CIA
0.5	Runoff (cfs) (Q)
Watershed Area (sq. ft.) (A)	3.47
78821	
Max. Rain (inches/hour) (I) (Worst 10-Year Storm in US)	10-Year Rainstorm
3.8	

Figure 75 - Runoff Analysis Results



Culvert Area (in.^{3})
216
Culvert Area (ft.^{3})
1.5

Figure 76 - Culvert Results

5.2.6 Soil Sampling

Soil samples were taken in seven locations in the La Marta Wildlife Refuge. Four were taken on the Mountaintop Ascent Trail, two at the end of the service road, and one at the historic site. Table 13 displays the results of those samples, while Figure 77 shows the results after drying.

Table 13 - Soil Results

Survey Point	Trail Section	Material
#2	Section 1	Clay
#15	Section 4	Sandy Clay Loam
#22	Section 6	Sandy Clay
#32	Section 9	Clay
Platform-1 (Surface)	N/A	Sandy Clay
Platform-1 (2' BG)	N/A	Sandy Clay Loam
Platform-2	N/A	Sandy Clay

Figure 77 - Soil Sample After Drying

6.0 Conclusions and Recommendations

The project team concludes that the designs in this report will help to make the La Marta Wildlife Refuge a better place to visit and succeeded in its three main goals:

> **(1)** Design a sustainable trail leading up a mountain to an observation tower
> **(2)** Design a transport system to allow mobility-impaired persons to cross the Gato River, making the historic area of the site accessible
> **(3)** Design all-persons accessible trails and features to allow mobility-impaired persons to enjoy the historic site

The first goal may be implemented as soon as the park rangers have the time to begin work since the materials are all harvested on site and there is no starting capital needed. The second goal, which became a cable car design, will need starting capital and can be included as a future project in coming years. UMCA can begin to set aside monies in the next year's budget to prepare for this project.[120] The third goal of making the historic area trails accessible will be very easy to achieve due to the current condition of the existing trails.

These goals, when implemented, will create a better experience for tourists when implemented and will allow mobility-impaired persons to access the historic site which is currently a main attraction of La Marta.

There is also a large number of possible projects that WPI and UMCA could partner for in the future. There are possible IQPs available to research and create signs that explain the processes that took place all over the historic site as well as a project that could research how the canal system worked. UMCA told the project team on its tour of the refuge that not only did the

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[120] Lluebre, Sergio. "Typical Rainfall in Costa Rica." Personal interview. 5 Mar. 2009.

canal system provide water to all of the processes that worked in the historic site but that was also an electric turbine that the water powered and provided hydro-electric power to the area as well. UMCA would like to look into that turbine in the future and possibly restoring it as a historical project, a possible MQP. [121]The refuge also has many more campsites, research outposts, and swimming areas. Many of the trails that lead to those areas throughout the refuge could also be improved but were out of the scope of this project. All in all, there are many future opportunities for projects in the refuge.

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[121] Viquez, Manuel. "La Marta Information." Personal interview. 28 Jan. 2009.

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US Forest Service - Caring for the land and serving people. 3 Dec. 2008 <http://www.fs.fed.us/recreation/programs/accessibility/FSORAG.pdf>.

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8.0 Appendices

8.1 Appendix A: Summary of FSTAG requirements

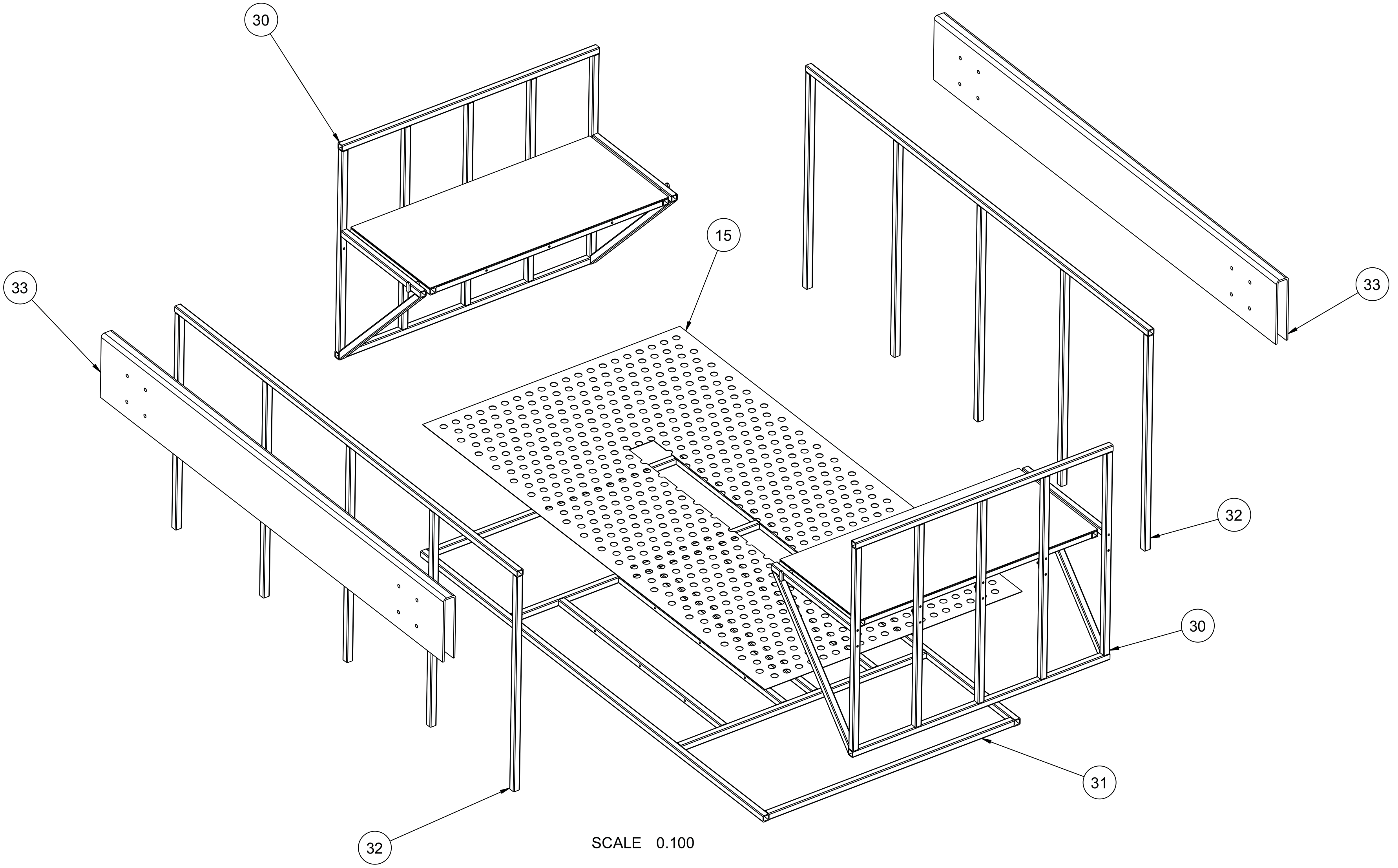
Section	Title	Guideline
T303.3	Surface	Firm and Stable
T303.4	Clear Tread Width	36 inches
T303.5	Openings	To prevent wheelchair wheels and cane tips from being caught in surface openings or gaps, openings shall be of a size which does not permit passage of a ½ inch diameter sphere; elongated openings must be perpendicular or diagonal to the direction of travel.
T322.1	Protruding Objects	Provide a warning if vertical clearance is less than 80 inches.
T303.6	Tread Obstacles	2 inch rocks, roots, ruts, and changes in level.
T303.7	Passing Space	At least 60 inches wide within 1,000 foot intervals.
T303.8.1	Cross Slope	1:20, except where drainage is needed, in which case use up to 1:10.
T303.8.2	Running Slope	1:20 – any length 1:12 – up to 200 feet 1:10 – up to 30 feet 1:8 – up to 10 feet *no more than 30% of the total trail shall exceed 1:12
T303.9	Resting Intervals	60 inches in length Less than 1:20 slope in all directions At intervals no greater than the lengths permitted under running slope
T303.10	Edge Protection	Where provided, the minimum height must be 3 inches. Handrails are not required.
T222	Trail Signs	Must indicate accessibility and total length of the accessible segment.

8.2 Appendix B: Mechanical Drawings

NOTES:

1 WELDS MUST ORIENT
PARTS TO ONE ANOTHER
AS SHOWN

2 BALLOONS COINCIDE WITH
ATTACHED BILL OF MATERIALS



SCALE 0.100

DRAWN BY:
BRYAN BIGDA
CHECKED BY:
RYAN SOTTOLANO
DATE:
04/13/09

WORCESTER POLYTECHNIC INSTITUTE

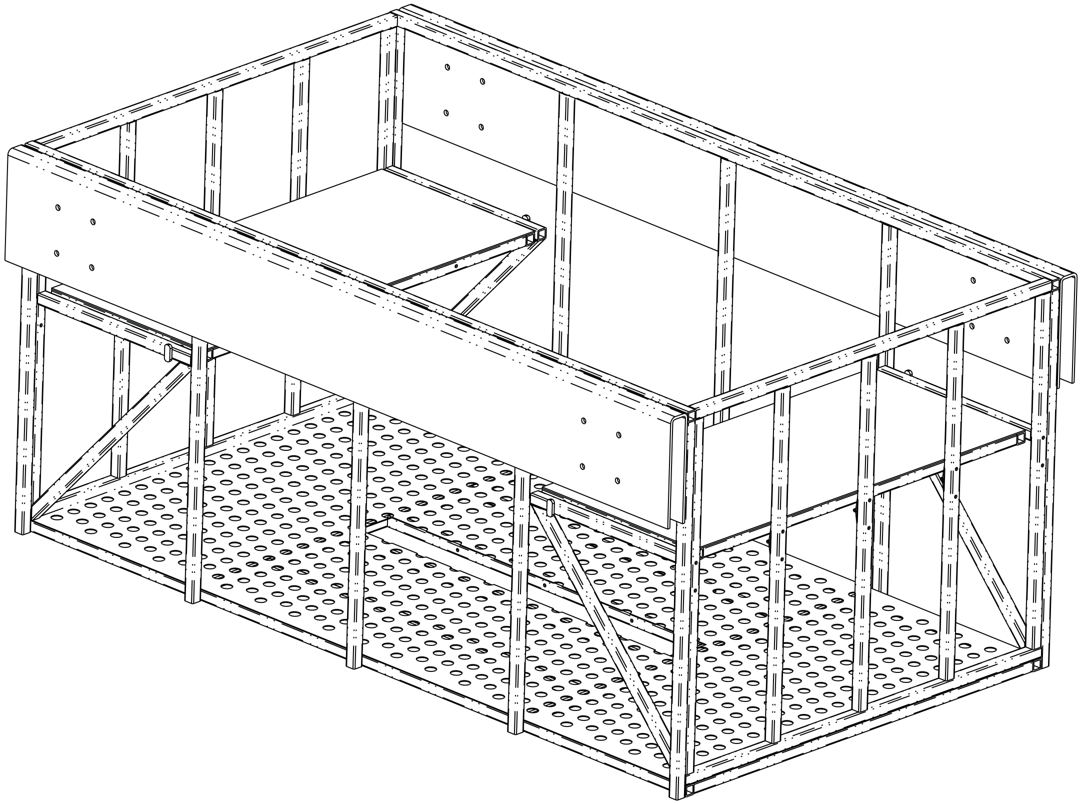
ZIP CAR

SIZE
C

TOLERANCES ±05 UNLESS OTHER SPECIFIED

SCALE: 1:10

ALL DIMENSIONS ARE IN INCHES

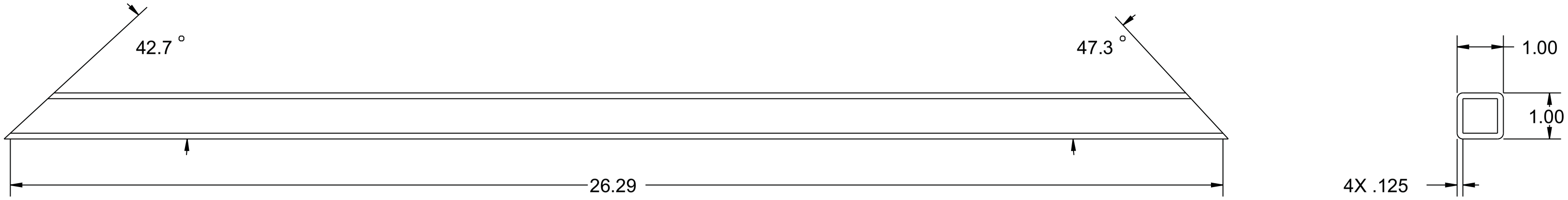


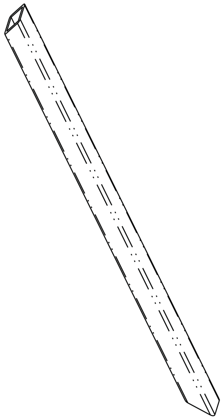
SCALE 0.125

NOTES:

1 MATERIAL: ASTM A500
GALVANIZED CARBON STEEL

2 RECOMMENDED SUPPLIER:
RYERSON CORPORATION
CHICAGO, ILLINOIS, U.S.A.





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CHECKED BY:
RYAN SOTTOLANO
DATE:
04/13/09

WORCESTER POLYTECHNIC INSTITUTE

STEEL SQUARE TUBING,
ANGLED

SIZE
C

TOLERANCES ±05 UNLESS OTHER SPECIFIED

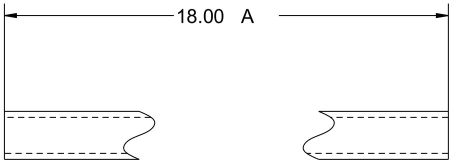
SCALE: 1:2
BILL OF MATERIALS #11
ALL DIMENSIONS ARE IN INCHES

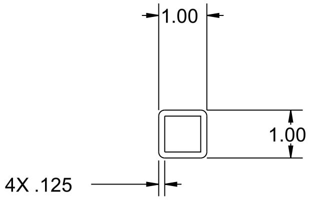
NOTES:

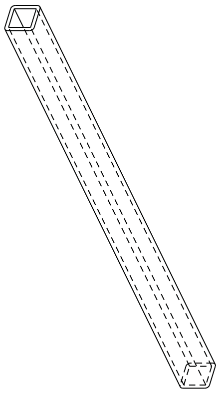
1 MATERIAL: ASTM A500
GALVANIZED CARBON STEEL

2 RECOMMENDED SUPPLIER:
RYERSON CORPORATION
CHICAGO, ILLINOIS, U.S.A.

PART NUMBER	A
1	18.00
2	19.50
3	32.00
4	34.00
5	37.00
6	40.00
7	42.00
8	78.00







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RYAN SOTTOLANO
DATE:
04/13/09

WORCESTER POLYTECHNIC INSTITUTE

STEEL SQUARE TUBING

SIZE
C

TOLERANCES ±05 UNLESS OTHER SPECIFIED

SCALE: 1:2

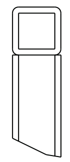
BILL OF MATERIALS #1-8

ALL DIMENSIONS ARE IN INCHES

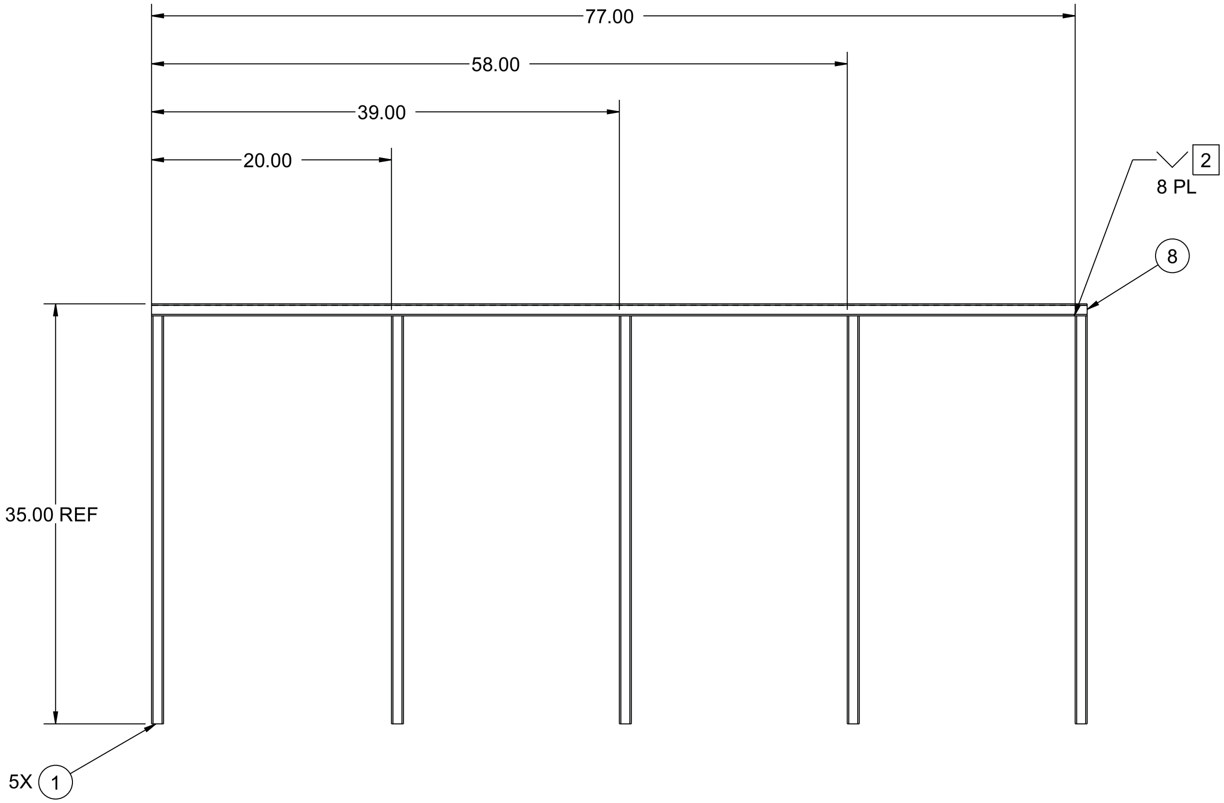
NOTES:

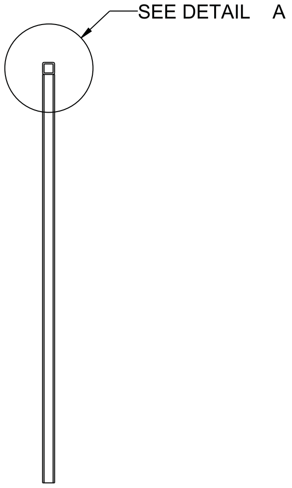
1 WELDS MUST ORIENT PARTS TO ONE ANOTHER AS SHOWN

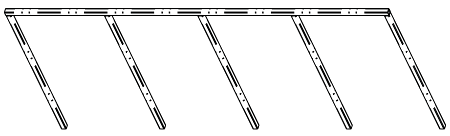
2 FILLET WELD



DETAIL A
SCALE 0.500







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RYAN SOTTOLANO
DATE:
04/13/09

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SIDE FRAME

SIZE
C

TOLERANCES ±05 UNLESS OTHER SPECIFIED

SCALE: 1:10

BILL OF MATERIALS #31

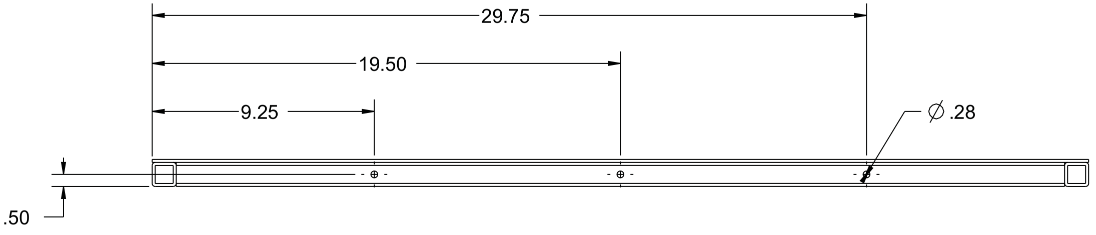
ALL DIMENSIONS ARE IN INCHES

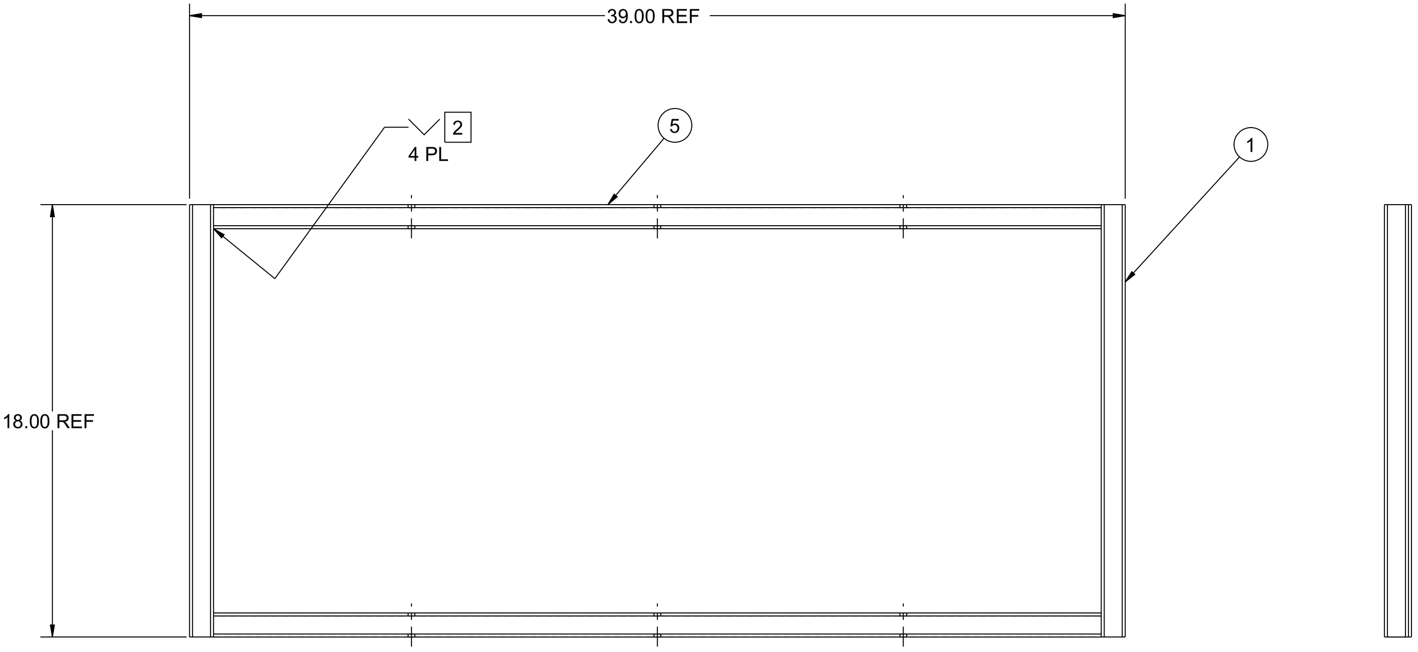
NOTES:

1 WELDS MUST ORIENT
PARTS TO ONE ANOTHER
AS SHOWN

2 FILLET WELD

3 ALL HOLES THROUGH





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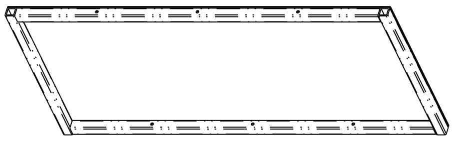


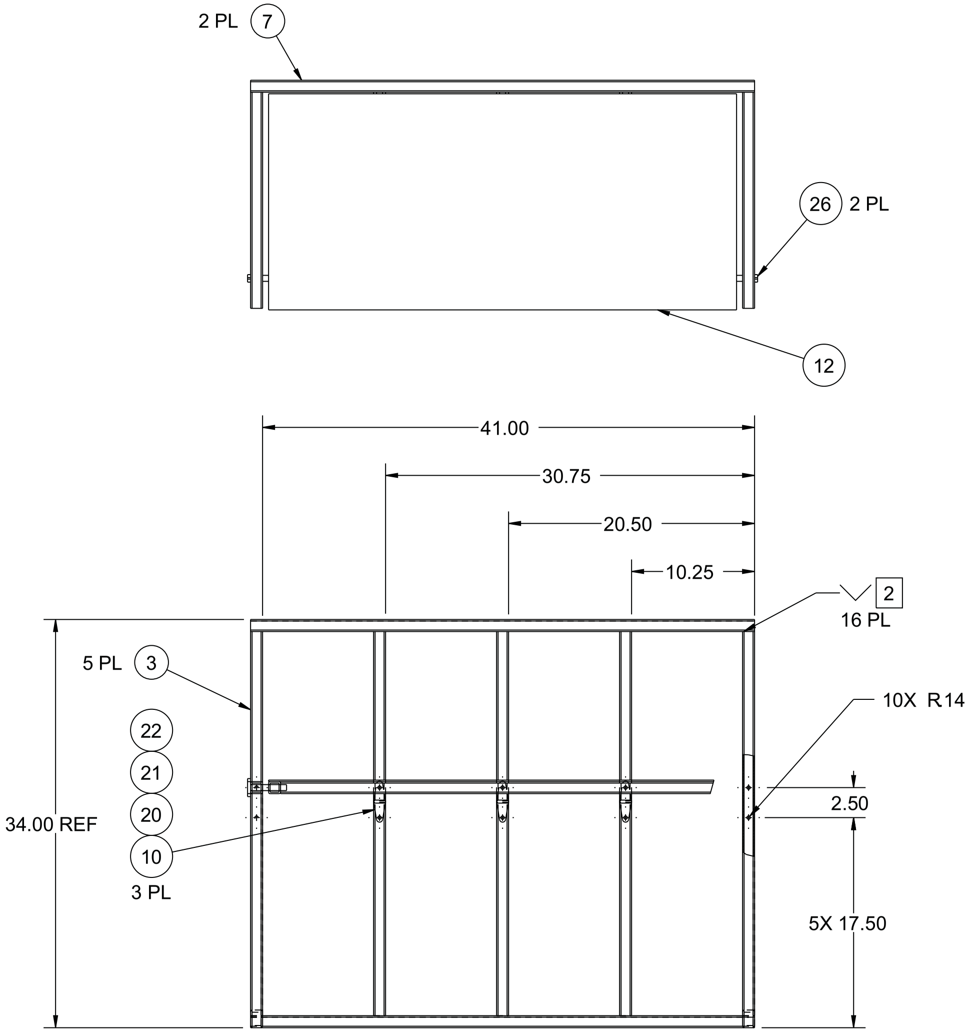
DRAWN BY: BRYAN BIGDA	*WORCESTER POLYTECHNIC INSTITUTE*
CHECKED BY: RYAN SOTTOLANO	
DATE: 04/13/09	SEAT FRAME
	SIZE C	TOLERANCES ±05 UNLESS OTHER SPECIFIED
	SCALE: 1:4	BILL OF MATERIALS #34	ALL DIMENSIONS ARE IN INCHES

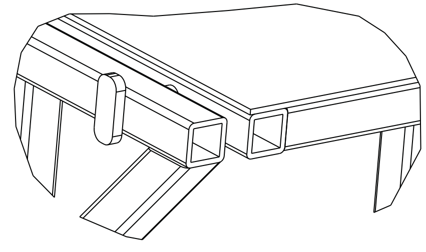
NOTES:

1 WELDS MUST ORIENT PARTS TO ONE ANOTHER AS SHOWN

2 FILLET WELD

3 ALL HOLES ARE THROUGH

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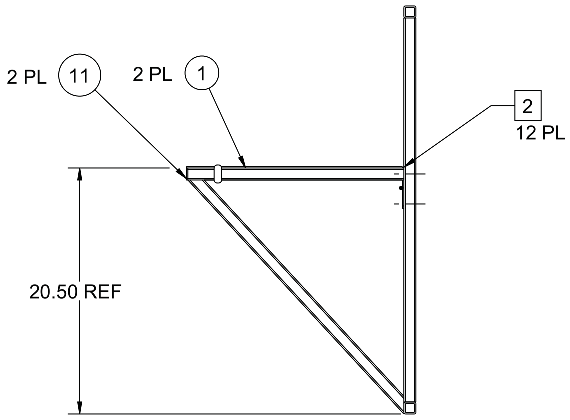

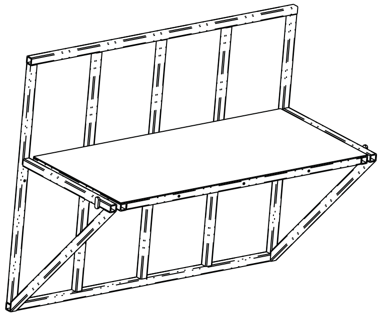

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CHECKED BY:
RYAN SOTTOLANO
DATE:
04/13/09

WORCESTER POLYTECHNIC INSTITUTE

GATE FRAME

SIZE
C

TOLERANCES ±05 UNLESS OTHER SPECIFIED

SCALE: 1:8

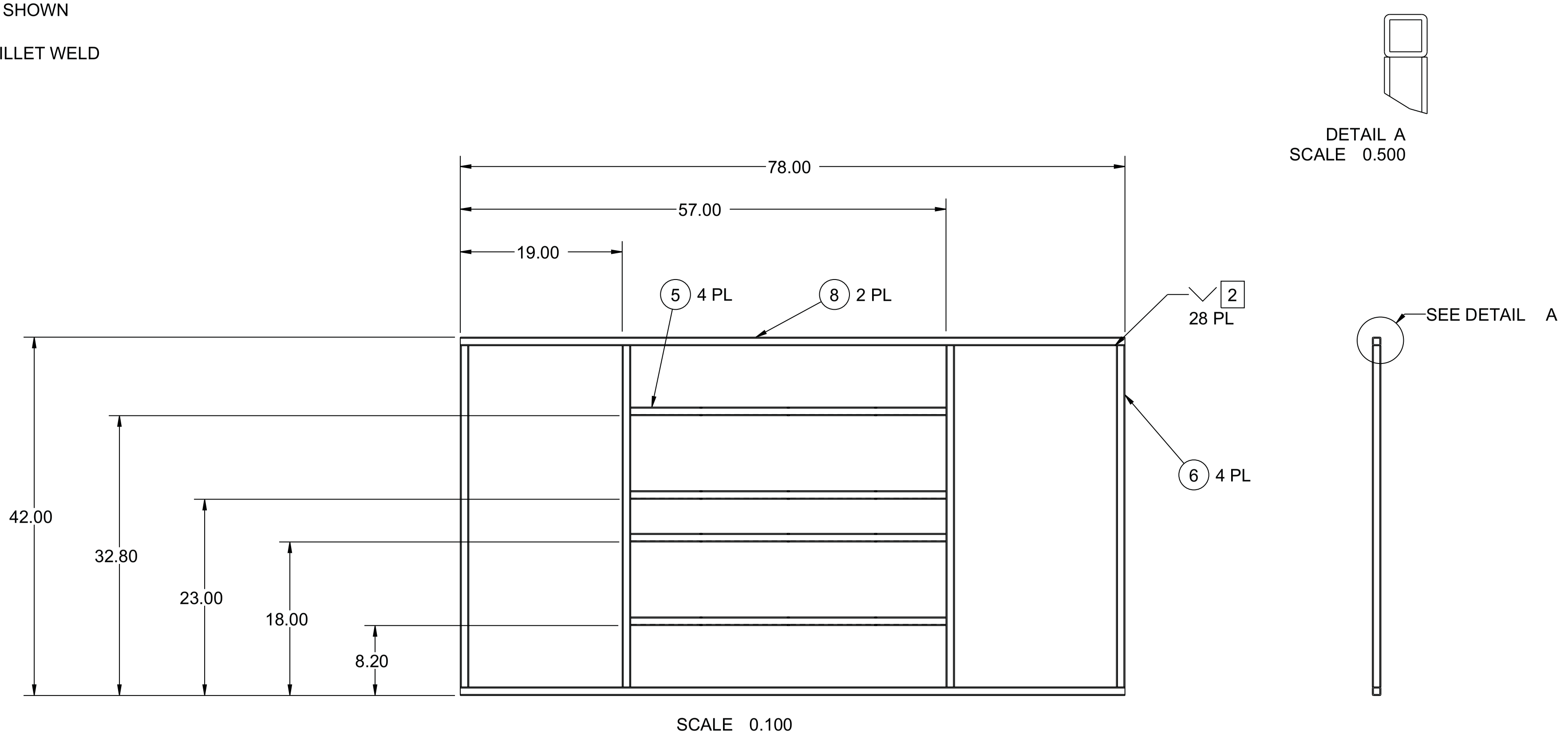
BILL OF MATERIALS #30

ALL DIMENSIONS ARE IN INCHES

NOTES:

1 WELDS MUST ORIENT
PARTS TO ONE ANOTHER
AS SHOWN

2 FILLET WELD



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RYAN SOTTOLANO
DATE:
04/13/09

WORCESTER POLYTECHNIC INSTITUTE

FLOOR FRAME

SIZE
C

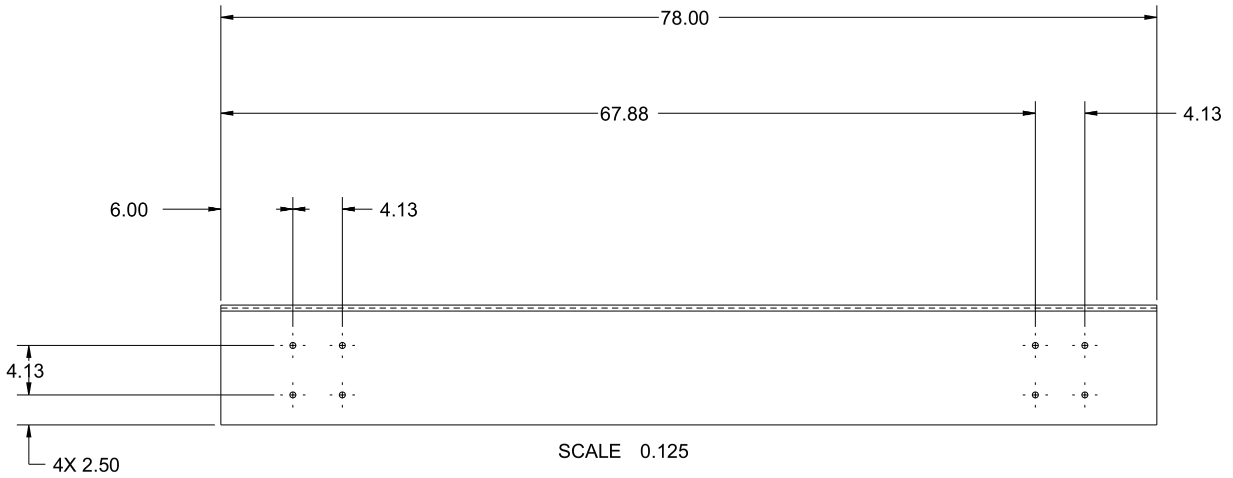
TOLERANCES ±05 UNLESS OTHER SPECIFIED

SCALE: 1:16
BILL OF MATERIALS #31
ALL DIMENSIONS ARE IN INCHES

NOTES:

1 MATERIAL: .25 THK ASTM A500
GALVANIZED CARBON STEEL

2 RECOMMEDED SUPPLIER:
RYERSON COMPANY
CHICAGO, IL, U.S.A.



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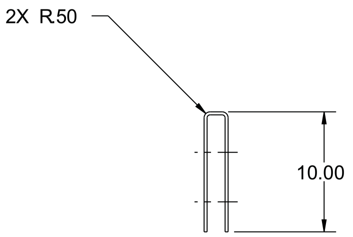
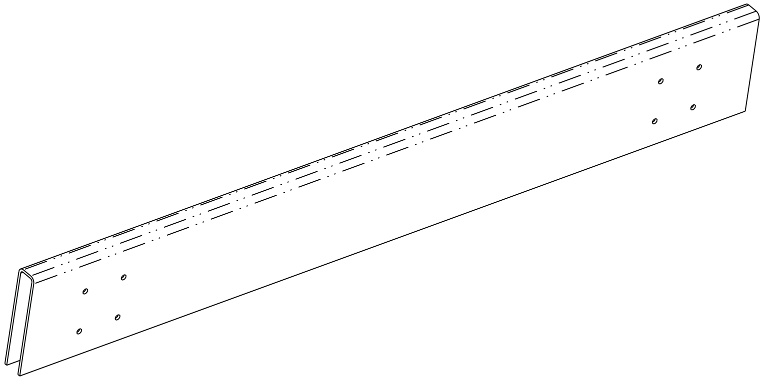




SCALE 0.125

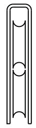
DRAWN BY: BRYAN BIGDA	*WORCESTER POLYTECHNIC INSTITUTE*	
CHECKED BY: RYAN SOTTOLANO		
DATE: 04/13/09	BEARING HOUSING	
	SIZE C	TOLERANCES ±05 UNLESS OTHER SPECIFIED
	SCALE: 1:8	BILL OF MATERIALS #13 / ALL DIMENSIONS ARE IN INCHES

NOTES:

1 ASSEMBLE BEARINGS TO BEARING HOUSING AS SHOWN

2 ASSEMBLE BEARINGS TO HOUSING USING HARDWARE PROVIDED BY BEARING SUPPLIER

SECTION A-A
SCALE 0.125



DRAWN BY:
BRYAN BIGDA

CHECKED BY:
RYAN SOTTOLANO

DATE:
04/13/09

WORCESTER POLYTECHNIC INSTITUTE

BEARING ASSEMBLY

SIZE
C

TOLERANCES ±05 UNLESS OTHER SPECIFIED

SCALE: 1:8

BILL OF MATERIALS #33

ALL DIMENSIONS ARE IN INCHES

8.3 Appendix C: Bill of Materials

Bill of Materials						
Part Number	Name	Quantity	Description	Suggested Supplier	Contact Information	Catalog Number
1	STEEL SQUARE TUBING	8	18 inches	Ryerson	773-762-2121	
2	STEEL SQUARE TUBING	4	19 inches	Ryerson	773-762-2121	
3	STEEL SQUARE TUBING	10	32 inches	Ryerson	773-762-2121	
4	STEEL SQUARE TUBING	10	34 inches	Ryerson	773-762-2121	
5	STEEL SQUARE TUBING	8	37 inches	Ryerson	773-762-2121	
6	STEEL SQUARE TUBING	4	40 inches	Ryerson	773-762-2121	
7	STEEL SQUARE TUBING	4	42 inches	Ryerson	773-762-2121	
8	STEEL SQUARE TUBING	4	78 inches	Ryerson	773-762-2121	
9	GATE HINGE	6	purchased part	Home Depot	1-800-553-3199	
10	SEAT HINGE	6	purchased part	Home Depot	1-800-553-3199	
11	ANGLE CUT TUBING	2	seat structure	Ryerson	773-762-2121	
12	SEAT SURFACE	2	ASTM A36 Hot Rolled plate steel, .25 thick	Ryerson	773-762-2121	
13	BEARING HOUSING	2	ASTM A36 Hot Rolled plate steel, .25 thick	Ryerson	773-762-2121	
14	BEARING	12	purchased part	NTN Bearing Co.	1-800-468-6528	MG-207-FFK
15	FLOOR SURFACE	1	ASTM 1010 bent sheet steel, .0625 thick	Ryerson	773-762-2121	
16	CHAIN LINK FENCE, SIDE	2	purchased part	Home Depot	1-800-553-3199	
17	CHAIN LINK FENCE, GATE	2	purchased part	Home Depot	1-800-553-3199	
18	FABRIC ROPE	160 FT	purchased part, 150 ft.	Home Depot	1-800-553-3199	
19	STEEL WIRE ROPE	280 FT	7 X 19 Galvanized Steel, 3/8 diameter	St. Pierre Manufacturing	508-853-8010	
20	BOLT, HINGE	12	.25 diameter galvanized, coarse thread, 4 in	Home Depot	1-800-553-3199	
21	NUT	12	.25 diameter galvanized, coarse thread	Home Depot	1-800-553-3199	
22	WASHER, LOCKING	12	.25 diameter	Home Depot	1-800-553-3199	
26	BALL LOCK PIN	6	.5 diameter, stainless stell, 4 inch length	Mcmaster Carr	(630) 833-0300	90293A416
30	GATE ASSEMBLY	2				
31	FLOOR FRAME	1				
32	SIDE FRAME	2				
33	BEARING ASSEMBLY	2				
34	SEAT FRAME	2				

8.4 Appendix D: Total Material Cost

Item	**Unit Price (Dollars)**	**Price (Dollars)**	**Price (Colones)**
Square Steel Tube (160ft)	N/A	560.00	316400.00
ASTM A36 Plate Steel (32 sqft)	N/A	150.00	84750.00
ASTM 1010 Sheet Steel (32 sqft)	N/A	70.00	39550.00
Bearings (12)	7.95	95.40	53901.00
7x7x19 Galvanized Steel 3/8 in (280 ft)	N/A	75.60	42714.00
Chain Link Fence (4 ft x 50 ft)	N/A	59.00	33335.00
Hinges (12)	10.47	125.64	70986.60
Bolt (12)	0.34	4.08	2305.20
Nut (12)	0.06	0.72	406.80
Lockwasher (box of 100)	N/A	11.67	6593.55
Fabric Rope (140ft)	.55 / ft	77.00	43505.00
Ball Lock Pin (6)	34.55	207.30	117124.50
Sand (As Needed)	0	0.00	0.00
Clay (As Needed)	0	0.00	0.00
Concrete (9.0 cu. Yds)	70.00	630.00	355950.00
4 X 4 X 8 (32)	11.97	383.04	216417.60
Post Base (32)	4.35	4.35	2457.75
2 X 6 X 8 (140)	5.95	833.00	470645.00
3/4" bolts (150)	0.90	0.90	508.50
3/4" lag screws (150)	0.90	0.90	508.50
carpentry nails (1 box)	14.98	14.98	8463.70
Railing System (As Needed)	0.00	0.00	0.00
Achiotillo Logs (As Needed)	0.00	0.00	0.00
Total		**3303.58**	**1866522.70**

8.5 Appendix E: Pairwise Reasoning and Decision Matrix

We chose to use a pairwise decision matrix to compare the six most important factors and give each of them a multiplier. One reason to limit the number of factors is to avoid one of the weaknesses of a pairwise comparison - more factors introduce arbitrary results. This is due to the fact that $\frac{n(n-1)}{2}$ comparisons must be made. Therefore with six factors a total of fifteen comparisons must be made. An increase to seven or eight factors would lead to twenty-one or twenty-eight comparisons respectively. With these added comparisons, it would be more difficult to keep all the factors in order. Thus we chose the six most important factors: Construction Cost, Safety, Ease of Operation, Durability, Maintenance and Aesthetics.

Table 14- Pairwise Comparison Chart

	Building Cost	Safety	Ease of Operation	Durability	Maintenance	Ambiance
Building Cost		1	0	1	0	0
Safety	0		0	0	0	0
Ease of Operation	1	1		0	0.5	1
Durability	0	1	1		0	0.5
Maintenance	1	1	0.5	1		1
Ambiance	1	1	0	0.5	0	
Total	3	5	1.5	2.5	.5	2.5

Table 14 is our Pairwise comparison. The horizontal and vertical headings represent the design criteria. They make a matrix where each factor is compared against each other factor. We totaled the values in the columns as opposed to rows; this means that the columns are of primary interest. A rating of 1 in a column means that the column header is deemed as more important than the row header. A rating of 0 is the opposite. A rating of 0.5 is used when the two factors are equivalent in importance to the design. Factors were not weighed against themselves, therefore a blank cell appears when the row and column header are the same.

The columns were then added to produce each multiplier for the decision matrix we will use later. The Safety multiplier is the highest at 5 making it the most important design factor. This means that each of our designs will have its safety rating multiplied by five and added to all the other ratings multiplied by their respective multipliers. The highest score should yield the best design based on the six factors used.

Construction Cost is the total cost of constructing the car. This includes all materials and labor. Safety measures all factors that involve reliability and safety of use. A high factor of safety and higher quality material selection both add to the overall safety of this device. Ease of Operation is how easy the design is for the operator to use. A lower required force and faster time of use both contribute to the Ease of Operation. Durability is how well the design will endure environmental factors and the regular wear and tear of use. A highly durable design will be resistant to the moisture and heat of the area and have a low fatigue factor leading to a long life cycle. Maintenance is the annual cost of maintaining the design. This includes repainting, lubricating and fixing broken parts. Aesthetics is the ability of the design to fit in well with the environment. La Marta has a special environment and maintaining the integrity of that environment is important.

The rationale for each decision is outlined in the next few paragraphs. It is important to keep in mind that these are subjective comparisons. Many different points of view were taken into account when we made these decisions. We met with several people who run the La Marta wildlife refuge to get their (the sponsor's) input. This input was the primary consideration. La Marta is run on a small budget and most of their improvements are financed by donations. Therefore price is a critical factor. Aesthetics, the general ambiance is also important to La Marta. Tourists at the attraction expect to see wildlife and facilities that fit in with the natural environment. Other points of view accounted for were the operator and that of a responsible citizen.

Rationale:

Building Cost vs. Safety: Safety. We are not willing to sacrifice safety for cost. If the device costs a certain minimum amount of money to be safe, then we cannot ethically design something unsafe that is cheaper. Failure of our design would result in significant physical peril to the users, making safety of utmost importance. However, this does not mean that we are willing to invest in safety past the point of reasonable diminishing returns.

Ease of Operation vs. Building Cost: Building Cost. UMCA is on a tight budget and it is acceptable to design something that is more difficult to use if it comes at a lower cost.

Durability vs. Building Cost: Durability. A higher building cost can justify a more durable structure. Higher durability would minimize maintenance costs and allow the device to remain in use for a longer period of time. The extra time between having to replace the design is worth the short term drawback of a higher price. The transport system must be durable enough to provide a return on investment. Therefore a higher building cost can be justified by making the design to an appropriate level of durability.

Maintenance Cost vs. Building Cost: Building Cost. The maintenance cost is relatively small when compared to building cost. Therefore a 10% decrease in building cost is much more important than a 10% decrease in maintenance cost.

Aesthetic vs. Building Cost: Building Cost. Aesthetic can be sacrificed in the vicinity of the device as there are many other areas that are completely natural and unaffected by this device. Again, building cost is a major concern because the UMCA budget is low.

Ease of Operation vs. Safety: Safety. If the device is not safe, serious ethical and economical ramifications can entail. The potential for human injury cannot be overlooked for a design that is easier to operate.

Durability vs. Safety: Safety. The device can be extremely durable and still be unsafe. One example is a bridge without guardrails can be durable but not necessarily safe. Durable materials cost more than less durable materials. In this case we would rather use less durable materials that allow for a guardrail thus being safer.

Maintenance Cost vs. Safety: Safety. We would rather have the device need routine maintenance than be dangerous.

Aesthetic vs. Safety: Safety. We will not forgo safety for the sake of using materials that blend in better with the general aesthetic.

Durability vs. Ease of Operation: Ease of Operation. We are willing to sacrifice a bit of durability for easier use. Durability affects long term cost of operation. A more durable structure is cheaper over the lifetime of the device. We are willing to sacrifice some Ease of Operation for the sake of a more durable design.

Maintenance Cost vs. Ease of Operation: Tie. The maintenance cost should be as low as possible. At the same time, an easier to use device is desirable. These two factors are linked. Routine maintenance should make the operation of the device easier.

Aesthetic vs. Ease of Operation: Aesthetic. The Aesthetic is a more important factor than ease of use. There are four park rangers at La Marta that are capable of operating the transport system, so maintaining the aesthetic integrity is more important than having an easier to operate device.

Maintenance Cost vs. Durability: Durability. A more durable structure would not need to be replaced as frequently. Even if we could halve the cost of maintenance, it would not make up for a less durable structure as the initial construction cost is much greater than the maintenance cost. This makes durability a clear choice.

Aesthetic vs. Durability: Tie. Durability and Aesthetic are both desirable qualities. We are not willing to sacrifice aesthetic for durability or vice versa.

Aesthetic vs. Maintenance Cost: Aesthetic. We would rather the device blend in with the environment than have cheap maintenance costs since the maintenance costs are minimal.

Each design was put into the following matrix where it was given a ranking in each of the factors from our pairwise matrix:

Table 15 - Decision Matrix

	Safety	Ease of Operation	Construction Cost	Maintenance Cost	Durability	Ambiance	Score
Gravity Feed	3	4	3	3	4	2	46.5
Pull Car	4	2	4	4	4	3	54.5
Pendelum	3	4	2	2	4	2	43
Rider Crank	4	3	3	3	4	2	50
Water Powered	3	5	2	1	3	2	41.5
Suspension Bridge	4	4	4	4	3	4	57.5
Wooden Truss Bridge	5	5	3	4	2	3	56
Steel Truss Bridge	5	5	1	5	5	1	53
Weight:	5	1.5	3	0.5	2.5	2.5	

Each prospective design was assigned a value from 1 to 5 for each of the design factors, 1 being the worst and 5 being the best. These values were then multiplied by the weighting factors derived from the pairwise comparison and added together to provide each design's score. This process is somewhat subjective and there is a large margin of error. To account for this, a tolerance of ten percent is afforded. Therefore any designs having a final score within ten percent of the highest score are deemed equal. Four of our designs fell within this ten percent tolerance: Pull Car, Suspension Bridge, Wooden Truss Bridge and Steel Truss Bridge.

The scale for each factor of our design matrix is as follows:

Safety: Weight = 5
1: Injury is highly likely
2: Injury is likely to occur, even with proper routine maintenance
3: Injury should not occur if proper routine maintenance is conducted, unless design is improperly used
4: Injury should not occur even if routine maintenance is neglected, unless design is improperly used
5: Injury should not occur

Ease of Operation: Weight = 1.5
1: Requires great physical stress that 25% of people are capable of using
2: Requires physical stress that 50% of population are not capable of performing
3: Requires moderate physical stress by operator – 75% of population can use device
4: Requires little force by operator – 90%+ of population can use device
5: Requires little force by operator – 99% + of population can use device

Construction Cost: Weight = 3
Labor is not a factor in the Construction cost because the labor will be performed by the park rangers already employed by the La Marta Wildlife Refuge. Any additional labor will cost a negligible amount. Hourly workers make less than the equivalent of three dollars per hour.
1: $2000 +
2: $1500 - $2000
3: $1000 - $1500
4: $500 - $1000
5: $0 - $500

Maintenance Cost: Weight = 0.5
1: Requires high frequency with many components, $500+ per year
2: Requires medium frequency with high cost or high frequency with med. cost, many components
3: Requires medium frequency with medium cost, few components, $300 - $500 per year
4: Requires infrequent with high cost or frequent with low cost, few components
5: Requires infrequent, low cost maintenance, very few components, $0 - $300 per year

Durability: Weight = 2.5
1: Expected service life of 0 - 20 years
2: Expected service life of 20 -40 years
3: Expected service life of 40 - 60 years
4: Expected service life of 60 -80 years
5: Expected service life of 80+ years

Aesthetic: Weight = 2.5
1: An eyesore, does not blend in whatsoever
2: Looks out of place
3: Blends in fairly well
4: Blends in very well
5: No discernable difference between atmosphere and device

The reasoning behind each decision in our design matrix is as follows:

Design 1: Gravity Feed

- Safety: 3. This rating is due to lower control over operating speeds as opposed to the other designs. Acceleration due to gravity causes the motion
- Ease of Operation: 4. Gravity does a majority of the work
- Construction Cost: 3. Requires steel beams, steel cable, structural components, a car, a crank
- Maintenance Cost: 3: Small crank mechanism to move empty car
- Durability: 4. Minimal moving parts. Made of steel. High service life expected
- Ambience: 2. Metal components, does not fit natural environment, machinery

Design 2: Pull Car

- Safety: 4. Motion is in a flat plane, the only moving parts are the bearings. It is highly unlikely that the bearings will fail.
- Ease of Operation: 2. Pulling a car/wheelchair/user would be strenuous
- Construction Cost: 4. Requires steel beams, steel cable, structural components, a car, rope
- Maintenance Cost: 4. Requires minimal maintenance.
- Durability: 4: Minimal moving parts. Made of steel. High service life expected
- Ambience: 3. Metal Components, does not fit natural environment well, but lack of machinery makes its appeal more rustic fitting the environment

Design 3: Counter-Balanced Dual Cable Car

- Safety: 3. Higher operating speed as well as need for a braking mechanism and a restraining mechanism
- Ease of Operation: 4. Gravity does a majority of the work
- Construction Cost: 2. Need for 2 cars, crank mechanism, braking mechanism, steel components
- Maintenance Cost: 2. Many components, two crank mechanism to move loaded cars final distance
- Durability: 4. Moving parts. Made of Steel. High service life expected.
- Ambience: 2. Metal components, does not fit natural environment, machinery

Design 4: Rider Crank

- Safety: 4. Motion in a flat plane. Slow operating speed.
- Ease of Operation: 3. Human power aided by machinery
- Construction Cost: 3. Requires steel beams, steel cable, structural components, a car, a crank
- Maintenance Cost: 3. Crank mechanism to move loaded car
- Durability: 4. Moving parts. Made of steel. High service life expected.
- Ambience: 2. Metal components, does not fit natural environment, machinery

Design 5: Water Powered

- Safety: 3. Motion in a flat plane, variable speed depending on river
- Ease of Operation: 5. Minimal user responsibility. Use of clutch will stop car

- Construction Cost: 2. Extra material needed for water wheel and clutch mechanism.
- Maintenance Cost: 1. Frequent maintenance needed. The wheel will need to be greased often as it will be in continuous motion. Many moving parts.
- Durability: 3. Many moving parts. Wood material for the waterwheel. Medium service life expected
- Ambience: 2. Disruptive to natural environment, machinery, many moving parts

Design 6: Suspension Bridge

- Safety: 4. No moving parts. On a flat plane. Bridge rocks back and forth on axis perpendicular to direction of motion
- Ease of Operation: 4. Wheelchair user has to maneuver self on non rigid surface
- Construction Cost: 4. Same steel cable required as other designs, wood materials needed for planking
- Maintenance Cost: 4. Use of water repellent / treated wood. Replacement of planks as necessary.
- Durability: 3. Wood is less durable than steel Medium service life expected
- Ambience: 4. No moving parts. Made of wood and steel.

Design 7: Truss Bridge (Wooden)

- Safety: 5. No moving parts. Flat plane.
- Ease of Operation: 5. Wheelchair user self-propels on flat, rigid surface
- Construction Cost: 3. Wood material is cheaper than steel.
- Maintenance Cost: 4. Use of water repellent / treated wood.
- Durability: 2. Structural integrity is reliant on wood
- Ambience: 3. No moving parts. Made of wood.

Design 8: Truss Bridge (Steel)

- Safety: 5. No moving parts. Flat plane.
- Ease of Operation: 5. Wheelchair user has to maneuver self on rigid surface that is flat
- Construction Cost: 1. Most expensive option requiring a large quantity of steel.
- Maintenance Cost: 5. Requires minimal maintenance
- Durability: 5. Highly durable. No moving parts
- Ambience: 1. Would not fit in with the natural aesthetic.