K’ellu Mayu River Pedestrian Footbridge Technical Report

A Technical Report submitted to the Department of Civil and Environmental Engineering

Presented to the Faculty of the School of Engineering and Applied Science

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In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction and Background

This report will describe the type, size, and location study performed by the UVA Capstone team for a pedestrian footbridge in Bolivia that crosses the Río K'ellu Mayu and links the Pocona Municipality to vital resources in the region (Figure 1).

The pedestrian bridge design consists of a suspension footbridge over the Río K'ellu Mayu and will serve the Pocona Municipality in Bolivia. Residents of the municipality requested this bridge because they cannot cross the river 150 days of the year due to flooding. The river's flooding is exacerbated during the rainy season that takes place from November to March[1]. The lack of a suitable river crossing restricts their access to schools, health clinics, markets, and other services. Children must cross the river daily to attend primary and secondary schools. These schools are located 18 kilometers (about 11.18 mi) away from the site. The nearest medical clinic is across the river and is also 18 kilometers away from the site. The community currently uses makeshift crossings over the Río K'ellu Mayu, and they are not safe, reliable, or durable for use as permanent crossings. There have been no reported river crossing deaths to date, but residents risk their lives when crossing the river during the high-water months and will continue to do so as it is their only connection to vital resources.

The K'ellu Mayu community's economy is centered around agriculture and animal tending. Cultivated crops include potatoes, corn, wheat, peas, beans, barley, peaches, and apples. Animal husbandry includes cows and sheep.

The bridge will be designed to safely support pedestrians traveling across the river on foot, as well as those with bicycles, motorcycles, wheelbarrows, and livestock. Constructing this bridge will directly aid the 190 residents of the community, 10 of whom are children. In addition, about 220 people in neighboring communities will use the bridge for year-round market access. Providing access to markets, health centers, and schools will together improve economic conditions and attract additional residents to the municipality.

The bridge is located in the Cochabamba region of Bolivia (Figure 1). According to the Project Social Evaluation report provided by the organization Engineers in Action (EIA) and prepared by Mr. Richar Galvez on May 7, 2022 (Appendix 5.4), the nearest pedestrian bridge is the Yana Gaga pedestrian bridge located 8 kilometers downstream of the site. Additionally, the site is 2 kilometers away from their nearest beneficiary community. The nearest town, Lopez Mendoza, is about 16 kilometers (about 9.94 mi) away to the west of the site, and the closest market, hospital, and school are 18 kilometers away to the east (Figure 1). In addition, the closest paved road to the site is Old Cochabamba Road Santa Cruz (Route 7).

[1] "When to visit Bolivia". Exoticca. Accessed December 5, 2023

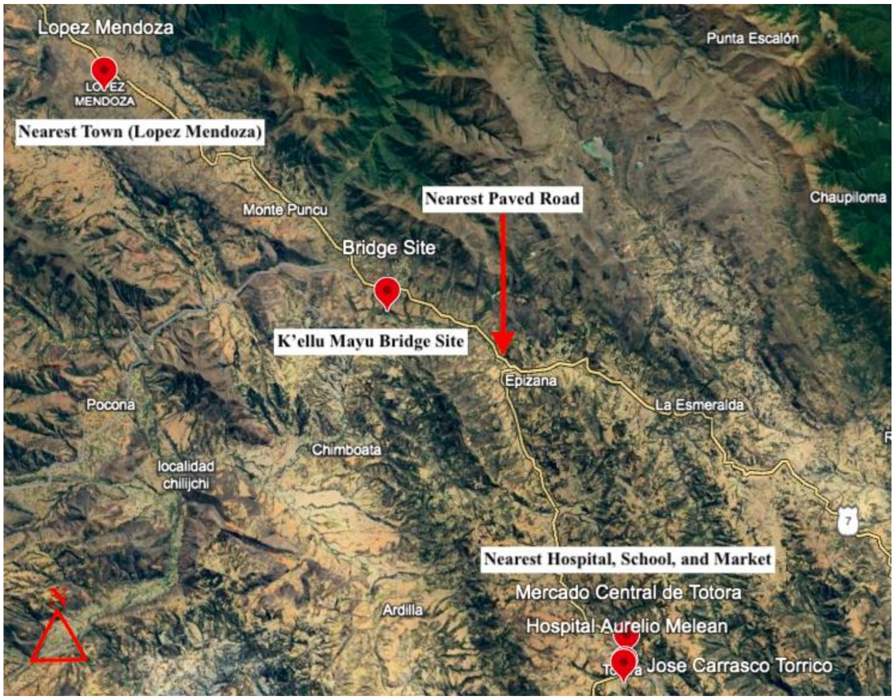

Figure 1. Bridge site location relative to other local resources

The bridge's proposed alignment is illustrated in Figure 2. According to EIA conventions, one should be facing in the direction of the river's downstream flow when determining which is the "left" and "right" abutment. The K'ellu Mayu river flows westward, meaning the left abutment faces the agricultural land and the right abutment faces unpaved vehicular road (Figure 2). This unpaved vehicular road is a different road than the paved Old Cochabamba Road and is located closer to the site.

Figure 2. Aerial view of bridge site

The Social Evaluation (Appendix C) provided by Engineers in Action describes the bridge site, allowing us to determine its vertical and horizontal clearances. In this description, they state that there are houses and agricultural land adjacent to the left riverbank, neither of which will affect or be affected by the bridge construction. The land on this side of the river is also described to be flat in both the longitudinal and transverse directions. There is little vegetation, including Sewenka plants and two Alder trees. On the river's right side, the land is sloped longitudinally and flat in the transverse direction. The vegetation on this side of the river is mainly native Kewinas trees. According to the Technical Evaluation provided by EIA (Appendix C), there are no obstructions such as adjacent structures, buried pipes, electrical lines, or drainage that need to be mitigated prior to the bridge construction.

Regarding material acquisition, Bridges to Prosperity developed a Bridge Builder Manual which dives into the organization's principles and strategies regarding pedestrian bridge projects (Appendix C). Importantly, the manual outlines the typical roles and responsibilities of key stakeholders in a bridge project (Table 1). EIA follows the same format as Bridges to Prosperity. Our project's material acquisition process will follow what is outlined in the table. The Municipal Government of Pocona, our site's local government, is responsible for heavy machinery work and the transportation of materials. The K'ellu Mayu community and Bridge Committee are responsible for building and maintaining the bridge. Lastly, EIA is responsible for acquiring materials that are not available in Bolivia.

Table 1. Key stakeholders' roles, responsibilities, and contributions table

Local Government		
Role	Responsibilities	Contribution
Lead project and support community	• Purchase of materials not available for collection • Transportation of materials • Heavy machinery work • Legal support	• Skilled labor • Purchased sand • Purchased gravel • Purchased stone • Purchased timber • Cement • Reinforcing steel • Fencing
Community and Bridge Committee		
Role	Responsibilities	Contribution
Build and maintain bridge	• Organization of work groups • Resolution of communiy related issues • Organize community contributions • Collection of local materials • Site Prep • Material Storage • Accomodation & food for any B2P staff on site	• Unskilled labor • Collected sand • Collected gravel • Collected stone • Collected timber
B2P or Other Qualified Partner		
Role	Responsibilities	Contribution
Facilitate and supervise project	• Engineering services/bridge design • Construction supervision • Acquisition of materials not available in country	• Construction drawings • Experienced construction supervisors • Cables and clamps • Steel towers (if applicable) • Steel crossbeams (if applicable)
Partner Organization		
Role	Responsibilities	Contribution
Support community in implementation of bridge project	Any of the responsibilities of the other three key stakeholders as agreed upon by all key stakeholders and based on organization's experience and strengths	Any of the contributions from other three key stakeholders dependent upon the agreed responsibilities

With regards to the K'ellu Mayu Bridge, components other than the cables will be constructed using locally sourced materials. According to the List of Materials, Services, and Project Financing Amounts that was provided by EIA (Appendix 5.10), the project's three material suppliers are Engineers in Action, the Municipal Government of Pocona, and the K'ellu Mayu Community. This material's list was stamped for approval by the Pocona Municipal Government as seen on the document (Appendix C). Per the list, EIA will supply galvanized steel cables, and other components such as galvanized clamps, tubes, and hooks. The Municipal Government of Pocona will be responsible for providing nearly all other materials, including Portland cement, tie wire, nails, screws, washed gravel, paint, and sand. Lastly, as stated in the project's Social Evaluation (Appendix C), the primary material that exists in the K'ellu Mayu river, community, and nearby communities is stone. Therefore, the K'ellu Mayu Community will supply stone for the bridge abutments. They will also provide the manpower to support the physical labor of constructing the bridge.

The Municipal Government of Pocona is transporting non-local and local materials to the site, which is accessible year-round by vehicle. On the right side of the river, there is no direct access to where the abutment will be placed. However, the community and the municipality will create an access route approximately 150 meters from the vehicular road. There is also direct access to the proposed left abutment location. According to the municipality, access to the left abutment will require cleaning of vegetation and other natural obstructions 100 meters from the vehicular road.

During bridge construction, vegetation and soil on both sides of the river will require removal. The construction team must be cautious when removing the existing vegetation and soil to reduce the risk of the river water being polluted by the removed materials. Also, the soil removed if not relocated properly could become suspended solids and pollute the air. Lastly, there will be environmental impacts such as water and air pollution during the mixing and pouring of concrete. The construction will have to be cautious during this process to prevent the concrete harming the surrounding land. The land on the right side of the river is owned by Mr. Sebastian Parra, who has agreed to the build. According to the social evaluation conducted by the community, Mr. Parra was present during the site survey. Based on the same evaluation, the owner is not listed, but the project will not disturb other private buildings. EIA has provided the signed confirmation documents from the K'ellu Mayu Board of Directors for the bridge to be constructed.

The goal of this project is to meet the K'ellu Mayu community's needs. To accomplish this goal, the team's approach to international development involves being empathic learners throughout this process. The team recognizes that this is an opportunity for the Pocona community to get safe access over the river throughout the year and for the capstone group to learn from Bolivian culture. We are grateful to be a part of the community building this necessary footbridge.

Geotechnical and Hydraulic Conditions

Before beginning the bridge's design, an overview of the site's geotechnical and hydraulic conditions was developed using materials that EIA provided. Figure 3 shows an aerial view of the Río K'ellu Mayu bridge site (coordinates -17.620584, -65.271513). Using EIA's naming conventions, the left riverbank is facing the agricultural land, and the right bank is facing the road.

Figure 3. Site overview

A topographic survey was completed by Mr. Richar Galvez on May 7, 2022. Mr. Galvez also conducted the site's Technical Evaluation (Appendix C). He provided a topographic profile of the site on AutoCAD, as well as site videos and photos. The original survey data and the AutoCAD survey profile generated were provided by EIA.

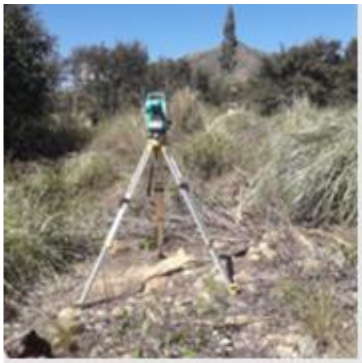

Figure 4. Total station survey

Figure 5. Dual grad prism pole

Figure 6. Survey marker **3.3**

Both sides of the river at the site are inaccessible by vehicles. Based on the Social Evaluation (Appendix A.4), the owner of the land on the left side of the river is not listed. To access the right side of the bridge, the community and municipality will build a 150-meter-long provisional road. This land is owned by Mr. Sebastian Parra. The left and right sides of the site will need vegetation cleared. The left side has little vegetation, while the right side has significantly more trees present. This is explained in greater detail in section 2.3. There are no known utility conflicts on our site.

Regarding existing soil conditions, the soil classification on the river's left side is sandy loam according to the Technical Evaluation (Appendix C). Per EIA's Bridge Program- Volume 2, the soil bearing capacity is 143 kPa or 20.7 psi[4]. According to EIA's Advanced Suspended Bridge Design Module, the soil has a safety factor of 2. The right-side soil is clay. The assumed soil bearing capacity on the right side is 95.3 kPa or 13.2 psi, and the factor of safety is 3.

The high-water line is the line at the riverbank where the water reaches during high water events (Figure 7). Per the Social Evaluation completed by Richar Galvez on May 07, 2022 (Appendix C), the river floods for approximately one day a year during the rainy season. The High-Water Line (HWL) was established by local elders from storm events they experienced in their lifetime. The HWL is 2732' above sea level. According to EIA's Bridge Program- Volume 2, all suspended bridge sites should be considered a gorge and will have a 3.0 meter freeboard[5]. Gorge flow only goes downstream quickly and rises. Freeboard is the minimum required height of the footbridge relative to the high-water line.

Figure 7. High-water line marking

Design

Standard Design

Figure 8 below illustrates an elevation view of the bridge's standard design. This shows the span and the abutments. A standard 3G60A abutment was chosen for the left riverbank. 3G60A consists of 3 tiers (3G60A) for a 40–60 meter span (3G60A) and a ground slope between 0 and 5 degrees (3G60A). A 1G60B abutment is designated for the right riverbank. A 1G60B abutment has 1 tier (1G60B) for a 40–60-meter span (1G60A) with a ground slope angle between 5 and 10 degrees (1G60B). A standard A4 anchor was used (Appendix A.9c). A standard T4 tower is used due to the 4-cable design (Appendix D.2). According to EIA's Bridge Program- Volume 2, "Empirical data has proven that bridges of up to 120-meters in span show no significant dynamic effects due to wind load. Therefore, no lateral stabilizing measures are considered in this suspended bridge design guide." Because our span is 44.50 meters this design did not consider wind loads.

A constraint of the location is the elevation difference of the lower left side to the right. A difference of 2.18 meters was measured.

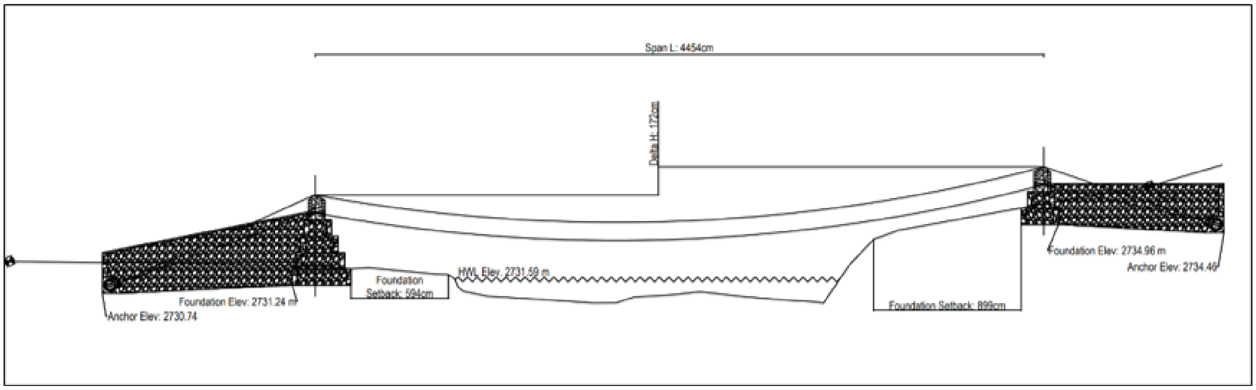

Figure 8. A dimensioned drawing of standard design bridge showing span and abutments

EIA Bridge Program- Volume 2, the footbridge is required to meet the below listed geometric evaluation criteria[7]:

- The maximum span shall not exceed 120 meters to avoid lateral stabilizing measures. The proposed footbridge spans approximately 44.50 meters (see figure 8).
- The foundation set-back from the edge of the riverbank to the top of the foundation must be at least 3 meters on either side due to soil conditions. 3 meters is the requirement under soil conditions, rock requires a different measurement. The setback reduces issues from erosion. The left side foundation setback is 5.94 meters, and the right-side setback is 8.99 meters. Start of the bank was assumed to be where the grade began sloping uniformly.t
- The foundation setback requires a maximum angle of friction of 35 degrees on each riverbank to reduce potential erosion issues. The proposed bridge has an internal angle of friction of 11.33 and 25.76 degrees on the left and right riverbanks respectively.
- The angle of the ground slope shall be 0 to 10 degrees. The ground slope is the uniform slope of the terrain past the bank. The proposed footbridge has an angle of 4 degrees on the left side and 10 degrees on the right. The slope angle approximates the ground slope. The difference in the height between the two towers is a serviceability design constraint to avoid a steep walkway. The height between the saddles shall not exceed 4% of the span. Under the standard design, the proposed footbridge The standard design has an elevation difference between the two sides of 3.86%.

Table 2. Proposed design geometric requirements summary

Variable	Value	Limit	Units	Checks
Left foundation setback	5.94	3.0	meters	OK
Right foundation setback	8.99	3.0	meters	OK
Left foundation behind angle of friction	11.33	35.0	degrees	OK
Right foundation behind angle of friction	25.76	35.0	degrees	OK
Span Length	44.54	120.0	meters	OK
Δ (delta) H	1.72	1.782	meters	OK
Left side ground profile slope β (Beta)	4.0	10.0	degrees	OK
Right side ground profile slope β (Beta)	10.0	10.0	degrees	OK
Left side number of tiers	3	3	tiers	OK
Right side number of tiers	1	3	tiers	OK
Freeboard	2.39	3.0	meters	NG

The required freeboard is 3 meters (river classified as gorge). The cable sag results in a freeboard of 2.39 meters. The proposed standard footbridge did not meet the freeboard requirement. This is discussed further in depth in Section 4.4 below.

Custom cable design sag values were provided by EIA as mentioned in the EIA Bridge Binder. Engineers in Action provided a hoisting sag value (h_2) of 4.08%, a dead load sag value (h_3) of 4.51%, and a live load sag value (h_4) of 5.51%. The live load sag value (2.39 meters) considers the theoretical maximum load case of dead load and live load and is 0.61 meters below the required minimum freeboard of 3 meters. The geometric requirement was not met.

The final geometric requirement is cable clearance. The dead load sag requires a 1.0-meter clearance from the bottom walkway cable to the top of the ground. If this requirement is not met, the live load sag is then considered with a requirement of 0.5-meter ground clearance. The proposed standard bridge does not meet the dead load sag ground clearance but meets the live load sag ground clearance of 0.5 meters.

The left and right anchors are EIA standard design anchors for bridges with span length, L, between 20 and 60 meters. The above ground soil angle beyond the anchor, β, is approximated to be zero as the existing ground slope beyond each anchor is less than 10 degrees. The height, H, of the active soil is the overall height of the ramp at the anchor. Less anchor sliding occurs due to no additional soil height about the top of the anchor.

This standard design outlined above does meet the geometric constraints outlined in the EIA Bridge Program Volume 2 – Design textbook. Therefore, the sag clearance requires a custom design. Increasing the height of the left foundation allows for this clearance. Proposing a 0.5-meter height increase of the foundation on the left foundation per Section 5.8 of EIA's

Bridge Program Volume 2 moves the cable sag closer to the required clearance. The manual states the following:

> "Consider raising the anchor 0.5-1.5 meters while maintaining minimum embedment for the abutment components. Note that an extra access ramp will be necessary to get from ground level onto the approach ramp if this is high above the ground."

An extra ramp at the end of the left abutment is required due to this adjustment. We are limited in increasing the foundation's height to avoid needing a long extra ramp. EIA defines a long extra ramp that exceeds 4 meters. An extra ramp Additional analysis will be performed for Review Call #2 regarding the custom design.

Table 3. Summary of factors of safety

Design Check	FS Required	High Side FS	Low side FS
Cable Design	3	3.567	
SuspenderDesign	5	17.551	
Tower Overturning	1.5	6.417	6.268
Bearing Pressure	2 (right), 3 (left)	13.791	3.436
Anchor Sliding	1.5	2.339	3.959
Anchor Uplift	1.5	1.489	1.403

Per each component:

1. Abutment
    a. 3G60A: Selected as the bridge is between 40 to 60 meters. Due to the lower elevation on the left side, 3 tiers would reduce the total elevation difference between the two tower saddles. Placed under a ground slope of less than 5 degrees (Appendix A.9a).
    b. 1G60B: Selected as the bridge is between 40 to 60 meters. Due to the lower elevation on the left side, 1 tier was placed on the right to not raise the elevation difference between the two abutments (Appendix A.9b).
2. Anchor
    a. A4 anchors were chosen as a result of the span length being between 20 to 60 meters (Appendix A.9c).
3. Tower
    a. Cable calculations resulted in a requirement of 4 cables, 2 walkway and 2 handrail cables. Therefore, the T4 tower choice was made (Appendix A.9d).
4. Walkway Details

a. Cable selection was provided by EIA; 6x19 Galvanized steel cable with a diameter of 1-⅜", which will require a 10% reduction in future calculations

Because of the standard design calculations, as well as the geometric sag issue, the anchor uplift check did not pass all factor of safety checks. Therefore, the team proposed alternative custom footbridge design will be used for the Rio K'ellu Mayu's footbridge.

Custom Design

The custom design was derived from the freeboard requirement and anchor sliding failing. In the standard design, the bridge did not meet the required freeboard of 3 meters. The standard design did not meet the anchor uplift factor of safety requirement. To resolve the low sag cable, the team decided to decrease the span length as it is directly proportional to increased sag values. The site location and geometric conformance restricted potential adjustments to the design. The custom element involved increasing the tower height elevation of the left abutment. This was achieved by adding 0.5 meters to the foundation to raise the bottom of the cable to meet the freeboard. The backstay cables, ramp, and fill were adjusted to meet the new height of the tower. The increased foundation height was also intended to address issues with the anchor uplift. Figure 9 below illustrates the bridge's custom design.

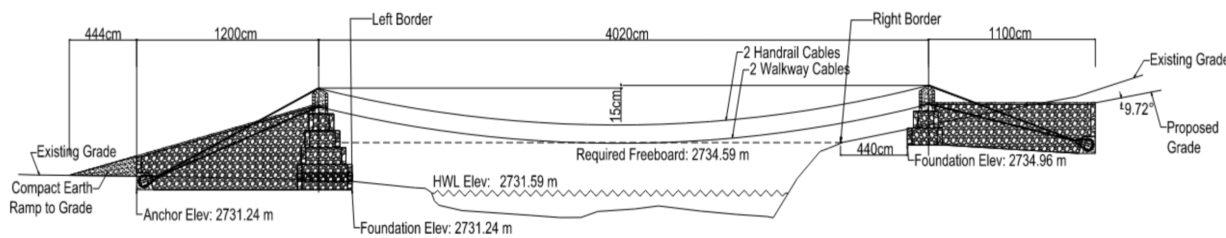

Figure 9. A dimensioned drawing of custom design bridge showing span and abutments

The changes outlined above allowed the design to provide the sufficient requirements needed to pass all but two design checks. Due to a combination of calculation errors and calculation checks late in the design process, it was discovered that the left anchor uplift and tower overturning checks did not meet the required factors of safety with the increased tower height and resulting backstay cable angles of the custom design. The shorter span of 40.2 meters (see Figure 9) decreased the sag values. Construction, hoisting, and dead load sag all rest above the required 3 meters of freeboard. The live load sag, which represents the worst-case scenario of all loads, falls slightly under by less than 10cm but within tolerance. The change in elevation from one end of the tower to the other is 0.65 meters, reducing steepness when walking across the footbridge. This change will improve serviceability for the Pocona community. The additional 0.5 meters in the foundation resulted in a custom 3G-60B abutment (see Appendix D.2). The increased height of the left abutment required an extra approach ramp to be able to access the approach ramp on the left side. The standard right abutment remained unchanged.

As outlined in the Bridge Binder Volume 2 Design Section 2.1, the primary objective of the footbridge is to provide public safety. Secondary aspects include durability, serviceability, maintainability, constructability, and economy.

1. Safety:
   Refers to the priority of structural integrity and user safety. There is little tolerance for failing to meet the minimum safety requirements.

2. Durability:
   Material selection and design should be selected to preserve the footbridge's usage over a long time. Design selections should protect the structure from weathering and frequent usage.

3. Serviceability:
   Deformations within the structure must be reduced to provide user comfort when crossing the bridge. Examples include reduced swaying and minimal slope across the span of the footbridge.

4. Maintainability:
   The lifespan of the structure should be designed with accessible maintenance points and economical solutions when replacement is needed.

5. Constructability:
   The design must also provide a safe means to erect the structure. Any structure is most vulnerable under construction and safety measures must be accounted for when designing the footbridge.

6. Economy:
   Engineers in Action believe in locally sourcing most materials to drive down the overall cost of the project. Materials include stone, and sand, but not the steel cables. Providing an economical solution will ensure that the community can have a footbridge.

7. Aesthetics:
   After the completion of the footbridge, the community is encouraged to decorate the bridge providing an opportunity to illustrate their culture so long as it does not interfere with the integrity of the bridge.

The original standard design failed to meet safety and serviceability requirements. Meeting the required freeboard provides a buffer from the highest water line to avoid the bridge sagging too close to the water. This buffer aims to prevent damage caused by the flowing water. The slope across the footbridge was also close to the maximum allowable slope, providing users with an uncomfortable trek across the bridge. The custom design created a large elevation difference from the ground to the approach ramp thus requiring an extra approach ramp.

The left anchor is standard. The design included extra anchor uplift capacity. Masonry sidewalls and backwall provided an increased overturning moment. That said, the anchor uplift factor of safety of 1.5 is still not satisfied.

The left abutment is a custom design and is illustrated in Figure 10. The left side of the site layout provided options for the abutment's design as the ground slope did not surpass the maximum 10 degrees.

The span had to remain shorter to reduce the sag values. The left abutment is placed 8.99 meters from the left riverbank. The customization added 0.5 to the foundation added 0.5 meters to the overall height of the abutment (see Appendix D.2 and Figure 10). This was done to raise the overall cable sag to meet the 3-meter freeboard requirement. Increasing the height of the foundation past 0.5 meters would require far more materials on the left abutment, a steep approach ramp, and a much longer extra approach ramp. To provide a more conservative approach, the abutment was modified to 3G-60B as the ground slope angle exceeded 5 degrees in multiple places on the left side.

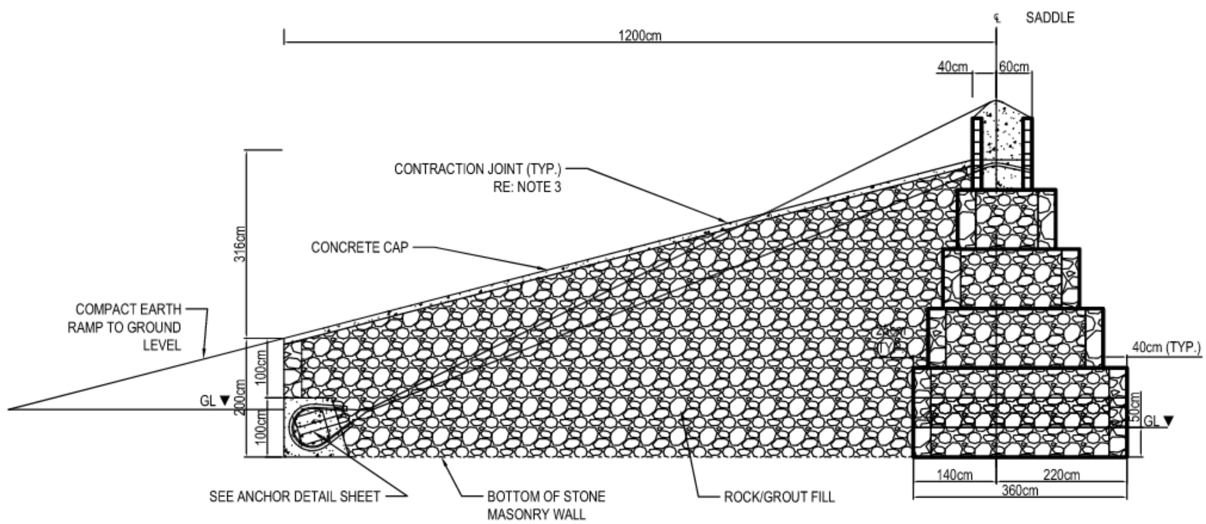

Figure 10. A dimensioned and labeled drawing of the custom left abutment.

The right anchor is standard. The design included extra anchor uplift capacity. Masonry sidewalls and backwall provided overturning moment. The anchor uplift factor of safety of 1.5 is satisfied.

The right bank has a steeper ground slope. The location of the abutment was determined by the ground slope angle. For a standard design, the ground slope required an angle of 0 to 10 degrees. The smallest angle was approximately 10 degrees and was found 5.94 meters away from the right bank. The right abutment is a standard 1G-60B abutment (see Appendix D.1). Due to the sloped nature of the layout, the right side will require heavy excavation. The sloped terrain will also require drainage to avoid settling on the abutment.

The standard design geometry of the Rio K'ellu Mayu footbridge provides an optimal layout for the site. Thus, the layout was not changed from the standard to the custom.

Table 5: Geometric Conformance Summary

Parameter	Value	Requirement
Span length, L	40.2 m	< 120 m
Height Differential, ΔH	0.65 m	< 1.61 m
Freeboard	2.94 m	> 3 m
Left Abutment Offset	5.94 m	≥ 3 m
Right Abutment Offset	8.99 m	≥ 3 m

The team considered alternative customizations to satisfy the freeboard. The right abutment was increased to a 2-tier system. Increasing the tower height raised the lowest point on the live load sag curve. This adjustment to the right abutment meant a large elevation change that did not meet the serviceability check. The walkway would have been far too steep. EIA suggested that the foundation be increased from 1 meter to 1.5 meters. Another consideration was increasing the foundation past 0.5 meters. The increased elevation change would result in a larger extra approach ramp and even higher backstay angles. The design already requires significant approach ramp volume. Another possibility the team considered was a longer span. The longer span would provide a larger factor of safety for the serviceability check but again would increase the sag value, which was already failing to meet the required freeboard.

The Rio K'ellu Mayu followed the Engineers in Action Bridge Binder procedure for the calculations. As stated by the EIA Bridge Binder, any Bolivia project will receive custom sag values. EIA provided the team with custom sag values (see Table 7 and Figure 11). To meet the required factor of safety for anchor uplift, the team decided to recalculate the forces of the abutment by completing the Tier 2 checks. The Tier 1 checked underestimated the total fill of the abutment thus decreasing the total vertical forces acting on the ground. The construction analysis for anchor sliding and uplift provides a design check for the footbridge while under construction. The anchor sliding check under construction can provide a recommendation of when to hoist the cables. The left abutment can hoist the cables with 10% of the ramp walls constructed and no backwalls. The right abutment can hoist the cables with 80% of the ramp walls constructed and no backwalls to provide the proper forces so that the footbridge can be safely erected.

Table 6: Factors of Safety (FS) of Custom Design

Failure Type	Minimum FS	FS Achieved Left Side	FS Achieved Right Side
Cable Design	3.0	5.66	
Suspender Design	5.0	26.33	
Bearing Pressure	3.0 (left), 3.0 (right)	3.04	13.52
Tower Overturning	1.5	1.28	1.59
Anchor Uplift	1.5	1.01	2.23
Anchor Sliding	1.5	4.36	4.17
Construction FS			
Erection Hook	3.0	4.12	4.03
Anchor Sliding Construction	1.5	1.88*	1.54**
Anchor Uplift Construction	1.5	7.48	11.35

* *The design check accounts for 10% of the ramp walls to be completed under construction and no backwalls. All other components are accounted for.*

** *The design check accounts for 80% of the ramp walls to be completed under construction and no backwalls. All other components are accounted for.*

Table 7: Custom Sag Values Summary

Sag Type	Sag Value (meters)	Design f Values (meters)
Construction (h1) 3.00%	1.21	0.90
Hoisting (h2) 4.08%	1.64	1.33
Dead Load (h3) 4.55%	1.83	1.52
Live Load (h4) 5.51%	2.22	1.90

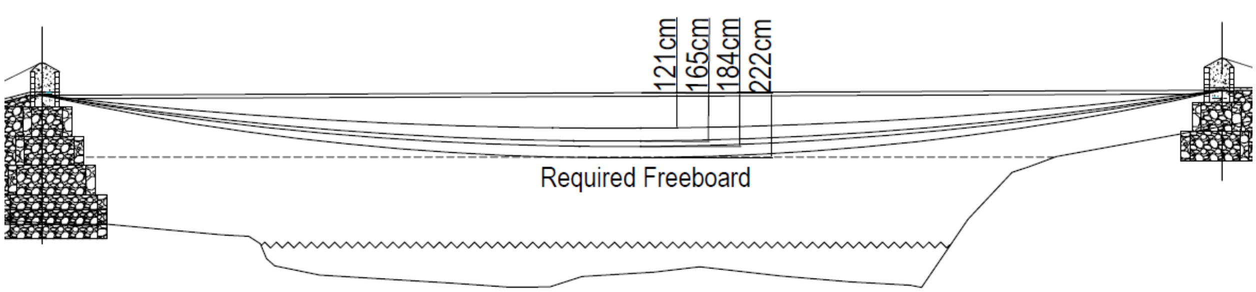

Figure 11. Illustration of the four sag values in profile view

Uplift

Initially, the anchor uplift did not meet the standard design factor of safety. The Tier 1 calculations conservatively estimated the total weight of the abutment thus reducing capacity. Tier 2 aimed to provide a more accurate abutment volume using the masonry weight. This change in calculation coupled with increased total fill volume that resulted from the increased foundation height was expected to cause the left side to pass, but the increased backstay angle caused a greater upward vertical force on the anchor and caused it to fail. The right side was also failing in the standard design. With Tier 2 calculations, the anchor sliding on the right achieved the factor of safety required.

Construction

The construction sag was the final check. This calculation provides a check for when hoisting the cable. An erection hook is connected to the anchor. The hook is connected to a chain winch that is attached to the cable when hoisted. When hoisting the cables under construction, the winch and erection hook bear the self-weight of the cable and are settled at the desire sag. In the construction analysis, the maximum capacity of the erection hook is 29.4 kN. The maximum force in the cables due to self-weight only as it is in construction, cannot exceed the capacity of the erection hook. This will ensure that the anchor will not slide or cause an uplift. The cables do not exceed and therefore 4 cables can be safely utilized under construction. The construction analysis also provides a recommendation for when to hoist the cables. The construction anchor uplift and sliding analysis can determine how much fill can be placed to safely hoist the cables. On the left side, 10% ramp wall fill and no backwall will be sufficient. On the right side, 80% ramp wall fill and no backwall will be sufficient (See Appendix C, Construction Sag). This recommendation will be accommodated in our construction schedule.

See Appendix C for an in-depth look at the design calculations.

Load Assumptions:

Permanent Load:
Dead Load (DL): 1.05 kN/m

Transient Load:
Live Load (LL): 4.07 kN/m
Reduced Live Load (LL): 3.89 kN/m

Primary Load Combination:
Distributed, Wc Primary (DL + LL): 4.93 kN/m

Future Design Considerations

The current custom design did not meet the tower overturning and anchor uplift factors of safety on the left abutment (see Table 6). After the second review call with Engineers in Action, discrepancies between EIA's calculations and the UVA team's calculations were brought to light, revealing a need for design changes due to the following reasons. Regarding anchor uplift, the backstay angles of the cable attached to the anchor were designed to be too steep. The steepness resulted in greater vertical component of the combined forces of the cables which in turn would cause the anchor to uplift. The steep backstay angle also resulted in tower overturning to not meet its required factor of safety. To address these issues in a new design iteration, the team would consider raising the left anchor or extending the length of the abutment. The raised anchor would decrease the backstay angle, decreasing the vertical force acting on the tower from the cables, and increasing the nominal capacity. Potential issues with raising the anchor would include decreasing the total volume of the fill for the abutment, decreasing the total downward force acting on soil, and would present issues with the bearing pressure capacity. Extending the abutment length would also decrease the backstay angle and solve the issue similarly to how raising the anchor would. The concern with extending the abutment length would be the required volume of materials would increase, driving the cost of the project higher. A possible solution would include a combination of raising the anchor and increasing the abutment length.

Construction

<u>Bridge Construction</u>

Table 8 below outlines the estimated Bill of Quantities (BOQ) for all the variable materials in our custom design. The list of materials and their corresponding quantity estimates were developed based on the following recourses provided by EIA: the EIA Bridge Program: Volume 2 Design Manual[7], the BP- 301 Construction Management course on Bridge EDU, as well as a sample BOQ for Bolivia found in the EIA Bridge Program: Volume 2 Design Manual[8]. Because these were the references given for developing the BOQ, the UVA team decided to use the same contingency factors as what was used in these references.

Table 8: Bill of Quantities (Variable Materials)

Bill of Quantities (Variable Materials)									
Description	Units	Left Abutment	Left Tower	Walkway	Right Abutment	Right Tower	Total Needed	Contingency Factor	Total
CABLE 1-3/8" Cable 1-3/8"	m			321			321	1.00	321
CLAMP 1-3/8" Abrazadera Forjado 1-3/8"	unit			56			56	1.05	59
TIMBER Madera Dura (200x20x5cm)	unit			101			101	1.08	109
TIMBER NAILER Madera Dura (100x20x5cm)	unit			41			41	1.08	45
CROSSBEAM Perfil U 4x5, 4 lb/ft	6m bar			41			41	1.04	43
SCREW (timber) Tirafondo 3/8" x 3 1/2"	unit			503			503	1.25	628
SCREW (timber nailer) Tirafondo 3/8" x 2"	unit			165			165	1.18	194
FENCING Malla O. Galv. N° 10 Alt 1.2m	m²			96			96	1.05	101
ROCK Piedra Bolón	m³	141			46		186	1.05	196
TUBING Manguera de Succion de 3"	m	6			6		12	1.10	13
CEMENT Cemento Portland (50 kg bolsa)	50kg bag	180	7		86	7	280	1.13	317
SAND Arena	m³	18	3		8	3	32	1.09	35
GRAVEL Grava Lavada	m³	4	3		4	3	14	1.05	15
REBAR (#4) Acero Corrugado 1/2" (12mmx12m)	12m bar	3			3		7	1.05	7
REBAR (#5) Acero Corrugado 5/8" (16mmx12m)	12m bar	1	2			2	4	1.05	4
REBAR (#6) Acero Corrugado 3/4" (16mmx12m)	12m bar	2			2		5	1.05	5
REBAR (#3) Acero Corrugado 3/8" (10mmx12m)	12m bar		1	13		1	16	1.05	17
PLASTIC HOSE Tuberia de Alta Densidad de 2"	m		4			4	8	1.10	9
BRICK Ladrillo Gambote 18H 25x12x6cm	unit		545			545	1090	1.02	1112

After calculating the BOQ, the UVA team compared the UVA estimate to the materials estimate provided by our in-country manager (found in Appendix 8.1) to determine if there are any major discrepancies. The comparison is illustrated in the table below (Table 9). Materials with a higher UVA estimate are highlighted in red, and materials with a higher EIA estimate are highlighted in yellow.

Table 9: Comparison of UVA Team's Estimate to In-Country Manager Estimate

Bill of Quantities (Variable Materials)					
Description	Units	UVA Estimate	In Country Manager Estimate	Difference (UVA - Manager Estimate)	Percent Difference
CABLE 1-3/8" Cable 1-3/8"	m	321	302	19	6
CLAMP 1-3/8" Abrazadera Forjado 1-3/8"	unit	59	44	15	25
TIMBER Madera Dura (200x20x5cm)	unit	109	115	-6	-6
TIMBER NAILER Madera Dura (100x20x5cm)	unit	45	48	-3	-8
CROSSBEAM Perfil U 4x5, 4 lb/ft	6m bar	43	12	31	72
SCREW (timber) Tirafondo 3/8" x 3 1/2"	unit	628	629	-1	0
SCREW (timber nailer) Tirafondo 3/8" x 2"	unit	194	200	-6	-3
FENCING Malla O. Galv. N° 10 Alt 1.2m	m²	101	114	-13	-13
ROCK Piedra Bolón	m³	196	220	-24	-12
TUBING Manguera de Succion de 3"	m	13	20	-7	-52
CEMENT Cemento Portland (50 kg bolsa)	50kg bag	317	320	-3	-1
SAND Arena	m³	35	80	-45	-129
GRAVEL Grava Lavada	m³	15	12	3	19
REBAR (#4) Acero Corrugado 1/2" (12mmx12m)	12m bar	7	4	3	42
REBAR (#5) Acero Corrugado 5/8" (16mmx12m)	12m bar	5	4	1	23
REBAR (#6) Acero Corrugado 3/4" (16mmx12m)	12m bar	5	2	3	62
REBAR (#3) Acero Corrugado 3/8" (10mmx12m)	12m bar	17	19	-2	-14
PLASTIC HOSE Tuberia de Alta Densidad de 2"	m	9	4	4	50
BRICK Ladrillo Gambote 18H 25x12x6cm	unit	1112	920	192	17

Upon comparing the two quantity estimates, the following differences were noted. The UVA team recognizes that there are some major discrepancies, however this is mainly because our design is quite different than the initial design assumed upon conducting the project's Technical Survey Form (Appendix A.5).

1. Number of Crossbeams
    a. The UVA estimate of 42.85 6m crossbeam bars is higher than EIA's estimate of 12 6m crossbeam bars (about a 72% difference). While this is a large discrepancy, it is likely because the initial estimate for the bridge's span was 20-100m as stated on page three of the Technical Survey Form (Appendix A.5). The lower limit of this estimate is much smaller than the actual bridge span of 40.204, which could have led to an underestimate of the number of cross beams needed.

2. Quantities of Rock and Sand
    a. The UVA estimate for the volume of rocks is 50.8% lower than the EIA estimate.
    b. The UVA estimate for the volume of sand is 142.77% less than the EIA estimate. Despite both the rock and sand quantities not aligning with the in-country manager's estimate, it should not cause any material acquisition or economic problems as we are below and not above the estimate provided by the in-country manager. In addition, the in-country manager's estimate likely provided a larger estimate as it is better to have more rocks and sand than not enough. A suggestion could be to meet halfway between the UVA and EIA estimates. This allows us to meet our requirements and reach contingency factors in case more material is needed.

3. Rebar Quantities
    a. The UVA estimates for the total quantities of #4 and #6 rebars are higher than the EIA estimate. The UVA's BOQ calls for 6.87 12m bars of #4 rebar while the in-country manager's estimate calls for four 12m bars. In addition, UVA's BOQ calls for 5.20 12m bars of #4 rebar while the in-country manager's estimate calls for two 12m bars. This difference can likely be because the initial estimate for the bridge's span was 20-100m as stated on page three of the Technical Survey Form (Appendix A.5).

Table 10 outlines a comprehensive list of equipment and tools necessary for the bridge's construction.

Table 10: List of Equipment and Tools

Tool Name	Construction Layout	Excavation	Foundation & Tiers	Towers	Anchor & Cables	Approach Ramp	Cable Hoisting	Walkway
Shovels		x	x	x	x	x		x
100-meter measuring tape	x	x		x	x	x	x	x
Level	x	x	x	x	x	x	x	
String Line	x	x	x	x	x	x	x	
Plumb Bob	x	x	x	x	x	x		
Spray Paint	x	x	x	x	x		x	
Stakes	x	x	x					
Machete	x							
Hammer	x	x				x		x
Auto level, tripod, and survey rod	x	x						
Tamping rod			x			x		
Excavation bars		x						
Picksaxe		x			x	x		
Wire cutters					x			x
Mallet					x			
Carpentry Nails		x						
Buckets		x		x	x	x		x
Water tube		x						
Masonry tools				x	x	x		x
Construction square				x	x	x		
Grinder				x				
Saw				x				x
Saw blades				x				
Hacksaw				x				
Angle grinder				x				
Angle grinder discs				x				
Generator				x				
Cement Mixer					x	x		x
Winch							x	
Torque wrenching							x	x
Sockets							x	x
Automatic level and tripod							x	
Duct tape							x	
Drill								x

The detailed excavation drawings are attached in Appendix E.1. The construction process for the abutment includes excavation for the foundation, ramp walls and gravity anchor. These plans provide dimensions for both Phase 1: Foundations and Phase 2: Approach Wall and Anchor. Each set of drawings covers elevation and plan views for both the left and right abutments.
Benching instructions are outlined in the OSHA handbook, (1926 Subpart P). The soil on the site is described in Appendix A.5, Technical Survey Form, the soil on the left and right side were classified as clay. By OSHA 1926 Subpart P, the maximum horizontal to vertical slope is ¾:1. Per EIA guidelines, benching is required for required if the excavation depth exceeds 1.5m. Spoil piles resulting from excavation must be at least 1 meter away from the edge of the excavation.

The detailed construction schedule is attached in Appendix B. The construction schedule includes the tasks, professional personal, and student roles needed for the week. Additionally, the schedule includes the materials needed for each week. The construction schedule was created from the template provided by EIA. Our schedule considers the accessibility to both sides of the river and decided that it would be best for larger tasks to be completed in full before it is started on the other side to reduce excessive movement of materials from being transported side to side.

Quality control will be the key to successfully constructing the K'ellu Mayu Bridge. Quality control processes are to be performed by the designer or the construction team to ensure that each construction phase is performed according to EIA Bridge Program: Volume 3 Field Operations[9], and that the bridge meets all design requirements.

Each part of the construction sequencing has its own specific quality control form that must be completed by the construction manager, and each quality control point must be signed by the Construction Manager and by the Technical Supervisor. Quality control activities listed in these forms include construction procedures, checking dimensions, sampling and testing, and material handling. All quality control forms can be found in Appendix E of this report. In addition, concrete quality control must be performed by the Quality Control Manager, who should oversee the mixing and proportioning of the concrete. Included in these forms are quality control photos, which must be taken during designated steps of the construction process. The quality control photos are all outlined in a checklist (Appendix E.3k). If the Quality Control Manager cannot be present, the Construction Manager is responsible for overseeing quality control operations.

Lastly, it is important to recognize that some quality control activities might be completed before the volunteer team arrives at the site. However, it is still necessary for all quality control points and photos to still be checked again upon the team's arrival.

The following table compiles all the major quality control concerns at each stage of construction using the information listed in Volume 3 of the bridge builder binder and the quality control forms.

Table 11: Major Quality Control Concerns

Construction Stage	**Major Quality Control Concerns**
Construction Layout	• Establish centerline • Establish foundation locations with respect to survey markers • Verify span length • Verify heigh difference between abutments • Confirm all dimensions with respect to design drawings and correct any discrepancies
Excavation	• Record bottom of excavation elevations for left and right foundations • Record bottom excavation elevations for left and right anchors • Record soil types for left and right anchors • Confirm all dimensions with respect to design drawings and correct any discrepancies • Provide drainage is water seeps into excavation

	• Record critical as-built dimensions
Foundation and Tier	• Ensure excavation is clear of debris • Check for water seepage and provide drainage if needed • Check all foundation and tier dimensions against drawings with emphasis on orientation relative to bridge centerline • Stone masonry perimeter wall must be constructed plumb and within an hour of mixing mortar • Use range of stone sizes when filling foundation and reach fill density noted in design • Fill must not exceed three lifts per day and must not include soil • Record all as-built elevations and dimensions
Tower	• Minimum concrete dimensions must be met • Steel reinforcing cage must be placed centered in the column and proper clearances must be kept on all sides • Handrail cable saddle must be properly aligned with bridge centerline • Verify vertical distance between handrail cable and walkway cable support points • Verify span length and elevation difference at top of tiers • Check all dimensions against design drawings and with emphasis on orientation relative to bridge centerline • Level cable support points across the walkway hump and between towers • Record as-built dimensions and distances
Anchor and Cable Preparation	• Concrete must be placed within an hour of mixing • Wet concrete surface if too much time elapses • Prevent debonding between layers if construction joint is required • Verify excavation dimensions and elevations before anchor construction • Check for water seepage • Verify anchor dimensions with design drawings with an emphasis on orientation relative to bridge centerline • Record as-built length, width, and height of each anchor beam • Record as-built number of clamps per cable and spacing of clamps at fixed anchor • Check tolerance limits for as-built dimensions
Approach Ramp Stage 1	• Verify excavation is free of debris and water • Verify wall thickness and outside-to-outside ramp width at base of walls • Verify that each stone masonry wall is constructed plumb • Ensure mortar is used within one hour of mixing • Verify all ramp wall dimensions against design drawings to ensure within tolerance • Record as-built dimensions of ramp walls

Cable Hoisting	• Recalculate and record f values using as-built elevation difference and as-built span • Ensure survey equipment is calibrated • Verify cable positions at least 24 hours after initial hosting • Verify cable positions again 24 hours after sag is set before decking • Ensure all cable positions are within tolerance • Ensure proper size and number of clamps are installed at the appropriate spacing • Coat cables inside approach ramp with tar or mastic to prevent corrosion • Record as-built number of clamps per cable and spacing between clamps, and all other critical as-built dimensions
Approach Ramp Stage 2	• Verify ramp wall thickness • Ensure interior fill only constructed with stone and gravel and no soil • Ensure voids are filled and cover fill with layer of concrete slurry • Ensure no more than 3 lifts per day of fill • Ensure design fill density is achieved • Ensure cables aren't damaged when filling approach ramp • Ensure cables and clamps are left fully exposed • Record as-built dimensions of approach ramp and ramp walls
Walkway	• Verify crossbeam, nailer, decking board, and suspender dimensions • Ensure each component of walkway, crossbeams, nailers, decking boards, suspenders, and fencing are installed per drawing set • Confirm crossbeam spacing and decking board dimensions • Confirm fencing is fixed to edge of decking boards • Measure level of deck at midspan, and adjust level of deck if tilted • Record as-built dimensions for crossbeams, nailers, decking boards, and locations of pre-drilled holes • Confirm as-built dimensions with tolerance limits
Approach Ramp Stage 3 and Completion	• Record as-built dead load sag of bridge • Mark handrail cables at the centerline of saddle to monitor cable movement in the future • Ensure area is free from all hazardous material after bridge completion • Grade surrounding area so bridge is easily accessible • Ensure water will not drain toward the structure • Revegetate area as much as possible to reduce erosion around abutment • Conduct final check of as-built drawing dimensions and survey the bridge's design sag post-decking

To identify and mitigate quality control concerns, it is necessary to perform all quality control activities and complete all quality control forms. These checks will bring to light any errors in a timely manner to make sure that if problems arise, they can be corrected without causing significant delays or costs. In the case that there are issues with the quality of work, it is the Quality Control Manager, technical supervisor, and construction manager's responsibility to identify such issues and make correctional changes. Between the quality control forms, a photo inventory that documents each phase of construction, and as-built dimensions marked on the design drawings, these records will confirm that the bridge was built within accepted construction tolerances and are necessary for future inspection of the bridge.

Conclusion and Discussion

Upon completing our design and developing a construction plan, it is important to note the following design and constructability elements that are expected to be challenging during the K'ellu Mayu Bridge's construction.

Material costs

One change made in the bridge's custom design was to increase the number of walkway cables from two to four. While this change was made to ensure that the bridge remains upright while under construction, it ultimately increases the project's total cost. This poses a challenge with material acquisition and funding as we will need to purchase, deliver, and store more steel for our design. It is important to recognize this design element as a challenge as steel is the most expensive material needed for the bridge's construction and is the only material not locally sourced.

Extra Approach Ramp

To make the bridge's approach ramp accessible to all members of the community, such as young children and the elderly, the design calls for an approach ramp with a gradual slope as opposed to a steep ramp. To achieve the gradual slope, however, the ramp must be 4.5 meters long. The longer ramp will require more materials as well as a longer construction time. The ramp will maintain the original slope of the existing approach ramp on the abutment. According to Bridge EDU Advanced Suspended Bridge Design course, in Bolivia "project materials account for everything through the back of the anchor and DO NOT include an extra access ramp behind the anchors". Therefore, it is suggested that this access ramp be built using compacted dirt and that the ramp's maintenance be designated as the community's responsibility.

Site access

As discussed in sections 2.6 and 3.3 of this report, both sides of the river of the bridge site are accessible by vehicle, but the right abutment's location is not directly accessible. In response, the community will need to build a provisional road. In addition, it is important to note that the owner of the left side of the river is not listed, and that clearing vegetation will be necessary to access the where the left abutment will be built. Enacting these measures will be challenging but necessary, as without them accessibility to the site and bringing materials to the site will be impossible. In addition, because moving back and forth between the right and left abutments is inconvenient, it is important to minimize the movement of people and materials as much as possible to save time. This practice is illustrated in the way construction activities are ordered in our schedule.

Excavation Drainage

A unique feature of our site's topography is that the elevation of the left riverbank is significantly lower than that of the right riverbank. During construction, the likelihood of hitting the water table will be higher when excavating the left abutment. Therefore, groundwater seepage might result in the need for drainage measures such pumping out water might be necessary.

Appendix A
Updated Gantt Chart schedule

Appendix B
See page 7 for changes from the standard design to fit location restraints.

Appendix C
Bridges to Prosperity Bridge Builder Manual
Engineers in Action Bridge Manual Volume 2
Engineers in Action Site Documents

- Social Evaluation of the Project pg. 10 - 15
- Technical Evaluation pg. 16 - 18

The custom design for the Rio K'ellu Mayu bridge satisfies the EIA Bridge Program Vol. 2 - Design requirements. The team's design process was guided by this document and by EIA Education modules (Suspended Bridge Design – EIA 201, Advanced Suspended Bridge Design – BP211). Custom design of the left abutment with the standard right abutment, walkway, crossbeam, and tower details meets the following design requirements set forth by EIA:

1. Cable design
2. Suspender design
3. Tower Overturning
4. Bearing pressure
5. Anchor Sliding
6. Anchor Uplift

The calculation package supports the design's requirement checklist.
The design considers geometric restraints EIA Bridge Program Vol. 2 – Design and the results of the onsite survey. Factors include:

1. Foundation setback
2. Angle of friction
3. Span
4. Change in height between abutments
5. Profile slope
6. Number of tiers
7. Freeboard

These design restraints are discussed further in the Design Section of the report.

FUNDACIÓN INGENIEROS EN ACCIÓN

Social Evaluation of the Project

Advisor: Richar Galvez. Date: May 7, 2022
(Full name)

1. Location information

-Name of proposed bridge: K'ellu Mayu River Pedestrian Bridge.
(Must be a unique name for this crossing, not just the name of the river or community)

-Name of the community or communities that are direct beneficiaries: K'ellu Mayu.

- Name of the municipality: Pocona.
- Department Name: Cochabamba.
- River name: Río K'ellu Mayu.
- Latitude Longitude: -17.620584°. -65.271513°.

2. Information about the site

- When is the site accessible in a light vehicle with 4x4 drive?

☐ Never ☑ All year round ☐ Sometimes: After the rainy season

-Name of the nearest paved or cobbled road: Old Cochabamba - Santa Cruz road.

- Name of the nearest town: Lope Mendoza.
- Travel time from the site to the nearest town: 15 minutes by light vehicle.
- Quality of cellular service: ☐ Not existing ☑ In some places ☐ Good
- Cellular service companies: Entel.
- Describe the accesses for the transfer of materials to the right side and the left side of the river: eitherLeft: There is no access to the place where the abutment will be located, but materials can be reached by vehicle to the place where the abutment is located. You will only need to do a clearing approximately 100 meters from the vehicular path.

  eitherRight: There is no access to the place where the abutment will be located, but the community and the municipality are going to enable a provisional road approximately 150 meters from the vehicular path.

-What local materials exist in the river, in the community, or in nearby communities?

☑ Stone
☐ Wood for formwork
☐ Sand
☐ Record
☐ Fine wood
☐ Others: ____________

-Are there trees, structures or property that would be affected by the construction of the bridge? ____________

-General site information and accessibility: On the left there is agricultural land, but the land will not be affected; The climate in this place varies, in summer it is hot and in winter it is cold; The road is passable for single trucks and lightweight vehicles.

3. Social Information

-Number of direct beneficiaries of the bridge: 190 inhabitants.
(People for whom access is consistently blocked)

- Number of boys and girls who would benefit directly: 10.
- Number of women of reproductive age (15 – 49) who would be beneficiaries: ____________

-Population of all direct and indirect beneficiary communities: 220 inhabitants.
(Total population of all communities that would potentially use the bridge, including those directly served)

-Primary and secondary economic activities: Agriculture and animal husbandry.

- Main crops: Potatoes, corn, wheat, peas, broad beans, barley, peaches, and apples.
- Animal husbandry: Cow and sheep.
- What are the months of planting, harvesting and other activities in the field of agriculture or other temporary jobs where people dedicate all their time, which would make it impossible for them to fully participate in the construction of the bridge?

☑ January
☑ July
☑ February
☑ August
☑ March
☑ September
☑ April
☑ October
☑ May
☑ November
☑ June
☑ December

-Notes on population: The families in this population are dedicated to agriculture and raising domestic animals; The families live in different sectors of the community, the houses built of adobe with tile and corrugated iron roofs.

-How often and where do the community(s) meet?*(Weekly, monthly, specific date)*
People meet every first Sunday of the month at their union headquaters.

FUNDACIÓN INGENIEROS EN ACCIÓN

4. Community map

Include characteristics such as the location of the community or major centers of the population, the location of the proposed bridge, main roads and paths, schools, health centers, markets, churches, bus stops and buildings or communal houses.

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5. Information about the river

-Description of important services, opportunities or destinations that the river isolates:
U. E. K'ellu Mayu, U. E. Monte Punko, Monte Punko Health Center, agriculture, transportation, social and cultural events.

(This may include primary or secondary schools, clinics or hospitals, farms or markets, government services, churches or any other important destination for the community. Be as detailed as possible and include the types of schools or health centers and how many people serve, the size of the markets and the frequency with which they occur, and other details that will help contextualize and particularize the needs of the community and, among them, that of a bridge)

- Number of people injured while crossing the river in the last three years: ___________
- Number of people killed while crossing the river in the last three years: ____________

-Description of the accident or death of the people when crossing the river, with dates: _____

(Include the number of injury or death accidents. For example, if there was a major flood and three people were injured during this single event trying to cross, clarify it. It should be clear how many injuries or deaths were one-time events)

-Flood time during rainy season: 1 day.
(When the river floods, how long does it last?)

-Current crossing method: Yana Gaga Pedestrian Bridge.
(Swimming, wooden bridge, etc.)

-Nearest crossing point: 8 km downstream of the located site.

- Information about properties or land on both sides of the bridge site proposed*(Who are the owners of the land, and if they have expressed interest in supporting or concern about a bridge)*:

  eitherLeft side: They have no owner.

  eitherRight side: Sebastián Parra (Agreed, he was present on the day of the site visit).

- Planned local and regional transportation infrastructure projects*(Include description and any known places or dates)*: __________________________

6. Isolation

- Number of days per year that the river is difficult or impossible to cross: 150 days.
- Distance from the proposed bridge site to the center of the nearest town *(km)*: 18.
- Distance from the center of the beneficiary community to the site of the proposed bridge *(km)*: 2.
- Distance from proposed bridge site to main market *(km)*: 18.
- Distance from the bridge site to the nearest health center *(km)*: 18.
- Distance from proposed bridge site to high school *(km)*: 18.

-Travel time from proposed bridge site to main market *(On foot, in minutes)*:

____

7. Contacts, municipality and community

1. Name and surname: Feliciano Coscio.

Post: Leader of K'ellu Mayu.

Tel.: 67517633. CI: ____________________

Email: ____________________________________

2. First and last name: Mario Rocha.

Post: Strio. of Aciendas of K'ellu Mayu.

Tel.: 67461220. CI: ____________________

Email: ____________________________________

3. Name and surname: Justino Coronado.

Post: Community member K'ellu Mayu.

Tel.: 72210715. CI: ____________________

Email: ____________________________________

4. First and last name: ____________________

Post: ____________________

Tel.: ____________________ CI: ____________________

Email: ____________________

5. Name and surname: ____________________

Post: ____________________

Tel.: ____________________ CI: ____________________

Email: ____________________

8. Bolivia addendum

- Does the Municipality have PTDI (Comprehensive Territorial Development Plan), census or any other support with data information for each community?

The municipality has the PTDI.

____

9. Rotary addendum

- What other types of projects are needed?

☐School/Classroom(s) ☐Health post ☐Bathrooms) ☐Irrigation ☐Drinking water
☐Other: Boarding School environments.

- Does the community/municipality already have final designs for some of these projects? If so, which ones?

____

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10. Notes

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ENGINEERS IN ACTION

TECHNICAL EVALUATION

Project name: Const. K'ellu Mayu River Pedestrian Bridge. Location: Pocona Municipality.
Advisor: Richard Galvez GPS: Latitud: -17.620584° y Longitud: -65.271513°.
Date: May 7, 2022.

PROFILE DRAWING

Suspended | Suspension

View AutoCAD file in Drive: Río Kellu Mayu_31AGO2022 Perfil de Terreno.

LEFT | WITH THE CURRENT | RIGHT

BM1	inst height			
BM2	inst height		Reference point	
BM3	inst height		Reference point	
BM4	inst height		Reference point	

SPOT	REF.	DESCRIPTION *	ADEL.(+) BACK(-)	LOW	HALF	HIGH	NOTES or ANGLE
E-1		STAKE 1					
E-2		STAKE 2					
E-3		STAKE 3					
E-4		STAKE 4					
E-5		STAKE 5					
HWL1							
HWL2							

ENGINEERS IN ACTION

SITE DESCRIPTION

▪ LEFT SIDE: On this side the terrain is flat longitudinally and transversely; On this side there is little vegetation, there are only sewenka plants and in between there are only two alder trees.

▪ RIGHT SIDE: On this side the land is flat longitudinally and transversely . On this side there is vegetation, most of are native trees of the place that are the kewinas, there are also smaller trees that are the tholas, and then you can also see grasslands on this side.

▪ Obstructions (stones, roads, canals, pipes, electricity lines, trees, drainage, erosion, crops, etc.):

▪ Access condition: There is no access on either side of the river. To reach the left side with materials it is only necessary to clean approximately 100 meters from the vehicular road, and to reach the right side with materials the community and the municipality are going to enable a temporary road for almost 150 meters. .

SOIL CLASSIFICATION

	Coarse-grained	Fine-grained	Rock
Side	☐ Gravel floor	☐ Silt soil	☐ Signature rock (fractured: Y/N)
Left	☐ Sand soil	☑ Clay soil	☐ Soft rock (fractured: Y/N)
Side	☐ Gravel floor	☐ Silt soil	☐ Signature rock (fractured: Y/N)
Right	☐ Sand soil	☑ Clay soil	☐ Soft rock (fractured: Y/N)

PHOTOS AND VIDEOS

☑ Left lifting limit	☑ Top of the left ravine
☑ Right lifting limit	☑ Top of the right ravine
☑ River bed	☑ Maximum water level
☐ Floor, left side	☐ Floor, right side
☐ Current crossing location	☑ Marked points
☐ Access to the site	☑ Site description
☐ Community	☐ Place for the brigade

GRADES

TECHNICAL STUDY CHECKLIST

☐ Walk 200 meters upstream and downstream from the proposed site or from the crossing point

☐ Measure 2 or 3 lines on the first visit

☐ Bridge length estimate: 20 m to 120 m

☐ Estimation of the "freeboard" (floodplain 2 m, gorge 3 m) with descent = 5%. Height difference between the lowest side and the maximum water level must be greater than L/20.

☐ Estimation of the height difference. Maximum 4% of the length, ± 2 meters with levels

☐ Space of 25 meters from the ravines on both sides, width of 5 meters

☐ Access to site for both sides, especially during construction season?

☐ Ask about land ownership! Make sure the owners agree!

☐ Ask at least two people for the HWL! Measure 2 points, one on each side if possible.

☐ Avoid utilities! Power lines, canals, light poles, roads, pipes, etc.

☐ Avoid confluences and curves (hydrological consideration)

☐ Signs of erosion? Banks and surroundings

☐ Soil classification, dig 1 meter if suspicious

☐ Draw the line in aerial view if necessary

☐ Suggest FFL and FFR in profile drawing

☐ Side slopes, steep?

☐ Don't forget the height of the instrument!

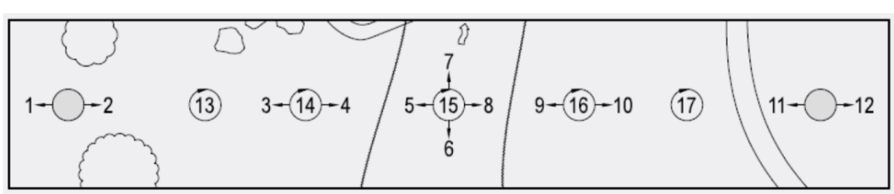
☐ Don't forget the HWL (2 points if possible) and the river bottom (right and left)!

☐ Leave stakes in the line, 4 if possible, or colored rocks

☐ Ask people in the community to remember and maintain the points marked with stakes/rocks

☐ Something or someone for proportion/perspective in photos and videos + comments

☐ The following figure shows where to take photos and videos



3

Appendix D

1. Calculation Book
2. Drawing Pack

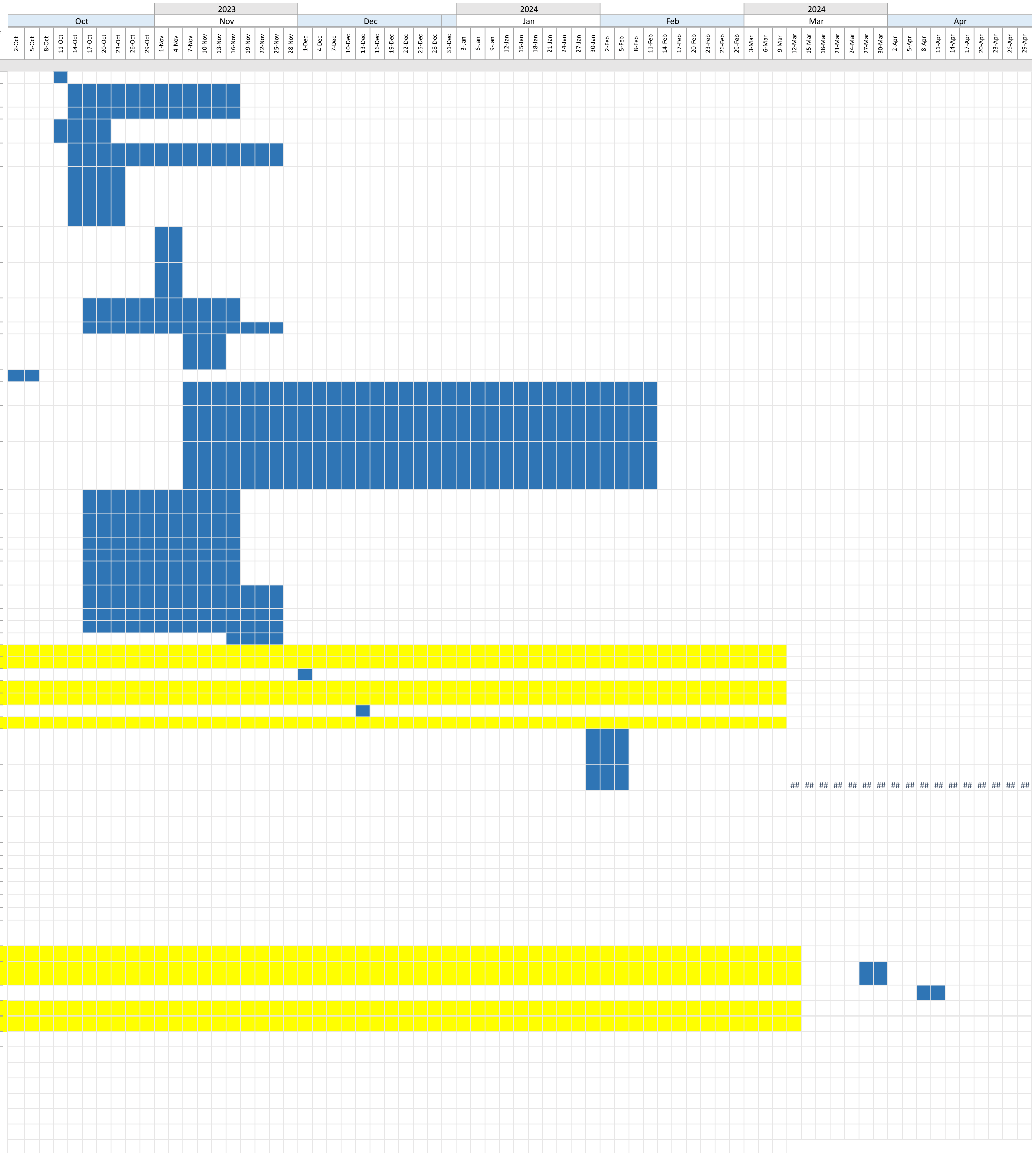
Appendix E: Project Schedule

Project Start Date: 10/11/2023

Project Name: Footbridge Capstone

#	Activity	Assigned To	Start	End	Days	Status	% Done
1	Interim Progress Report	All	Oct-11	Oct-13	2	Complete	100%
2	Project Development and Justification	Sacha	Oct-12	Nov-16	35	Complete	100%
3	Project Location Review	Sacha	Oct-12	Nov-16	35	Complete	100%
4	Suspended Bridge Module Geometric Design & CAD Practice	All	Oct-9	Oct-20	11	Complete	100%
5	Summarize Horizontal and Vertical Clearances	Sacha	Oct-12	Nov-27	46	In Progess	10%
6	Suspended Bridge Module - Standard suspended bridge design, non standard design, and conclusion sections (MODULE COMPLETE)	All	Oct-13	Oct-23	10	Complete	100%
7	Advanced Suspended Bridge Module- Intro, Loads, and Cables sections	Structures Team	Nov-1	Nov-6	5	Complete	100%
8	Project Management Module - Welcome and PM Methodologies Sections	Sacha and Jessie	Nov-1	Nov-6	5	Complete	100%
9	State Restrictions and Utility Conflicts	Sacha	Oct-16	Nov-16	31	Complete	100%
10	Summarize Material Acquisition	Sacha	Oct-16	Nov-27	42	In Progess	90%
12	Project Management Module - Management Tools and In-Country Leadership Sections	Sacha and Jessie	Nov-6	Nov-13	7	Complete	100%
13	Outline Roles and Responsibilities	All	Oct-2	Oct-6	4	Complete	100%
11	Advanced Suspended Bridge Module - Drafting Section	Calvin	Nov-6	Feb-12	98	In Progess	25%
	Advanced Suspended Bridge Module - Rebar and Design Tips Sections	Gabriel	Nov-6	Feb-12	98	In Progess	50%
14	Advanced Suspended Bridge Module - Soil Behavior, Abutment Sliding, Erosion Control, and Tiers Sections	Ronald	Nov-6	Feb-12	98	In Progess	50%
15	Describe Environmental Impact and Land Usage	Jessie	Oct-16	Nov-16	31	Complete	100%
16	Create Statement on International Development	Jessie	Oct-16	Nov-16	31	Complete	100%
17	Highlight Site Specific Conditions	Gabriel	Oct-16	Nov-16	31	Complete	100%
18	Describe Existing Soil Conditions	Calvin	Oct-16	Nov-16	31	Complete	100%
19	Summarize Hydraulic Conditions and High Water Line	Calvin	Oct-16	Nov-16	31	Complete	100%
20	Summarize Anchor Type and Location	Ronald	Oct-16	Nov-28	42	Complete	100%
21	Describe Geometric Evaluation	Ronald	Oct-16	Nov-28	42	Complete	100%
22	Create Bridge Details	Ronald	Oct-16	Nov-28	42	Complete	100%
	Polish Report	All	Nov-16	Nov-27	11	Complete	100%%
MILESTONE	Complete Report; Send to R&L	Sacha	Nov-28			Complete	
MILESTONE	Hold Mock Review call #1	All	Nov-30			Complete	
23	Edit Report after Mock call	All	Nov-30	Dec-5	4	Complete	100%
MILESTONE	Submit Review Call #1 Report	Sacha	Dec-5			Complete	
MILESTONE	Hold Review Call #1	All	Dec-11			Complete	
24	Post review call edits	All	Dec-11	Dec-15	4	Complete	0%
MILESTONE	START OF SPRING SEMESTER						
25	Suspended Bridge Construction Module	Sacha and Jessie	Jan-29	Feb-7	9	Complete	100%
26	Cross Cultural Competency Module	Sacha	Jan-29	Feb-7	9	Complete	100%
27	Construction Management Module	Sacha and Jessie	Feb-5	Feb-11	6	Complete	100%
28	Advanced Suspended Bridge Design Module	Design Team	Jan-29	Feb-12	14	Complete	100%
29	Excavation Drawings	Jessie	Feb-5	Mar-20	11	Complete	100%
30	Finalized Calculations	Design Team	Jan-22	Mar-13	25	Complete	100%
31	Bill of Quantities	Sacha	Feb-5	Mar-20	18	In Progess	10%
32	Finalize CAD Drawings	Design Team	Feb-12	Mar-13	11	Complete	100%
33	Construction Schedule	Jessie	Feb-19	Mar-20	11	In Progess	75%
34	Quality Control Points	Sacha	Feb-24	Mar-1	5	Complete	100%
35	Challenging Design and Construction Elements	Sacha	Feb-26	Mar-1	5	Complete	100%
MILESTONE	Complete Report; Send to R&L	Sacha	Mar-20				
MILESTONE	Hold Mock review call #2	All	Mar-25				
34	Edit Report after Mock call	All	Mar-25	Apr-1	5	Complete	100%
MILESTONE	Submit Review Call #2 Report	Sacha	Apr-1				
MILESTONE	Hold Review Call #2	All	Apr-8				
35	Post review call edits	All	Apr-8	Apr-12	4	Not Started	0%

Week Starting:



Statuses
Not Started
In Progess
Blocked
Complete

EIA BRIDGE PROGRAM
VOLUME 2 - DESIGN

Photo by Kyle Abrahm
Nyawoluhle, Eswatini 2023

Dear Engineers in Action Bridge Program student chapters, capstone programs, technical mentors, volunteers, faculty advisors, and more.

We are excited about your decision to pursue a project with the Engineers in Action Bridge Program! Our student teams bring a unique vision and energy to Engineers in Action (EIA) projects and can share that passion with communities around the world as ambassadors of EIA and our mission.

This Binder is broken into three volumes. **Volume 2: Design** outlines the technical protocols for completing a custom-design bridge project. It does not include the Project Development phase, which is covered in Site Feasibility and Surveying (321). It is not currently a requirement of the student team to participate in Project Development. This volume aligns with the required material from Review Call 1 (Concept Definition Report) through Review Call 2 (Design Report). This Binder was written using open-source information from Bridges to Prosperity and Helvetas, and adapted to fit our own design model and improved with further research in our specific program areas. It will continue to be an open-source educational material for students and volunteers!

Note that this Binder is intended to be a **reference** to the comprehensive series of asynchronous online course content on BridgeEDU. It is not intended to replace course content, as we believe deeper learning is possible through the online video and problem content, paired with Review Calls and the mentorship of our volunteers. If conflicting information arises, please contact education@eiabridges.org, and assume the content on BridgeEDU is the most up to date until you receive a response. If you have any other questions about this process that are not covered here, please don't hesitate to contact us!

Happy bridge building!

Brenton Kreiger

Bridge Program Education Manager | 401-808-9575
brenton.kreiger@engineersinaction.org

Bridge Binder Overview

The Bridge Binder is divided into three volumes

1. Volume 1: Campus Operations
2. Volume 2: Design
3. Volume 3: Field Operations

The Bridge Binder provides resources and instructions for all phases of the project that occur while the student team is on campus (Volumes 1 and 2) or in the field (Volume 3). Please contact education@eiabridges.org if you have questions, comments, or suggestions related to the Binder.

Useful Links:
SEED File
EIA.ctb
Drawing Checklist
Example Drawings (Markup)
Required Checks for Custom Designs
Tier 2 Example Calculations
Standard Design Templates
Standard Bridge Design (201)
Advanced Standard Bridge Design (211)
Bridge Binder Appendices (Campus)
Collaboration Folder

Bridge Binder Update History

The following is a list of important updates that have been made to this edition of the Bridge Binder. This is provided to make it easier to see what has been updated since the last time you have downloaded the Binder, without needing to search through the entire document for changes.

- **October 14, 2022 –** 3-tier ramp wall configuration updated to 40, 60, and 70-centimeter thick walls to accommodate the aesthetics of the structure and reflect in-country construction practices in Bolivia. Standard drawings and SEED file were updated as well, adding a BO-3G-XX version for Bolivia projects.

Table of Contents

Introduction

The designs and design processes included in this Binder originated with Helvetas Nepal's Short Span Trail Bridge Handbook that reflects the experience of Helvetas assisting with the construction of more than 8,000 bridges over the past 40+ years. By taking the suspended bridge design around the world, Bridges to Prosperity (B2P) honored Helvetas' leadership in addressing the global challenge of rural isolation. Now, the Engineers in Action (EIA) Bridge Program staff have adapted this open-source information to aid student learning, and we hope to honor both B2P's and Helvetas' leadership in addressing the global challenge of rural isolation. In 2003, B2P staff traveled to Nepal to train with Helvetas to learn about their cable-suspended bridge technology. In addition to learning about the design and construction of the suspended bridge, Helvetas also taught B2P their approach to participatory bridge building at the community level. B2P has introduced this highly efficient and economical suspended footbridge design to countries in need of this technology all around the world. Similarly, EIA (formerly known as the University Program when a part of B2P) was spun off from B2P to pursue a focus on student engagement, empowering today's students to become tomorrow's global changemakers. Currently, EIA works in Bolivia and Eswatini. The designs have been modified and adapted to better suit local conditions in each area. EIA has also modified construction practices and expanded flexibility in custom design alternatives to ensure that the suspended pedestrian bridge remains a locally sustainable option for communities in varying topographic and geographic regions of the world.

TERMS OF USE AND DISCLAIMER

No representations or warranties are implied or expressed herein. In consideration of this Binder being provided free to others, all users agree to allow a listing and brief description of footbridges built with this Binder on EIA website, so that others in the same geographic region can visit such bridges for observation and training. Furthermore, all users agree to hold EIA, its employees, partners, sponsors, contractors, and agents harmless from all liability arising from the use or application of the information provided herein.

Section 1 – Design Philosophy

Structural engineering involves ensuring the capacity of a structure (its ability to carry load) will exceed the demand on that structure. The purpose of this bridge design Binder is to ensure bridge safety by providing background information regarding the structural engineering utilized to generate standard designs and offering guidance to design a custom suspended cable bridge. To account for uncertainties with determining both the capacity and demand of a structural element or system, this design Binder utilizes the Allowable Stress Design (ASD) methodology with safety factors determined from reliability of loading and structural performance. This includes all the global checks (*e.g.*, sliding, uplift, overturning, shear failure) and timber material analyses. When dealing with reinforced concrete and masonry, it is more common to use the Load and Resistance Factor Design (LRFD) methodology. Given there is no "Authority Having Jurisdiction" (AHJ) in the areas where we work and implement bridges, this Binder will pull from various US-based code resources and pertinent research papers to establish reasonable design methodologies using engineering judgement and empirical evidence from thousands of past bridges. Design theory and practice have continued to evolve due to increased understanding of structural behavior and construction best practices gained through experience and research. This is the primary reason for establishing the newest version of this Binder for EIA designs.

1.1 Scope and Limitations

The guidelines in this Binder are intended for the design of suspended cable bridges with the stated assumptions. As with any modulated design, usage assumptions must be made by the bridge designer and engineering judgement must be implemented. For situations falling outside of the modulated design parameters, the design philosophies of this Binder may be applied with additional design criteria accounted for where required. For example, as discussed below, completely "standard" designs using only standard drawings and fulfilling all geometric requirements outlined in Section 2.3 may be checked with "Tier 1" design checks. These are the simple design parameters outlined in the Suspended Bridge Design (201) course on BridgeEDU. Partially modulated designs, or designs with custom abutments, require "additional design criteria" outlined by "Tier 2" design checks. These are the more advanced checks outline in the Advanced Suspended Bridge Design (211) course on BridgeEDU. *Tier 1 and Tier 2 design checks are both outlined in Required Checks for Custom Designs* (See **Useful Links**). An example of all "Tier 2" checks is also provided under **Useful Links**.

The suspended cable bridge is intended for pedestrians, livestock and narrow transportation aids (bicycles, wheelbarrows, motorbikes, etc.). For this reason, a 1.0-meter-wide walkway width (1.04-meters to be exact) was selected for all bridge designs. Widening the walkway up to 1.5-meters is possible with further engineering of the anchor, tower, and decking details, but any additional width more than one and a half meters risks the inevitable and inadvisable use by small cars. It is recommended that any bicycles, animals, or motorbikes be walked across, but all are considered acceptable for crossing.

The maximum span length for the modulated suspended cable bridge designs in this Binder is 120-meters. Due to dynamic effects of lateral wind loadings for spans exceeding 120-meters, lateral stabilizing measures (wind guys) must be implemented. For locations with exceptionally high wind speeds, a qualified engineer should be consulted to determine the necessity of lateral stabilization.

1.2 Allowable Stress Design Methodology

EIA has adopted the use of Allowable Stress Design (ASD), also known as "working stress design" or "service load design," for designing suspended cable bridges. ASD methodology is based on a principle that stresses developed in a structural component under normal service loading conditions do not exceed a predetermined limit. The general ASD equation is as follows:

$$\sum Q_i \leq \frac{R_n}{FS} \tag{1.2.1}$$

The left side of the equation, Q_i, is the stress in a component from a given load effect and is determined by elastic structural analysis. The right side of the equation represents a nominal stress limit (Rn) such as yielding or fracture, divided by a factor of safety (FS). The value of the factor of safety depends on the importance of the structural element and the level of uncertainty involved with calculating demand and capacity of that component.

1.3 Load and Resistance Factor Design

An alternative design methodology is Load and Resistance Factor Design (LRFD). LRFD is a probability-based design philosophy in which reduction factors are applied to materials and magnification factors are applied to loads to account for differing variability of each component. Both reduction factors and magnification factors are catered to specific materials and loading conditions. The current AASHTO standard (and most U.S.-based codes) utilizes LRFD methodology. Conversely, ASD treats all loads in a given load combination with the same variability and does not consider the concurrent situation with higher-than-expected loads with lower than expected strengths. The factor of safety takes care of that dual situation. The ASD approach has served very well with suspended cable bridge design and produced safe structures around the world. Just make sure not to combine the two methods (*e.g.,* use ASD loads and LRFD combinations). Primarily EIA will utilize ASD methods, but a few load cases are analyzed using the LRFD method.

1.4 Standard Designs

The primary purpose of this Binder is to provide users with a basic engineering background, serve as a reference or "textbook" to the design courses on BridgeEDU, provide background on the development of specific design checks, and lay out a safe and practical way to design suspended cable bridges. Previously, B2P engineered a series of modulated design drawings and details that accommodate different geometric conditions. These modulated design drawings used in conjunction with the design guide presented in this book are what is referred to as a standard design. Each standard design captures a range of span lengths and slope conditions, and eliminates the need for detailed engineering calculations for the bridge projects that meet those criteria. As such, the standard designs not only promote time efficiencies by reducing engineering and drafting time requirements, but also permit use by those without advanced engineering education. They serve as an excellent *starting point* in the design process, but to provide a more efficient product to the communities in which we work, as well as better education for our students, the large portion of this Binder will focus on *custom design*.

Because each standard is designed for a worst-case scenario for a given set of conditions, they are not the most economical design from a material and labor standpoint. Sometimes a more site-specific solution may be a better alternative, and the principles outlined in **Section 4 - Structural Analysis and Evaluation** must be employed. For bridge designs that do not fit the standard design assumptions, a site-specific solution must also be generated. These site-specific bridge designs are deemed “non-standard” and an engineer with proper education must be involved in the design process (this is referred to as the Design Engineer in Charge or DEIC). Remember, “Tier 2” checks must always be performed for non-standard designs.

Beginning in 2022, EIA requires all student teams to generate "non-standard" designs because (1) most sites necessitate non-standard design anyway and (2) more research and information has allowed us to refine the design process and create more "optimal" designs that reduce material use and excavation. The "standard drawings" are still provided and work as a helpful template to get started. DWG versions of these can be found in the SEED file, and PDF versions can be found in Collaboration Folder > BridgeEDU > 201 Suspended Bridge Design (see **Useful Links**). Remember that all "non-standard" designs must be held to a series of more robust checks - these are thoroughly explained in Advanced Suspended Bridge Design (211) course on BridgeEDU and listed in Required Checks for Custom Designs (see **Useful Links**).

1.5 Design Timeline

The timeline we use for student teams is complex, and for newer teams or design managers, this can both be confusing and overwhelming. For the sake of clarity, and reference, below is an approximate timeline for those serving in the “Bridge Designer”, “Junior Bridge Designer”, or “DEIC” role. A more in-depth “design process” detailing the steps for creating a custom design is provided in **Section 5 – Suspended Bridge Design**.

September

- Begin taking BridgeEDU courses focusing on design.
    - New design managers and assistant design managers should take Suspended Bridge Design (201).
    - Returning design managers and DEICs should take Advanced Suspended Bridge Design (211) only, unless they want the refresher of 201.
- *Returning design managers only need to take Advanced Suspended Bridge Design (211), but need to confirm that a Junior Design Manager will take the Suspended Bridge Design Course (201) so that the following deliverables are met:
    - A Mock Review Call and calculation package is a deliverable of the Suspended Bridge Design (201) course. This is required from ***all teams each year*** and serves as a time to share updates to the SEED file and answer any basic design questions.
    - If you are using a precedent design tool (usually in the form of an excel spreadsheet) it should be checked and validated with all new design checks, values, and parameters.
- Conference is held. Make sure to participate in the “basic/advanced design track” for students.

October

- Continue working through design courses (201, 211).
- Mock Review Calls should be assigned and scheduled.

November

- Continue working through design courses (201, 211).
- By this time, you should be wrapping up all coursework for Suspended Bridge Design (201).
- Finish all Mock Review Calls.
- Turn in calculation package deliverables for Suspended Bridge Design (201).

December

- By this time, you should be wrapping up all coursework for Advanced Suspended Bridge Design (211).
- Receive site assignments and begin working towards Review Call 1. Before making any design progress, make sure your ".dwg" survey file provided by the In-Country Program Manager matches the format of the SEED file.
- Review Call 1 requires a geometrically feasible design (proper freeboard, meets Delta H requirements, etc.).
- Any head start you can get on optimizing your abutments at this point is ideal. Feedback will be given on Review Call 1.
- Bolivia projects will receive custom sag values at the same time you receive your project site information. This information will be in a Google Doc within your Site Info folder.
- Bolivia projects will receive the project "convenio" (agreement with municipality) at this time in your Site Info folder. Your final design should aim to either match or use *less* materials than this estimate.

January

- Work toward Review Call 1.
- Ping the Bridge Program Education Manager via Basecamp with questions.
- Reach out to education@eiabridges.org if you don't receive a response within 24 hours.

February

- Complete Review Call 1. Your design must pass all "Tier 1" design checks.
- Receive feedback on your preliminary designs.
- Eswatini projects will receive custom sag values and a preliminary BOQ at this time.
- Begin working toward Review Call 2 and final design. This means "optimizing" your design by exploring less excavation, shortening abutments, raising anchors, and more. Advice on how to do this is given in the Advanced Suspended Bridge Design (211) course on BridgeEDU.
- Remember all custom designs must perform the minimum checks listed in the Required Checks for Custom Designs (see **Useful Links**).
- Remember all drawing sets must be labeled according to the Drawing Checklist and Example Drawing Set (see **Useful Links**).

March

- Complete Review Call 2.
- Usually 1-2 weeks of iteration will occur post-review to arrive at final designs with accurate material estimates and bills of quantities (BOQ) and sufficient drawing sets Released For Construction (RFC).
- Work towards any edits to your design, material estimate, and final drawings set.
- Begin working toward Review Call 3.

April

- Complete Review Call 3.
- Excavation drawings should be completed with Review Call 3. Guidance on excavation drawings is provided in the Construction Management (301) course on BridgeEDU.
- A table of construction tolerances informed by the design should be developed in collaboration with your DEIC.

Travel (May – August)

- Download your design tool offline; make sure this is available in-country via USB drive.
- Print all required design-related documentation (see **Volume 3: Field Operations**).
- Be available via WhatsApp for any technical changes to the design.

Section 2 – General Design and Location Features

This section provides minimum requirements for bridge layout, geometric clearances and constraints, geotechnical investigation, and hydrology and hydraulics. Additional design objectives such as safety, durability, serviceability, maintainability, constructability, economics, and aesthetics are also addressed. You can think of this section as the minimum required design work for Review Call 1 (Concept Definition Report).

In addition to technical feasibility, selection of a bridge site should also take into consideration the local economics, social and environmental concerns, land ownership impacts, and long-term maintenance and inspection responsibilities. Refer to the Site Feasibility and Surveying (321) course on BridgeEDU for more information on these topics. Note that site and centerline selection is *not a requirement* of student teams, as a Site Info folder with technical surveys, social surveys, site media, and custom sag values, will be provided to the team. However, it is good practice to understand these documents and the qualitative conditions of your site. It may provide insight on your design or improve your travel experience!

2.1 Design Objectives

The design engineer's primary objective is public safety. Other aspects of design including durability, serviceability, maintainability, constructability, economics, and aesthetics are secondary.

Safety:
Safety is of utmost importance not only from a structural integrity standpoint but also from the aspect of users. Considerations should be made for user safety such as adequate railings, walkway materials that will accommodate bare feet, and safety fencing with a mesh sufficient to prevent passage of objects or small children. Minimum requirements to ensure structural safety are presented in **Section 4 - Structural Analysis and Evaluation**.

Durability:
Quality materials should be selected in conjunction with proper detailing to maximize resistance to usage and weather thereby extending the structure's lifespan. Detailing examples that enhance durability include: sufficient concrete cover for reinforcing bars, galvanized fasteners, treated wood, and corrosion protection measures for buried cables and components in direct contact with soil and/or water.

Serviceability:
Suspended cable bridges without lateral stabilization are inherently flexible structures that can sway in the wind and bounce with pedestrian traffic. Nonetheless, bridges should be designed to limit the typical deformations experienced during use such that negative psychological effects such as feeling queasy can be avoided. Additional considerations should be made for limiting the walkway slope on approach ramps and at the ends of the bridge span near abutments.

Maintainability:
Considerations should be made for economical maintenance of the bridge to extend the overall lifespan of the major structural components. Safety fencing, suspenders, decking, and crossbeams should be detailed in a way that permits ease of replacement. Untreated timber, such as pine, may

only last a year or two in high moisture environments whereas treated tropical hardwoods may last more than ten years.

Constructability:
The standard and custom design methodology presented in this Binder and the construction methods discussed in **Volume 3: Field Operations** have evolved through experience to ensure fabrication and erection can be completed in a safe, economical, and efficient manner. Bridge sites present a wide array of challenges for construction and specific requirements designated by the engineer should be incorporated into construction drawings.

Economy:
EIA optimizes the economic efficiency of its bridges by utilizing locally available materials. For instance, construction of the anchorage systems typically sources locally gathered stones from nearby rivers. Additionally, sand can be sifted from the river so long as the quality can be maintained. Availability of materials, fabricators, labor, and shipping should be considered.

Aesthetics:
Bridge aesthetics are not prioritized by EIA, this is usually up to the local community to paint fencing and crossbeams desired colors. However, anti-corrosive paint for crossbeams and cables is an important construction requirement. Decorating bridges is allowed so long as the structural integrity is maintained.

2.2 Bridge Layout

A bridge site should be selected with adequate room for foundation placement in a location that satisfies all clearance requirements. Considerations should also be made for proximity to existing roadways and potential impact damage from both road and waterway vehicles. Basic examples of a typical profile (elevation) and plan diagrams for suspended cable bridges are shown in the figures below. Use the Example Drawing Set (see **Useful Links**) for a detailed example of a typical drawing set.

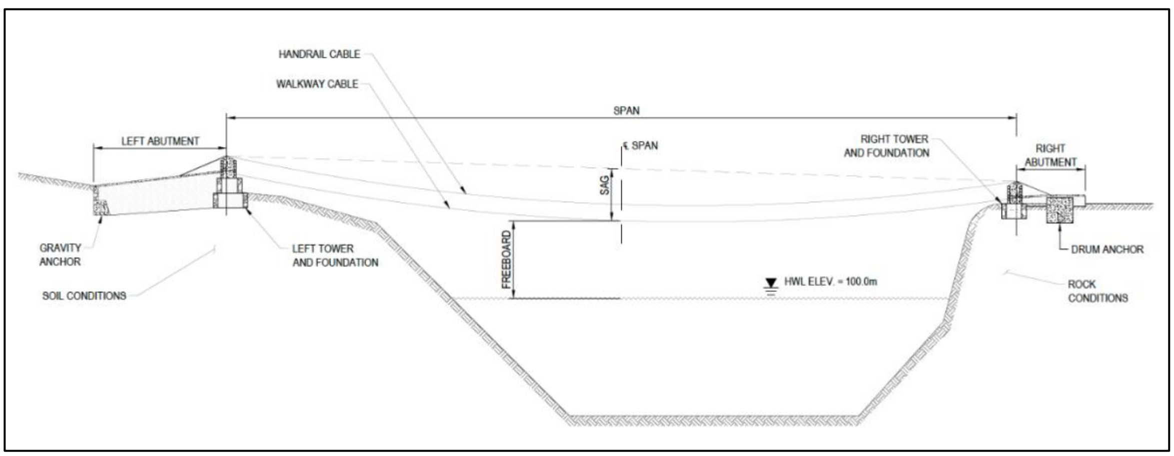


Figure 2.2.1: Typical bridge profile view.

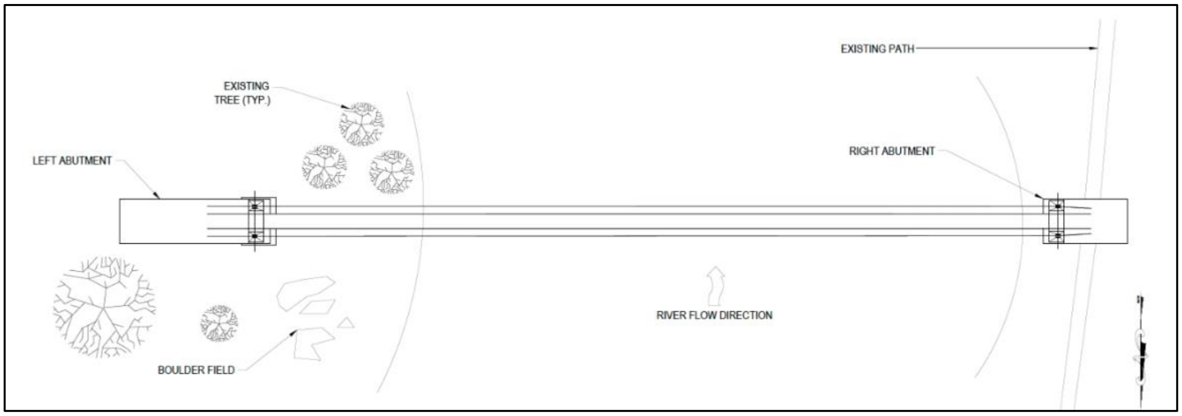


Figure 2.2.2: Typical bridge plan view.

2.3 Geometric Requirements

The following geometric requirements are implemented to reduce the engineering (*e.g.,* no extensive soils testing, lack of material data) needed for each project, limit the exposure to certain environmental effects such as wind and floods, maintain serviceability with maximum walkway slopes, and avoid other hazards such as powerlines and overhead tree branches.

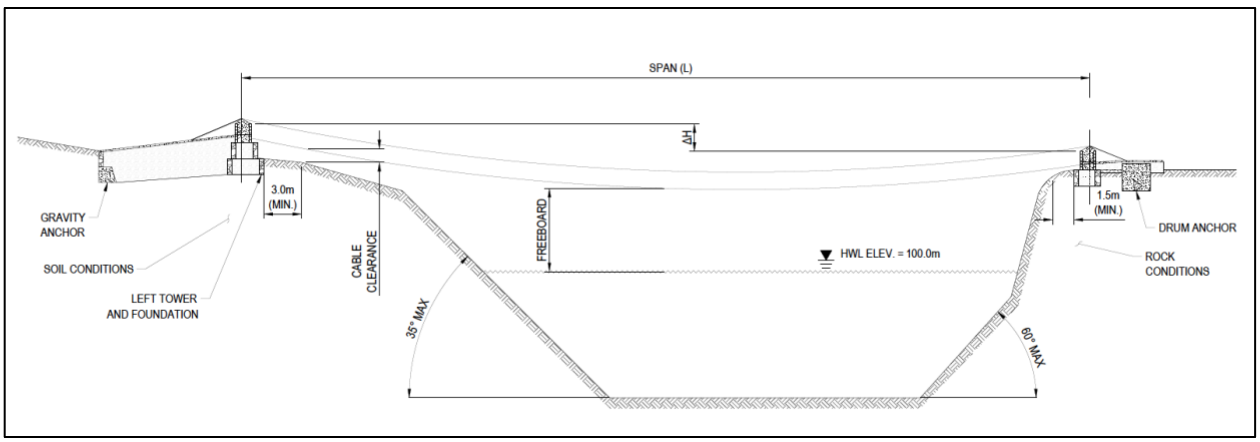


Figure 2.3.1: Major geometric constraints.

Span Length (L):
The maximum span length for the suspended cable bridge designs in this Binder is 120-meters. Due to dynamic effects of lateral wind loadings for spans exceeding 120-meters, lateral stabilizing measures (wind guys) must be implemented. For locations with exceptionally high wind speeds, a qualified engineer should be consulted to determine the necessity of lateral stabilization.

Maximum Span 120 meters

Foundation Setback:
The tower foundations should be at least 3.0-meters from the top edge of each riverbank for soil conditions and 1.5-meters for rock. Edge of bank will be clearly labeled on the provided site survey. Also note that most suspended bridge sites are in soil conditions. If this isn't the case, EIA staff will provide a heads up to the design team. This setback helps avoid situations where erosion or

rock fall may encroach upon the foundations. To avoid slope stability concerns, the tower foundations should also be placed behind the line of the angle of internal friction of the bank from any point along the slope. For a foundation placed in soil, a 35° angle should be used, and for foundations placed in rock, a 60° angle should be used. When drawing lines with the appropriate angle, the entire tower foundation should be located on the opposite side of the line as the river. Where top and bottom of bank locations are not very well defined, the slope stability and potential erosion may be less of a concern and these provisions should be applied as best possible.

Difference In Elevation:
A large height differential from one side of the river to the other not only has adverse structural effects, such as excessive eccentricity on the abutment tower, but also decreases serviceability by producing steep walkways. The final design dictates the height difference between the cable saddles shall not exceed 4% of the span length (L/25) to limit these effects. The maximum height difference (ΔH) equation is as follows:

Maximum Height Difference $$\Delta H \leq \frac{L}{25}$$

Freeboard:
Freeboard is the clear distance from the lowest point of the bridge walkway to the high-water level. The high-water level is the absolute highest point the river level has reached including such cases as a hurricane or other large flood events. If the high-water level represents a flood so large that it renders most bridges infeasible (*e.g.,* Hurricane Mitch in Central America or Zamcolo in Eswatini), a lower high-water level is sometimes acceptable. Maintaining a proper freeboard is important to prevent the bridge from being damaged by vegetation or other debris drifting down the river during high water events. Such an event may lead to a catastrophic failure of the structure. The topography of the area will dictate the magnitude of required freeboard. For flatter areas with substantial floodplains, a freeboard value of 2.0-meters *may be* acceptable because increased volume of water flow results in nominal increases in water level. In locations with steeper slopes, a minimum freeboard of 3.0-meters is required because channelized waterways can rise rapidly with increased flow. **All suspended bridge sites should be considered as a gorge unless special permission is granted by EIA staff**. If so, permission for a new target freeboard will be granted during or before Review Call 1. Otherwise, any request to lower freeboard below 3.0-meters will need to be well-justified. Foundation heights may be increased to achieve proper freeboard, but there is a structural limitation to how high they may be constructed (typically 1.5-meters).

Cable Design Sag:
The Cable Design Sag for the permanent at-rest position of the completed bridge is set to be 4.55% of the span length (L/22). While suspended cable forces decrease with increased sag percentages (*i.e.*, when cables sag lower), this restriction is imposed to limit the inclination of the walkway surface for serviceability. Conversely, because cable forces increase with decreased sag percentages (*i.e.*, when cables sag less and are more straight across the river), the resulting forces from cables with less sag require larger foundations and the eccentricity of the cable forces on the abutment towers increases. "Custom Sags" are now generated for each bridge site to better predict cable forces and behavior. Depending on your program country, these values will be provided before or immediately after the Review Call 1 preliminary design phase by EIA staff in your Site Info folder.

Cable Clearance:
Sometimes, clearance of the cable above the ground can become an issue. This can be hard to see, because we use the "design" or "dead load" sag to find the geometry of our bridge. When the bridge is weighted with people or livestock, it will sag further. Because of this, ensure that the cables are a minimum of 1.0-meter above the ground at any point using the design sag geometry. If the cable geometry violates this check, further exploration is required. The next step is to check if the cable is a minimum of 0.5-meters above the ground using the live load + dead load sag geometry. If the cable geometry violates this check, extra excavation to reach proper clearance is required. Equations for calculating span geometry are in **4.1 Cable Analysis**.

Environment and Utilities:
Bridge sites are often located near existing low water vehicular crossings that also may have power lines running alongside the roadway. Projects may also be in heavily vegetated areas where large trees are obstructive or pose threats to damage the bridge. EIA requires the following clearance requirements:

Minimum overhead power line clearance:	10.0 meters in any direction
Minimum horizontal roadway clearance:	3.0 meters from any roadway to bridge component
Minimum vertical roadway clearance:	5.0 meters beneath suspended bridge cables
Trees that threaten falling on the structure:	Shall be removed
Trees that do not pose falling risk:	Shall be at least 2.0 meters clear from bridge components
Tree branches:	All branches should be removed from above the bridge structure

2.4 Geotechnical Investigation

For both abutment locations, one must determine the type of anchorage best suited for the geological conditions of the site. A geotechnical investigation should be conducted to determine the type anchor and basic soil class (see **Table 2.4.1** below).

Table 2.4.1: Basic Soil Class

Coarse Grained	**Fine Grained**	**Rock**
Gravelly soil	Silty soil	Hard rock (fractured yes/no)
Sandy soil	Clayey soil	Soft rock (fractured yes/no)

For rock and coarse grained soil, the conservative International Building Code (IBC) values for Class 3 Materials from Table 1806.2 are sufficient (ultimate bearing pressure of 286 kPa and allowable bearing pressure of 143 kPa). Following Table 1806.2, bearing pressure values for fine grained soil (silty and clayey) are significantly less, so it is important to work with the DEIC to determine if 143 kPa, or a reduced capacity should be used for fine grained soil classes. Independently, the EIA technical committee has analyzed the soil bearing capacities for fine grained silty and/or clayey soils for strip and spread footings on a slope. DEICs can reach out to education@eiabridges.org to discuss this method in the determination of their site-specific soil bearing capacities.

Regarding test pits and rebar tests, at this time, EIA staff will not provide additional testing unless proper justification is made (*e.g.,* bearing pressure safety factor is extremely close and we want to gather confidence in the reference values). Efforts to carry a soil penetrometer to each site are being made, and if testing values are available, they will be reported in the technical survey.

2.5 Hydrology and Hydraulics

Two of the biggest threats to the lifespan of a bridge are the potential for erosion that may compromise the bridge abutments, and high water carrying large debris.

Hydrologic investigations should be conducted as best possible by using historical flood information and/or talking to local community members about flood events. This will be done before the site information is released to the team; however, information is always subject to change with new storms or new information from the community. In addition to maximum flood levels, the flood frequency, water velocities, and distribution of flow will be reported when possible. In the event a bridge is in an area where there are not many houses or a high-water mark cannot be sufficiently determined, a detailed hydrologic study may be warranted. Hydraulic studies should investigate the channel migration (*i.e.*, whether the river channel has meandered from its current location), bank stability, potential for large debris, and high-water levels. The study should include a larger portion of the watershed upstream and not be restricted to the immediate bridge vicinity. For example, surveying of cross-sections upstream and downstream at significant bends in the river. Furthermore, any effect the proposed bridge structure may have on flood flow patterns or potential for scour should be investigated.

As a reminder, all suspended bridge sites will be assumed a gorge and require 3.0-meters of freeboard to limit the possibility of damage from debris and high water. This decision was made due to the uncertainty of changing climates and to increase the potential lifespan of our bridges. If 3.0-meter freeboard renders a site infeasible, this is open to discussion on a case-by-case basis.

Section 3 – Loads and Materials

This section describes loads and load combinations that should be used for bridge designs along with their appropriate application. This section also discusses material property assumptions used for the standard and custom design methodology presented in this Binder. Country-specific values are referenced (when available) to refine design checks based on the build country. Make sure not to confuse values between countries. If a specific country isn't referenced, this value is universal across programs.

3.1 Loads

During the analysis and design process, various loads affecting the bridge need to be considered. There are two primary types of loads that must be considered: Permanent Loads and Transient Loads. Each type of load has various contributors that together define the magnitude of the Permanent Loads and Transient Loads.

Permanent Loads:
Permanent Loads are ones that remain relatively constant over time including the weight of the structure itself and earth pressures constantly in contact with the bridge structure.

Dead Load (DL):
The Dead Load includes the weight of all permanent components of the bridge structure. The actual dead load of the bridge is based on material takeoffs and will vary according to crossbeam and decking materials used, cable sizes, fencing weight, stone and concrete volumes and densities, etc. For suspended cable bridges using timber decking, 1.0 kilonewtons per square meter (20.89 lb/ft^2) is a conservative assumption for the dead load of the cables and walkway surface including the suspenders and fencing for a bridge with a 1.0-meter-wide walkway. This is generally sufficient for Tier 1 checks. For Tier 2 checks, the dead load of each component shall be calculated based on actual volumes and materials used. A step-by-step procedure is taught in the Advanced Suspended Bridge Design (211) course on BridgeEDU and the pertinent equations are summarized below. Refer to the standard drawings for walkway details (marked with "W") and crossbeam details (marked with "C") to calculate the material volumes.

$$W_{fence} = 2 * h_{fence} * \rho_{fence} \tag{3.1.1}$$

where:
ρ_{fence} = 2.2 kg/m^2
h_{fence} = 1.2 m

$$W_{suspender} = \frac{2 * V_{suspender} * \rho_{steel}}{s} \tag{3.1.2}$$

where:
ρ_{steel} = 7850 kg/m^3
$V_{suspender}$ = suspender volume, m^3
s = suspender spacing of 1 m

$$W_{beam} = \frac{V_{nailer} * \rho_{timber} + V_{crossbeam} * \rho_{steel/timber}}{s} \tag{3.1.3}$$

where:
ρ_{timber} = 900 kg/m^3

$V_{nailer} =$ nailer volume, m^3
$V_{crossbeam} =$ crossbeam volume, m^3

$$W_{deck} = t_{deck} * w_{deck} * \rho_{timber} \tag{3.1.4}$$

where:
t_{deck} = deck board thickness, m
$w_{deck} =$ deck width, m

$$W_{cables} = refer\ to\ \textbf{Table 3.1.1} \tag{3.1.5}$$

$$DL = W_{fence} + W_{suspender} + W_{beam} + W_{deck} + W_{handrail\ cables} + W_{walkway\ cables} \tag{3.1.6}$$

Lateral Earth Pressure (EH):
Lateral Earth Pressure is the pressure a soil exerts in the horizontal direction and should be included with abutment, wall, and retaining structure designs. The two types of lateral earth pressures to be considered are "at-rest" and "active". "At-rest" pressure is the in-situ lateral pressure and should be used when the resisting structural component can tolerate little or no movement. An "active" soil pressure occurs when a soil mass is allowed to relax or deform laterally to the point of mobilizing its available shear resistance in trying to resist lateral deformation. Active soil pressure should only be used on structural components such as retaining walls or abutments that will move or rotate away from the soil until the "soil active state" (state in which active soil pressure affects the structure) is reached. Determination of lateral earth pressures is covered in **Section 4 - Structural Analysis and Evaluation**.

Transient Loads:
Transient Loads include any temporary or brief forces that act on the bridge structure. Transient Loads include people, vehicles, wind, seismic, surcharge, ice, snow, thermal, and buoyancy loads.

Wind Load (WL):
The design Wind Load is taken as a uniformly distributed load based on a wind speed of 160 kilometers per hour acting horizontally on the walkway. This corresponds to a wind pressure of 1.3 kN/m^2 acting on the lateral bridge area of 0.3 m^2 per meter span. Using a wind drag coefficient of 1.30, the lateral design wind load is 0.50 kN/m span. A more in-depth explanation of this calculation is described in Advanced Suspended Bridge Design (211) course on BridgeEDU. Wind-on-ice loads are also considered to be negligible where we build bridges.

Wind Load also affects the dynamic behavior of the bridge. However, empirical data has proven that bridges of up to 120-meters in span show no significant dynamic effects due to wind load. Therefore, no lateral stabilizing measures are considered in this suspended bridge design guide. For special cases with spans more than 120-meters, or extremely windy areas exceeding wind speeds of 160 kilometers per hour, a qualified engineer should be contacted to design a wind guy system for lateral stabilization and flutter mitigation.

While not required for strength reasons, lateral stabilization and flutter mitigation may be desired for spans larger than 80-meters to reduce the amount of movement the bridge undergoes at mid-span during a wind event and increase user comfort while crossing. It should be noted that lateral stabilization and flutter mitigation using wind guys adds significant cost and time to a bridge project.

Distributed Live Loads (LL):
A Distributed Live Load is a uniform force applied to the full length of the walkway surface representing people, animals, or motorbikes. Primary load-carrying structural components, including cables, anchors and foundations, shall be designed for a distributed live load of 4.07 kilonewtons per square meter (kN/m^2) (85 lb/ft^2) of bridge walkway area. If the bridge walkway area exceeds 37 square meters $(400\ ft)^2$, the distributed live load may be reduced by the following equation:

$$w = 4.07\frac{kN}{m^2} * \left(0.25 + \frac{4.57}{\sqrt{A}}\right) \ni w \begin{cases} \geq 3.14\frac{kN}{m^2}\ (65\frac{lb}{ft^2}) \\ \leq 4.07\frac{kN}{m^2}\ (85\frac{lb}{ft^2}) \end{cases} \qquad (3.1.7)$$

where:
w = the design live load (kN/m^2)
A = the walkway area (m^2).

This reduction accounts for the reduced probability of the entire bridge being fully loaded simultaneously. The minimum live load that should be applied regardless of span length is 3.14 kN/m^2 (65 lb/ft^2). Secondary members, including bridge deck, crossbeams, and suspenders, shall be designed for a live load of 4.07 kN/m^2 (85 lb/ft^2), with no reduction allowed. A more recent version of the AASHTO Guide Specification for Design of Pedestrian Bridges has been published with an increased Distributed Live Load value of 4.22 kN/m^2 (90 lb/ft) with no reduction for increased loading area. We agree with the assessments of Helvetas and B2P that the likelihood of a rural footbridge being fully loaded to this level at any span length is unrealistic and have decided not to adopt this revision.

Point Live Load (PL):
A Point Live Load is a singular force acting on any structural component. For the cases of rural pedestrian bridges, loads such as livestock, horses, and motorbikes may be larger in magnitude than the calculated Distributed Live Load and may act on a smaller area. The walkway system, including decking and crossbeams, shall support a point load of 2.22 kilonewtons (500 lb) anywhere between suspenders.

Ice and Snow Load (SL):
Ice and snow gravity loads in EIA project countries are assumed to be less than the minimum live load of 3.14 kN/m^2 (65 lb/ft^2) covered by the Design Live Load and are not utilized independently in this Binder.

Seismic Load (EQ):
Suspended cable bridges are inherently flexible structures and an independent load case for seismic forces is not considered due to the low probability of an earthquake occurring simultaneously with a full live load.

Buoyancy Load (BL):
It is unlikely that suspended bridges with 3.0-meters of freeboard will experience buoyant forces on the abutment structures. However, if standing water is present in the anchor excavation, the structure must be analyzed considering buoyant forces and friction under saturated conditions. If the loading is temporary, a reduced factor of 1.25 is permissible.

$$BL = \gamma_{water} * g * V_{displaced} \tag{3.1.8}$$

where:
γ_{water} = density of water (kg/m3)
g = gravitational constant
$V_{displaced}$ = volume of water displaced, m3

Temperature Load (TU):
Additional forces resulting from thermal effects on cables is negligible and are not included in the standard design process.

Surcharge Load (ES):
A surcharge load is any load that is applied on a surface close enough to a structural system that it results in a lateral pressure acting on the system in addition to earth pressure. For a suspended bridge project, is could be the weight of a large trucking driving the road next to a bridge site.

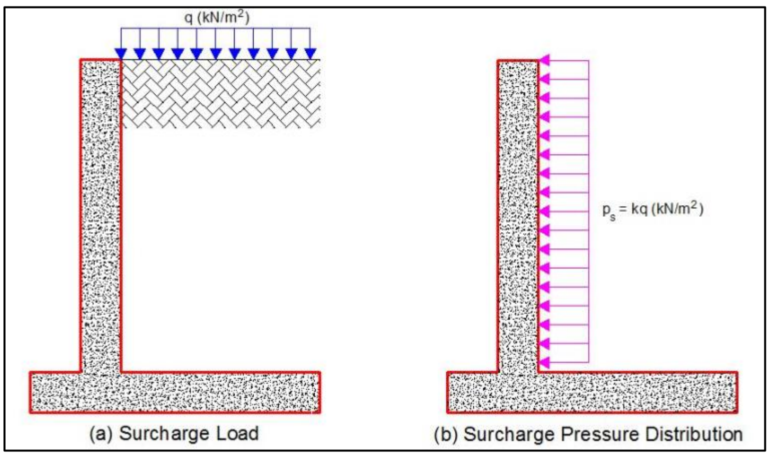


Figure 3.1.1: Image of surcharge loading from Structville Integrated Services ©

Surcharge loads for bridge abutments close to roads should be calculated and considered. This process is explained in more detail in the Advanced Suspended Bridge Design (211) course on BridgeEDU. It is likely that bridges are built near roadways, and because of this, we've added a section to consider the effects of surcharge loading on bridge abutments. This section utilizes the recommended loading from the *AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, 2012*.

A live surcharge load (LS) from vehicular traffic on the backfill surface is calculated using equation 3.11.6.4-1, reported below as **Equation 3.1.9**.

$$\Delta_p = k * \gamma_s * h_{eq} \tag{3.1.9}$$

where $\Delta_p = 0$ if abutment is more than 1.5-meters from the road

$k = coefficient\ of\ lateral\ earth\ pressure$
$\gamma_s = soil\ density\ in\ kips\ per\ cubic\ foot$
$h_{eq} = equivalent\ height\ of\ soil\ for\ vehicular\ load$

Note that k is the same as K_a, active earth pressure coefficient, calculated for P_{active}.

Table 3.11.6.4-1—Equivalent Height of Soil for Vehicular Loading on Abutments Perpendicular to Traffic

Abutment Height (ft)	h_{eq} (ft)
5.0	4.0
10.0	3.0
≥20.0	2.0

Table 3.11.6.4-2—Equivalent Height of Soil for Vehicular Loading on Retaining Walls Parallel to Traffic

Retaining Wall Height (ft)	h_{eq} (ft) Distance from wall backface to edge of traffic	
	0.0 ft	1.0 ft or Further
5.0	5.0	2.0
10.0	3.5	2.0
≥20.0	2.0	2.0

Figure 3.1.2: Screenshots of AASHTO tables for h_{eq}.

3.2 Load Combinations

It is not probable for all the potential load effects on a bridge to occur simultaneously. As a result, it is necessary for an engineer to consider different combinations of loads that may occur at the same time to ensure the bridge can withstand various loading scenarios that it may experience throughout its lifespan. The following load combinations account for the practical combinations of loads that may be applied (remember not to combine ASD methods with LRFD load factors and vice versa):

ASD:
For low span suspended cable bridges (<120m):

$$DL + EH + LL + ES \tag{3.2.1}$$

For high wind or long span suspended cable bridges requiring lateral stabilization (>120m):

$$DL + EH + LL + ES + 0.3 * WL \tag{3.2.2}$$

$$DL + EH + ES + WL \tag{3.2.3}$$

LRFD:
For analysis of hoisting and decking stages of construction:

$$1.4 * DL \tag{3.2.4}$$

For analysis of complete suspended cable bridges:

$$1.2 * DL + 1.6 * LL + 1.6 * EH \tag{3.2.5}$$

3.3 Material Properties

Actual strength values should be determined via certification and or testing. Values below are for specific EIA program countries, and **product specifications can usually be provided upon request**. EIA otherwise assumes the following (conservative) strengths for suspended cable bridges. f_c' is concrete compressive strength, f_m' is masonry compressive strength, f_y is the yield strength of steel, q_u is ultimate bearing capacity of soil, ϕ is the internal angle of friction of the assumed soil, F_b is the flexural capacity of timber, and F_v is the shear capacity of timber.

Concrete	$f_c' = 15\ MPa\ \left(2200\,\frac{lb}{in^2}\right)$	*mixed by drum mixer*
	$f_c' = 10\ MPa\ \left(1500\,\frac{lb}{in^2}\right)$	*mixed by hand*
River Rock Masonry	$f_m' = 1.5\ MPa\ \left(220\,\frac{lb}{in^2}\right)$	
Structural Steel (Crossbeams)	$f_y = 240\ MPa\ \left(35{,}000\ \frac{lb}{in^2}\right)$	*general value*
	$f_y = 355\ MPa\ \left(55{,}000\ \frac{lb}{in^2}\right)$	*Eswatini projects*
Steel Reinforcing Bar	$f_y = 275\ MPa\ \left(40{,}000\ \frac{lb}{in^2}\right)$	

General Soil

$$*q_u = 286\ kPa\ \left(6{,}000\ \frac{lb}{ft^2}\right)$$
$$**\phi = 30°$$

Note that ultimate bearing strength of the soil depends on the soil classification. 286 kPa has historically been used for thousands of suspended bridges and is a relatively conservative estimate for even silty and clayey soils in the slope and setback range we operate. Refer to **Section 2.4 – Geotechnical Investigation for more details.*

***Remember ϕ is taken to be 30°, rather than the previous 33° (B2P, 2016). Paired with a cohesionless soil assumption, this increases the conservatism of our soil properties. However, this design change was made in tandem with altering the soil friction equation in the sliding check **(Equation 4.5.4)**, resulting in more efficient designs. For more information on why this change was made, along with background research, reference the Advanced Suspended Bridge Design (211) course on BridgeEDU.*

Cable (Steel Wire Rope) — See **Table 3.3.1** for Cable Tensile Strength

Timber

$$F_b = 3.96\ MPa\ \left(574\ \frac{lb}{in^2}\right)$$
$$F_v = 1.44\ MPa\ \left(210\ \frac{lb}{in^2}\right)$$

Table 3.3.1: Cable Properties (Hanes Supply Manual for galvanized 6x19 IWRC – 7x7 wire core rope)

Diameter		Area		Weight		Tensile Strength*	
in	mm	in²	mm²	lb/ft	kg/m	kip	kN
3/8	9.53	0.068	44.0	0.260	0.39	12.8	57.1
7/16	11.1	0.093	59.9	0.350	0.52	17.3	77.1
1/2	12.7	0.121	78.2	0.460	0.68	22.6	101
9/16	14.3	0.153	99.0	0.590	0.88	28.6	127
5/8	15.9	0.189	122	0.720	1.07	35.0	156
3/4	19.1	0.273	176	1.04	1.55	50.0	222
7/8	22.2	0.371	240	1.42	2.11	67.7	301
1	25.4	0.485	313	1.85	2.75	87.9	391
1-1/8	28.6	0.614	396	2.34	3.48	111	492
1-1/4	31.8	0.758	489	2.89	4.30	136	604
1-3/8	34.9	0.917	592	3.50	5.21	173	768
1-1/2	38.1	1.09	704	4.16	6.19	194	862

*Tabulated tensile strength is reduced to 85% from reported manual values because cable is used (not new), galvanized, and due to end condition (sheave size ratio).

Table 3.3.2: Material Properties

Material Unit Weights		
Material	SI Units	Imperial Units
Steel	7850 kg/m^3	490 lb/ft^3
Concrete	2400 kg/m^3	150 lb/ft^3
Timber	900 kg/m^3	56 lb/ft^3
General Soil	1800 kg/m^3	112 lb/ft^3
Stone Masonry	2100 kg/m^3	131 lb/ft^3
*Tier & Abutment Fill (Slurry Mix)	1900 kg/m^3	120 lb/ft^3
*River Rock (pile)	1600 kg/m^3	100 lb/ft^3
*Grout (from Slurry Mix)	2150 kg/m^3	134 lb/ft^3
Water	1000 kg/m^3	62.4 lb/ft^3
Cable	See Table 3.3.1	See Table 3.3.1

*See the Advanced Suspended Bridge Design (211) course on BridgeEDU for derivation of grout and abutment fill density values.

Section 4 – Structural Analysis and Evaluation

The following section details basic design criteria and assumptions used by EIA when designing cable suspended bridges. This section is intended for use in custom design verification. For standard bridge projects, skip to **Section 5 - Suspended Bridge Design**. Design of all structural elements shall be per recognized design codes using safety factors consistent with ASD and/or LRFD methodology.

Referenced design codes and standards include:

- AASHTO Guide Specification for Design of Pedestrian Bridges, 1997
- AASHTO LRFD Bridge Design Specifications, 7th Edition, 2014
- ACI 318-14 Building Code Requirements for Structural Concrete
- AISC (American Institute of Steel Construction) Steel Construction Manual, 14th Edition
- NDS (National Design Specification for Wood Construction), 2015 Edition
- PE Civil Reference Manual, 16th Edition, 2016
- IBC (International Building Code), 2018
- ACI 530-13 Building Code Requirements and Specifications for Masonry Structures
- ASTM-A853 Standard Specification for Steel Wire, Carbon, for General Use
- ASTM-A392 Standard Specification for Zinc-Coated Steel Chain-Link Fence Fabric
- Bridges To Prosperity Bridge Builder Manual, 5th Edition, 2016 (The B2P Manual)
- NAVFAC DM7-02 Foundations and Earth Structures

Material within this section has also been developed using third party research papers. All research used within is peer reviewed, and the associated papers are cited along with video explanations in the Advanced Suspended Bridge Design (211) course on BridgeEDU.

4.1 Cable Analysis

Overview:
A cable hanging between two supports and carrying a uniformly distributed load along its length (as opposed to the true horizontal dimension) forms a catenary curve. However, the cable can be analyzed as a parabolic curve for simplicity since the difference between catenary and parabolic profiles is negligible in the range of sag values used for suspended cable bridges. There are four sag values to consider when designing the main cables for a bridge: Construction Sag, Hoisting Sag, Dead Load Sag, and Live Load Sag.

Construction Sag (h_1): is the initial position the cables are hoisted to, before lowering them into their hoisting position. The construction sag should always be the smallest sag percentage. The construction sag should be set at 3% and checked to ensure that no early failure of the anchor, winch, or erection hooks, could occur during the construction process. The process for this calculation is detailed in the Advanced Suspended Bridge Design (211) course on BridgeEDU, with the associated equations in **4.8. Construction Analysis**.

Hoisting Sag (h_2): is the resting position of the cables when only supporting their own weight. During the construction process, the cables are let down from the construction sag value to the hoisting sag value by slightly loosening the clamps and striking the cable near the anchor to let small amounts of cable slide through.

Dead Load Sag (h_3): is the cable's position under full dead load. This can also be known as the "design" sag or the "post-decking" sag value. The dead load sag (h_3) should be measured as part of the as-built documentation process to verify sag percentages.

Live Load Sag (h_4): is the cable's position under full dead load plus full live load. This sag value is for structural design purposes only and is only "theoretical" because it is unlikely the bridge will see its full live load + dead load. This sag is based on the "design" sag value for how much a cable should theoretically stretch under a higher loading due to its properties.

In the latest iteration of this Binder, the various sag names have been replaced with numbers to avoid confusion during the construction process. The numbers should both correspond to size (*i.e.,* sag 1 should be the smallest sag % and sag 4 should be the largest %) and order in the construction process (*i.e.,* sag 1 is the first cable position, sag 2 is the second cable position, etc.).

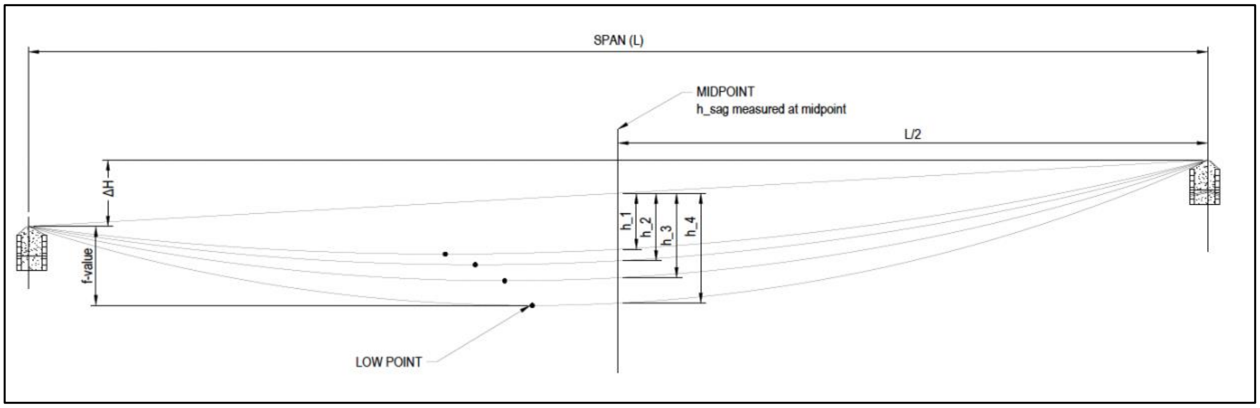


Figure 4.1.1: Various cable sags and low points plotted on an example suspended bridge outline.

Standard Sag:
The change in sag values from one loading condition to the next reflects the elastic elongation in the cables as more load is applied. EIA bases designs upon the geometric profile created using the Design Sag value (h_3). Standard sag values come from the B2P Manual and correspond to the geometry that is formed by a fully loaded cable (Factor of Safety = 3.0). This is explained in detail in the Advanced Suspended Bridge Design (211) course on BridgeEDU, and the standard sag values are as follows:

$$h_{Hoist} = h_2 = 4.6\% * L \quad (4.1.1)$$

$$h_{DL} = h_3 = 5.0\% * L \quad (4.1.2)$$

$$h_{LL} = h_4 = 6.1\% * L \quad (4.1.3)$$

This assumption, however, is neither valid nor a conservative approach to bridge design. For example, consider you have two 50-meter-long bridges. If you build one with (4) 1" cables and the other with (5) 1-3/8" cables, the bridges will not deflect the same when decked and ultimately loaded. The (5) 1-3/8" cable bridge will be much stiffer, deflect less, and have a *lower* sag value which corresponds to a *higher* horizontal tension. Therefore, we have moved to custom sag values to (1) increase freeboard, (2) increase serviceability of the bridge, and (3) more accurately model cable force transfer into the abutments.

Here is a "real world example". In 2021, the Lubanjiswano bridge was built using standard sag values (hoisted to 4.6%, expected to sag to 5.0% of span when decked, and design checks performed using a 6.1% live load sag). It is a 50-meter bridge, but 1-3/8" cables were used because that was the only size available in-country. As-built documentation shows that it only sagged to 4.85%, which subsequently indicates a 5.61% live load sag (was assumed to be 6.1%). That 0.5% difference can be tracked to an 8.7% *increase* in Ph (horizontal cable force). This is enough deviation to cause significant problems, especially if the design has been highly optimized.

Custom Sag:
The Design Sag value (h_3) is now taken as 4.55% of the span length (L/22). The initial position of the cables prior to adding the walkway (Hoisting Sag, h_2) and the final position of the cable under full dead and live load (Live Load Sag, h_4) are determined iteratively with known loadings and cable properties (area and modulus of elasticity). This is done with a finite element analysis program developed internally by the EIA Technical Committee. The necessary inputs come from bridge geometry: span (L), height difference (ΔH), number of tiers, and abutment geometry) If you are a Design Engineer in Charge (DEIC) and want to learn more, please reach out to education@eiabridges.org.

As of 2022, the process for receiving custom sag values is as follows. These values can be found in a Google Doc in your Site Info folder (20XX EIA Bridge Program Projects > "Your Project Name" > Site Info > Custom Sag). Team bridge designers should reach out during the iterative design process (between RC1 and RC2) to receive updated sag values. Significant changes to span, cable number, or abutment geometry can affect sag.

- Bolivia projects will receive custom sag values when they receive their site information at the beginning of the project. Custom sag will be in the Site Info folder with information about the date of last update and any assumptions used to generate these values.
- Eswatini projects will receive custom sag values based on their Review Call 1 submission. Up to this point, please use the standard sag values to generate a preliminary design.

Geometry and Forces:
The following diagram and equations describe the theory governing the geometry of the main span cables and the resulting forces. It is important to note the distinction that the low point (f) does not occur at the midpoint of the span (unless the height difference happens to be zero). However, h_{sag} is measured at the midpoint of the span.

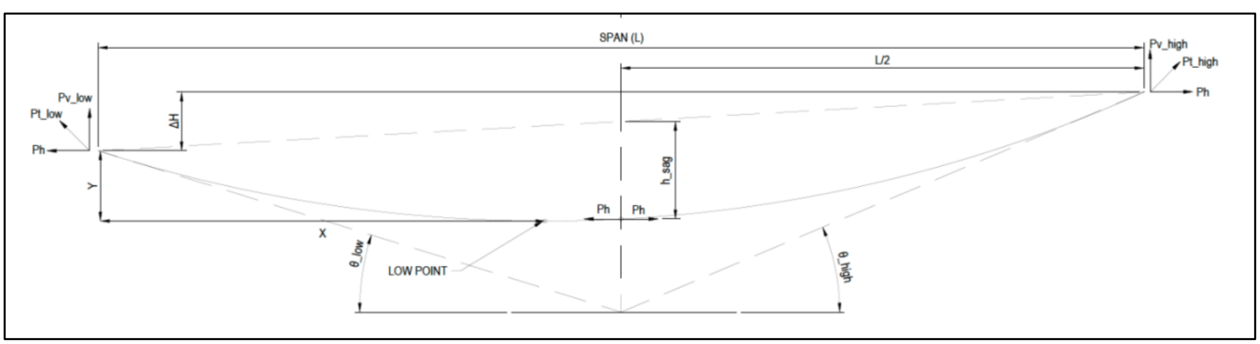


Figure 4.1.2: Cable geometry and mainspan forces (Uniform Distributed Load) on an example cable outline.

Cable Geometry:

Following the parabolic cable assumption, we can then derive a set of equations for the geometry of cable. The Advanced Suspended Bridge Design (211) course on BridgeEDU details the derivation of these values, and the supplemental "cable sag bulletin" goes through an example calculation.

<u>Construction Sag Geometry (h_1)</u>

Low Tower to Low Point; $Y_1 = \frac{(4*h_1 - \Delta H)^2}{16*h_1}$ (4.1.4)

<u>Hoisting Sag Geometry (h_2)</u>

Low Tower to Low Point; $Y_2 = \frac{(4*h_2 - \Delta H)^2}{16*h_2}$ (4.1.5)

<u>Dead Load/Design Sag Geometry (h_3)</u>

Low Tower to Low Point; $X_{low} = L * \frac{4*h_3 - \Delta H}{8*h_3}$ (4.1.6)

Low Tower to Low Point; $Y_{low} = \frac{(4*h_3 - \Delta H)^2}{16*h_3}$ (4.1.7)

High Tower to Low Point; $X_{high} = L * \frac{4*h_3 + \Delta H}{8*h_3}$ (4.1.8)

High Tower to Low Point; $Y_{high} = \frac{(4*h_3 + \Delta H)^2}{16*h_3}$ (4.1.9)

<u>Live Load/Fully Loaded Sag Geometry (h_4)</u>

Low Tower to Low Point; $X_{low} = L * \frac{4*h_4 - \Delta H}{8*h_4}$ (4.1.10)

Low Tower to Low Point; $Y_{low} = \frac{(4*h_4 - \Delta H)^2}{16*h_4}$ (4.1.11)

Low Tower Cable Angle; $\theta_{low} = (\frac{4*h_4 - \Delta H}{L})$ (4.1.12)

High Tower to Low Point; $X_{high} = L * \frac{4*h_4 + \Delta H}{8*h_4}$ (4.1.13)

High Tower to Low Point; $Y_{high} = \frac{(4*h_4 + \Delta H)^2}{16*h_4}$ (4.1.14)

High Tower Cable Angle; $\theta_{high} = (\frac{4*h_4 + \Delta H}{L})$ (4.1.15)

Cable Forces:

In this section, the various cable forces are extrapolated from our parabolic cable assumption and basic trigonometry. Before diving into the equations, it is important to establish a labeling scheme for cable forces. All cable force variables will start with "P", and the horizontal force in the cable derived from the bridge geometry will be labeled "Ph". Moving forward, "h" will represent a horizontal force, "v" will represent a vertical force, and "t" will represent an axial force in line with the cable at any given point. Forces can occur in the main span (river side of the tower) or backstay (anchor side of the tower) and will be distinguished as handrail cable or walkway cable forces.

Cable force nomenclature will be established as follows:

$Ph, low_{hand,back}$ is the "P" cable force acting "h" horizontally on the "low" low side from the "$_{hand}$" handrail cable in the "$_{back}$" backstay. If "low" or "high" is not specified, the equation is the same regardless of orientation.

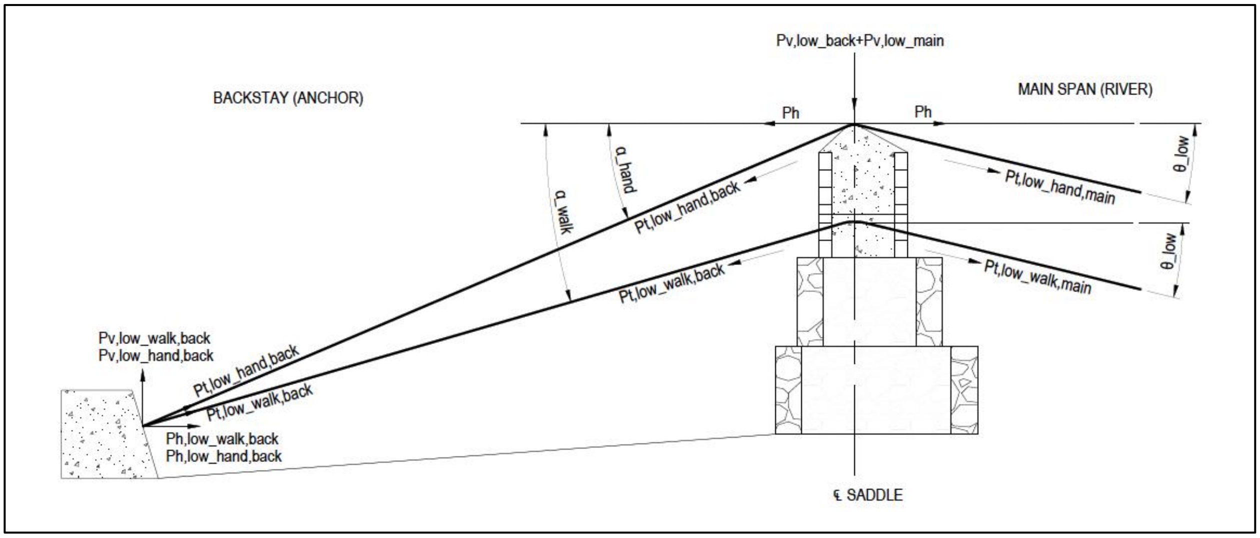


Figure 4.1.3: Low side backstay cable geometry and forces (cable forces split into handrail and walkway components) on an example abutment outline.

<u>Main Span Forces:</u>

Horizontal Tension; $P_h = \frac{w_c * L^2}{8 * h_{sag}}$ (4.1.16)

where:
P_h = horizontal cable tension, kN
w_c = distributed load, kN/m
h_{sag} = cable sag, meters (h_1, h_2, h_3, or h_4)

Vertical Tension; $Pv_{main} = P_h * tan\ (\theta)$ (4.1.17)

where:
θ = mainstay cable angle, degrees

Total Tension; $Pt_{main} = \frac{P_h}{cos\ (\theta)}$ (4.1.18)

<u>Backstay Forces (Basic):</u>

Total Backstay Tension; $Pt_{Back} = \frac{P_h}{cos\ (\alpha_{hand})}$ (4.1.19)

where:
α_{hand} = backstay angle of the handrail cable

Vertical Backstay Tension; $Pv_{back} = Pt_{back} * sin\ (\alpha_{hand})$ (4.1.20)

Total Main Span Tension; $Pt_{main} = MAX(Pt_{high}, Pt_{low})$ (4.1.21)

Vertical Main Span Tension; $Pv_{main} = Pt_{main} * sin\ (\theta)$ (4.1.22)

Total Vertical Reaction at Tower; $R_{Tower} = Pv_{back} + Pv_{main}$ (4.1.23)

This concludes the cable analysis performed in the B2P Manual, and the "Tier 1" design checks. However, to further optimize cable design (as well as sharpen the pencil on subsequent abutment and anchor design checks), the cable forces should be split by area.

Backstay Forces (Advanced):

$$Pt, low_{hand,back} = Pt, low_{main} * \left(\frac{A_{c,hand}}{A_c}\right) \quad (4.1.24)$$

where:
A_c = cable area, m²

$$Pt, low_{walk,back} = Pt, low_{main} * \left(\frac{A_{c,walk}}{A_c}\right) \quad (4.1.25)$$

Backstay forces in the handrail and walkway cables can be further broken into horizontal and vertical components using trigonometry and associated cable angles ($\alpha_{hand}, \alpha_{walk}$). To save space, these equations are not shown. See a full explanation in the Advanced Suspended Bridge Design (211) course on BridgeEDU.

Cable Design:

Available cable diameters and associated breaking strengths are provided in **Table 3.1.1**. Inquire with EIA field staff about what cable diameter(s) will be available for your project. If you are a DEIC and have further questions regarding these values, reach out to education@eiabridges.org.

Cable design shall satisfy:

$$P_s \leq \frac{P_u}{FS} \quad (4.1.26)$$

where:
P_s = maximum axial tension in cable, kN
P_u= ultimate breaking strength of cable, kN
FS= factor of safety = 3.0

Note that maximum axial tension in the cable (P_s) can be found three different ways with varying levels of conservatism. All these methods are acceptable checks for cable design. Final method should depend on the preference of the DEIC.

1. (Most conservative) Assume no friction over the tower/walkway saddles and calculate the maximum axial tension. Mathematically, this maximum axial tension will always occur in the handrail cable in the backstay of the side with the largest handrail cable angle, $Pt_{hand,back}$.
2. (Somewhat conservative) Assume no friction over the tower/walkway saddles and calculate the axial backstay tension in both the handrail and walkway cables (the walkway will always be less than handrail due to a lower angle). Take the handrail and walkway portion of the forces, by area, and sum together. Divide by total amount of cables.
3. (Most efficient) Assume that friction over the tower/walkway saddles will always result in backstay cable forces *less than* main span cable forces. Take the $Pt,high_{main}$ value (high side will always be greater than low side mathematically) as the maximum axial tension.

Minimum Ground Clearance:

Ground clearance is the distance from the cable to ground level (grade) at any point. This can become an issue on sites that require greater than 3.0-meter setbacks and/or have fewer tiers because the cable sags close to the edge of bank. **Figure 2.3.1** illustrates this dimension as "CABLE CLEARANCE". The Advanced Suspended Bridge Design (211) course on BridgeEDU recommends a 1.0-meter distance during the design iteration phase. However, in practice we can allow the live load bridge geometry (h_4) to get as low as 0.5-meters. If the dead load geometry (h_3)

of the cables *violates* the 1.0-meter distance, check the live load bridge geometry (h_4) to confirm the design has over 0.5-meters of clearance. If this constraint is violated, extra excavations must be stipulated and accounted for in the construction schedule.

Coefficient of Friction:
Basic suspended bridge design uses a saddle friction coefficient of 0.1 for all cases. This is conservative in some cases, and not conservative in others. For example, a higher friction coefficient results in more force transfer into the tower/tier assembly at the saddle. When analyzing the anchor for sliding and uplift, we want to use a smaller saddle friction coefficient to consider maximum force acting on the anchor. On the contrary, when analyzing the tower overturning, we want to use a larger saddle friction coefficient to consider maximum force contributing to the overturning moment. *Because of this, we've adopted a sliding scale for saddle friction coefficients*. The sliding scale is governed by AASHTO Table 5.9.5.2.2b-1 – Friction Coefficients for Post-Tensioning Tendons. This information is discussed further in the Advanced Suspended Bridge Design (211) course on BridgeEDU.

Type of Steel	Type of Duct	K	μ
Wire or strand	Rigid and semirigid galvanized metal sheathing	0.0002	0.15–0.25
	Polyethylene	0.0002	0.23
	Rigid steel pipe deviators for external tendons	0.0002	0.25
High-strength bars	Galvanized metal sheathing	0.0002	0.30

Figure 4.1.4: Screenshot of AASHTO Table 5.9.5.2.2b-1 – Friction Coefficients for Post-Tensioning Tendons. We are interested in, μ, the coefficient of friction. K is the "wobble friction coefficient" not used in this Binder.

Use the following guidelines when performing "Tier 2" (advanced) design checks.

Tower Saddle (Steel-Steel) for Tower Analysis: $\mu = 0.2$
Anchor Sliding and Uplift Analysis: $\mu = 0.15$
Walkway Saddle (Steel-Plastic): $\mu = 0.23$

4.2 Walkway Analysis

Overview:
EIA standard timber or steel crossbeams and decking boards have been designed according to NDS 2015 and AISC 14th edition. Each crossbeam and decking board shall be designed to carry the applied loads without exceeding the adjusted design values. Adjusted design values take into consideration the conditions under which the timber will be used, including moisture content, load duration, and shape. It is the responsibility of the engineer to apply the appropriate design values along with adjustment factors when conducting crossbeam and decking design. An in-depth superstructure analysis is performed in the Advanced Suspended Bridge Design (211) course on BridgeEDU. The following standard drawings are the common details used in each program country (follow the **Useful Links** on the cover page to access the standard details). If for any reason you wish to use a detail that is not specified below, please provide justification.

Eswatini:
W3E Walkway Detail (C5E Steel Crossbeams w/ Nailer and Timber Decking)
C5E Steel Crossbeam Detail [Steel Channel C4x7.25 (SI C100x10.8)]
F2E Fencing Detail

Bolivia:
W3 Walkway Detail (C1 Steel Crossbeams w/ Nailer and Timber Decking)
C1 Crossbeam Detail [Steel Channel C4x5.4 (SI C100x8)]
F3 Fencing Detail

Walkway Load Analysis:
Decking boards and crossbeams are secondary members and shall carry unreduced distributed live load values and point live loads in accordance with **Section 3 - Loads and Materials.** Each timber element shall be checked for both flexure and shear. Typically, the point load case will govern decking design. Refer to walkway details (W1, W2, W3, etc.) for specific dimensions. New standards have been developed and are being used on EIA builds in our program countries. For all EIA standard designs, a minimum of three equally spaced walkway cables must be used with timber crossbeams.

Distributed Moment; $M_{distributed} = \frac{w_{TL} * s^2}{8}$ or $\frac{w_{TL} * L^2}{8}$ (4.2.1)

where:
s = crossbeam spacing, m
w_{TL} = unreduced total load (DL+LL), kN/m

*Point Load Moment; $M_{point} = \frac{13 * PL * s}{64}$ or $\frac{PL * L}{4}$ (4.2.2)

*Distributed Shear; $V_{distributed} = \frac{5 * w_{TL} * s}{8}$ or $\frac{w_{TL} * L}{2}$ (4.2.3)

*Point Load Shear; $V_{point} = \frac{19 * PL}{32}$ or $\frac{PL}{2}$ (4.2.4)

*For deck boards we will take the maximum loading between two design conditions: (1) Simply supported beam from edge of nailer to edge of nailer or (2) continuous beam from middle of nailer to middle of nailer or L=s. For crossbeams we will assume simply supported beam conditions.

Steel Crossbeam Analysis:
Nominal Moment Capacity; $M_n = F_y * Z_y \leq 1.6 * F_y * S_y$ (4.2.5)

where:
Z_y = Plastic Section Modulus (based on section properties)
S_y = Elastic Section Modulus (based on section properties)
F_y = Steel yield strength*
*Remember Fy varies based on program country steel specifications

Allowable Moment Capacity; $M_r = \frac{M_n}{1.67}$ (4.2.6)

Check $M_r \geq M_{distributed\ or\ point}$ (4.2.7)

Timber Analysis:

Distributed Bending Stress; $fb_{distributed} = \frac{M_{distributed}}{S_{deck}}$ (4.2.8)

where:
S_{deck} = deck board section modulus, m^3

Point Load Bending Stress; $fb_{point} = \frac{M_{point}}{S_{deck}}$ (4.2.9)

Distributed Shear Stress; $fv_{distributed} = \frac{3*V_{distributed}}{2*A_{deck}}$ (4.2.10)

where:
A_{deck} = deck board section area, m^2

Point Load Shear Stress; $fv_{point} = \frac{3*V_{point}}{2*A_{deck}}$ (4.2.11)

Adjusted Bending Capacity; $F_b' = F_b * C_D * C_M * C_t * C_L * C_F * C_{fu} * C_i * C_r * C_e$ (4.2.12)
Adjusted Shear Capacity; $F_v' = F_V * C_D * C_M * C_t * C_i * C_H$ (4.2.13)

where:
C_D = Load Duration Factor = 1.0 if distributed, 1.6 for point loads (NDS Specifications Table 2.3.2)
C_M = Wet Service Factor = 0.85 in bending, 0.97 in shear (NDS Supplement Table 4A)
C_t = Temperature Factor = 1.0 (NDS Specifications Table 2.3.3)
C_L = Stability Factor = 1.0 (NDS Specifications Table 3.3.3)
C_F = Size Factor = 1.2 (NDS Supplement Table 4A)
C_{fu} = Flat Use Factor = 1.15 (NDS Supplement Table 4A)
C_i = Incising Factor = 1.0 (NDS Specifications Table 4.3.8)
C_r = Redundancy Factor = 1.0 (NDS Specifications Table 4.3.9)

Check $F_b' \geq fb$ (4.2.14)
Check $F_v' \geq fv$ (4.2.15)

Guardrail (Fencing) Analysis:
The guardrail (fencing) design check is not required. This analysis is explained in the Advanced Suspended Bridge Design (211) course on BridgeEDU, and standard details have been developed based on procurable materials in our program countries. The process follows the AISC specifications to evaluate stresses in the posts and the IBC to check embedment depth. The standard details are linked in the Google Drive folder for standard details starting with “F”.

4.3 Suspender Analysis

Overview:
The suspenders transfer load from the walkway cables into the handrail cables. The suspenders are subjected to environmental factors and cyclical bending within the flexible structure. As a result, EIA uses a factor of safety of 5.0 to account for the likelihood of potential fatigue failure and corrosion of the steel over time. Even though smaller bars or wires may be used, we recommend using no less than a 10-millimeter deformed reinforcing bar (#3 bar), with a minimum yield strength of 274 MPa (40,000 lb/in^2). The increased factor of safety also reduces the risk of progressive failure where if a single suspender breaks and neighboring suspenders must transfer additional load. Smooth reinforcing bar often is of inferior quality and strength, and thus should be avoided (see **Volume 3: Field Operations** for construction-related uses for smooth reinforcing bar).

Suspender Design Check:
For the axial design check of suspenders, the calculated stress in the member due to the maximum axial load must be less than or equal to the yield stress divided by a factor of safety. A more detailed explanation is provided in the Advanced Suspended Bridge Design (211) course on BridgeEDU.

Axial Stress shall satisfy:

$$f_s \leq \frac{f_y}{FS} \tag{4.3.1}$$

in which:

$$f_s = \frac{P}{A_s} \tag{4.3.2}$$

f_y = reinforcing bar yield strength, MPa
P= axial load, kN
A_s= steel reinforcing bar area, mm²
FS= factor of safety = 5.0

4.4 Tower and Foundation Analysis

Overview:
Vertical forces generated in the cables are transferred through the towers and tiers into the foundation. Additional vertical load is also generated from the self-weight of the towers, tiers, and ramps. Due to friction over the tower and walkway saddles, a horizontal force component is also transferred into the towers and tiers. To distinguish between the elements we are checking, we'll define both a global overturning check and a tower analysis (which includes a tower overturning check). In our global check, the resultant cable force, considering the backstay and main span components of the cable's influence on the tower saddle, must not cause overturning of the entire tower and tier structure. In our tower analysis, we'll zoom into a singular tower column to analyze overturning and internal stresses. See the Advanced Suspended Bridge Design (211) course on BridgeEDU for a more detailed explanation.

Global Overturning Check:
Global overturning occurs when horizontal overturning loads from the cables exceed the restorative forces generated by the vertical component of the cables along with the self-weight of the towers, tiers, and foundation. Global overturning would result in catastrophic bridge failure.

Global overturning shall satisfy:

$$M_o \leq \frac{M_r}{FS} \tag{4.4.1}$$

M_o = total overturning moment, kN-m
M_r= total restorative moment, kN-m
FS= factor of safety = 1.5

The total overturning and restorative moments can be calculated using static analysis. A free body diagram of associated loads acting on the tower is shown below. A conservative friction coefficient between the cable and wheel (top of tower) saddle of 0.20, and cable and walkway saddle of 0.23, is included to account for additional horizontal load that may occur at the top of the tower. Note that eccentricity is measured from a line that goes from directly below the saddle all the way straight down to where the foundation tier rests on the soil below, as shown in the figure as the saddle centerline (this does not correspond to the center of the towers nor to the center of the foundation tier). Eccentricity checks are covered in following sections.

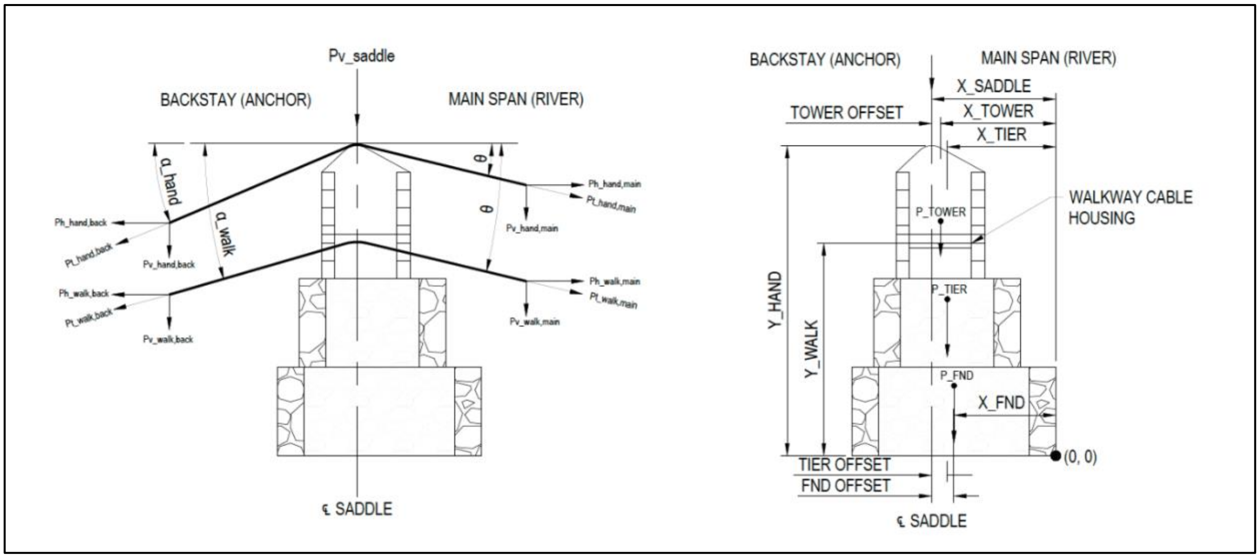


Figure 4.4.1: Tower cable forces, self-weight forces, and tier/tower lever arms.

Instead of using the B2P Manual Equation 4.19, we have adopted the AASHTO belt friction equation (5.9.5.2.2b-2). This equation converts main span forces to backstay forces as follows:

$$P_{Back} = P_{Main} * e^{-\mu(\alpha+\theta+0.04)}) \qquad (4.4.2)$$

where:
$\mu = 0.2$
θ = Main Span Cable Angle, degrees
α = Backstay Cable Angle, degrees

This equation can, and should, be applied to each main span component to find its associated backstay tension. You may notice that $Pt_{hand,main} = Pt_{walk,main}$, but because $\alpha_{hand} \neq \alpha_{walk}$ then $Pt_{hand,back} \neq Pt_{walk,back}$. The following equations are to calculate global overturning forces split into cable components.

$$Ph_{Saddle} = (Pt_{hand,main} + Pt_{walk,main}) * cos\ (\theta)\ - (Pt_{hand,back} + Pt_{walk,back}) * cos\ (\alpha) \qquad (4.4.3)$$

$$Pv_{Saddle} = Pv_{hand,main} + Pv_{hand,back} + Pv_{walk,back} + Pv_{walk,main} \qquad (4.4.4)$$

where:
Pv_{hand} *and* Pv_{walk} are the sum of *all* vertical forces in the handrail and walkway cables at the tower

$$M_o = (Ph_{hand,main} - Ph_{hand,back}) * Y_{Hand} + (Ph_{walk,main} - Ph_{walk,back}) * Y_{Walk} \qquad (4.4.5)$$

$$M_r = Pv_{Saddle} * X_{Saddle} + \sum_{i=1}^{n} P_{Tier,n} * X_{Tier,n} + P_{Foundation} * X_{Foundation} \qquad (4.4.6)$$

Tower Analysis:
In the tower-specific analysis section, we will zoom into the tower columns and walkway. For more information on dimensions, reference the standard tower details in the **Useful Links** section at

the beginning of the Binder. All the equations referenced below are explained in detail in the "Tower Analysis" section of the Advanced Suspended Bridge Design (211) course on BridgeEDU. In this section, we'll reference:

- Tower overturning (global check)
- Eccentricity
- Biaxial loading (tower column acting as a beam-column)
- Moment capacity (tower acting as a beam)
- Minimum reinforcing requirements (tower acting as a beam)

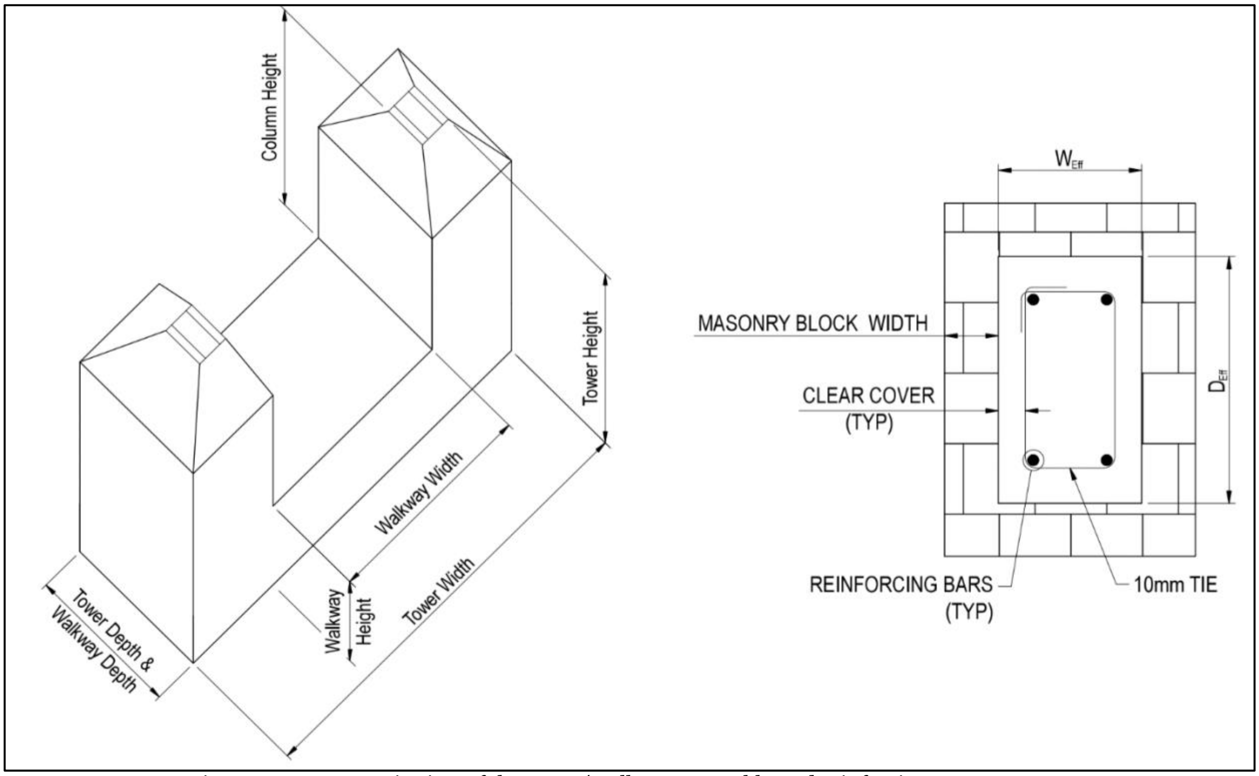


Figure 4.4.2: Isometric view of the tower/walkway assembly and reinforcing arrangement.

Tower Overturning:

$$Pt_{hand,back} = Pt_{hand,main} * e^{-\mu((\alpha_{hand}+\theta)+0.04)} \quad (4.4.7)$$

$$Pt_{walk,back} = Pt_{walk,main} * e^{-\mu((\alpha_{walk}+\theta)+0.04)} \quad (4.4.8)$$

$$Pv_{hand,main/back} = Pt_{hand,main/back} * sin\ \alpha_{hand} \quad (4.4.9)$$

$$Ph_{hand,main/back} = Pt_{hand,main/back} * cos\ \alpha_{hand} \quad (4.4.10)$$

$$Pv_{walk,main/back} = Pt_{walk,main/back} * sin\ \alpha_{walk} \quad (4.4.11)$$

$$Ph_{walk,main/back} = Pt_{walk,main/back} * cos\ \alpha_{walk} \quad (4.4.12)$$

$$Ph_{hand} = 0.5 * \left|Ph_{hand,back} - Ph_{hand,main}\right| \quad (4.4.13)$$

where Ph_{hand} is the horizontal handrail force on a single tower column!

$$Ph_{walk} = |Ph_{walk,back} - Ph_{walk,main}| \tag{4.4.14}$$
$$Pv_{hand} = \frac{1}{2}(Pv_{hand,back} + Pv_{hand,main}) \tag{4.4.15}$$
$$Pv_{walk} = Pv_{walk,back} + Pv_{walk,main} \tag{4.4.16}$$
$$OM_{tower} = 2 * Ph_{hand} * H_{tower} + Ph_{walk} * (H_{walk} - 0.10m) \tag{4.4.17}$$
$$RM_{tower} = (2 * Pv_{hand} + Pv_{walk}) * (\frac{D_{eff}}{2} + E_{saddle\ offset}) + (P_{Tower} * \frac{D_{eff}}{2}) \tag{4.4.18}$$

where:
H_{tower} = tower height of 1.5m
H_{walk} =walkway height of 0.5m
D_{eff} = effective column depth of 0.7m
$E_{saddle\ offset}$ = 0.1m saddle offset
P_{tower} = self-weight of the tower

$$FS_{tower\ overturning} = \frac{RM_{left}}{OM_{left}} \geq 1.5 \tag{4.4.19}$$

Eccentricity:

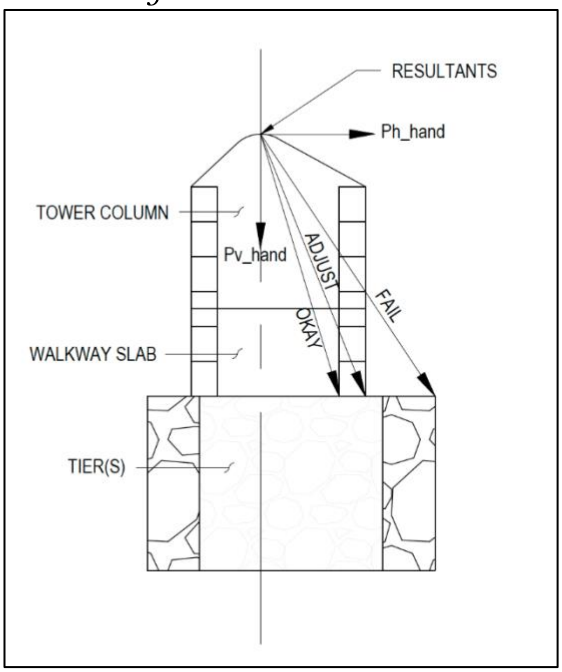


Figure 4.4.3: Elevation view of the tower column, walkway hump, and tier assembly. Resultant of horizontal and vertical cable friction forces shown superimposed.

While the previous "Tower Overturning" and subsequent "Moment Capacity" checks are more indicative of tower failure, the tower eccentricity check is a "best practice check" to ensure that the resultant force is still within the footprint of the concrete portion of the tower column. This indicates that the tower column is in full compression, with no uplift on the anchor-side of the tower. In this case, we don't need to rely on the connection to the walkway hump below. If the resultant is such that uplift occurs on the anchor-side of the tower, it would cause torsion in the walkway hump and potential failure. This check begins to govern when the length of the abutment (from back of anchor to front of foundation) is severely shortened (~6-7 meters) without being able to sufficiently raise the anchor to maintain the optimal cable angle. The check is performed using the resultant of the horizontal and vertical portions of the cable force transferred into the tower via friction.

There are three options for the resultant force:

1) Force is within the max eccentricity limit (E_{max}). Okay.
2) Force lands within the masonry wall. Adjust design or consult Section 8.2 of ACI 530-13 with the help of a qualified engineer.
3) Force lands outside the tower. Fail.

Maximum Eccentricity; $E_{max} = \frac{D_{eff}}{2} + E_{saddle\ offset}$ (4.4.20)

Resultant Angle; $\delta_{hand} = TAN^{-1}\left(\frac{Ph_{hand}}{Pv_{hand}}\right)$ (4.4.21)

Column Eccentricity; $E_{column} = H_{column} * TAN\ \delta_{hand}$ (4.4.22)

Biaxial Loading:
Checking the biaxial loading condition of the tower columns is explained in-depth in the Advanced Suspended Bridge Design (211) course on BridgeEDU. This explanation follows the process laid out in ACI-318-11 and walks through generating a biaxial loading diagram to check the combined moment and axial loading condition of the towers. This is not currently a required check for custom designs, so specific equations are not provided within this Binder.

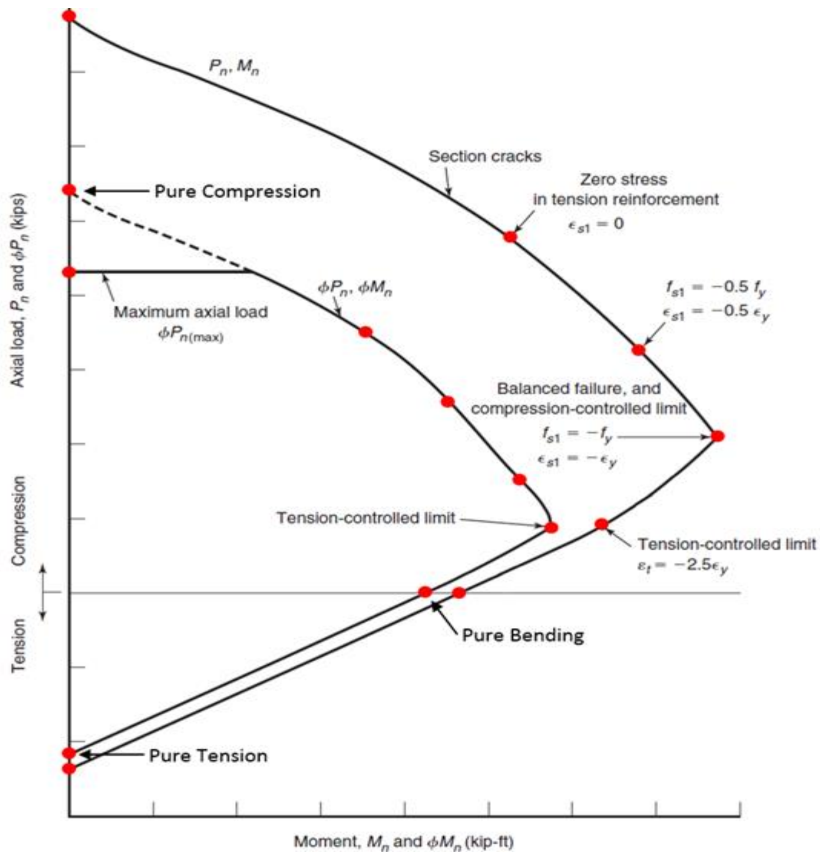


Figure 4.4.4: Example biaxial loading diagram.

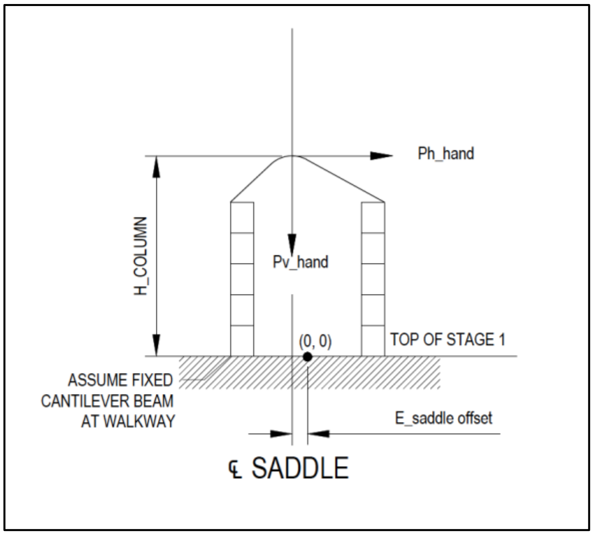


Figure 4.4.5: Tower moment capacity loads at walkway hump.

Moment Capacity:
In this check, the tower acts as a cantilevered reinforced concrete beam, where the friction-induced horizontal cable forces cause flexure. Given the eccentricity check and tower overturning checks pass, we can make the reasonable assumption that the tower column portion is fixed at its connection to the walkway (top of stage 1 pour from the standard details). We subsequently need to check its moment capacity, assuming this will govern over shear capacity, and minimum reinforcing requirements for serviceability. Both analyses are derived from ACI 318 Chapter 9.

Moment Capacity; $M_n = A_s * f_y * \left(d - \frac{a}{2}\right)$ (4.4.20)

where:
A_s = total steel area (typically using #5 bars), A_s = 395.9 mm² for a typical tower
f_y = yield strength of rebar, kN/mm²
d = depth to reinforcing, d = 62.5 cm for a typical tower
a = concrete block width (Whitney stress block) calculated as $\frac{A_s * f_y}{0.85 * f_c' * W_{eff}}$, m
W_{eff} = section width, W_{eff} = 40cm for a typical tower
f'_c = compressive strength of concrete, kN/mm²

Moment; $M = -Pv_{hand} * E_{saddle\ offset} + Ph_{hand} * H_{column}$ (4.4.21)

$FS_{tower\ moment} = \frac{M_n}{M} \leq 1.5$ (4.4.22)

$S = \frac{W_{eff} * (D_{eff})^2}{6}$ (4.4.23)

Modulus of Rupture; $f_r = 0.53 * \sqrt{f'_c}$ (4.4.24)

Cracking Moment; $M_{cr} = f_r * S$ (4.4.25)

Check $\phi M_n > MIN(1.33 * 1.625 * M, M_{cr})$ (4.4.26)

where:
ϕ = load reduction factor of 0.9

4.5 Soils Analysis

Overview:
The soil properties at each site are generally not well known, and the basic soil classification is rudimentary at best. These are part of the many challenges we experience at remote, rural sites. Because of this, a conservative analysis is performed in tandem with using a 35-degree (soil) or 60-degree (rock) angle of internal friction and 3.0-meter (soil) or 1.5-meter (rock) minimum setback between edge of bank and front of abutment for slope stability. This section will focus on

the capacity check itself, while soil strength values were provided and explained in more detail in **2.4. Geotechnical Investigations**. Please direct any questions to education@eiabridges.org.

Bearing Pressure Check:

Because the backstay cable angle is typically steeper than the main span cable angle, an eccentric load is generated that can cause overturning about the tower/tier structure and increase the bearing pressure on the front edge of the foundation (the edge closest to the river). The load per unit area at which shear failure in soil occurs is called the ultimate bearing capacity. To perform satisfactorily, the maximum bearing pressure generated must not exceed the allowable bearing capacity of the soil. The allowable soil bearing capacity is the ultimate bearing capacity divided by a factor of safety. Reported values for ultimate bearing capacity and factor of safety can vary greatly based on methods and soil properties; because of this it is important that the check is performed as a *comparison* between calculated bearing pressure and allowable bearing capacity as opposed to a calculated factor of safety.

Bearing pressure shall satisfy:

$$q_s \leq \frac{q_u}{FS} \tag{4.5.1}$$

q_s = maximum bearing pressure, kPa
q_u= ultimate bearing capacity, kPa
FS= factor of safety = 2.0 (for sandy soils) or 3.0 (for clayey soils)

Due to the eccentricity of the load on the tower, the bearing pressure beneath the foundation is not uniform. The maximum bearing pressure can be calculated using the equivalent width method as shown in the following diagram:

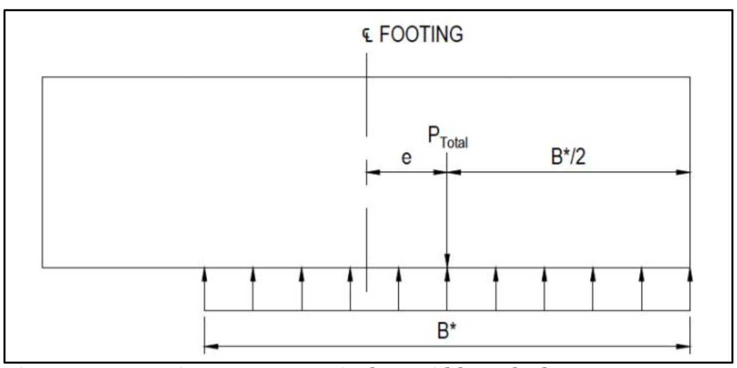


Figure 4.5.1: Bearing pressure Equivalent Width Method.

$$B^* = 2 * \frac{M_O - M_r}{P_{Total}} \tag{4.5.2}$$

$$q_s = \frac{P_{total}}{B^* * l} \tag{4.5.3}$$

in which:

$$P_{Total} = Pv_{Saddle} + P_{Tower} + P_{Foundation} + \sum_{i=1}^{n} P_{Tier,n} \tag{4.5.4}$$

where:
l = length of foundation, m
B^*= effective width, m

Minimum Embedment:

While customizing abutments, it is important to establish a *minimum embedment depth*. This is necessary to avoid differential settlement, scour, and potential frost heave. Soil will need to reach its full bearing capacity at this minimum embedment depth to resist the material weight and avoid movement that can create cracking and a loss of capacity in structures. IBC Section 1809.4 cites that the minimum depth of shallow foundations should be no less than 12" (~30 cm) below undisturbed ground. This is extrapolated to ramp walls, access ramps, and anchors in **Table 4.5.1** below. Using a [frost depth prediction model](), along with a worst case scenario of 100 days below freezing, 30-centimeters is the approximate depth necessary to satisfy IBC Section 1809.5, Frost Protection. This process is discussed in-depth within the Advanced Suspended Bridge Design (211) course on BridgeEDU under "cold weather conditions". Further research, however, suggests that shallow foundations in high plasticity, clayey soils need further embedment anywhere from 75 – 100 centimeters.

Table 4.5.1: Summary of Minimum Embedment

System	Minimum Embedment (m)
Foundation Tier	ε 1.0 meters
Anchor	ε 0.3 meters
Ramp Walls	ε 0.3 meters
Extra Access Ramps	ε 0.3 meters

Soil Shear Failure:

The soil shear failure check was developed because of design customization. All standard details should mitigate this concern, but after customization was encouraged, it quickly became clear that this check should be performed. When performing this check, there are two options:

1. If the anchor is *above* the bottom of the foundation, we want to confirm that the soil "steps" won't shear off. It is important that the ramp wall is at minimum horizontal from the anchor to foundation so there is no component of the ramp weight pulling towards the river.

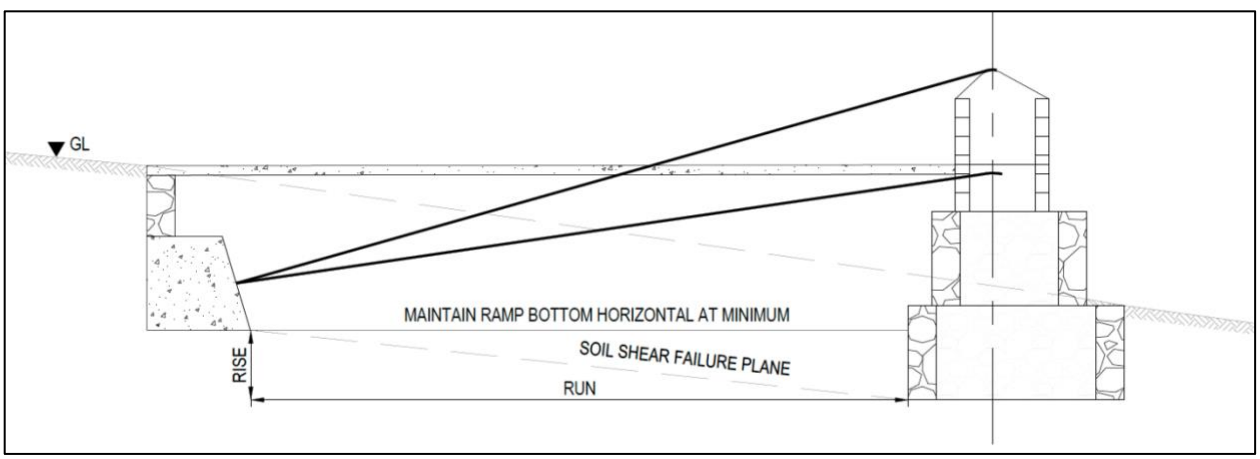


Figure 4.5.2: Soil Shear Failure Plane for anchor above foundation.

2. If the anchor is *below* the foundation, we want to confirm that the triangle of soil between the anchor and foundation doesn't begin to fail and pull out of the slope.

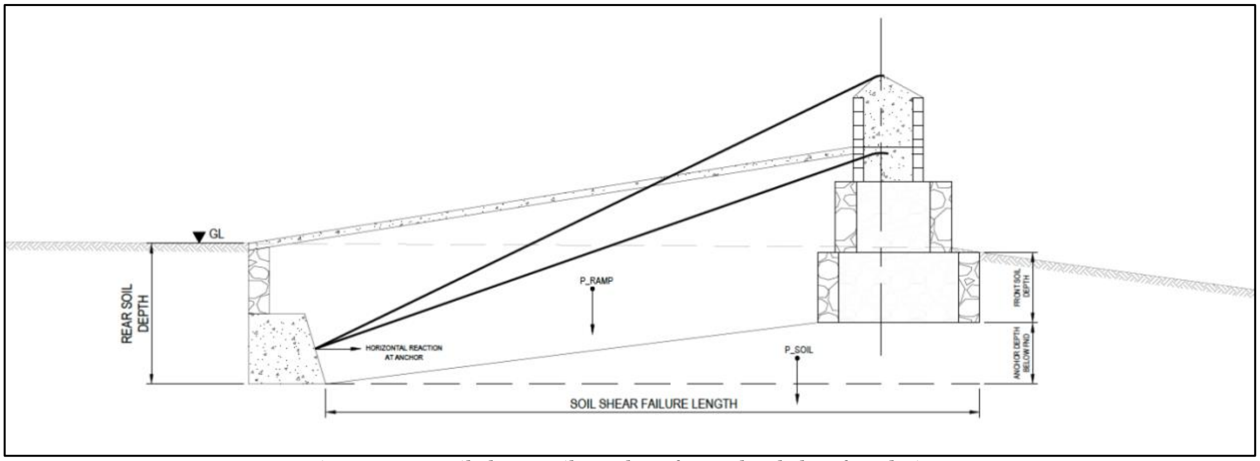


Figure 4.5.3: Soil Shear Failure Plane for anchor below foundation.

Both checks will follow a similar process, calculating the soil shear capacity based on the vertical forces and comparing this to the total horizontal forces on the anchor. If this check fails, consult with your DEIC for a more refined analysis.

Condition 1: Anchor Above Bottom of Foundation:
It is not recommended to use soil steps, or a downward sloping ramp wall. If the anchor is not significantly above the bottom of the foundation, consider raising where the bottom of the ramp wall meets the foundation (see **Figure 4.5.2**). Associated reductions in sliding capacity for doing this will be discussed in **4.6. Anchor Analysis**.

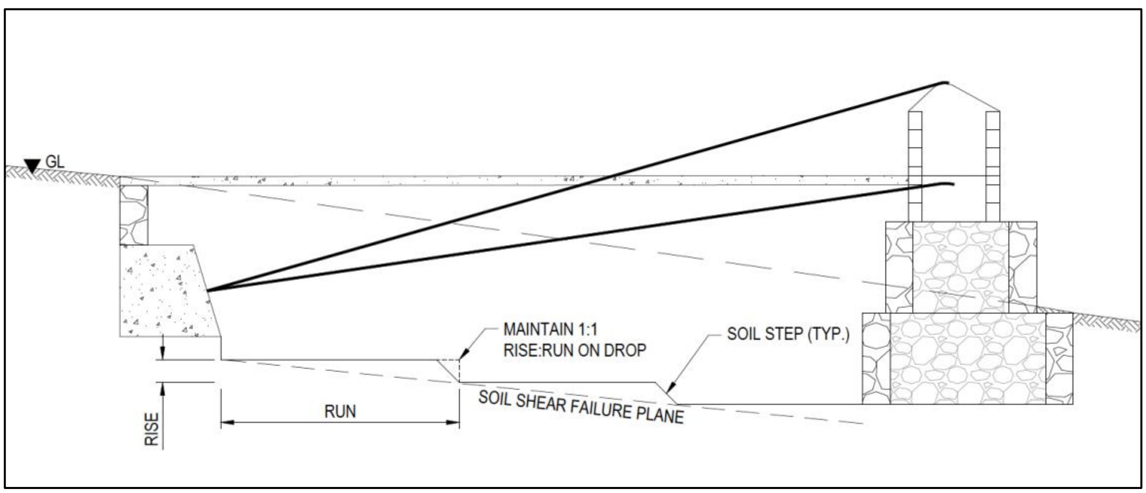


Figure 4.5.4: Soil "steps" created by a stepped bottom of ramp wall.

If steps are absolutely necessary, we will first apply some empirical rules.

Rule 1: Maintain a 3:1 (RUN:RISE) ratio for steps in the ramp wall with 1:1 drops to avoid shear concentration.
Rule 2: If the ratio is less than 2:1 (RUN:RISE), the design is not feasible.

If a 3:1 ratio is not possible, but a greater than 2:1 ratio is maintained, the design needs soil steps that should be checked for failure using **Equations 4.5.5-4.5.7** below.

Condition 2: Anchor Below Foundation:
When the anchor is below the bottom of the foundation, we consider "Bottom Slope Effects" to increase the sliding capacity. This can be conceptualized if you were to think about pulling an object on flat ground versus up a ramp. However, we can't consider the "Bottom Slope Effects" to add capacity without double checking that the soil triangle forming our upward slope doesn't shear at the soil-soil interface on the same horizontal plane as the anchor beam. This soil slope should be checked for failure using **Equations 4.5.5-4.5.7**.

Normal Force on Soil; $N = (Total\ Vertical\ Load + W_{soil})$ (4.5.5)
Soil Shear Capacity; $\tau = N * TAN(\phi)$ (4.5.6)

where:
ψ = angle of the soil shear failure plan from the back of anchor to front of foundation, degrees
ϕ = internal angle of friction of the soil; taken as 30 degrees.
W_{soil} = self-weight of the soil triangle under review, kN
Total Vertical Load = see equation 4.6.3

$$FS_{soil\ shear} = \frac{\tau}{R_s} \quad (4.5.7)$$

where:
R_s = total horizontal force on the anchor, kN

4.6 Anchor Analysis

Overview:
The bridge anchors are primary structural elements that resist the horizontal sliding load and vertical uplifting load from the cables. Three typical ground conditions exist – soil, hard rock, and fractured or soft rock. EIA projects commonly exist in soil conditions where gravity anchors are used to resist cable forces via friction and self-weight. In hard rock conditions, a reinforced concrete drum anchor or a rock anchor is used. For anchorage in fractured or soft rock, a reinforced concrete drum is socketed into the rock.

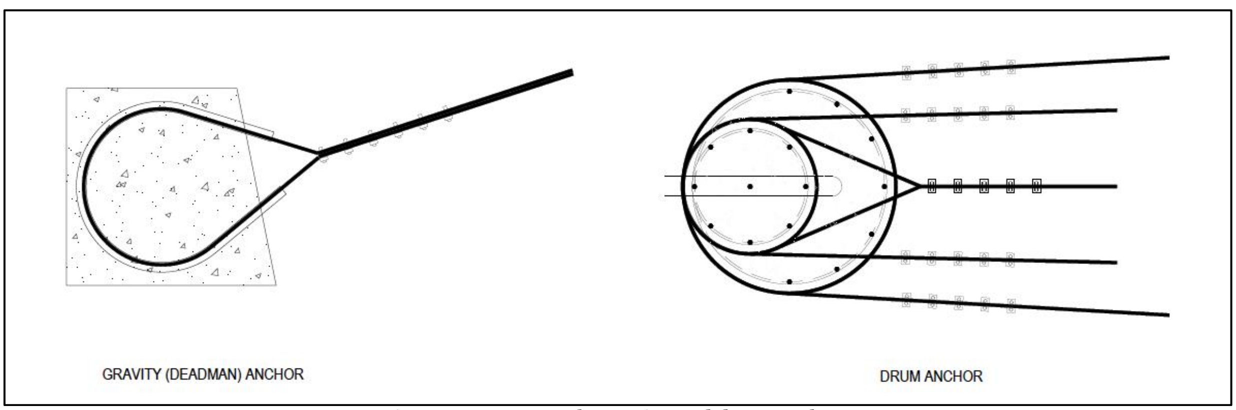


Figure 4.6.1: Example gravity and drum anchors.

All anchor types shall satisfy the following design criteria:
- Sliding
- Uplift
- Minimum reinforcement per ACI 318

Soil Anchor Design:
Gravity anchors are used in soil conditions. In a gravity anchor, the predominant sliding resistance is provided by a normal force from the weight of the abutment (ramp walls, ramp fill, concrete cap, anchor, tower, and tiers) and a coefficient of friction from stone and concrete against a soil surface. The abutment mass is activated by a gravity anchor beam at the rear of the ramp where the cables are anchored. The concrete anchor is connected to the tower foundation and tiers via a rock masonry wall continuously supported at its base against lateral movement on either side by soil or stone fill. Note that these walls are imperative to the design and cannot be omitted without a thorough design check of the anchor acting by itself without the help of the rest of the abutment weight. The ramp walls and fill act as a compression strut between the anchor and tower/tiers, the entire abutment is analyzed globally as a sliding block. The uplift resistance is provided by the weight of the anchor beam itself as well as weight placed above the concrete beam known as the "overburden".

The following assumptions are made in the design process. More detailed explanations of why these assumptions are made can be found in the Advanced Suspended Bridge Design (211) course on BridgeEDU:

- Friction acts on the base of the foundation and approach ramp
- Friction acts laterally along the ramp walls, but is conservatively reduced to 50%
- Undisturbed soil captured between the ramp walls and above the anchor contributes to sliding resistance.
- The top 30-centimeters of soil does not contribute to frictional resistance.
- Soil is cohesionless (*e.g.*, c = 0)
- Seismic forces are assumed to be negligible
- Design has been completed assuming non-saturated soil conditions

Soil Anchor Sliding Check:
An abutment employing a gravity anchor resists sliding through friction with the soil along each interface. The entire abutment, including the concrete anchor beam, stone masonry approach walls and fill, foundation, tiers, and tower, all contribute to the total vertical load. In addition to a horizontal driving force from the cables at the anchor and tower, an active earth pressure behind the abutment contributes to the driving force. The following checks will detail a "basic sliding factor of safety" (FS_{basic}) and a "maximum sliding factor of safety" (FS_{max}). The "basic sliding factor of safety" will follow the B2P Manual design process and corresponds to the "Tier 1 Checks", while the "maximum sliding factor of safety" will sharpen the pencil on these calculations, eliminating some assumptions to realize more capacity in our designs. The development of the "maximum sliding factor of safety" comes from an effort to increase material and labor efficiency of EIA designs and is based on careful research and analysis.

Generally, gravity anchor sliding factor of safety can be found as:

$$FS_{basic} = \frac{R_n}{R_s} \tag{4.6.1}$$

where:
R_s = horizontal driving force, kN
R_n= horizontal resisting force, kN
FS_{basic}= basic factor of safety ε 1.5

The total driving and resisting forces can be calculated using static analysis. A free body diagram of associated loads acting on the abutment is shown in **Figure 4.6.1**. This figure shows two scenarios:(1) the anchor is placed below the foundation, with a ramp wall bottom slope of ψ and (2) the anchor is placed above the foundation with a horizontal ramp wall connecting to the foundation above its base.

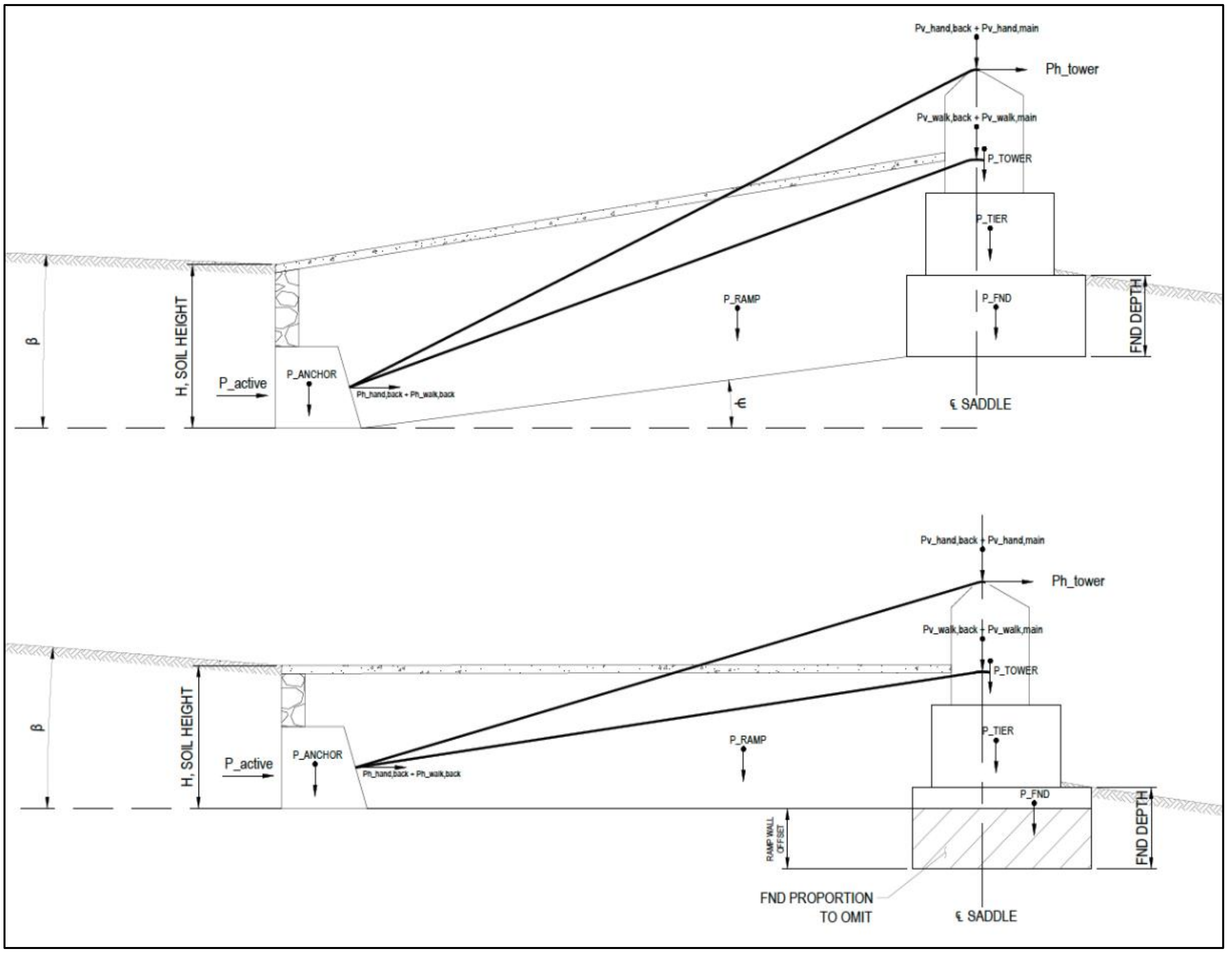


Figure 4.6.2: Anchor Sliding Free Body Diagram and associated geometries.

Basic Factor of Safety:
To calculate the basic factor of safety, we will consider the sliding forces from the cables at the anchor, active earth pressure, and friction of the cables at the tower ("Ph_{Tower}"). The B2P Manual does not consider this "Ph_{Tower}" term, however, if we are to consider the ramp walls acting as compression struts, we must consider them as tension tie that could transfer force from the tower/tiers into the anchor.

Horizontal Forces:
P_{Active} = active earth pressure, kN
Ph_{Anchor} = total cable force on the concrete anchor beam ($Ph_{hand,back} + Ph_{walk,back}$), kN
Ph_{Tower} = resultant frictional force on the tower from the cables, kN

Vertical Forces:

$Pv_{hand,back}$ = vertical component of handrail backstay cable force, kN
$Pv_{walk,back}$ = vertical component of walkway backstay cable force, kN
$Pv_{hand,main}$ = vertical component of handrail main span cable force, kN
$Pv_{walk,main}$ = vertical component of walkway main span cable force, kN
P_{Tower} = self-weight of tower (30.1 kN for standard details), kN
P_{Tier} = self-weight of tiers, kN
$P_{Foundation}$ = self-weight of foundation (subtracting material below the ramp wall connection), kN
P_{Anchor} = self-weight of anchor beam, kN
P_{Ramp} = self-weight of approach walls and fill material including extra weight for walls used during 2-tier and 3-tier construction (respectively), kN

The total horizontal driving force is found by summing the horizontal forces:

$$R_s = P_{Active} + Ph_{Anchor} + Ph_{Tower} \tag{4.6.2}$$

The total horizontal resisting force is found by summing the vertical forces and multiplying by a coefficient of sliding friction:

$$R_n = \mu * (Pv_{cables} + P_{Tower} + P_{Tiers} + P_{Foundation} + P_{Ramp} + P_{Anchor}) \tag{4.6.3}$$

where:

$$Pv_{cables} = Pv_{hand,back} + Pv_{walk,back} + Pv_{hand,main} + Pv_{walk,main} \tag{4.6.4}$$

in which the coefficient of sliding friction can be taken as:

$$\mu = tan\,(\phi) \tag{4.6.5}$$

where:
ϕ = internal angle of friction taken as 30°, degrees
μ = coefficient of sliding friction at the abutment and soil interface

The horizontal tower force, as described above, is included considering the ramp walls to act as tension ties, transferring the tower and walkway saddle friction into the foundation and into the abutment.

$$Ph_{Tower} = (Ph_{hand,main} + Ph_{walk,main}) - (Ph_{hand,back} + Ph_{walk,back}) \tag{4.6.6}$$

The active earth pressure (Pa) can be calculated according to Rankine theory. The coefficient of earth pressure (Ka) is the term used to express the ratio of the lateral earth pressure to the vertical earth pressure (weight of the soil above). The general equation for the coefficients according to Rankine's theory are given by the following expressions:

$$K_a = cos\beta * \frac{cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}} \tag{4.6.7}$$

where:
β = soil angle at ground surface behind anchor, degrees

If the soil behind the anchor is level ($i.e., \beta = 0$), the above equation can be reduced to a simplified form:

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} \tag{4.6.8}$$

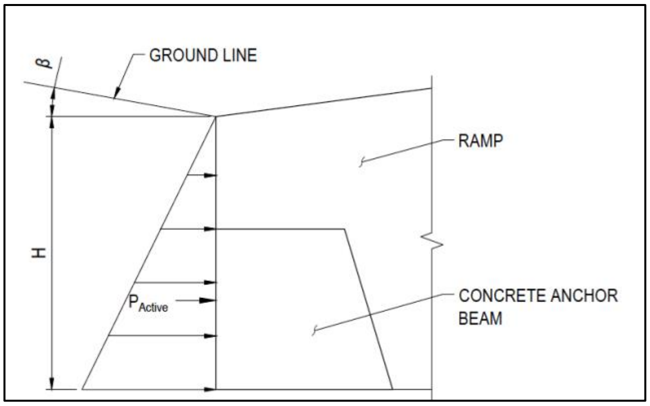


Figure 4.6.3: Active Earth Pressure distribution.

The lateral active earth pressures acting on the anchor are proportional to the weight of soil behind the anchor. The resultant force on the anchor due to the pressures acts at one third of the height from the base of the anchor and is shown in **Figure 4.6.2**.

$$P_{Active} = \frac{1}{2} * K_a * \gamma_s * H^2 * w \tag{4.6.9}$$

where:
P_{Active} = force due to active earth pressure, kN
K_a = active earth pressure coefficient, unitless
γ_s = soil density, kN/m³
H = soil height, m
w = width of the anchor beam, m

Anchor sliding is often a governing check for bridge designs. The sliding factor of safety can be used to describe the "efficiency" of your design. For example, if the sliding factor of safety is 3.2, the design is safe but over-engineered. If the sliding factor of safety is 1.5, the design is efficient but there is little room for error or tolerance during the construction process. Use the above equations to calculate the basic sliding factor of safety, then you can refine your analysis with the following:

Maximum Sliding Factor of Safety:
To reiterate, the "maximum sliding factor of safety" is not a new analysis, but a refined version of the "basic sliding factor of safety" check. In the following section, we will describe the various methods you can employ to refine your analysis, ultimately defining a "maximum sliding factor of safety". For detailed explanations of these methods and the research behind them, refer to the Advanced Suspended Bridge Design (211) course on BridgeEDU.

1. Undisturbed Soil Area

Generally, the underground area between the ramp walls and between the anchor and foundation up to ground level is left undisturbed, and not counted as self-weight resisting sliding. However, if the anchor began to slide, this soil mass would be along for the ride, therefore we can consider the weight of the "undisturbed soil" here as contributing to our total vertical forces. **Figure 4.6.3** details in red what we would distinguish as "undisturbed soil", notice how space around the cables and foundation is left out as this will inevitably be excavated during construction.

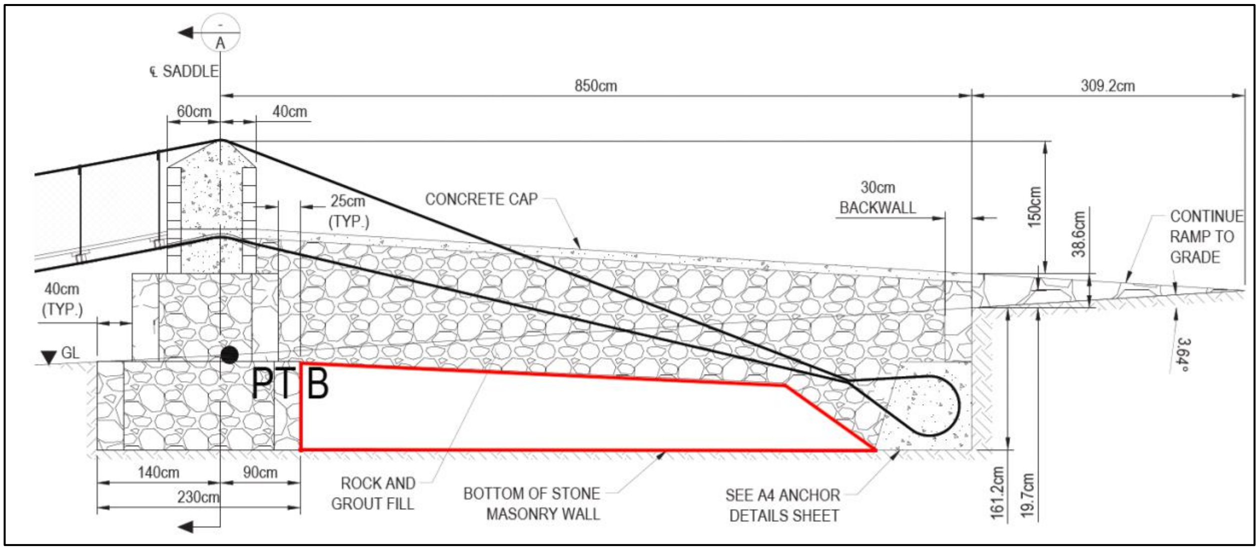


Figure 4.6.4: Undisturbed Soil Area outlined in red on a screenshot of a drawing set.

$$W_{soil} = A_{soil} * w_{ramp} * \gamma_s \quad (4.6.10)$$

where:
A_{soil}= arbitrary "undisturbed" soil area, m²
w_{ramp} = width of the anchor beam, m

$$A_{rampwall} = A_{fill} + A_{soil}\ ^{*} \quad (4.6.11)$$

*Note when you are calculating $A_{rampwall}$, a good sanity check is to remember that the ramp wall area should be equivalent to the sum of the undisturbed soil area and rock/grout fill area.

2. Sidewall Friction

When we look at the entire abutment as a block sliding on a slope, it is also natural to consider the "sidewall friction" or skin friction of the sides of the ramp walls against the surrounding soil. To be conservative, we will only consider 50% of the sidewall friction, as well as assume this is only activated at a 30cm depth below the surface. See Advanced Suspended Bridge Design (211) course on BridgeEDU for more details. The equation below is presented in a 2016 thesis; [Modeling of pullout resistance of concrete anchor block embedded in cohesionless soil].

$$\text{Sidewall Friction; } F_s = 2 * K_0 * \delta_{soil} * \left(\frac{H_{avg}}{2}\right) * TAN(\delta) * (H_{avg} * t) \quad (4.6.12)$$

where:
K_o = at rest coefficient of lateral earth pressure, unitless
H_{avg} = average embedment, m
δ_{soil} = soil density, kg/m³
δ = angle of friction between the soil and surface, commonly taken as 15°
t = embedment length of the abutment from the front of foundation to the back of anchor, m

$$\text{At Rest Lateral Earth Pressure Coefficient; } K_o = (1 - SIN(\phi)) \quad (4.6.13)$$

$$\text{Average Embedment; } H_{avg} = \frac{(FND\ Depth - 30cm) + (H - 30cm)}{2} \quad (4.6.14)$$

3. Bottom Slope Effects

Bottom slope effects refer to the process of considering the anchor being "pulled uphill". When we transform all the forces into the coordinate plane normal to the ramp wall bottom slope, you notice there is a component of the ramp wall weight that is now acting horizontally to act against sliding. This strategy reduces the horizontal sliding forces by considering that a portion of the vertical self-weight forces are acting against them. It can only be considered if the ramp wall has a positive slope (*i.e.*, is sloping upward toward the foundation, not downward toward it). Once again, conservatively only 50% of the bottom slope effect is considered. This concept is explained in more detail in the Advanced Suspended Bridge Design (211) course on BridgeEDU. The equations are posted here for reference:

$$R'_s = P_{active} + Ph_{tower} + Ph_{anchor} * COS(\psi) - (P_{ramp} + W_{soil}) * 50\% * SIN(\psi) \quad (4.6.15)$$

$$R'_n = \mu * (P_{anchor} + Pv_{anchor} + Pv_{cables} + P_{abut} + W_{soil} + P_{ramp} * COS(\psi) + Ph_{anchor} * 50\% * SIN(\psi)) \quad (4.6.16)$$

where:
ψ = bottom slope angle measured along the ramp wall bottom
P_{abut} = sum of tier, tower, and foundation weight, kN

4. Summary

To summarize, we can now define our "maximum sliding factor of safety" by including undisturbed soil, sidewall friction, bottom slope effects (when applicable), and discounting any foundation weight that falls below the anchor. See Advanced Suspended Bridge Design (211) course on BridgeEDU for more details.

$IF\ \psi > 0$

$$R_n = R'_n + F_s \quad (4.6.17a)$$

$$R_s = R'_s \quad (4.6.18a)$$

$$FS_{sliding,max} = \frac{R_n}{R_s} \quad (4.6.19a)$$

$IF\ \psi \leq 0$

$$R_n = R_n + F_s + \mu * W_{soil} - \mu * \left(d'_{FND} * t'_{FND} * l'_{FND} * 17.65\frac{kN}{m^3}\right) \quad (4.6.17b)$$

where d', t', and l' are the proportions of the foundation that are beneath the anchor elevation

$$R_s = R_s \quad (4.6.18b)$$

$$FS_{sliding,max} = \frac{R_n}{R_s} \quad (4.6.19b)$$

Calculating Additional Ramp Weight:

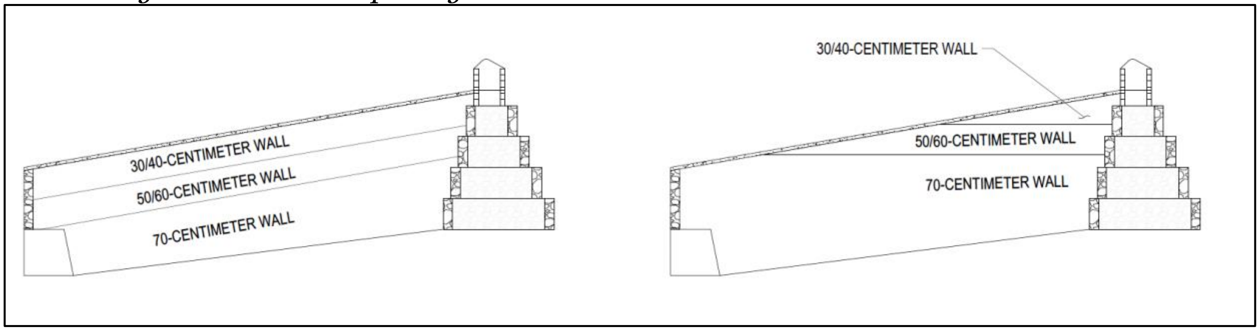


Figure 4.6.5: "Sloped" versus the "Level" method

Calculating additional ramp weight due to thicker ramp walls can be tricky and depends significantly on the method you use. As we build up 2-tier and 3-tier structures, thicker walls are used to resist lateral pressures from the abutment fill and increase sliding resistance. **Figure 4.6.5** above shows the difference between the "sloped" and "level" methods of constructing ramp walls. This is thoroughly explained in the Construction Management Course (301) on BridgeEDU. Below, here are two great examples of each method in the field:

Huaraca, Bolivia (Level)

Uganda (Sloped)

Figure 4.6.6: Field examples of the "Sloped" and "Level" method

It is important to note that although there are two options, **almost always** the masonry technique used on EIA sites will be the "level" method. Please complete all calculations assuming this method. **Section 4.8** discusses a step-by-step process for calculating additional wall amounts.

Soil Anchor Uplift Check:

An abutment employing a gravity anchor resists uplift through the self-weight of concrete anchor beam and the material activated above the beam known as the "overburden". The following checks will detail a "basic uplift factor of safety" (FS_{basic}) and a "max uplift factor of safety" (FS_{max}). The "basic uplift factor of safety" will follow the B2P Manual design process, and the "maximum uplift factor of safety" will sharpen the pencil on these calculations, conservatively eliminating some assumptions to realize more capacity in our designs. The development of the "maximum uplift factor of safety" comes from an effort to increase material and labor efficiency of EIA designs and is based on careful research or analysis.

Gravity anchor uplift shall satisfy:

$$V_s \leq \frac{V_n}{FS} \tag{4.6.20}$$

where:
V_s = vertical uplift force, kN
V_n= vertical resisting force, kN
FS= factor of safety = 1.5

The total vertical uplift and resisting forces can be calculated using static analysis. A free body diagram of associated loads acting on the gravity anchor is shown in **Figure 4.6.7**.

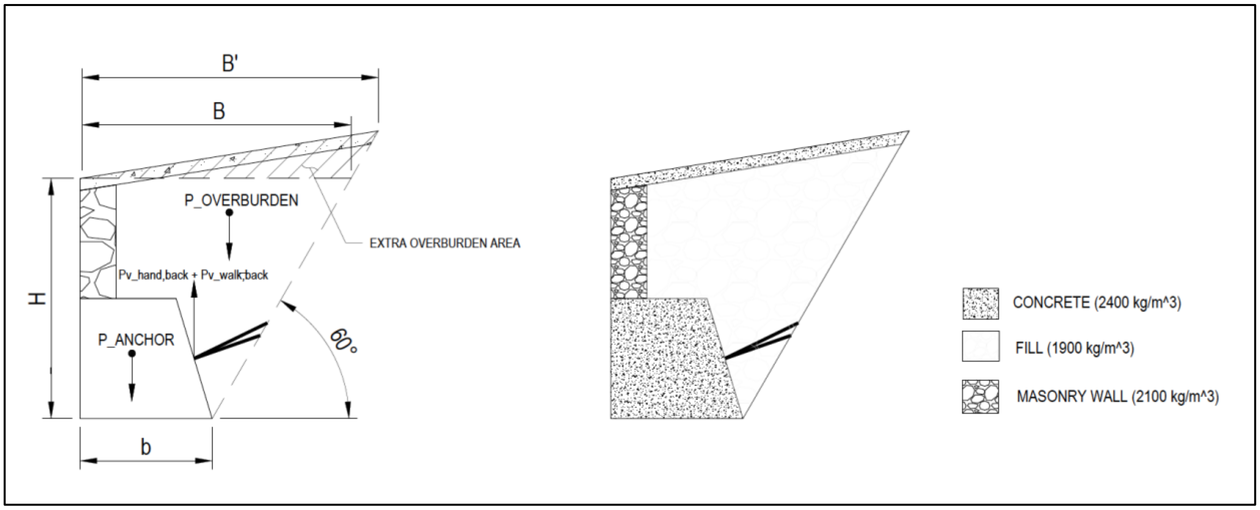


Figure 4.6.7: Anchor Uplift free body diagram and materials.

The volume of overburden resisting uplift can be found by:

$$P_{Overburden} = \left(\frac{b+B}{2} * H - A_{Anchor}\right) * w * \gamma * g \tag{4.6.21}$$

in which:

$$B = b + H * tan\ (30°) \tag{4.6.22}$$

where:
b = concrete anchor beam base width
H = depth of the anchor beam and overburden, m
A_{Anchor} = area of anchor, m²
w = width of anchor beam, m
γ = density of overburden taken as 1900 kg/m³ for basic factor of safety
g = gravity = 9.81 N/kg

$$V_n = P_{Overburden} + P_{Anchor} \tag{4.6.23}$$

$$V_s = Pv_{hand,back} + Pv_{walk,back} \tag{4.6.24}$$

$$FS_{basic} = \frac{V_n}{V_s} \tag{4.6.25}$$

When applying **Equation 4.6.23**, you may notice that two major assumptions are made:

1. "B" is taken horizontally from the top of the backwall to meet the overburden line (60° from horizontal).

   To improve upon this assumption, **Figure 4.6.7** details the "extra overburden" area that falls within the 60° line for overburden. This is easiest to measure in AutoCAD and apply to your overburden, rather than formulate, but it can be formulated as well using the approach ramp slope.

2. The entire overburden volume is considered to have a density of 1900 kg/m3.

   To improve upon this assumption, **Figure 4.6.7** details the three different materials that make up the overburden area (all of which have densities greater than 1900 kg/m3, listed in the figure above). Breaking up the overburden by material into concrete, masonry wall, and fill, we can add capacity by refining our overburden value. Extra overburden should also be divided by material density.

$$V_n = V_{concrete\ overburden} * \gamma_{concrete} + V_{masonry\ overburden} * \gamma_{masonry} + V_{fill\ overburden} * \gamma_{fill} + P_{Anchor} + P_{extra\ overburden} \quad (4.6.26)$$

$$V_s = Pv_{hand,back} + Pv_{walk,back} \quad (4.6.27)$$

$$FS_{max} = \frac{V_n}{V_s} \quad (4.6.28)$$

Water Table and Buoyant Forces:
If the water table rises above the base of the concrete anchor beam, the unit weights of the soil and concrete must be taken as buoyant unit weights, i.e., typical unit weight of the material minus the buoyant force acting on the material. The buoyant force is equal to the amount of water displaced. In the case of concrete, it can be assumed that it will displace 100% of its volume that is submerged whereas soil will displace approximately 60% of its volume that is submerged. As such, the submerged situation will significantly decrease the resisting self-weight forces. Also note that submerged conditions can result in erosion, scour, corrosion, and other damages to the abutment; these situations should be avoided when possible.

Depending on the duration of the submerged case, the factors of safety may be reduced. For a Temporary Case (referring to a single event in a season), FS = 1.25. For a Long-Term Case (referring to the entire rainy season), FS must remain 1.5. However, it is unlikely the water table will rise over the base of the concrete anchor beam at suspended bridge sites with minimum 3m freeboard. This will be avoided whenever possible.

Hard Rock Anchor Design:
Hard rock anchors consist of a reinforced concrete drum with reinforcing bars doweled into the rock below. The dowel bars must be designed to resist both the horizontal and vertical components of the cable force. The following section is taken directly from the B2P Manual. EIA does not currently create custom designs for hard rock sites, as this is relatively uncommon for our projects.

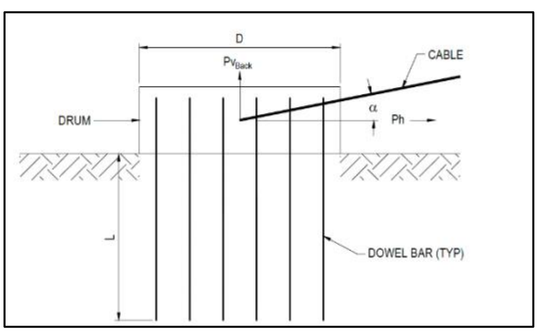


Figure 4.6.8: Hard Rock Drum Anchor (Screenshot from B2P Manual)

Sliding (Shear) Check:
The reinforcing bars doweled into the rock shall have sufficient shear capacity to resist the horizontal cable force.

Dowel bars shall satisfy:

$$f_s \leq \frac{f_y}{FS} \tag{4.6.29}$$

in which:

$$f_s = \frac{P_h}{A_s} \tag{4.6.30}$$

where:
f_s = shear stress in rebar, MPa
f_y = yield stress, MPa
P_h = horizontal cable force, kN
A_s = total area of reinforcing, mm²
FS = factor of safety = 3.0

Uplift Check:
The reinforcing bars doweled into the rock shall have sufficient axial capacity to resist the vertical cable force. Additionally, the bond strength of the grout or epoxy material used to embed the reinforcing bars shall have sufficient capacity to develop the required tensile strength.

Dowel bars shall satisfy:

$$T_s \leq T_n \tag{4.6.31}$$

in which:

$$T_n = A_b * N * f_a \tag{4.6.32}$$

where:
T_s = vertical cable force, kN
T_n= axial capacity of dowel bars, kN
A_b = area of reinforcing bar, mm²
N = number of reinforcing bars
f_a = allowable axial tensile stress of dowel bar, MPa

Fractured or Soft Rock Anchor Design:
Drum anchors socketed into the rock are used in fractured or soft rock anchor designs. The drum is designed to withstand the shear failure from horizontal loads and uplift from vertical loads. The following section is taken directly from the B2P Manual. EIA does not currently create custom designs for hard rock sites, as this is relatively uncommon for our projects.

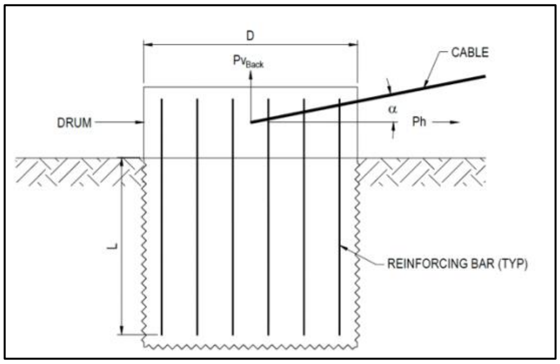


Figure 4.6.9: Fractured or Soft Rock Drum Anchor

Sliding (Shear) Check:
Standard reinforced concrete design methodology shall be used to determine the shear capacity of the drum.

Drums shall satisfy:

$$V_r = \frac{V_n}{FS} \quad (4.6.33)$$

in which:

$$V_n = 2 * \sqrt{f_c'} * A_c + A_v * f_y \quad (4.6.34)$$

where:
f_c' = compressive strength of concrete, MPa
A_c = horizontal cross-sectional area of concrete, mm²
A_v = total area of reinforcing, mm²
f_y = yield strength of steel, MPa
V_r = maximum shear force (P_h), kN
FS = factor of safety = 2.0

Uplift Check:
The concrete drum anchor shall have sufficient axial pullout capacity to resist the vertical cable force. Pullout capacity is generated by friction along the perimeter of the drum.

Drum uplift shall satisfy:

$$R_s \leq \frac{R_n}{FS} \quad (4.6.35)$$

in which:

$$R_n = \pi * D * q_s \quad (4.6.36)$$

where:
D = diameter, mm
q_s = nominal unit side resistance, kPa
R_s = maximum uplift force (Pv_{Back}), kN
FS = factor of safety = 2.0

4.7 Component Analyses

Overview:
Component analysis is a new design section that focuses on individual components. Most of the previous checks assume the entire abutment structure (tower, tiers, foundation, anchor, ramp walls, concrete cap, and fill) acts as a singular block sliding down or up a hill. We use this assumption to develop global checks in sliding, uplift, and overturning. In this section, the lens will zoom into other components such as additional masonry wall and anchor beam checks. The checks in this section are based on ACI 530-13 and ACI 318-14 which only provide equations in the imperial system; do not try to multiply metric values in these equations as the multipliers are imperial unit specific. To perform these checks, convert all inputs into imperial units and then the final values can be computed back to metric.

Masonry Walls (Compression Struts):
Most of our analyses assume that the entire abutment acts as a single block sliding uphill or downhill depending on the site. This allows us to use sidewall friction and include the tier/tower weight in our sliding resistance checks, **significantly increasing** the sliding resistance of our bridge abutments. However, there is a missing link. To make this assumption, we assume that the ramp walls act as compression struts, supported by the interior fill on one side for the full

height of the wall and by native soil on the exterior side but only for the embedded portion of the ramp walls. The walls transfer a portion of the cable force into the foundation, so we'll check them in compression, as shear walls, and in flexure (when the anchor is offset from the foundation causing eccentric loading). Conservatively, we can assume a percentage of the horizontal cable force (by area and stiffness) is transferred into the wall at the anchor-ramp wall interface. We use the point of "max force" to perform our checks.

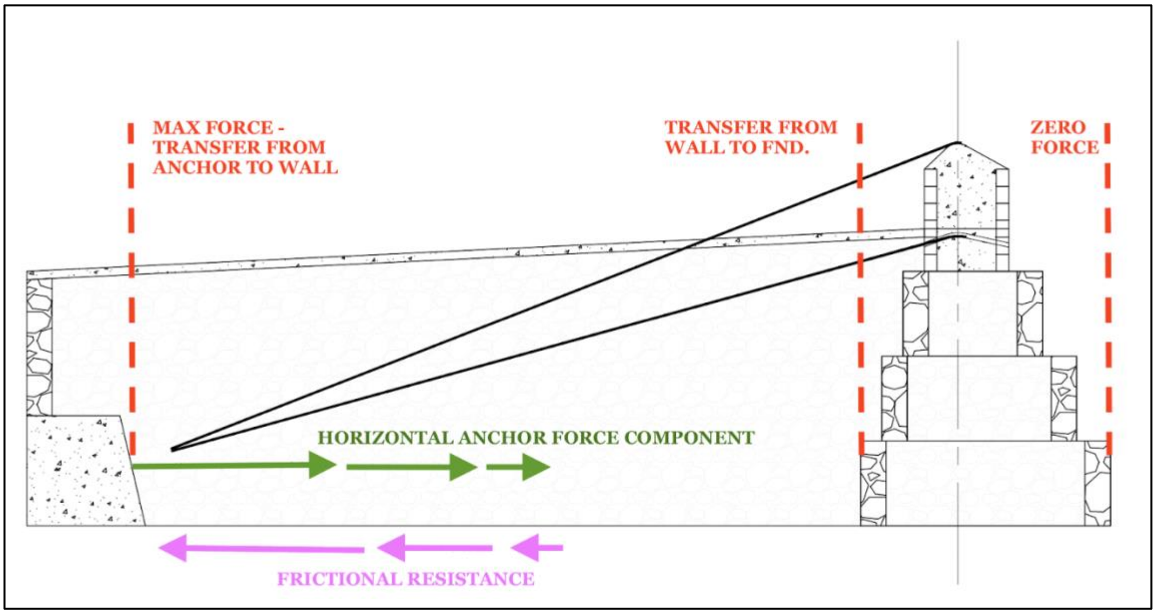


Figure 4.7.1: Ramp wall compression struts force diagram.

Ramp Wall Bearing Capacity:
Bearing capacity checks follow ACI 530-13 Section 8.1.5. See Advanced Suspended Bridge Design (211) course on BridgeEDU for more details. We'll check two governing conditions:

1. Finished bridge abutment; full cable load that is partially distributed to ramp fill based on stiffness.
2. After decking, full dead load is resisted by ramp walls only.

$$Adjusted\ Horizontal\ Load; \quad Rs' = Ph_{anchor} - P_{overburden} * \mu \tag{4.7.1}$$

$$Ramp\ Wall\ Load; P_{wall} = 0.5 * Rs' * K \tag{4.7.2}$$

where:
K= % stiffness (take as 60% for full load condition and 100% for self-weight condition)

$$Bearing\ Area; A_b = 2 * b * h \tag{4.7.3}$$

where:
b =width of the wall taken as 30cm
h =length of the sloping anchor face, m

$$Bearing\ \ Stress\ Demand; f_{bearing} = \frac{P_{wall}}{A_b} \tag{4.7.4}$$

$$Allowable\ Bearing\ Stress; F_{bearing} = 0.33 * f_m' \tag{4.7.5}$$

$$Check\ \frac{F_{bearing}}{f_{bearing}} \geq 1.5 \quad (4.7.6)$$

Ramp Wall Shear Capacity:
Shear capacity checks follow ACI 530-13 Section 8.2 (Unreinforced Masonry Walls). We'll classify our stone masonry walls as solid blocks in running bond that are not "fully grouted". A factor of safety is built in to the "allowable shear condition" set by the ACI standard.

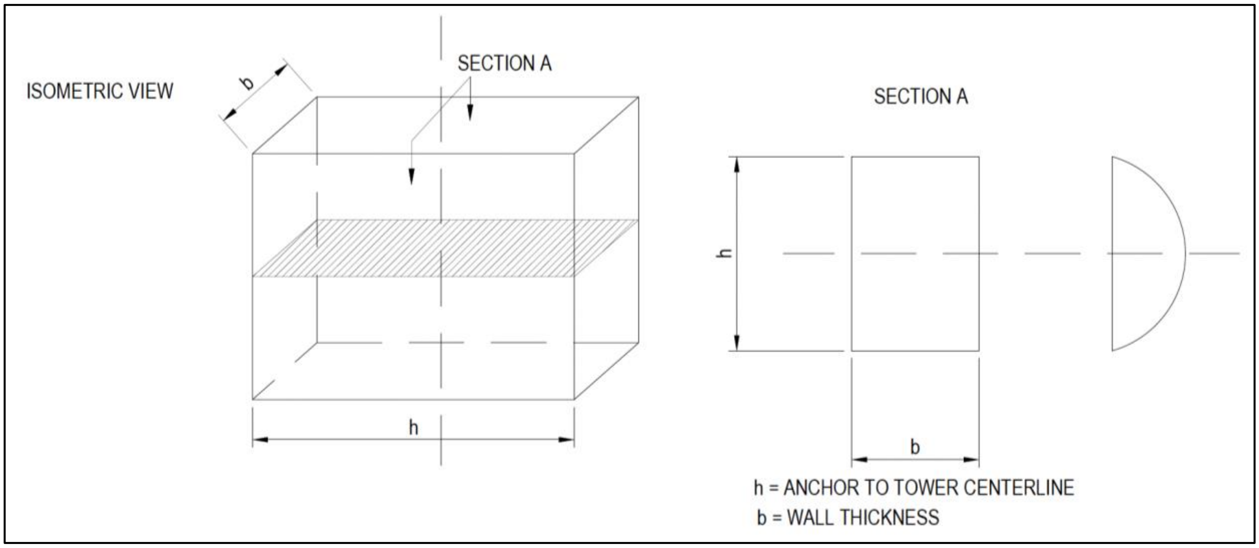


Figure 4.7.2: Ramp wall section resisting shear.

$$Shear\ Stress;\ f_v = \frac{3*P_{wall}}{2*A_w} \quad (4.7.7)$$

where:
A_w = b x h = area of wall section resisting shear (wall width x distance backwall to centerline)

$$Allowable\ Shear\ Condition;\ F_v = 37\ psi + 0.45 * (\frac{N_v}{A_n}) \quad (4.7.8)$$

where:
N_v = compressive force normal to the bond direction, lbs
A_n = total cross sectional area, in²

$$Check\ F_v \geq f_v \quad (4.7.9)$$

Ramp Wall Combined Flexural Capacity:
Finally, we'll check combined flexural and compressive strength of the ramp wall, along with euler buckling capacity using Section 8.2 of ACI 530-13.

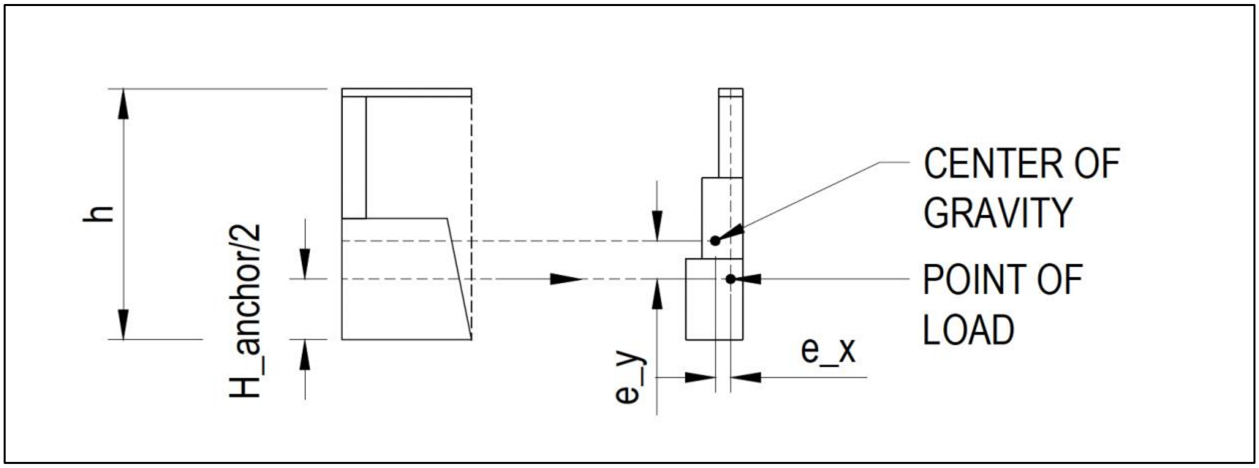


Figure 4.7.3: Ramp wall eccentricity

$$Check\ combined\ capacity;\quad \frac{f_a}{F_a}+\frac{f_b}{F_b}\leq 1 \tag{4.7.10}$$

$$Check\ axial\ capacity;\quad P_{wall}\leq\left(\frac{1}{4}\right)P_e \tag{4.7.11}$$

$$f_a=\frac{P_{wall}}{A_w} \tag{4.7.12}$$

$$f_b=\frac{M_{wall}}{S_w} \tag{4.7.13}$$

where:
M_{wall} = moment caused by the eccentric loading of the ramp wall, kN-m
A_w = cross-sectional area of wall being loaded, m²
S_w = section modulus of the wall cross-section, m²

$$M_{wall}=\mathrm{e}*P_{wall} \tag{4.7.14}$$

where:
d = distance from top of saddle to bottom of where ramp wall meets foundation, m*
e = eccentricity defined by; $e_y=\bar{y}-\frac{H_{anchor}}{2}, e_x=\bar{x}-0.15$
$\bar{x},\ \bar{y}$ = distance to the center of gravity of the ramp wall cross section.

$$F_a=\begin{cases}0.25*f'_m*\left[1-\left(\frac{l}{140*r}\right)^2\right]\ for\,\frac{h}{r}<99\ (strong\ axis)\\ 0.25*f'_m*\left(70*\frac{r}{l}\right)^2\ for\,\frac{h}{r}>99\ (weak\ axis)\end{cases} \tag{4.7.15}$$

where:
r = radius of gyration defined by $\frac{h}{\sqrt{12}}$, m
l = length of wall approximated by the distance from back of anchor to centerline, m

$$F_b=0.33*f'_m \tag{4.7.16}$$

$$P_e=\pi^2*E_m*I_n*\left(\frac{1}{l}\right)^2*\left(1-0.577\left(\frac{e}{r}\right)\right)^3 \tag{4.7.17}$$

where:
E_m = elastic modulus of masonry taken as $900*f'_m$, MPa
I_n = second moment of inertia in the buckling direction of interest, m^4

*Note that where the bottom of the ramp wall meets the foundation will not always be at the bottom of the foundation

Gravity Anchor Beam:

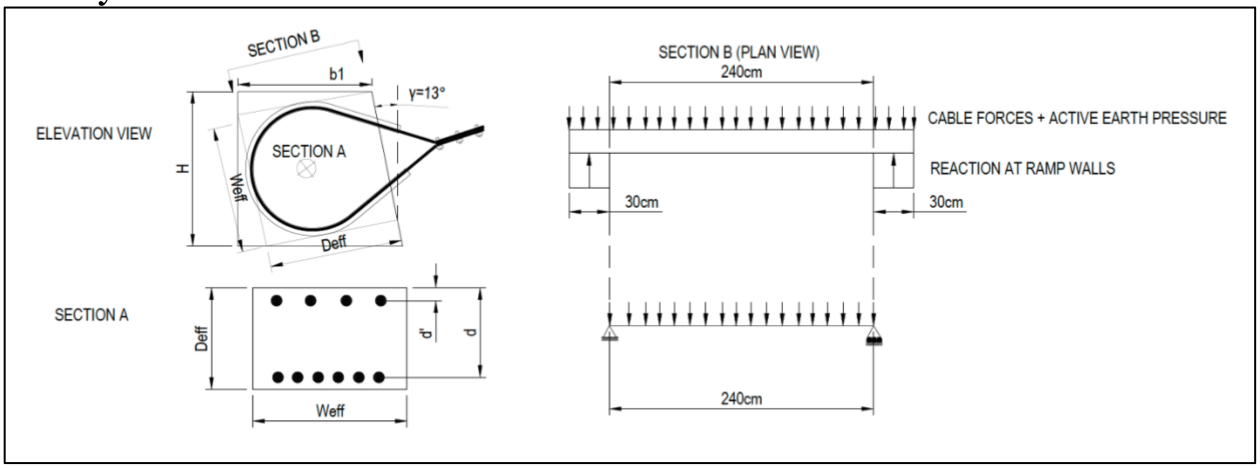


Figure 4.7.4: Gravity anchor section dimensions.

Although the standard anchor designs work well, sometimes a full analysis of the anchor beam is necessary. For example, if a 104-meter bridge with 1-3/8" cables satisfies all global design checks, it is more efficient to use the "medium anchor" (60 to 100-meter spans) than "large" anchor (100 to 120-meter spans). In this case, the standard "medium" anchor might suffice, but it must be thoroughly checked to comply with the forces from the larger span. In addition, if an anchor re-design is necessary (this is not recommended!), this process can be used as a starting point. The following sections summarize the process of checking the standard design; more detailed explanations can be found in the Advanced Suspended Bridge Design (211) course on BridgeEDU.

Code Requirements:
The first step is to confirm our anchor beam meets all reinforcement specifications from ACI 318-14. We are interested in the following:

- Minimum flexural reinforcement (9.6.1)
- Minimum shear reinforcement (9.6.3)
- Minimum concrete cover (9.7.1.1)
- Reinforcing bar development length (9.7.1.2)
- Minimum spacing of parallel bars (25.2.1)
- Maximum spacing of shear reinforcement (9.7.6.2.2)
- Minimum inside bend diameter of hooks/bars in tension (25.3.1)
- Minimum inside bend diameter of stirrups (25.3.2)

Next, for the sake of analysis, we'll define our concrete member properties and load factors as follows:

- λ = 1.0 (normal weight concrete)
- E_s = 29,000,000 psi
- $E_c = 57{,}000 * \sqrt{f_c{}'}$ (normal weight concrete)
- ε_{cu} = 0.003
- ϕ (flexure) = 0.9 (tension controlled) or 0.6 (compression controlled)
- ϕ (shear) = 0.75
- ϕ (bearing) = 0.6

Load Analysis:
In this case, we will be analyzing the anchor beam under strength considerations only. For the anchor analysis, we will use the Load Reduction Factor Design (LRFD) Method with the general methodology;

$$U \leq \phi * (Nominal\ Sectional\ Strength) \tag{4.7.18}$$

The governing load combination with the addition of active earth pressure (EH) is as follows;

$$U = 1.2 * DL + 1.6 * LL + 1.6 * EH \tag{4.7.19}$$

We'll assume the anchor beam is simply supported by the ramp walls, and due to the difference in flexibility of ramp walls and fill, we neglect the contributions of the fill.

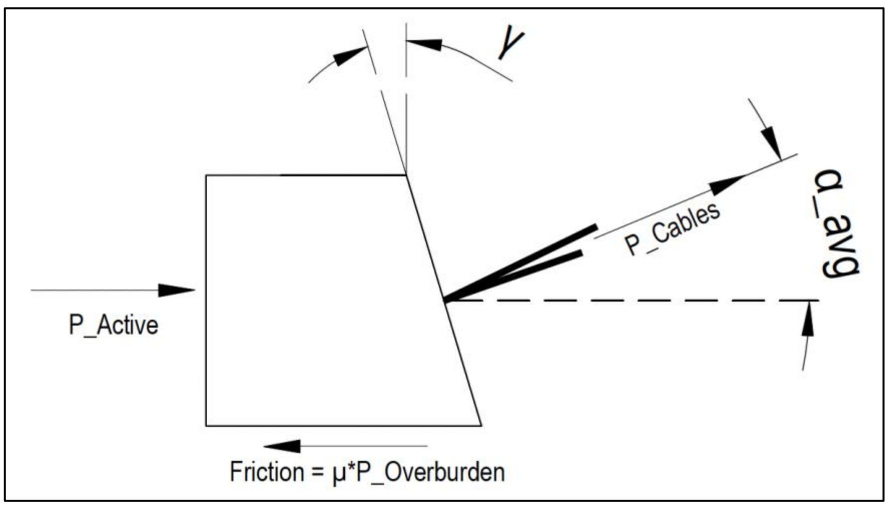


Figure 4.7.5: Gravity anchor section dimensions.

$$V_u = \frac{w*l}{2} \tag{4.7.20}$$
$$M_{u,simple} = \frac{w*l^2}{8}, M_{u,fixed} = \frac{w*l^2}{12} \tag{4.7.21}$$

where:
l = unsupported beam length, m (should be 2.4m for standard anchor designs)
w = factored distributed load on the anchor beam defined by $\frac{U}{l}$

$$DL = \left(Pt_{hand,back} + Pt_{walk,back}\right)_{DL} - \mu * P_{overburden} * cos\ (\alpha_{avg}) \tag{4.7.22}$$
$$LL = \left(Pt_{hand,back} + \mathrm{Pt}_{\mathrm{walk,back}}\ \right)_{LL} \tag{4.7.23}$$
$$H = \mathrm{P}_{\mathrm{active}} * cos\ (\alpha_{avg})$$

where:
α_{avg} = average backstay angle between the handrail and walkway cables
DL = reminder that these loads are due to dead load geometry and dead loading only (h3)!
LL = reminder that these loads are due to live load geometry and live loading only (h4)!

Flexure:

$$M_n = A_{s1} * f_y * \left(d - \frac{a}{2}\right) \quad (4.7.24)$$

where:
A_{s1} = bottom steel area, mm²
f_y = reinforcement steel yield stress of 275 MPa
d = distance from top of section to bottom steel centroid, mm
$a = \frac{A_{s1} f_y}{0.85 * f_c'(t) * W_{eff}}$ (Whitney Stress Block)
$f_c{}'$ = concrete compressive strength, MPa

Check; $\phi M_n \leq M_{u,simple}$ (4.7.25)

Shear:

$$V_n = V_c + V_s \quad (4.7.26)$$

Concrete Shear Strength; $V_c = 2 * \sqrt{f_c{}'} * W_{eff} * D_{eff}$ (4.7.27)

Steel Shear Strength; $V_s = \frac{A_v * f_y * d}{s}$ (4.7.28)

where:
W_{eff} = effective width of the section, mm (approximated as $W_{eff} = \left(\frac{H_{anchor}}{COS(\gamma)}\right) - b_1 * SIN(\gamma)$)
D_{eff} = effective depth of the section, mm (approximated as $D_{eff} = \left(\frac{b_1}{COS(\gamma)}\right) - (H_{anchor} - b_1 * SIN(\gamma)) * SIN(\gamma)$)
A_v = steel area per stirrup spacing, mm²
s = stirrup spacing, mm (should be 300mm for standard design)

Check; $\phi V_n \leq V_u$ (4.7.29)

Bearing:

$$B_n = 0.85 * f_c'(t) * A_b \quad (4.7.30)$$

where:
$A_b = 2 * cable\ diameter * D_{eff}$, mm²
t = time, days

$$B_u = \frac{1.2 * DL + 1.6 * LL}{total\ cable\ number} \quad (4.7.31)$$

Check; $\phi B_n \leq B_u$ (4.7.32)

*Note that this is a basic analysis of a singly reinforced anchor beam. To realize extra capacity, it is up to the discretion of the DEIC and one could consider the following, which are discussed in the advanced suspended bridge design course (211):

- Contribution of compression steel.
- Fixed anchor beam moment.
- Additional capacity from ramp fill in shear and flexure.

4.8 Construction Analysis

Overview:
Construction analysis is a new section of design checks that focuses on safe structures during the construction process. With updated sag values and unique, custom abutment designs, it is important to re-visit items that are inherently satisfied with the standard designs to ensure failure will not occur in custom designs.

Construction Sag (h_1):
As a reminder, in order to let the cables settle down to the hoisting sag (h_2), we need to raise the cables *above* hoisting sag (h_2) in order to drop them into place (raising the cables to the exact hoisting sag will not work since they always drop a bit when the hoisting device is removed). Previous practice involved raising the cables as high as possible, but we now will need to check the (1) winch capacity, (2) erection hook capacity, and (3) early sliding and uplift capacity to confirm a a construction sag (h_1) of 3%. All the checks referenced below are explained in detail in the Advanced Suspended Bridge Design (211) course on BridgeEDU.

1. *Winch Capacity:*

Cable Self-Weight Horizontal Tension; $P_{h,self-weight} = \frac{w_{cable}*L^2}{8*h_1}$ (4.8.1)

Maximum Single Cable Force; $P_{max} = P_{h,self-weight}/COS(\alpha_{max})$ (4.8.2)

Solve for $h_{1,min}$ by substituting; $W_n \geq P_{max}$ (4.8.3)

where:
W_n is winch capacity with a built in factor of safety (this is usually 3-ton capacity but should be verified).
w_{cable} = cable weight, kN/m
α_{max} = maximum cable angle in the backstay, degrees

2. *Erection Hook Capacity:*

Erection Hook Capacity; $T_{hook} = 2 * A_{bar} * f_{y,rebar}$ (4.8.4)

where:
A_{bar} is most commonly the area of #5 bar. Update according to drawing details.

Erection Hook FS; $FS_{erection\ hook} = \frac{T_{hook}}{P_{max}}$ (4.8.5)

Solve for $h_{1,min}$ by substituting; $FS_{erection\ hook} \geq 3$ (4.8.6)

3. *Early Sliding and Uplift Capacity:*

A set of equations for early abutment capacity checks is not presented here because this will be identical to the cable analysis and sliding/uplift analysis from **4.6. Anchor Analysis**. The steps are as follows:

1. Re-calculate cable forces using $P_{h,self-weight}$ instead of the full load horizontal force. If you use your values for the full bridge load, this factor of safety will fail.
2. Re-calculate anchor sliding and uplift forces under the following assumptions:
    a. Tiers, tower, and anchor have been constructed.
    b. Minimal ramp wall is complete from the anchor to foundation. This means the ramp wall has been completed from the top of the anchor to the top of the foundation forming a compression strut. If ramp walls connect above the foundation, complete subgrade ramp walls at a minimum.
    c. Back wall is complete above the anchor.

3. Check new anchor sliding and uplift factors of safety.

Concrete and Masonry Early Strength:
Concrete early strength checks are taught in the Advanced Suspended Bridge Design (211) course on BridgeEDU, but are not required checks. The course follows a regression model from this study to check the early strength of the reinforced concrete towers under a reduced "self-weight" loading. That being said, there are still best practice recommendations during the construction process to avoid a blowout.

Best practice recommendations are:
- Wait a minimum 6 days after anchor or tower construction to set sag (*i.e.,* tension cables).
- Wait a minimum 24 hours after building brick or CMU formwork to fill the towers.
- No more than one successive tier per day.
- No more than 1.0-meter rise in approach ramp wall height per day.

Concrete Early Strength; $f_c{}'(t) = A * ln\ (t)\ + B$ (4.8.7)

where:
$f_c{}'(t)$ = concrete compressive strength at time t, MPa
A = empirical coefficient with a "goodness of fit" of 0.98
B = empirical coefficient with a "goodness of fit" of 0.91

$A = 1.4035 * ln\ (B)\ + 2.9956$ (4.8.8)

$B = 0.005 * f_c'^{2.2}$ (4.8.9)

Early Strength Tower Checks:
If you wish to hoist cables to their construction sag (h_1) value before the 6-day minimum waiting period, an early strength check must be performed with the following steps:

1. Calculate the adjusted concrete compressive strength (f_c') at time t.
2. Re-calculate cable loads using the same process as the cable self-weight loading ($P_{h,self-weight}$) from above. Make sure to calculate hoisting loads and post-decking loads.
3. Insert both values into your tower checks (**Section 4.4**) to re-evaluate tower moment capacity.

Early Strength Anchor Checks:
If you wish to hoist cables to their construction sag (h_1) value before the 6-day minimum waiting period, an early strength check must be performed with the following steps:

1. Calculate the adjusted concrete compressive strength (f_c') at time t.
2. Re-calculate cable loads using the same process as the cable self-weight loading ($P_{h,self-weight}$) from above. Make sure to calculate hoisting loads and post-decking loads.

The governing load combination when only dead load is applied will be:
$U = 1.4 * DL$ (4.8.10)

3. Check the anchor beam flexural capacity (ACI 318-11 Chapter 10). Use the same process as **Section 4.7** above. Remember to adjust the loads accordingly.
4. Check the anchor beam shear capacity (ACI 318-11 Chapter 11). Use the same process as **Section 4.7** above. Remember to adjust the loads accordingly.

5. Check the anchor beam bearing capacity under cable forces (ACI 318 Chapter 22). Use the same process as **Section 4.7** above. Remember to adjust the loads accordingly.

Cold Weather:
Cold weather can affect concrete cure time and recommended embedment depths due to frost heave.

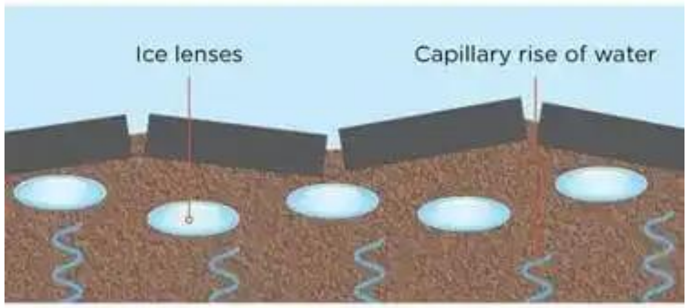


Figure 4.8.1 Frost heave representation.

Frost Heave:
Frost heave is the upward motion of soil due to ice formation underneath. IBC Chapter 18 Section 1809.5 requires that the embedment of foundation structures remain beneath the frost line depth. However, frost line depth isn't exactly a commonly measured metric in rural Bolivia and/or Eswatini. Using a general prediction model, we can estimate the frost line depth:

$$\text{Frost Line Depth; } D = -0.45 * k + 1.9614 * CFI^{0.0913k+0.4143} \quad (4.8.10)$$

where:
k is the thermal conductivity of soil, taken as 1.01 BTU/(ft-h-F)

$$CFI = \sum_{i=1}^{n} daily\ freezing\ index\ \geq 0 \quad (4.8.11)$$

$$daily\ freezing\ index = 32^{o}F - (T\_ + T\_min)/2 \quad (4.8.12)$$

Daily temperature data is very difficult to accurately find for our remote sites, so we'll take a different approach. The "CFI" is essentially the amount of days where the mean temperature is greater than 32°F. If we conservatively assume 60 days (most data shows the mean daily temperature is never below 32°F in the countries we work), the frost line depth is calculated at **30 centimeters of embedment**; giving confidence that frost heave should never be a problem on site.

Cold Weather Curing:
Curing concrete in cold weather can be detrimental to the process of strength development. Freezing water in the concrete pores can expand to create cracks and halt the hydration process (where strength is developed). We can define "cold weather" as more than three consecutive days with mean temperatures below 40°F (or air temperature below 50°F degrees for 12 hours consecutively). Fresh concrete can begin to freeze at 25°F. Now, as stated in the previous section, accurate temperature data is hard to find and will vary based on site. If your site is particularly cold, or at an extreme altitude (*e.g.*, ~14,000+' in the altiplano of Bolivia), it is good to be prepared and to consider the following:

- Consider using concrete blankets. During the hydration process (exothermic reaction) heat is released. These blankets help keep the heat in like a sleeping bag for your anchor beams.
- Place concrete early in the day and keep an eye on weather conditions to do this during a sunny day.
- In extreme cold conditions consider using admixtures in the structural concrete (tower and anchor). Accelerant is the best choice. Specific products and a comparison between accelerant and other admixtures are discussed in the Advanced Suspended Bridge Design (211) course on BridgeEDU.

Masonry Wall Stability:

Ramp Wall Stability:
The Advanced Suspended Bridge Design (211) course on BridgeEDU goes into depth on the subject with an example analysis and justification of the current method. The design process follows the steps below and corresponds to the “level method” for calculating ramp wall areas:

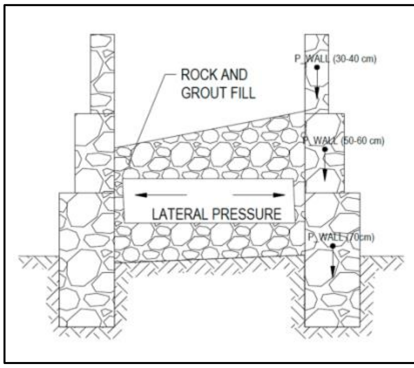


Figure 4.8.2: Lateral Pressure from Rock and Grout Fill

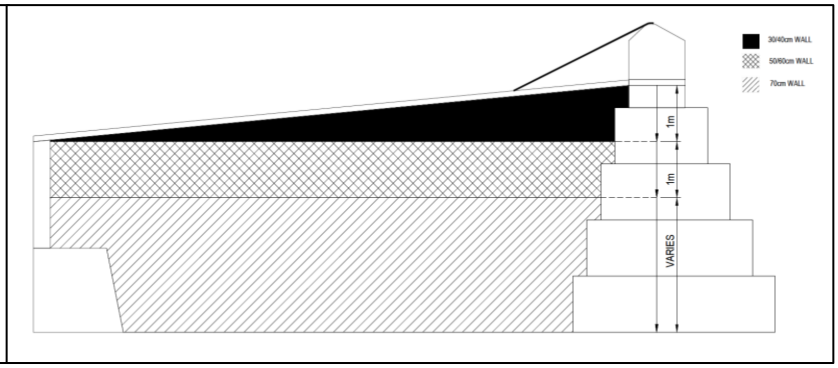


Figure 4.8.3: “Level Method” for calculating ramp wall thickness.

1. Is your maximum ramp wall height above ground level less than 1.4-meters?
   a. Yes – only 30-centimeter thick ramp walls are required.
   b. No? Proceed to #2
2. Is your max ramp wall height above ground level greater than 1.4-meters but less than 2.4-meters?
   a. Yes – Following the figure above, draw a vertical line 1.0-meter down from the walkway saddle and a horizontal line until it meets either the ramp cap, backwall, or anchor. This area should be 30-centimeter wall, the rest of the area should be 50-centimeter wall.
   b. No? Proceed to #3
3. Is your max ramp wall height above ground level greater than 2.4-meters but less than 3.4-meters?

***Note that the ramp wall thicknesses change here to accommodate the aesthetics of the structure and reflect in-country practices in Bolivia! See graphic below with explanation.**

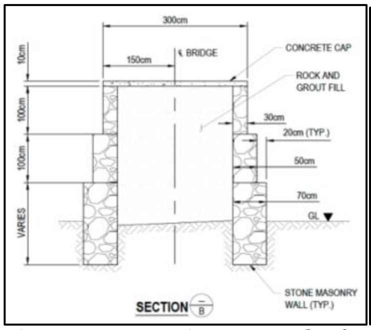


Figure 4.8.4a: Section B example of 3-tier ramp wall configuration (Eswatini).

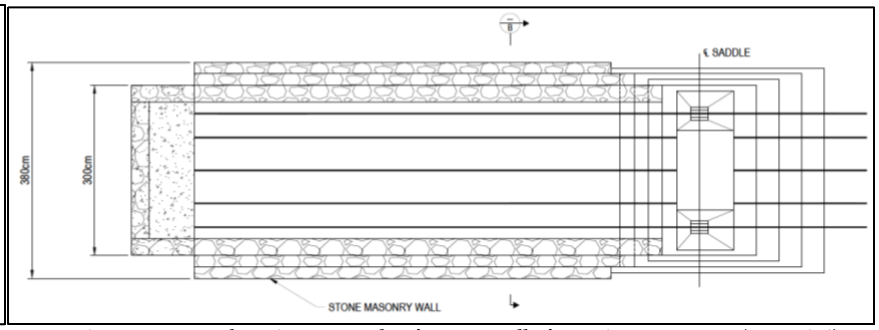


Figure 4.8.5a: Plan view example of ramp walls for 3-tier structures (Eswatini).

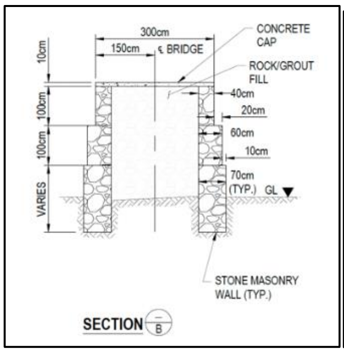


Figure 4.8.4b: Section B example of 3-tier ramp wall configuration (Bolivia).

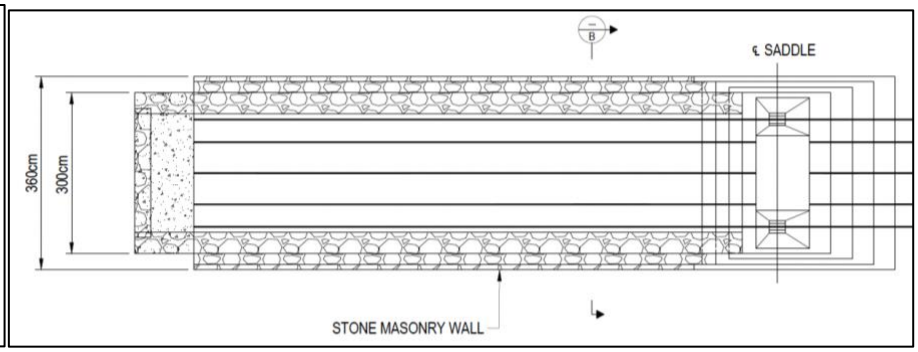


Figure 4.8.5b: Plan view example of flush ramp walls for 3-tier structures (Bolivia).

In Bolivia, to ensure the 70-centimeter wall fits flush against the foundation, the wall is shifted 10-centimeters inward and the subsequent (above) walls are increased by 10-centimeters to 60-centimeters and 40-centimeters.

a. Yes – Following the figure above, draw a vertical line 1.0-meter down from the walkway saddle and a horizontal line until it meets either the ramp cap, backwall, or anchor. This area should be **40-centimeter wall (Bolivia) or 30-centimeter wall (Eswatini)**. Repeat this step once more. This area should be **60-centimeter wall (Bolivia) or 50-centimeter wall (Eswatini)** and the rest of the area should be **70-centimeter wall (Both)**.
b. No? This shouldn't be the case, foundations require 1.0-meter embedment, and we currently don't build abutments with more than 3 tiers and a 1.5-meter tall foundation. Do not move forward with your design until discussing geometric layout with your DEIC.

To support the design process above, a more detailed explanation is provided in the Advanced Suspended Bridge Design (211) course on BridgeEDU that presents the following:

- Global overturning of the ramp walls experiencing lateral, hydrostatic forces from fill material.
- Internal stresses on stone masonry ramp walls (shear and flexure) while resisting lateral, hydrostatic forces from fill material.

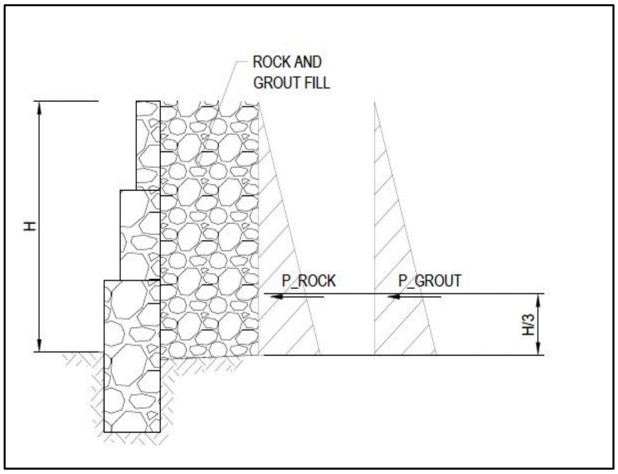


Figure 4.8.6: Ramp wall forces during construction.

Ultimately, the grout or slurry mix reduces the development of lateral pressures from the rock fill. During the construction process, the grout fill increases the lateral pressure on the ramp walls. But after curing, the grout reduces lateral forces from the rock onto the ramp walls that will develop over time.

Section 5 – Suspended Bridge Design

This section outlines the steps to select and modify appropriate drawings from EIA and Bridges to Prosperity's standard suspended bridge design drawings, found in the **Useful Links** section at the beginning of this document.

5.1 Bridge Design Procedure

Designing a *standard* suspended cable bridge requires minimal technical background (1st-2nd year engineering student) and should meet the geometric constraints and "Tier 1" checks required for structural design. Designing a *custom* suspended cable bridge requires sufficient technical background (3rd-4th year engineering student) with the assistance of a professional engineer (DEIC) for final approval. This should meet the "Tier 2" checks required for structural design. The general procedure for completing a set of bridge drawings after completion of a topographic survey (which is provided in your Site Info folder) is as follows:

1. Determine bridge foundation locations, number of tiers, and sizes.
2. Select standard abutment drawings to meet ground profile slope and span requirements as best as possible. This will serve as a good starting point.
3. Determine cable size and quantity.
4. Select detail drawings (Anchor, Tower, Walkway, Crossbeams, Fencing). None of these should change during your customization process.
5. Perform Tier 1 checks.
6. Customize abutment drawings.
7. Perform Tier 2 checks.
8. Iterate steps 6-7 and then compile the final set of drawings and calculations.
9. Calculate material quantities, also known as the BOQ or Bill of Quantities (this process is detailed in the Construction Management Course (301) on BridgeEDU).

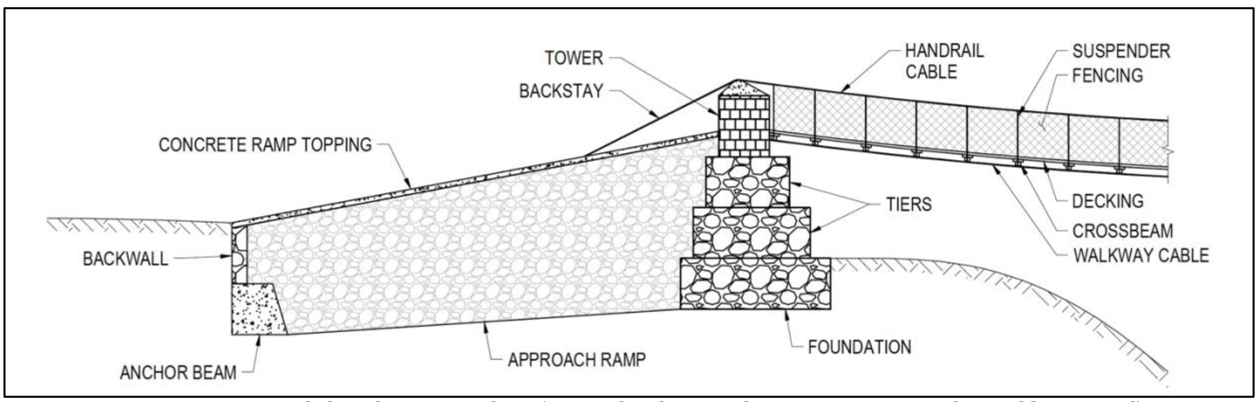


Figure 5.1.1: Suspended Bridge Terminology (Screenshot from Bridges to Prosperity Bridge Builder Manual).

5.2 Verify Topographic Profile and Site Media

A complete bridge profile survey will be provided in your Site Info folder. However, everybody makes mistakes from time to time. Take a moment to go through all your site information to verify it is correct. Some things to think about are:

1. Does all of the site media match up?
2. Does all of the site media match your survey profile?
3. Do the elevations (if provided) on the survey profile make sense?
4. Are there any obvious erosion concerns or mislabeled "edge of bank" points?
5. Is the survey file using the latest version of the SEED file (see link in **Useful Links**)?

5.3 Determine Tower Foundation Locations and Sizes

The tower foundation locations determine the span of the bridge. When determining the foundation locations and sizes, the following criteria must be met:

- The maximum span length of 120-meters.
- Foundations must be placed at least 3.0-meters back from the edge of bank in a soil slope and 1.5-meters from edge of bank in a rock slope.
- Foundations must be placed behind an angle of internal friction of the soil (35^o) or rock (60^o) as measured from the toe of slope
- The ground profile slope behind the foundation in soil conditions must not exceed 20 degrees. Standard designs must be under 10 degrees, but customization allows this to increase.
- The difference in height between cable saddles on either side of the span shall not be more than 4% of the span (L/25).
- The minimum walkway cable saddle elevation above ground is 0.9-meters (half tier) and the maximum elevation is 3.9-meters (3 tiers with a 1.5-meter tall foundation).
- The minimum freeboard between the lowest point of the cable under dead load and the high-water level shall be a minimum of 3.0-meters in gorges and valleys.
- Cables should be kept a minimum of 0.5-meters from the ground (live load + dead load geometry) and recommended 1.0-meters from the ground.
- Keep foundation out of floodplains.

The geometric design criteria and background information is discussed further in depth in **Section 2 - General Design and Location Features**.

Step-by-Step Design Process:
Step 1 - Place each foundation such that the front of foundation fulfills the required minimum setback. Verify the foundation is located behind the appropriate slope line. If the foundation does not satisfy the slope line setback, shift the location away from the river until the requirements are met. Verify the span length is less than 120-meters and the ground slope behind foundation (uphill) is less than 20 degrees if bearing on soil. If other soil stability or erosion concerns exist at this point, make sure to set the foundation back further and note this in your design.

Step 2 - Determine the number of tiers required by checking the difference in elevation. Starting with the minimum walkway saddle elevation of 1.4-meters by using a single tier, check that the elevation difference does not exceed the Span/25 limit. If the level difference exceeds this amount, add one or two one-meter-tall tiers to the lower abutment or consider shortening the higher tower to a half tier until the requirement is met. Alternatively, the foundations may be shifted further away from the river to gain elevation if located on a slope or increased to 1.5-meter tall. In some cases, a combination of adding tiers and shifting the foundation back generates the most efficient design. When the difference in elevation parameter is fulfilled, once again verify the span does not exceed 120-meters and the ground slope does not exceed 20 degrees if bearing on soil.

Step 3 - Verify the freeboard between the lowest point of cable and high water elevation using the Dead Load cable geometry. Freeboard is verified by taking the low side walkway saddle elevation, subtracting the sag value 'f' and subtracting the elevation of the High Water Level. If the value of freeboard is less than required, the designer must increase the walkway saddle height on either one or both foundations by either increasing the number of tiers or shifting the foundations back on a hill slope.

The vertical distance, f, between the lowest point of the cable and the lower walkway saddle is calculated by:

$$f = \frac{(4*h_3-\Delta H)^2}{16*h_3} \tag{5.3.1}$$

in which:

$$h_3 = 0.0455 * L \tag{5.3.2}$$

Step 4 - If all the geometric requirements have been met after following Steps 1 through 3, the final foundation locations along with tier quantities and cable profile can be drawn (note these can still change based on the abutment customization process, but it is unlikely).

5.4 Select Standard Abutment Drawings

Based on a given span length, geologic conditions, and the number of tiers, two Standard Abutment drawings can be selected, one for each side of the river. The standard suspended cable bridge designs in this Binder utilize two types of cable anchorages: Gravity Anchors and Drum Anchors. Gravity Anchors may be used in either soil or rock conditions and rely on self-weight for horizontal and vertical resistance. Drum Anchors are used in rock conditions and either use doweled bars or shear capacity of the rock along with interface friction to develop resistance. Hard or fractured rock conditions must be present for drum anchors to be used.

Gravity Anchor abutment design drawings are broken down into 20-meter increments of span length from 40-meters up to 120-meters. For each span increment, designs are provided for one (1), two (2), and three (3) tier alternatives as well as ground slope conditions of either (0-5°) or (5-10°).

1G-40A ONE TIER GRAVITY ANCHOR, 20-40 METER SPAN (0° -5°)
1G-60A ONE TIER GRAVITY ANCHOR, 40-60 METER SPAN (0° -5°)
1G-80A ONE TIER GRAVITY ANCHOR, 60-80 METER SPAN (0° -5°)
1G-100A ONE TIER GRAVITY ANCHOR, 80-100 METER SPAN (0° -5°)
1G-120AONE TIER GRAVITY ANCHOR, 100-120 METER SPAN (0° -5°)
1G-40B ONE TIER GRAVITY ANCHOR, 20-40 METER SPAN (5° -10°)
1G-60B ONE TIER GRAVITY ANCHOR, 40-60 METER SPAN (5° -10°)
1G-80B ONE TIER GRAVITY ANCHOR, 60-80 METER SPAN (5° -10°)
1G-100B ONE TIER GRAVITY ANCHOR, 80-100 METER SPAN (5° -10°)
1G-120B ONE TIER GRAVITY ANCHOR, 100-120 METER SPAN (5° -10°)

2G-40A TWO TIER GRAVITY ANCHOR, 20-40 METER SPAN (0° -5°)
2G-60A TWO TIER GRAVITY ANCHOR, 40-60 METER SPAN (0° -5°)

2G-80A TWO TIER GRAVITY ANCHOR, 60-80 METER SPAN (0° -5°)
2G-100A TWO TIER GRAVITY ANCHOR, 80-100 METER SPAN (0° -5°)
2G-120A TWO TIER GRAVITY ANCHOR, 100-120 METER SPAN (0° -5°)
2G-40B TWO TIER GRAVITY ANCHOR, 20-40 METER SPAN (5° -10°)
2G-60B TWO TIER GRAVITY ANCHOR, 40-60 METER SPAN (5° -10°)
2G-80B TWO TIER GRAVITY ANCHOR, 60-80 METER SPAN (5° -10°)
2G-100B TWO TIER GRAVITY ANCHOR, 80-100 METER SPAN (5° -10°)
2G-120B TWO TIER GRAVITY ANCHOR, 100-120 METER SPAN (5° -10°)
2G-40C TWO TIER GRAVITY ANCHOR, 20-40 METER SPAN (10° -15°)
2G-60C TWO TIER GRAVITY ANCHOR, 40-60 METER SPAN (10° -15°)
2G-80C TWO TIER GRAVITY ANCHOR, 60-80 METER SPAN (10° -15°)

3G-40A THREE TIER GRAVITY ANCHOR, 20-40 METER SPAN (0° - 5°)
BO-3G-40A THREE TIER GRAVITY ANCHOR, 20-40 METER SPAN (0° - 5°)
3G-60A THREE TIER GRAVITY ANCHOR, 40-60 METER SPAN (0° -5°)
BO-3G-60A THREE TIER GRAVITY ANCHOR, 40-60 METER SPAN (0° -5°)
3G-80A THREE TIER GRAVITY ANCHOR, 60-80 METER SPAN (0° -5°)
BO-3G-80A THREE TIER GRAVITY ANCHOR, 60-80 METER SPAN (0° -5°)
3G-100A THREE TIER GRAVITY ANCHOR, 80-100 METER SPAN (0° -5°)
BO-3G-100A THREE TIER GRAVITY ANCHOR, 80-100 METER SPAN (0° -5°)
3G-120A THREE TIER GRAVITY ANCHOR, 100-120 METER SPAN (0° -5°)
BO-3G-120A THREE TIER GRAVITY ANCHOR, 100-120 METER SPAN (0° -5°)
3G-40B THREE TIER GRAVITY ANCHOR, 20-40 METER SPAN (5° -10°)
BO-3G-40B THREE TIER GRAVITY ANCHOR, 20-40 METER SPAN (5° -10°)
3G-60B THREE TIER GRAVITY ANCHOR, 40-60 METER SPAN (5° -10°)
BO-3G-60B THREE TIER GRAVITY ANCHOR, 40-60 METER SPAN (5° -10°)
3G-80B THREE TIER GRAVITY ANCHOR, 60-80 METER SPAN (5° -10°)
BO-3G-80B THREE TIER GRAVITY ANCHOR, 60-80 METER SPAN (5° -10°)
3G-100B THREE TIER GRAVITY ANCHOR, 80-100 METER SPAN (5° -10°)
BO-3G-100B THREE TIER GRAVITY ANCHOR, 80-100 METER SPAN (5° -10°)
3G-120B THREE TIER GRAVITY ANCHOR, 100-120 METER SPAN (5° -10°)
BO-3G-120B THREE TIER GRAVITY ANCHOR, 100-120 METER SPAN (5° -10°)

Drum Anchor drawings are only available up to 60-meter spans. No further classification is needed as rock anchors do not lend themselves to more than one tier due to the short distance between the anchor and the saddles because of sloped rock conditions. There are two sizes of drum anchors: small (up to 40-meter spans) and large (40 - 60-meter spans). Projects in rock with spans larger than 60-meters require design support from a qualified engineer.

D1 HARD ROCK DRUM ANCHOR, 20-40 METER SPAN
D2 HARD ROCK DRUM ANCHOR, 40-60 METER SPAN
D3 SOFT ROCK DRUM ANCHOR, 20-40 METER SPAN
D4 SOFT ROCK DRUM ANCHOR, 40-60 METER SPAN

5.5 Select Cable Size and Quantity

Once span length is determined, the size and quantity of cables can be selected. Note that cable sizing is usually "fixed" because of what is available in country. Make sure to reach out to education@eiabridges.org to confirm cable size for your design. **Table 3.1.1** above will give cable ultimate breaking strength. Then use the cable analysis procedures discussed in **4.1. Cable Analysis** to confirm a sufficient cable quantity. Remember that when using timber crossbeams, the minimum number of walkway cables is three. Therefore, the minimum total number of cables for any standard suspended bridge is five. The quantity and spacing of clamps can be determined using **Table 5.5.1**:

Table 5.5.1: Clamp Number, Spacing, and Torque Requirements

Cable Diameter		Number of Clamps	Spacing		Torque
(in.)	(mm)		(in.)	(cm)	ft-lb
3/4	19	4	5	12	130
7/8	22	4	5	13	225
1	25	5	6	14	225
1-1/8	29	6	6	15	225
1-1/4	32	7	6	16	360
1-3/8	35	7	6	16	360
1-1/2	38	8	7	18	360

*Note that all clamps must be drop-forged.

5.6 Select Bridge Detail Drawings

Once the approximate span length has been set, the abutment drawings selected, and cable size and quantity determined, the final drawings to select are the Tower, Anchor, Walkway, Crossbeam, and Fencing Details. **These details should not be changed without specific instruction from your DEIC.** The Tower Details drawing details the top of abutment tower along with cable saddles. The Anchor Details drawing provides dimensions and reinforcing details for the concrete anchor beam. The Walkway Details drawing shows crossbeam, decking, cable spacing, suspender and fencing details for constructing the bridge deck. The Crossbeam Details drawing goes into depth for specific crossbeam types. The Fencing details are required if any point on the bridge the surface of the ramp walkway exceeds 1.8-meters above the ground, and show the various guardrail types. One of each drawing type should be selected for the complete drawing set.

Tower Details:
T1 THREE WALKWAY CABLES
T2 FOUR WALKWAY CABLES
T3 FIVE WALKWAY CABLES
T4 TWO WALKWAY CABLES
T5 FOUR WALKWAY CABLES (NO CENTER)

Anchor Details:
A1 20-60 METER SPAN (3 WALKWAY CABLES)
A2 60-100 METER SPAN (3 WALKWAY CABLES)
A3 100-120 METER SPAN (3 WALKWAY CABLES)
A4 20-60 METER SPAN (2 WALKWAY CABLES)
A5 60-100 METER SPAN (2 WALKWAY CABLES)
A6 60-100 METER SPAN (4 WALKWAY CABLES)

A7 100-120 METER SPAN (4 WALKWAY CABLES)

Walkway Details:
W1 TIMBER CROSSBEAM WITH NAILER
W1c TIMBER CROSSBEAM WITH NAILER (curb)
W2 TIMBER CROSSBEAM WITHOUT NAILER
*W3 STEEL CROSSBEAM WITH NAILER AND TIMBER DECK
*W3E ESWATINI STEEL CROSSBEAM WITH NAILER AND TIMBER DECK (6 boards)
W3c STEEL CROSSBEAM WITH NAILER AND TIMBER DECK (curb)

Crossbeam Details:
*C1 STEEL CROSSBEAM (C4X5.4)
C1a STEEL CROSSBEAM (C4X5.4) – with center cable guide
*C5E ESWATINI STEEL CROSSBEAM (100X50)
C5Ea ESWATINI STEEL CROSSBEAM (100X50) – with center cable guide

Fencing Details:
F2 SUSPENDED FENCE DETAIL
*F2E ESWATINI SUSPENDED FENCE DETAIL
*F3 BOLIVIA SUSPENDED FENCE DETAIL

Drainage Details:
D1 DRAINAGE DETAIL (NO BENCHING)

Safety Details:
SC SAFETY LINE ANCHORAGE

Detail drawings with a "" are the most used in country. Those marked with an "E" are commonly used in Eswatini.

5.7 "Tier 1" Checks

"Tier 1" checks are the basic checks associated with the Suspended Bridge Design (201) course on BridgeEDU and the B2P Manual. At this point it is good to perform these checks as a litmus test for what may be governing your design. If you haven't employed all the tips, tricks, and refinements from **Section 4 – Structural Analysis and Evaluation**, the following section will outline this process.

5.8 Customize Abutment Drawings

After an initial check helps to identify what may be governing your design, it is time to customize! Our recommendations for customization are as follows:

- Consider raising the anchor 0.5-1.5 meters while maintaining minimum embedment for the abutment components. Note that an extra access ramp will be necessary to get from ground level onto the approach ramp if this is high above the ground.
- Remember, the bottom of the ramp wall can connect to the foundation at a point above the bottom of the foundation and all component weight below that connection point is

disregarded for sliding resistance. This is a good strategy to decrease uplift forces (raise anchor) where sliding is not governing bridge design.

- Consider shortening the abutment 1-3 meters. This will steepen your cable angle and decrease uplift safety factors, so it is best to try and do this in tandem with raising the anchor.
- If your span is close to 60, 100, or 120-meters, consider dropping the anchor size (*e.g.*, using an A5, 60-100m anchor for a 102-meter span bridge instead of the A3, 100-120 meter anchor).
- Consider moving the foundation location and adjusting tier or foundation sizes throughout this process.
- Think about materials, time, and excavations. Sometimes 1-2 hours of brain power can save 1-2 weeks in the field!
- Do not exceed 22% approach ramp slope (measured as the angle of the approach ramp concrete cap to horizontal) as this starts to become difficult to walk up in rain, snow, or icy conditions.

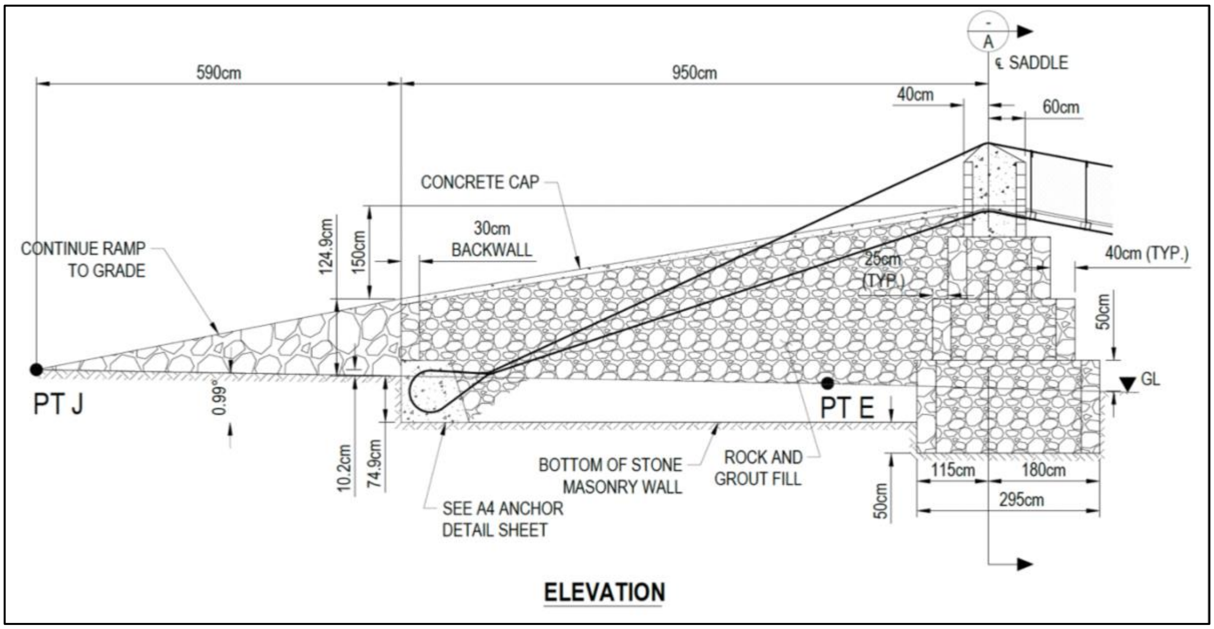


Figure 5.8.1: Example customized abutment from Motane, Eswatini 2022.

5.9 "Tier 2" Checks

"Tier 2" checks are the advanced checks associated with the Advanced Suspended Bridge Design (211) course on BridgeEDU. They are an updated set of checks required if you are making modifications to the standard designs. The concepts and background for all these checks are detailed in the Advanced Suspended Bridge Design (211) course on BridgeEDU, with relevant equations and brief descriptions in **Section 4 – Structural Analysis and Evaluation**.

A complete example set can be found in the **Useful Links** under "Tier 2" Example Calculations. This example follows all the Required Checks for Custom Designs.

5.10 Compile Final Set of Drawings

Before compiling your final drawings, you'll want to iterate between the previous two (**Section 5.8 and 5.9**) steps until you have an efficient and safe design. When you are ready, a complete set of bridge drawings should include a Title Page, Layout sheet with Plan and Elevation views, Custom Abutment Details (Left and Right), Tower, Anchor, and Walkway, Crossbeam, and Fencing (if applicable) drawings.

Ensure you have all critical dimensions by following the Drawing Checklist with the associated Example Drawings (Markup) for visual reference.

All revisions should be named appropriately, with consistent updates in the title block of your drawing set.

Revisions:
Drawing Set_Country_Bridge Name_Team(s)_Date_Revision #
Calculations_Country_Bridge Name_Team(s)_Date_Revision #
Report_Country_Bridge Name_Team(s)_Date_Revision #

Title Block:
Update the title block with the following lettering and numbering scheme:

REV.	DESCRIPTION	DATE	ISSUED BY
A	ISSUED FOR INFORMATION	XX/XX/XX	XXX
B	ISSUED FOR APPROVAL	XX/XX/XX	XXX
0	ISSUED FOR CONSTRUCTION	XX/XX/XX	XXX
1	FIELD CHANGE DESIGN REVISION	XX/XX/XX	XXX
2	AS-BUILT DRAWINGS	XX/XX/XX	XXX

Figure 5.10.1: Title block labeling scheme for drawing revisions.

Approval:

ENGINEERING RECORD
DATE: DD/MMM/YY
DRAWN BY: ABC
CHECKED BY: CDE
APPROVED BY: EFG
REVIEWED BY: HJK

Figure 5.10.2: Title block approval.

Final drawings need to be approved by your Design Engineer in Charge (DEIC). Include the bridge engineer initials under "drawn by" and your technical committee member (EIA staff) initials under "checked by". Your DEIC should be filled out in the "approved by" row, along with any other major reviewer in "reviewed by". Stamping the drawing set is not currently a mandatory requirement of DEICs, however this is preferred if possible.

Working with the SEED File:
Remember to use the SEED File to create your drawings along with the EIA.ctb (see **Useful Links**) to ensure the correct plot style. Suspended Bridge Design (201) provides a detailed

walkthrough on how one can install the EIA.ctb file, working with the SEED file, dimensioning, and general AutoCAD help.

5.11 Construction Tolerance

Having a predetermined set of tolerances can help speed up construction significantly - especially if your site has poor service, where it could take hours to hike to better service or load a photo. Not only this but going through a set of agreed upon tolerances is a great learning experience for the traveling student team. You (1) should be familiar with these tolerance values to watch out for them in the field, and (2) will gain a greater understanding of the structural systems through this exercise.

Make time to meet with your DEIC to fill out the following table. This information should be provided AFTER your final drawing set (Released For Construction - RFC) is approved and along with your Review Call 3 material.

*Table 5.11.1: Construction Tolerances**

Name of Construction Milestone	Tolerance +/-
Excavation Dimensions	+/- xx cm
Anchor Dimensions (all)	+/- xx cm
Anchor Location (relative to tower)	+/- xx cm
Anchor Cage Rebar Spacing	**+/- 2 cm**
A03 Reinforcing Bars (bend dimensions)	+/- xx cm
Deviations in Mix Design (structural concrete, mortar, slurry)	+/- ratio
Masonry Wall Thickness	+/- xx cm
Masonry Wall Height	+/- xx cm
Foundation and Tier Dimensions (all)	**+/- 2 cm**
Abutment Height (foundation to walkway hump)	+/- xx cm
Tower Dimensions (all)	+/- xx cm
Tower Saddle (ΔH verification)	+/- xx cm
Tower Saddle (relative to each other)	+/- xx cm
Tower Rebar Placement (maintain 7.5cm clear cover)	**+/- 2 cm**
Crossbeam Spacing	+/- xx cm
Clamp Spacing	**+/- 0 cm**
Cable Sag Set (cables relative to each other)	**+/- 0 cm**
Cable Sag Set (cable “f_hoist” value)	+/- xx cm
Bridge Span	+/- xx cm

*This is not a comprehensive list of construction milestones. Feel free to add to this list as your discussion progresses. **Bold items** are set by EIA Technical Committee.

Section 6 – Other Structures

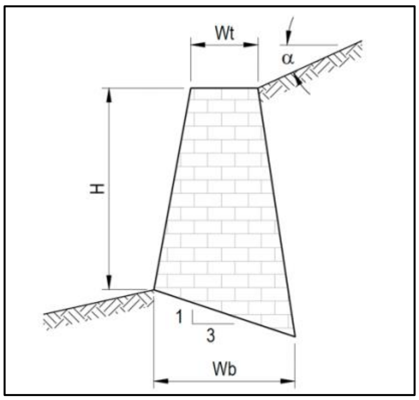
In addition to the bridge itself, other structures may be required as a greater part of the entire project. Some of these other structures may include:

- Retaining walls
- Wind guys
- Drainage
- Bank protection

This section outlines some general design criteria for each of these structures.

6.1 Bank Protection and Slope Stability

Slope Stability:



Retaining walls may be necessary in locations where excessive excavation into soils or fractured rock is required behind abutments or anchorages and would become unstable if left alone. Retaining walls may be comprised of gabion baskets, timber, dry stone, traditional masonry walls or cast-in-place concrete. Dry stone retaining walls typically are preferable as they require only local materials and are constructed with the least amount of additional cost. Timber wall designs are also readily available but require subsurface drainage.

Figure 6.1.1: Retaining Wall Parameters (Screenshot from B2P Manual)

In lieu of a more rigorous analysis along with a soil study, the guidelines in **Figure 6.1.1** and **Table 6.1.1** can be used for dry stone retaining wall design. Depending on the topography of the site, the slope of the walls may vary greatly. A maximum height of dry-stone wall is suggested to be no greater than 3.0-meters and used when hill slopes are no greater than 35 degrees above the wall. Sites with greater slope angles should not be considered, as stability issues are likely.

Table 6.1.1: Retaining Wall Design Parameters

Parameter	Value
Top Width, Wt	0.6m – 1.0m
Base Width, Wb	(0.5 - 0.7) - H
Front Batter	varies
Rear Batter	varies
Foundation Depth	ε 0.5m
ϕ	< 35°
H	< 3m

Bank Reinforcement:
River training structures should be avoided, as they are only a temporary solution and require frequent maintenance. Normal bridge abutment placement should be well back from river channels thereby eliminating the need for the same. Riverbank protection should be used when a river meanders and at locations where the bridge foundation would be susceptible to river scour. One such scenario would be if the bridge was placed at a river bend. As river bends are not recommended for crossing sites, river training structures should not be considered.

Gabion walls are the most common type of riverbank protection and are commonly used with simple span bridges to create a flush abutment surface. Filling the gabion walls requires considerable time and effort by the community and must be accounted for during planning stages of bridge construction. Gabion walls are generally designed as gravity structures, which use their own weight to resist earth and water pressures. Horizontal layers of wire mesh cages may be stepped either on the front or back side depending on the required application. An engineer is required to design the structure and specify the fill material. The fill material must have both strength and durability to resist the effects of water and weathering. Typically, 8–25-centimeter diameter stone is specified, and if well-graded stone-fill is specified, the volume of stone required to fill the casing is nearly the volume of the empty containers. The Advanced Suspended Bridge Design (211) course on BridgeEDU references a Gabion Wall Design Guide but given how uncommon it is to need these structures on site, it is not explained in further detail.

6.2 Wind Guys

Wind guys are required for any span exceeding 120-meters and at bridge sites with extreme wind conditions as deemed necessary by the design engineer. The suspended bridges herein are designed to withstand a 160 kilometer per hour (100 miles per hour) wind load without any additional lateral support. Wind guys significantly increase the cost of the bridge as two additional cables, considerable additional cable clamps and four additional anchorages are required.

The following additional information is required when wind guys are determined to be necessary:

- Additional topographic information is needed up and downstream from the bridge center axis, typically a distance equal to 20% of the span
- Additional geotechnical site-investigation is also required for each anchor location

A basic plan view of a wind guy system is shown in **Figure 6.2.1**. Given how uncommon this is for suspended bridges, an entire design process is not repeated here. However, Chapter 9 of Volume A: Long Span Trail Bridge Standard from [Nepal Trail bridges]() provides an entire standard design process for wind guy arrangements.

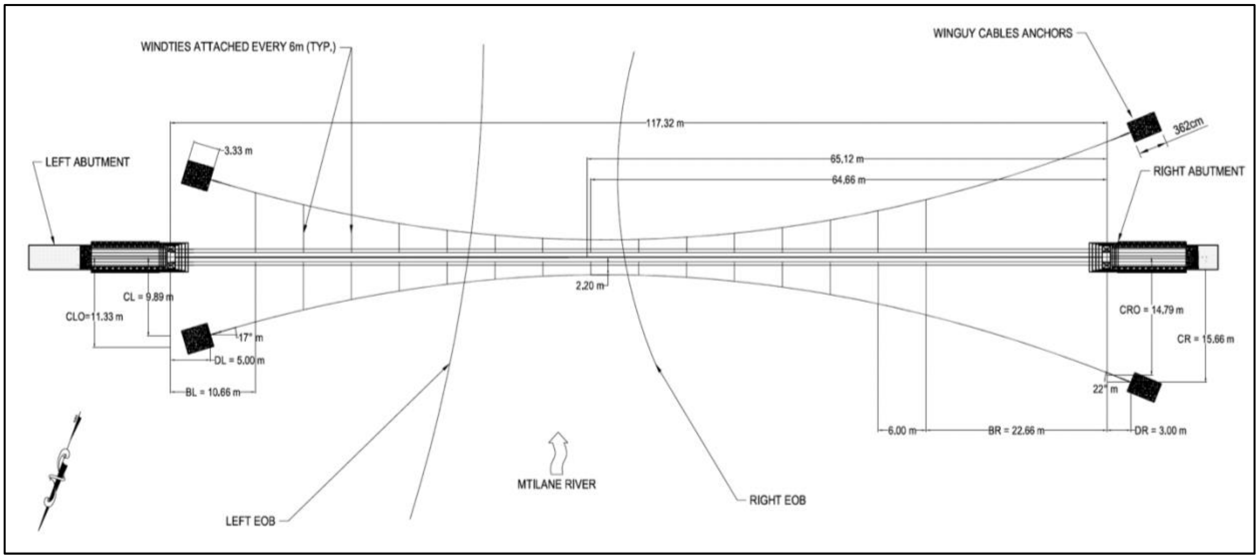


Figure 6.2.1: Example Plan View of a suspended bridge with wind guys (courtesy of the 2022 Georgia Tech Capstone team).

6.3 Drainage

Drainage Behind Abutment:
Slope protection and drainage systems are required at sites when excess run-off may influence the slope stability or cause damage to the approach ramp and decking. We generally avoid sites where instability is prevalent, but if unavoidable, it is necessary to drain out the runoff and seepage to ensure the stability of the slope and to avoid the scouring of these structures. Water should be collected as closely as possible to its origin and navigated away from the bridge structures. This may require a surface catch drain on a slope, drainage around the structure, or both. In the areas directly affected by seepage, sub-surface drainage may be required around the anchorage and/ or foundation areas. A recommended sub-surface drain system is shown below. If the excavation finds sitting water, subsurface drainage is a must.

Additional surface drainage channels assist in redirecting unwanted surface water. To avoid scouring to the drainage channel, additional protection in the form of protection walls and or sheeting should be considered. **Figures 6.3.1 and 6.3.2** below show a sample detail for drainage behind the anchor and abutment. This follows a basic “French drain” concept and was developed using recommendations from the B2P Manual and an Iowa Department of Transportation Study. Note that for accurate pipe sizing, a full analysis to determine surface and groundwater peak discharge would be required. In lieu of this site-specific analysis, a common pipe size range is provided.

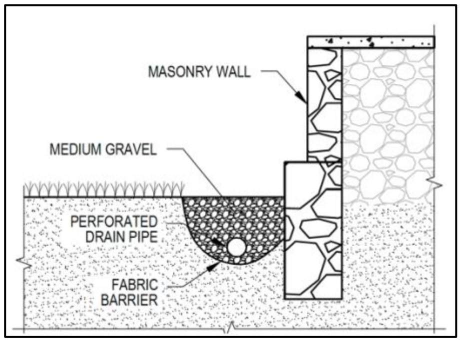


Figure 6.3.1: Drainage detail concept section, see [D1 – Drainage Detail](#) for more information.

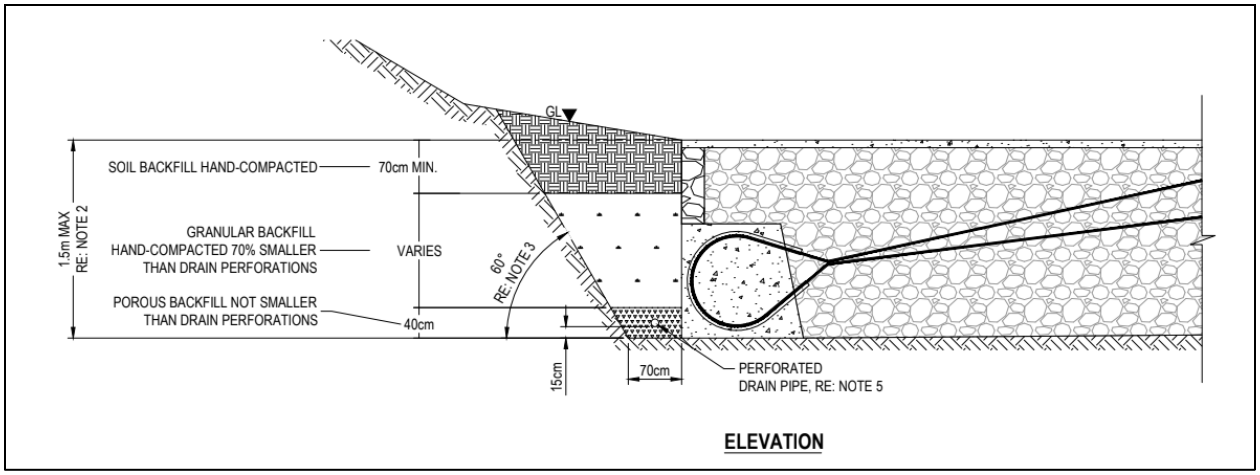


Figure 6.3.2: Drainage detail concept, see [D1 – Drainage Detail](#) for more information.

Flat Approach Ramps:

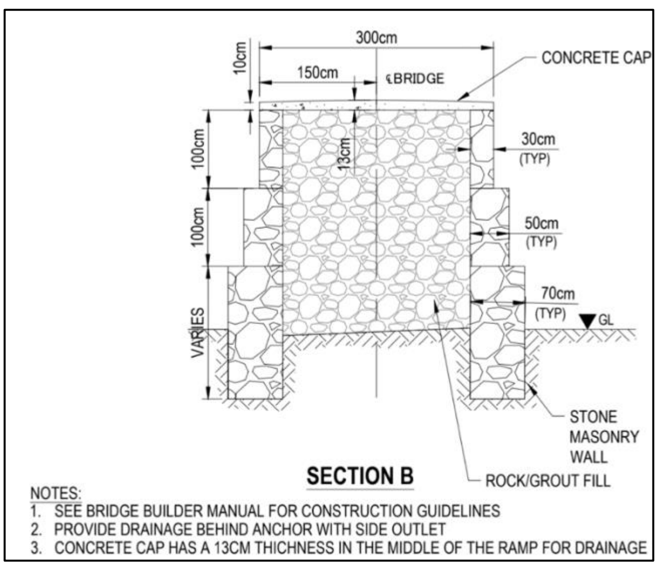


Figure 6.3.3: Flat approach ramp drainage crown detail example.

First, it is important to ensure the approach ramp is never sloping down toward the river. This will cause large runoff into the tower saddle, crossbeams, and decking, with the potential for pooling and the quick degradation of initial deck boards.

Second, when utilizing a flat approach ramp, it is important to maintain a “drainage gradient” or “crown” from the interior to the exterior of the approach ramp. Common road drainage gradients are 1-3% slope. To use an average of 2% gradient, flat approach ramps should be 13cm thick in the center down to 10cm thick on the exterior edges.

Section 7 – Material Estimate

The following section details material quantity take-offs. This section is intended only for EIA suspended bridges. It is recommended that you begin this process simultaneously while developing your bridge design so that data-driven decisions on material usage can be utilized to inform the design. Additional materials may be required for modified structures (*e.g.,* extra approach ramps, gabion walls, wind guys, etc.)**.** More detailed explanations and information for this section are provided in the Construction Management Course (301) on BridgeEDU.

7.1 Cable and Clamps

Cables should be chosen based on availability and efficiency of design. Availability is discussed in **4.1. Cable Analysis** and should be confirmed by reaching out to education@eiabridges.org before beginning design. Three cable estimates should be made:

1. **Use the standard equation.** Note that this includes a contingency factor already. This equation is good as a rough estimate for weight but should not be used to estimate length for cable cutting as it wastes too much cable.

$$L_{cable} = 1.04 * (L + 14 + d_{left} + d_{right})$$

where:
L_{cable} = total length of each singular cable, m
L = span of the bridge, m
d_{left} = distance from centerline of saddle to back of anchor, m
d_{right} = distance from centerline of saddle to back of anchor, m

2. **Measure using AutoCAD.** The exact method for this is explained in detail the Construction Management Course (301) on BridgeEDU under the "Cable and Clamps" section. This method should be used to determine the cable length for cutting.
3. **If your site is in a particularly deep gorge,** this may require coordination with the EIA Country Program Manager to arrange for extra tools and materials on site (*e.g.*, rope, cable hooks, etc.).

Equation 7.1.1 is an empirical formula developed through experience in the field. 14-meters provides excess horizontal length that is helpful while laying out cables (particularly with longer spans) and provides length to account for cable sag and wrap-back around the anchors. The distance between anchors and towers d_{left} and d_{right} are per the construction drawings. An additional 4% is used as contingency. The quantity of clamps per cable is dependent on the size of the cable. Refer to **Table 5.5.1** for cable amount and clamp spacing.

Cable lengths must be approved by EIA staff before cutting cable.

7.2 Steel Reinforcement Bar

Rebar quantities are specified in the standard construction detail drawings except for the bar needed for the suspenders. When estimating the number of reinforcing bars required on a project, it is important to consider the available length of bars in the region in which materials are being purchased. For example, if bars are delivered in 12-meter sections bent in half, there will be a "bending loss" associated with larger diameter bars that is unusable. Reinforcing bars should be Grade 280 (40 ksi). Sourcing reinforcing and verifying strength and durability is important as there are bars available made from materials other than steel that are very brittle.

Bolivia: bars are delivered in 12-meter sections bent in half. 10-millimeter and 12-millimeter bars can be bent back to straight with relative ease, while other bars should have an assumed "bending loss" of 60-centimeters at the "U". Reworking deformed bar can increase the ductility of the bar, making it more susceptible to breaking (brittle). Limit amount of re-bending when possible.

Eswatini: bars are delivered in 6-meter sections.

It is also important to consider that your lineal calculation of rebar necessary divided by the size of the delivered bars will be less than you need to build the bridge. Consider three, 6-meter lengths of 13-millimeter bar (18m total). Say you need 1.8-meter bar lengths cut. 18-meters divided by 1.8-meter lengths would yield 10 desired bar lengths, but in reality, you would only be able to get 3 desired bar lengths out of a 6-meter bar (1.8*3 = 5.4 meters) with 0.6-meters of waste. In total, you'd only get 9 lengths out of your three delivered bars instead of the predicted 10!

7.3 Decking

EIA's standard details use steel crossbeams, nailers and timber decking. The quantity of crossbeams (and nailers, if applicable) will be one more than the nominal bridge span. The quantity of decking boards can be estimated based on the nominal bridge span. The increased length of the deck due to sag does not need to be considered as it will be covered by the contingency.

7.4 Concrete and Masonry

Concrete quantities for tier and tower construction are specified in the standard construction detail drawings. These values can be verified with hand calculations as well. The concrete required for the ramp cap is variable and must be calculated per the final design. Refer to **Volume 3: Field Operations** for concrete mixing ratios to determine the quantities of sand, gravel, and cement. The amount of cement used in masonry construction can be highly variable as it depends on several factors including the masonry techniques used, the size and shape of rocks available, and whether formwork is used (shutter board formwork is sometimes used in Eswatini and should be included in estimates). Each bridge we build, we gather data to help inform the empirical estimates below. The size of the ramp walls and cap will depend not only on the design of the bridge, but the topographical features of the site (*e.g.*, how much undisturbed soil will be left between ramp walls). Refer to the drawings to calculate material volumes.

Generally:

- Abutment fill is made up of 85% rock volume and 15% slurry mix (1 part cement to 4 part sand)

- Masonry walls are made up of 80% rock volume and 20% mortar mix (1 part cement to 4 part sand)

Depending on sand quality, cement to sand ratio is adjusted in-country accordingly. See **Volume 3: Field Operations** for approved alternate mix ratios.

Table 7.4.1: Country Specific Material Estimates

Eswatini		**Bolivia**	
Ratio	Value	Ratio	Value
kg cement/m^3 concrete	360	kg cement/m^3 concrete	350
kg cement/m^3 masonry	75	kg cement/m^3 masonry	80
kg cement/m^3 fill	36	kg cement/m^3 fill	20
m^3 sand/m^3 concrete	0.5	m^3 sand/m^3 concrete	0.6
m^3 sand /m^3 masonry	0.21	m^3 sand /m^3 masonry	0.4
m^3 sand /m^3 fill	0.1	m^3 sand /m^3 fill	0.25
m^3 gravel/m^3 concrete	0.75	m^3 gravel/m^3 concrete	0.6
m^3 rock/m^3 masonry	0.8	m^3 rock/m^3 masonry	0.8
m^3 rock/m^3 fill	0.85	m^3 rock/m^3 fill	0.95

7.5 Other Materials

Quantities for additional miscellaneous materials must be calculated. The Construction Management Course (301) on BridgeEDU includes these quantities, costs, and general tool estimates. **Table 7.5.1** adds to this list, but is by no means comprehensive.

Example BOQ – Eswatini
Example BOQ – Bolivia

Table 7.5.1: Other Material Estimates

Material	**Quantity**
Bricks	See construction course (varies)
Wheel cable saddle	4 pieces
Roofing tar (asphalt paint)	1 gallon
75mm flexible plastic tubing	See tower and anchor details
50mm flexible plastic tubing	See tower and anchor details
Tie wire	10kg
Lag screw (10mm x 90mm long)	5 or 6 per deck board + 4 per crossbeam
Lag screw (10mm x 50mm long)	Depends on center cable guide
20cm x 5cm x 10cm wood cable guide	Depends on center cable guide
Fencing (1.2m tall)	Span x 2

Galvanized tie wire	5 kg
U-nails	1kg per 10 lineal meters
Paint	Depends on bridge span
Cable grease	See example BOQ
Galvanized tube (1-1/2" and 1-1/4")	See guardrail details

7.6 Additional Structures

Don't forget to include estimations for modified or additional structures. That may include:

- Extra access ramps from the ground level to top of back wall
- Wind guys
- Drainage systems behind anchor
- Gabion walls
- Retaining walls

7.7 Contingency

As with any material estimation, it is best practice to include a contingency to prevent a shortage of materials on site and subsequent delay in construction. **Table 7.7.1** gives a template for material contingency estimates. Refer to the Construction Management (301) course on BridgeEDU for a detailed explanation on how to better calculate contingency factors.

Table 7.7.1: Contingency Factor Template

Material	Factor
Portland Cement (50kg bag)	1.13
Sand	1.09
Gravel	1.05
Stone	1.05
Lag Screws (large)	1.25
Lag Screws (small)	1.18
Rebar	1.05
Timber Decking and Nailers	1.08
Clamps	1.05
Fencing	1.05
Bricks	1.02
Crossbeams	1.04
Plastic Tubing (Tower)	1.1
Suction Tubing (Anchor)	1.1

ENGINEERS IN ACTION

Photo by Destin Saba
Quinamara, Bolivia 2022

www.eiabridges.org

RÍO K'ELLU MAYU SUSPENDED BRIDGE

GPS COORDINATES	-17.620584, -65.271513
COUNTRY	BOLIVIA
DEPARTMENT	COCHABAMBA
MUNICIPALITY	POCONA
COMMUNITY	K'ELLU MAYU
SPAN	40.20 METERS

GENERAL NOTES:

BRIDGE CONSTRUCTION SHALL BE EXECUTED BY THE MEANS AND METHODS STATED IN THE ENGINEERS IN ACTION, 2022 BRIDGE BINDER VOLUME 3.

CONCRETE:
PORTLAND CEMENT (ASTM C150, TYPE I OR TYPE II) SHALL BE USED. CEMENT MUST BE USED WITHIN 60 DAYS OF PURCHASE.
WATER SHALL BE CLEAN, CLEAR, AND FREE OF HARMFUL MATERIAL.
COARSE AGGREGATE SHALL BE COMPRISED OF GRAVEL (CRUSHED LIMESTONE, GRANITE, OR GRAVEL), NO GREATER THAN 2.5 cm IN DIAMETER. MATERIAL SHALL BE CLEAN AND FREE OF DEBRIS.
FINE AGGREGATE SHALL BE CLEAN, DRY SAND GRADED WITH A 4mm SIEVE BEFORE MIXING WITH CEMENT.

REINFORCEMENT:
ALL REINFORCEMENT SHALL BE MINIMUM GRADE 280 (GRADE 40) WITH A YIELD STRENGTH OF 275 MPa (40 ksi).
RIBBED STEEL SHALL BE USED FOR ALL REINFORCING BARS INCLUDING SUSPENDERS.
ALL REINFORCEMENT SHALL BE SUPPORTED BY CONCRETE BLOCKS OR STEEL CHAIRS TO AVOID CONTACT WITH GROUND OR FORMS.

MASONRY:
BLOCKS SHALL BE FREE OF CRACKS AND CHIPS. THERE SHALL BE NO DEFORMATIONS. USED BLOCK IS NOT PERMITTED.
MASONRY UNITS SHALL BE WET BEFORE APPLYING MORTAR.
MAINTAIN A CONSISTENT JOINT THICKNESS OF 15mm+/- 5mm. JOINTS BETWEEN BLOCKS SHALL BE COMPLETELY FILLED.
STAGGER BLOCKS IN RUNNING BOND PATTERN.

CABLE:
CABLE IN PERMANENT CONTACT WITH THE GROUND SHALL BE COVERED WITH PLASTIC PIPE AND FILLED WITH GROUT OR COATED WITH TAR.
CLAMPS SHALL BE DROP FORGED AND NOT MALLEABLE.

TIMBER:
TIMBER SHALL BE FREE OF KNOTS, HOLES, AND SPLITS.
WOOD SCREWS AND NAILS SHALL BE GALVANIZED.

DESIGN DATA:

ENGINEERS IN ACTION, 2022 BRIDGE BINDER VOLUME 2.

DESIGN LOADS:

DEAD LOAD	=	1.05	kN/m^2
LIVE LOAD$_{PRIMARY}$	=	3.89	kN/m^2
LIVE LOAD$_{SECONDARY}$	=	4.07	kN/m^2
WIND LOAD	=	0.50	kN/m

MATERIAL PROPERTIES:

CONCRETE	f'c	=	10	MPa	(1450 psi)
REINFORCING	F_y	=	275	MPa	(40 ksi)
TIMBER	F_b	=	3.96	MPa	(574 psi)
TIMBER	F_v	=	1.44	MPa	(210 psi)
SOIL	q_a	=	144	kPa	(3000 psf)
FRICTION ANGLE	Ø	=	30	degrees	
CABLE	Pn	=	785	kN	(174 kips)
CROSSBEAM STEEL	F_y	=	240	MPa	(35 ksi)

UNIT WEIGHTS:

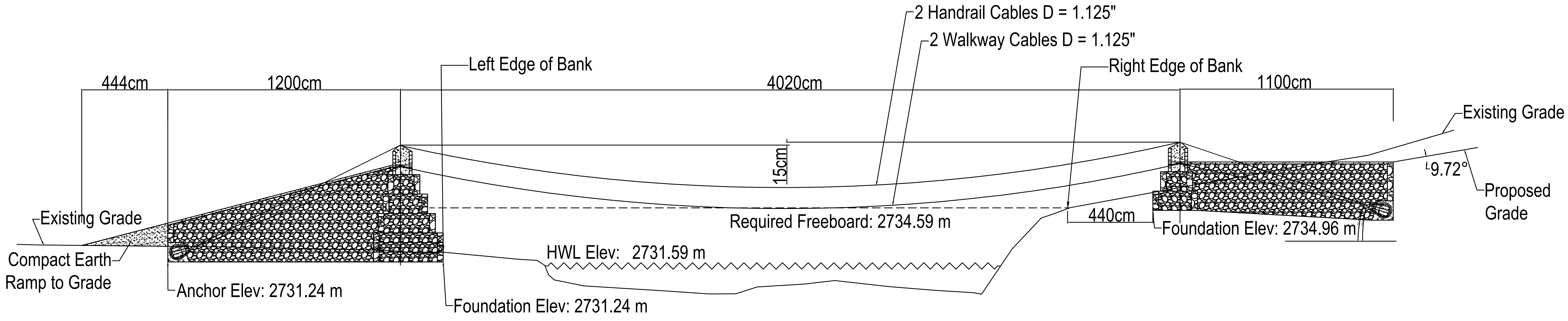
STEEL	=	7850 kg/m^3	(490 lb/ft^3)
CONCRETE	=	2400 kg/m^3	(150 lb/ft^3)
TIMBER	=	1100 kg/m^3	(56 lb/ft^3)
BROKEN ROCK	=	1600 kg/m^3	(100 lb/ft^3)
MASONRY	=	2100 kg/m^3	(131 lb/ft^3)
SOIL	=	1800 kg/m^3	(112 lb/ft^3)

FACTOR OF SAFETY FOR SLIDING AND UPLIFT = 1.5
FACTOR OF SAFETY FOR CABLE CAPACITY = 3.0

DECK SHALL CLEAR FREEBOARD ENVELOPE WITH A MINIMUM FREEBOARD OF 3.00METERS.

PROVIDE 7 DROP FORGED CABLE CLAMPS SPACED AT 16 cm OC.
MAX TORQUE TO 360 ft-lb. PER HANDRAIL CABLE AT EACH ANCHOR.
PROVIDE 7 DROP FORGED CABLE CLAMPS SPACED AT 16 cm OC.
MAX TORQUE TO 360 ft-lb. FOR THE WALKWAY CABLE AT EACH ANCHOR.

INDEX:



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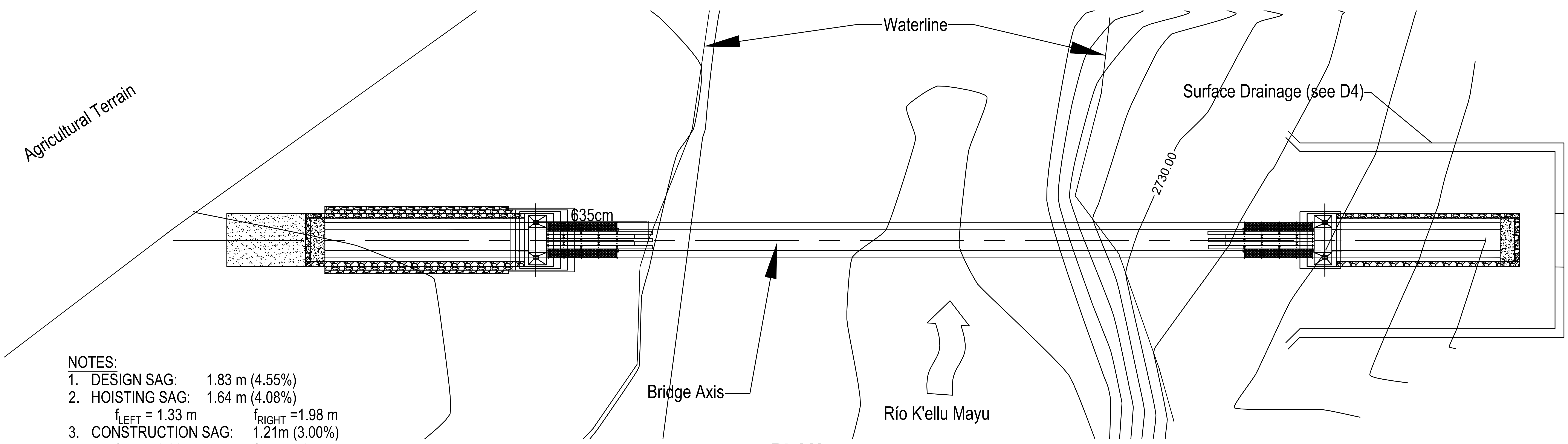


PLAN

NOTES:
1. DESIGN SAG: 1.83 m (4.55%)
2. HOISTING SAG: 1.64 m (4.08%)
   f_{LEFT} = 1.33 m f_{RIGHT} =1.98 m
3. CONSTRUCTION SAG: 1.21m (3.00%)
   f_{LEFT} = 0.90 m f_{RIGHT} = 1.55 m
4. LIVE LOAD SAG: 2.22 (5.51%)
5. SURVEY INFORMATION PROVIDED BY RICHAR GALVEZ ON MAY 7, 2022.
6. LANDMARKS INCLUDED IN PLAN VIEW ARE FOR INFORMATION ONLY, ARE NOT DRAWN TO SCALE, AND IN APPROXIMATE LOCATIONS.

HOOS BUILDING BRIDGES

ENGINEERS IN ACTION

REV.	DESCRIPTION	DATE	ISSUED BY
X	ISSUED FOR REVIEW	31/03/2024	GW

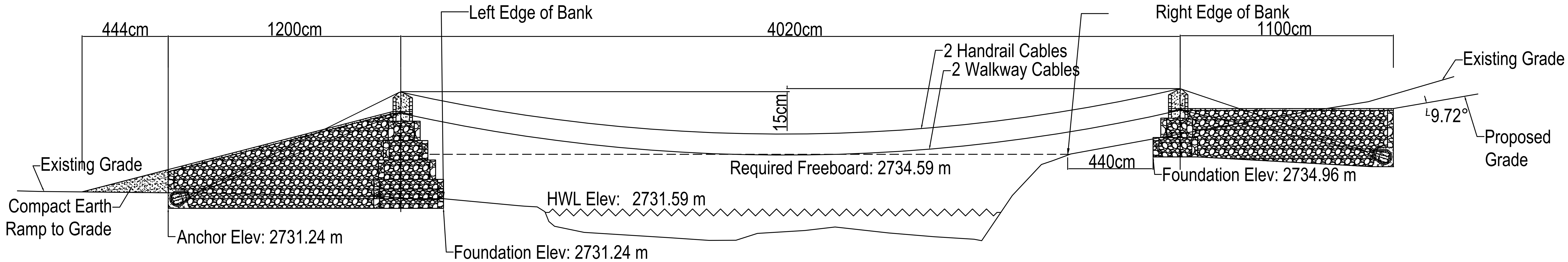
COUNTRY: BOLIVIA
DEPARTMENT: COCHABAMBA
MUNICIPALITY: POCONA

PROJECT: RÍO K'ELLU MAYU
PROGRAM MANAGER: ETHAN GINGERICH

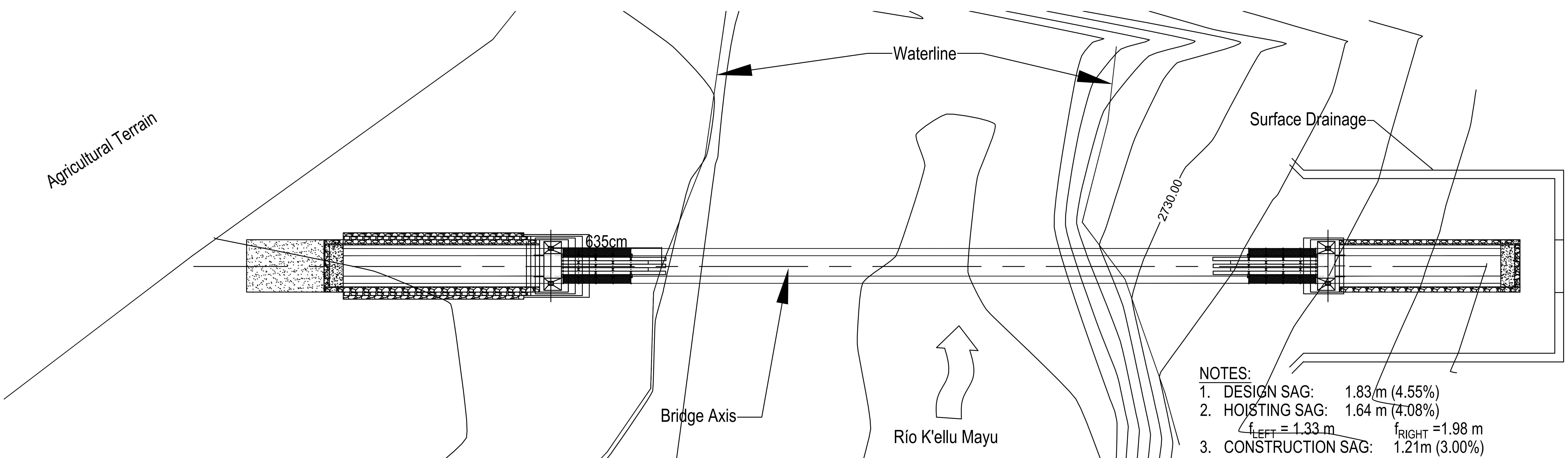
ENGINEERING RECORD
DATE: March 25, 2024
DRAWN BY: GW
CHECKED BY: XXX
APPROVED BY: XXX
REVIEWED BY: XXX

RÍO K'ELLU MAYU SUSPENDED BRIDGE LAYOUT

PROJECT NUMBER	DRAWING NUMBER
23-001	2



ELEVATION



PLAN

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2. HOISTING SAG: 1.64 m (4.08%)
   f_{LEFT} = 1.33 m f_{RIGHT} =1.98 m
3. CONSTRUCTION SAG: 1.21m (3.00%)
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HOOS BUILDING BRIDGES
ENGINEERS IN ACTION

REV.	DESCRIPTION	DATE	ISSUED BY
X	ISSUED FOR REVIEW	31/03/2024	GW

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USE OF THESE PLANS FOR ANY OTHER PURPOSE SHALL NOT BE ATTRIBUTABLE TO ENGINEERS IN ACTION AND USERS AGREE TO HOLD ENGINEERS IN ACTION HARMLESS TO ANY AND ALL LIABILITY.

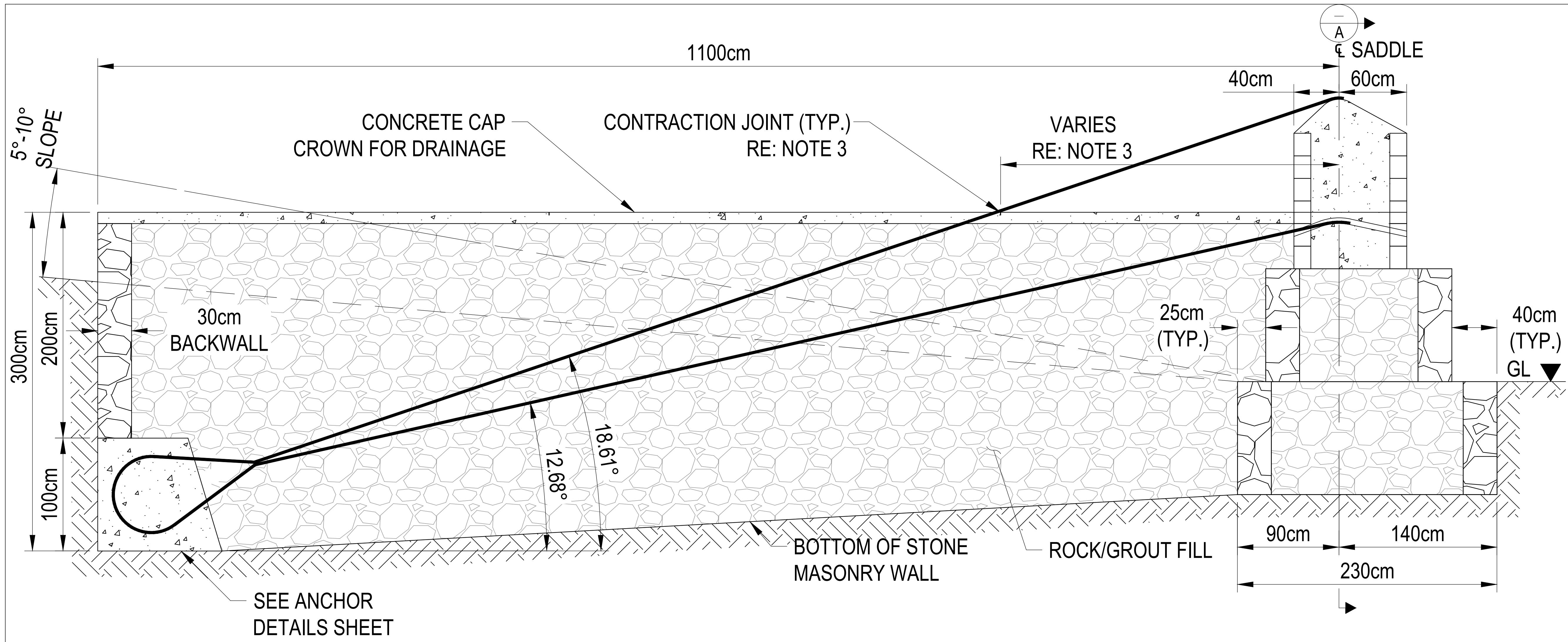
COUNTRY: BOLIVIA
DEPARTMENT: COCHABAMBA
MUNICIPALITY: POCONA

PROJECT: RÍO K'ELLU MAYU
PROGRAM MANAGER: ETHAN GINGERICH

ENGINEERING RECORD
DATE: March 25, 2024
DRAWN BY: GW
CHECKED BY: XXX
APPROVED BY: XXX
REVIEWED BY: XXX

RÍO K'ELLU MAYU
SUSPENDED BRIDGE
LAYOUT

PROJECT NUMBER	DRAWING NUMBER
23-001	2



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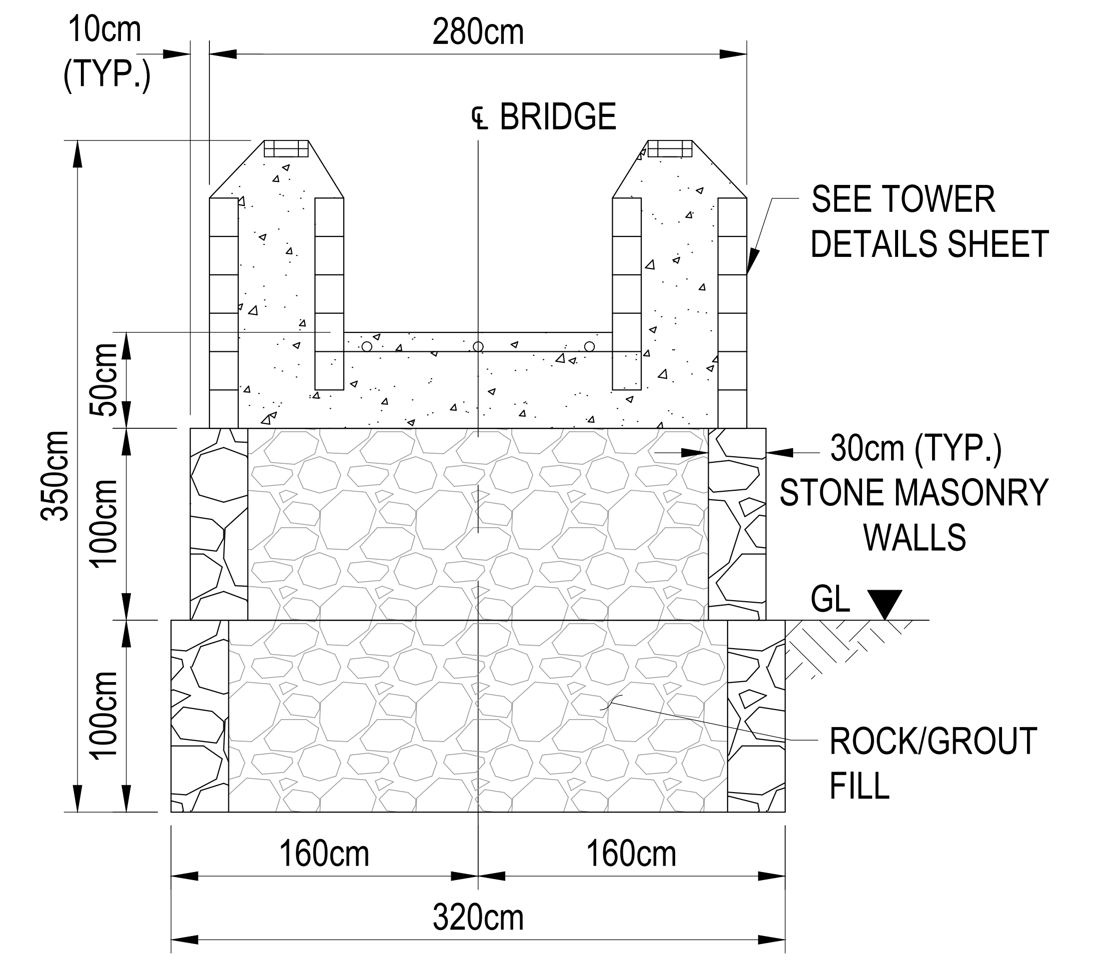
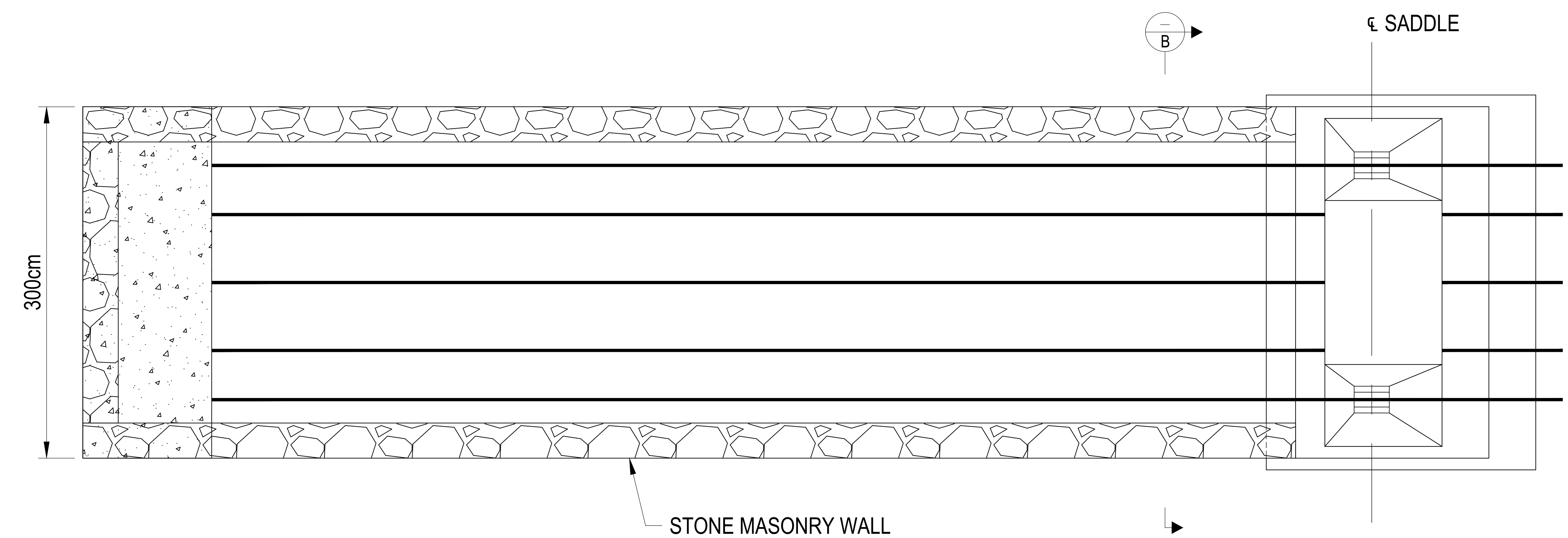


SECTION A



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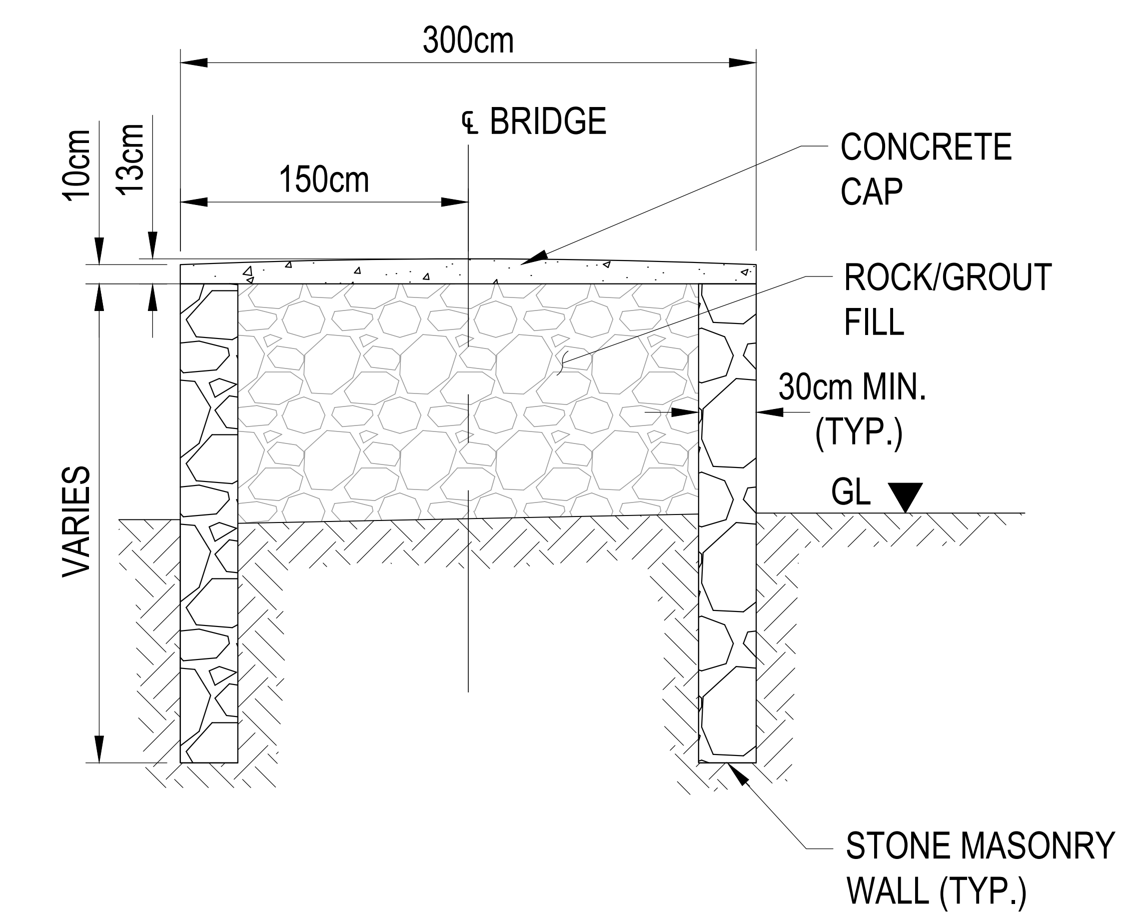


SECTION B

NOTES:
1. SEE ENGINEERS IN ACTION BRIDGE BINDER FOR CONSTRUCTION GUIDELINES.
2. PROVIDE DRAINAGE BEHIND ANCHOR WITH SIDE OUTLET IN CASE OF SEEPAGE.
3. PROVIDE CONTRACTION JOINT OF 2.5cm DEPTH USING MAXIMUM 3mm CONCRETE BLADE. JOINTS SHOULD BE SPACED EVENLY EVERY 3-4m ALONG APPROACH RAMP.

HOOS BUILDING BRIDGES

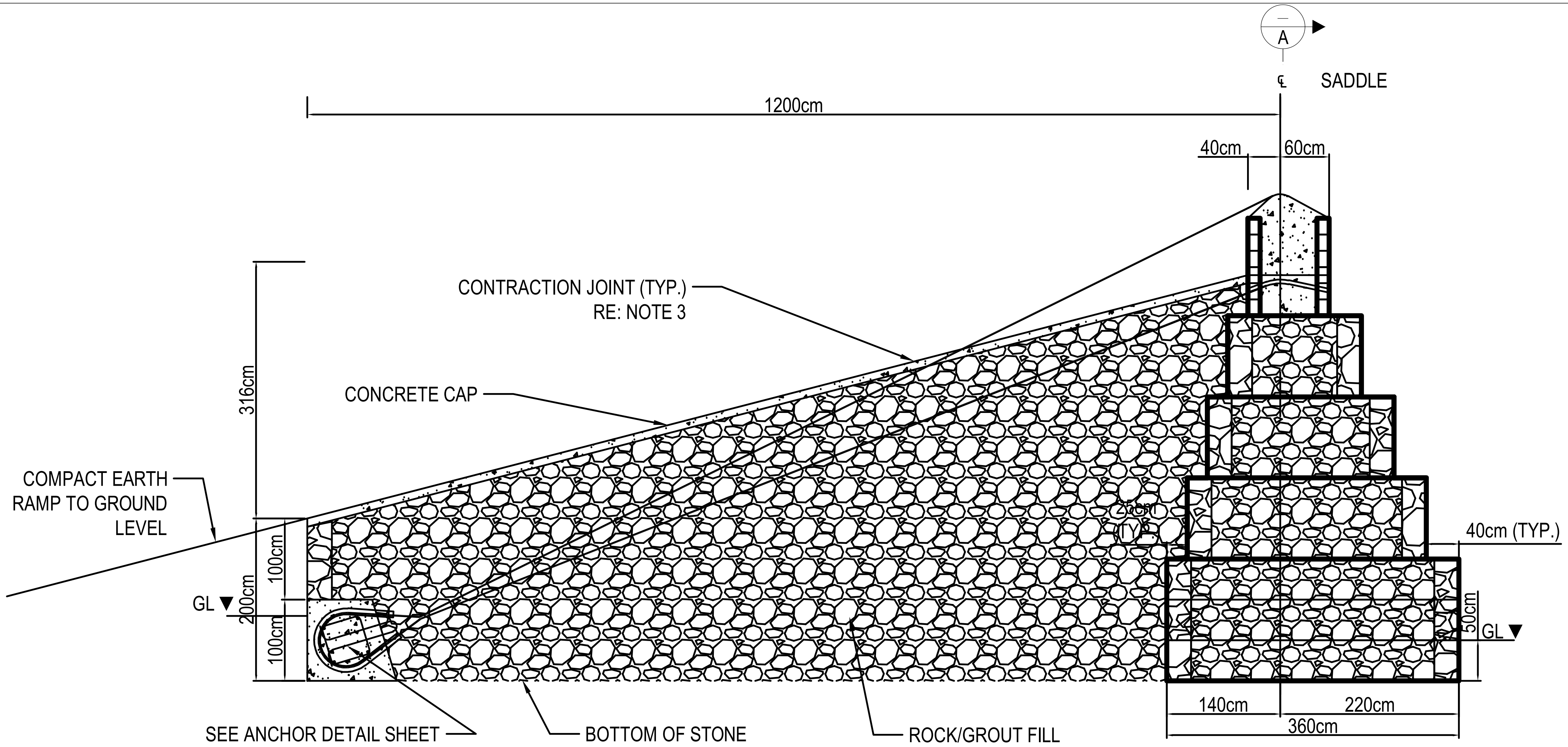
ENGINEERS IN ACTION

PRODUCED BY:
ENGINEERS IN ACTION
6910 E. 14TH STREET
TULSA, OK 74112

LAST REVISION: NOVEMBER, 2023

RIGHT ABUTMENT DETAILS
ONE TIER GRAVITY ANCHOR
40-60 METER SPAN (5-10°)

PROJECT	DRAWING NUMBER
23-001	1G-60B



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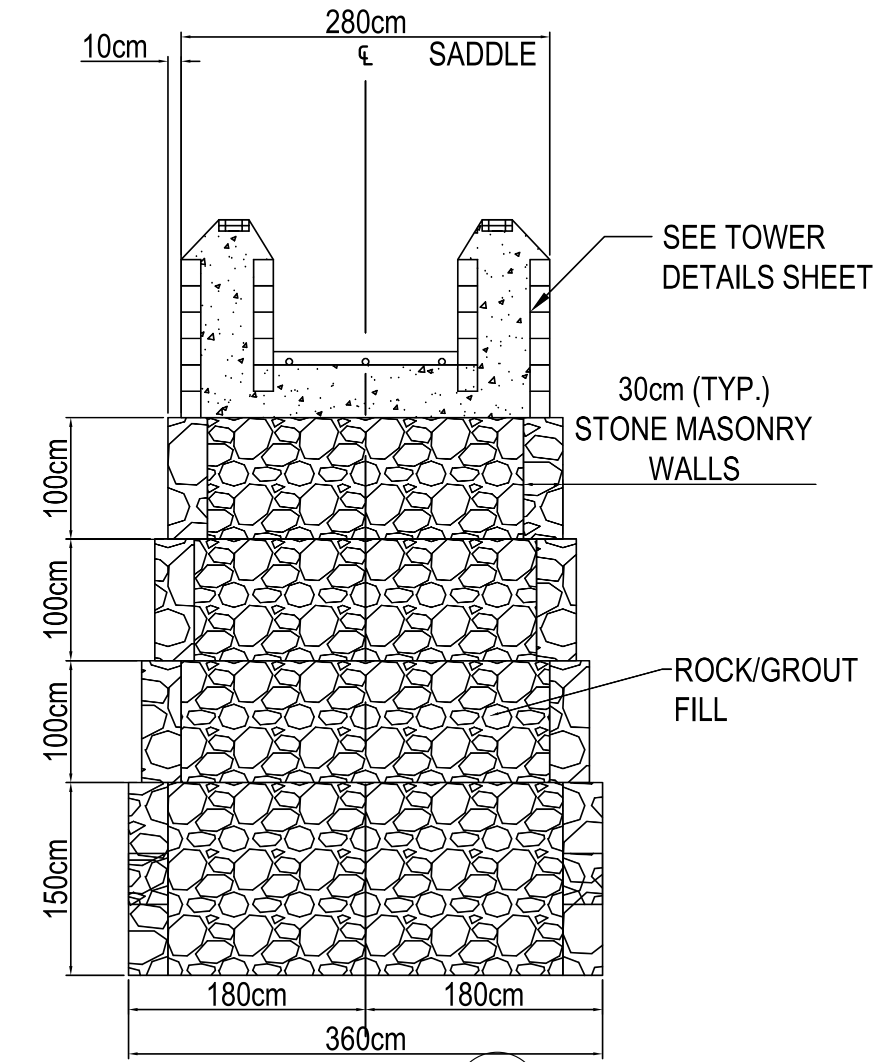
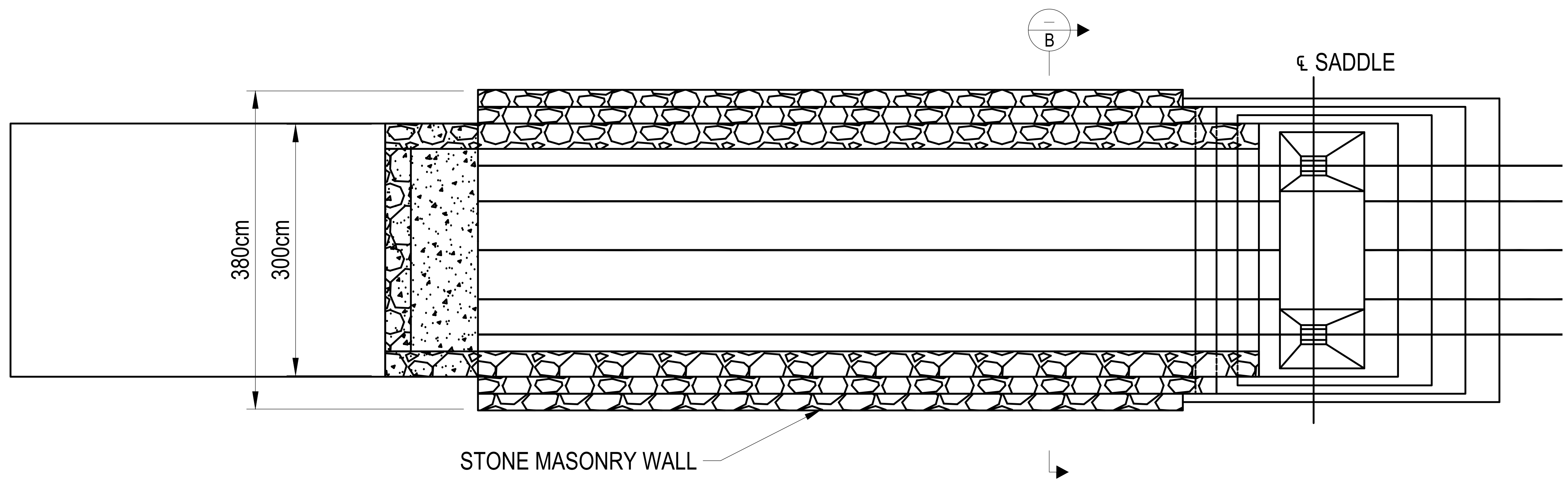


SECTION A



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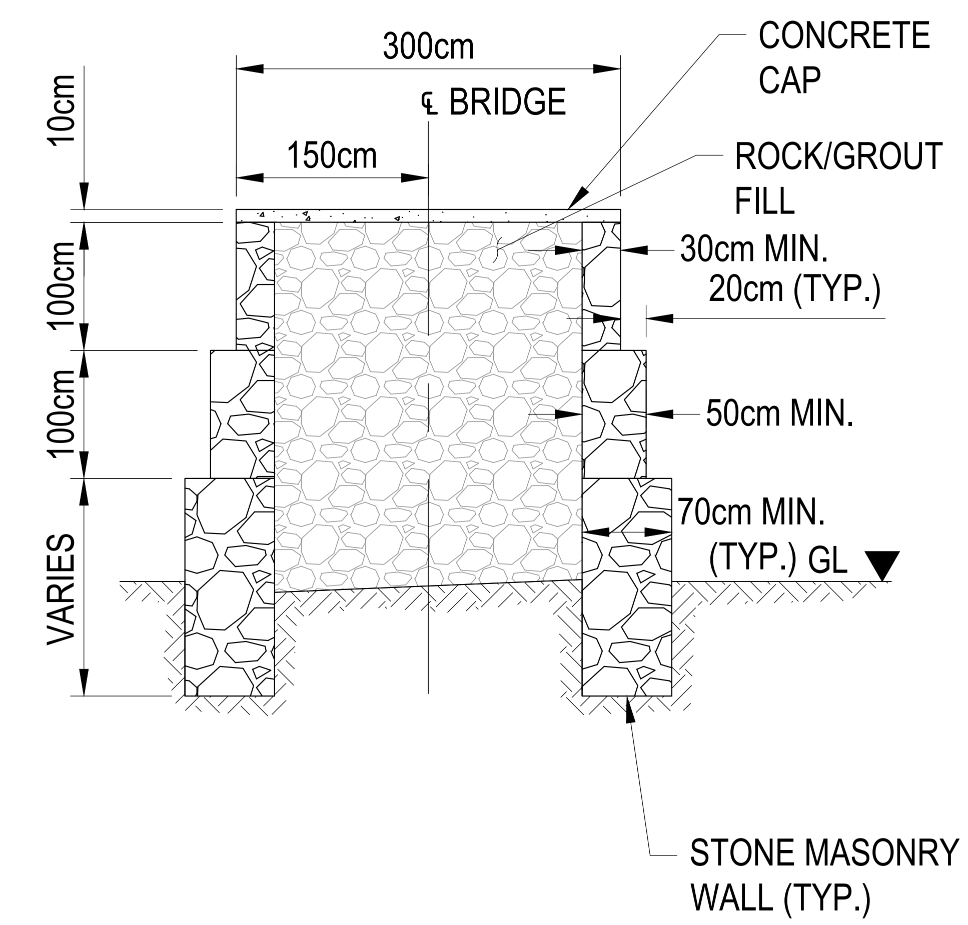

SECTION B

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1. SEE ENGINEERS IN ACTION BRIDGE BINDER FOR CONSTRUCTION GUIDELINES.
2. PROVIDE DRAINAGE BEHIND ANCHOR WITH SIDE OUTLET IN CASE OF SEEPAGE.
3. PROVIDE CONTRACTION JOINT OF 2.5cm DEPTH USING MAXIMUM 3mm CONCRETE BLADE. JOINTS SHOULD BE SPACED EVENLY EVERY 3-4m ALONG APPROACH RAMP.

HOOS BUILDING BRIDGES

ENGINEERS IN ACTION

REV.	DESCRIPTION	DATE	ISSUED BY
X	ISSUED FOR REVIEW	31/03/2024	GW

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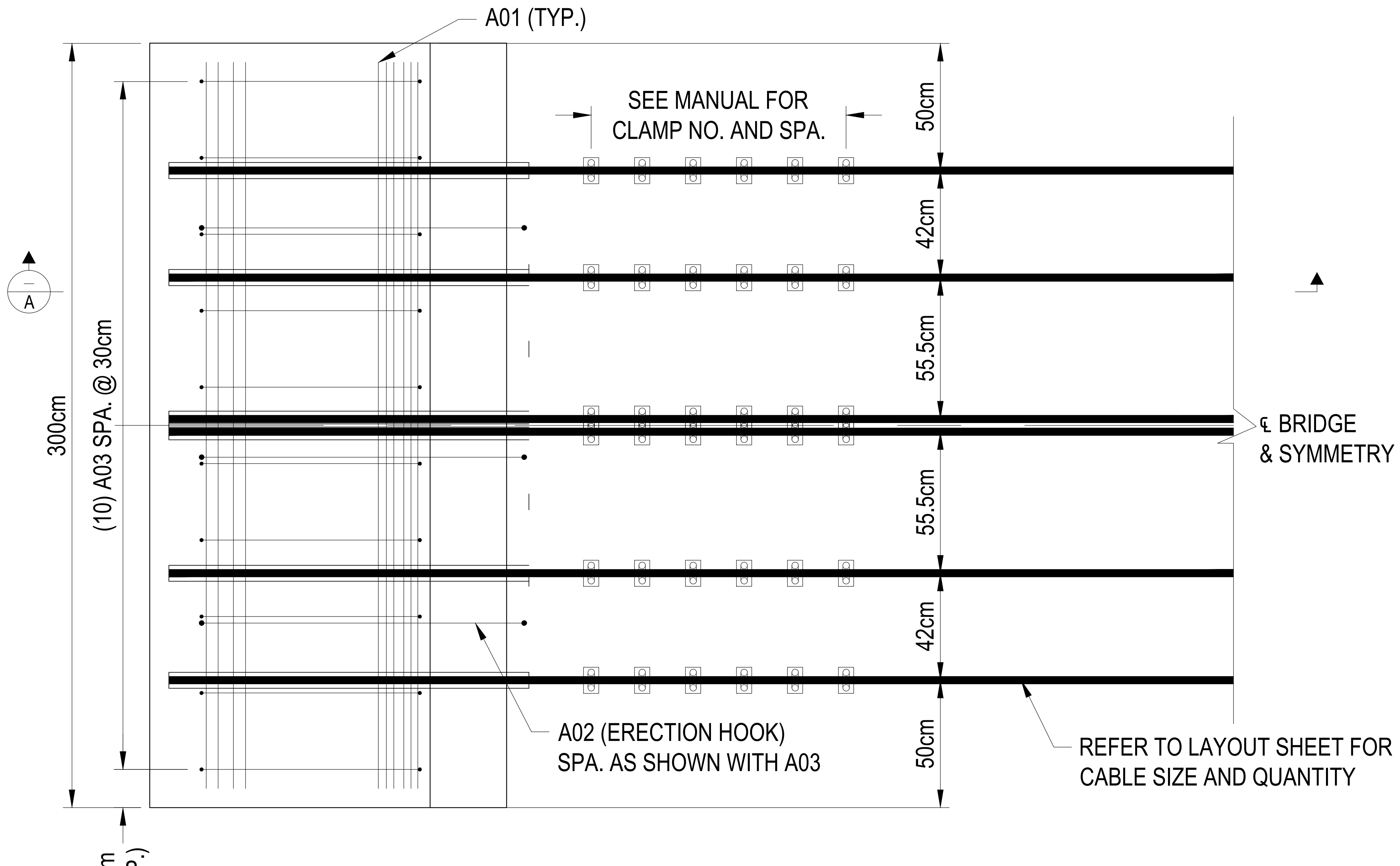
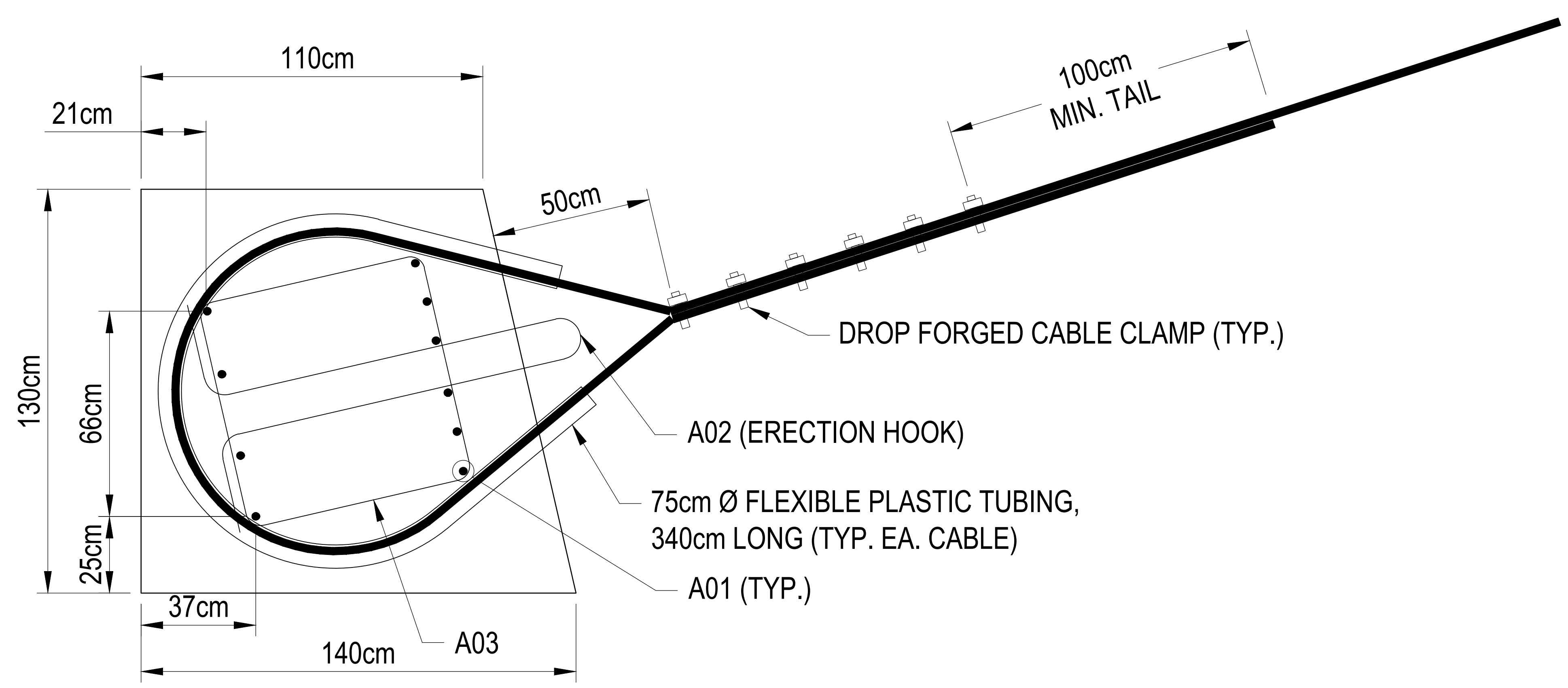
LEFT ABUTMENT DETAILS
THREE TIER GRAVITY ANCHOR
40-60 METER SPAN (5-10°)

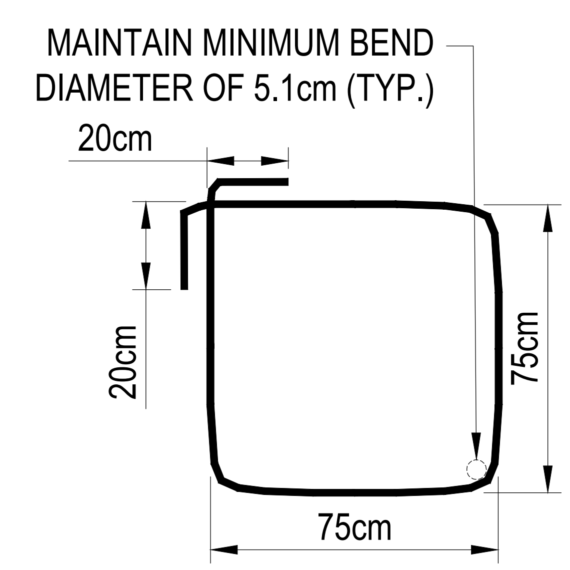
PROJECT	DRAWING NUMBER
23-001	3G-60B



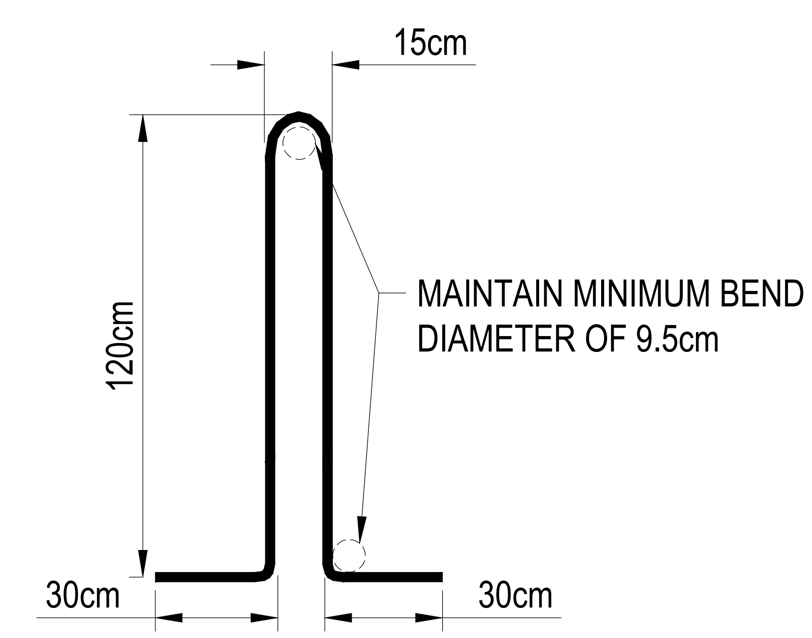
PLAN



SECTION A



A03



A02

BILL OF MATERIALS

REINFORCING BARS (PER ANCHOR)

NAME	BAR SIZE (mm)	LENGTH (cm)	QUANTITY	LENGTH (m)
A01	19 (#6)	285	10	28.5
A02	16 (#5)	300	2	6.0
A03	13 (#4)	325	10	32.5

ITEM	QUANTITY
CONCRETE	4.88m^3
FLEXIBLE PLASTIC TUBING x 340cm	VARIES

CLAMP SPACING AND TORQUE REQUIREMENTS

CABLE SIZE		NUMBER OF CLAMPS	SPACING		TORQUE REQUIREMENTS (ft-lb)
(in.)	(mm)		(in.)	(cm)	
1	25	5	6	14	225
1-1/8	29	6	6	15	225
1-1/4	32	7	6	16	360
1-3/8	35	7	6	16	360

NOTES:

1. SEE ENGINEERS IN ACTION BRIDGE BINDER FOR CONSTRUCTION GUIDELINES.
2. 7.5cm CLEAR COVER SHALL BE PROVIDED FOR ALL REINFORCING AND PLASTIC TUBING.
3. ERECTION HOOK AND TUBING OPTIONAL FOR ANCHOR DETERMINED TO BE NON-ADJUSTABLE OR FIXED.
4. REINFORCING BAR DIMENSIONS ARE TAKEN TO OUTSIDE.OF BAR.
5. IF USING GREATER THAN 4 WALKWAY CABLES, FOLLOW CABLE GEOMETRY ON TOWER DETAILS.

HOOS BUILDING BRIDGES

ENGINEERS IN ACTION

REV.	DESCRIPTION	DATE	ISSUED BY
0	ISSUED FOR CONSTRUCTION	04/11/2022	BKK
1	UPDATED BEND DIM.	10/7/2023	BKK
2	ADDED CLAMP TABLE	13/11/2023	BKK

COUNTRY: BOLIVIA
PROJECT: RÍO K'ELLU MAYU
DEPARTMENT: COCHABAMBA
PROGRAM MANAGER: ETHAN GINGERICH
MUNICIPALITY: POCONA

ENGINEERING RECORD
DATE: 13/11/2023
DRAWN BY: BKK
CHECKED BY:
APPROVED BY:
REVIEWED BY:

ANCHOR DETAILS
60-100 METER SPAN
4 WALKWAY CABLES

PROJECT	DRAWING NUMBER
23-001	A6

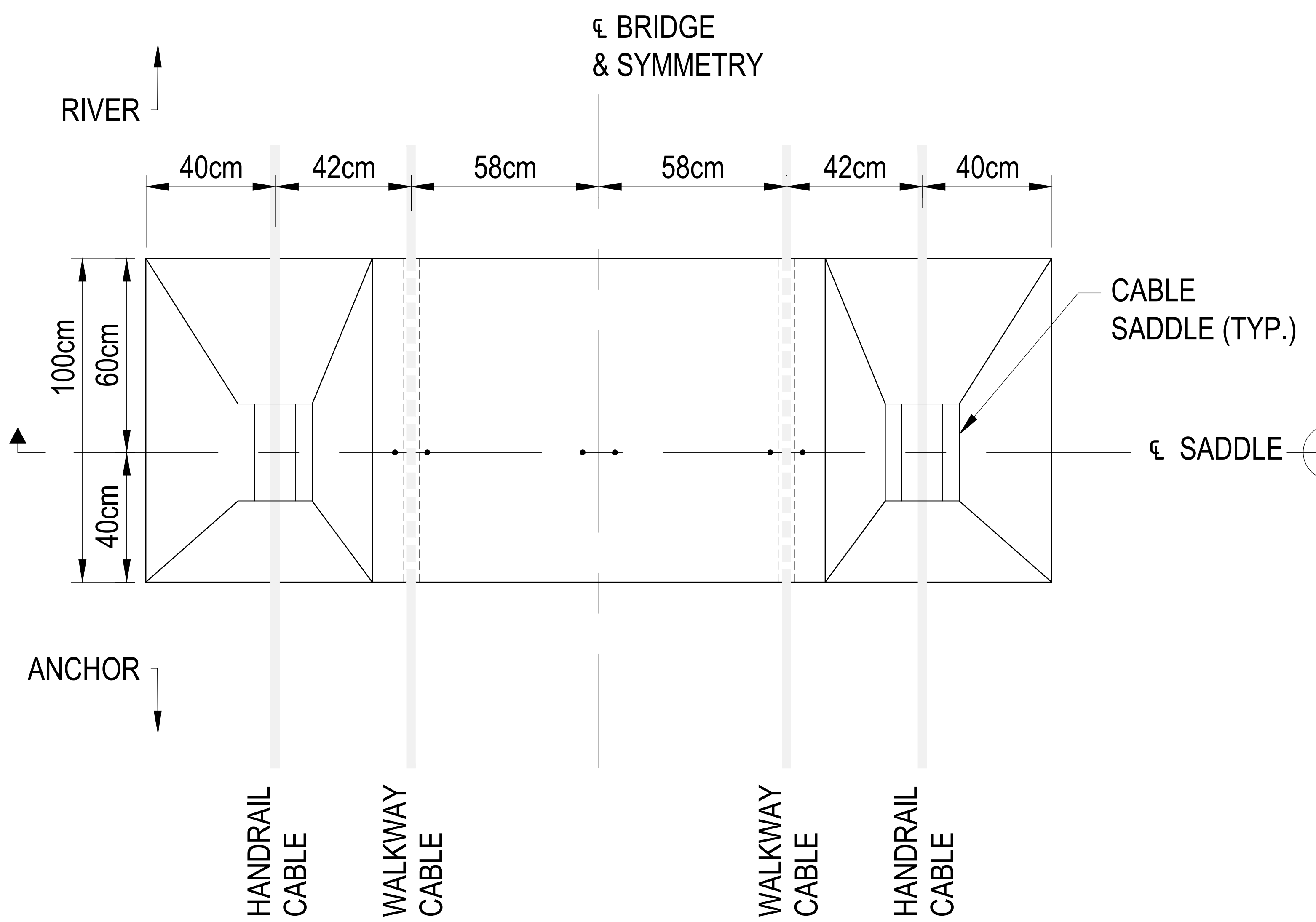
NOTES:
1. SEE ENGINEERS IN ACTION BRIDGE BINDER FOR CONSTRUCTION GUIDELINES.
2. 7.5cm CLEAR COVER SHALL BE PROVIDED FOR ALL REINFORCING AND PLASTIC TUBING.
3. CONSTRUCTION STAGES:
   STAGE 1 - BASE LEVEL MASONRY PERIMETER FILLED WITH CONCRETE.
   STAGE 2 - CONSTRUCT TOWERS IN LIFTS OF 20-40cm.
   STAGE 3 - CAST WALKWAY HUMP AND STAB T03 CABLE GUIDE BARS.
   STAGE 4 - CAST WALKWAY TOPPING SLAB OVER SLEEVED CABLES.

BILL OF MATERIALS

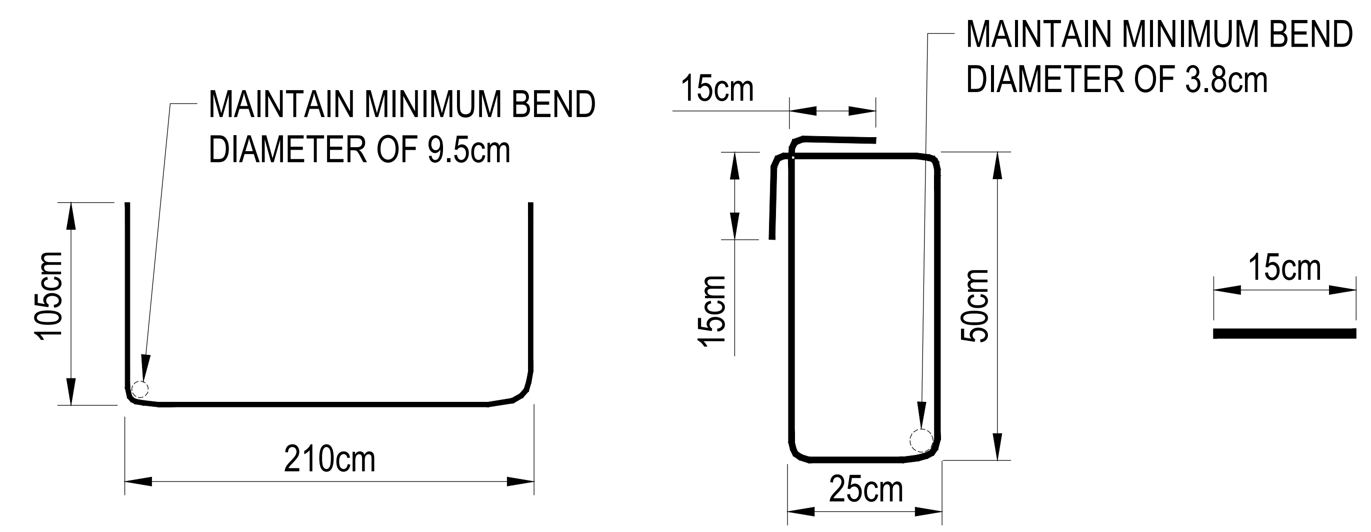
REINFORCING BARS (PER TOWER)

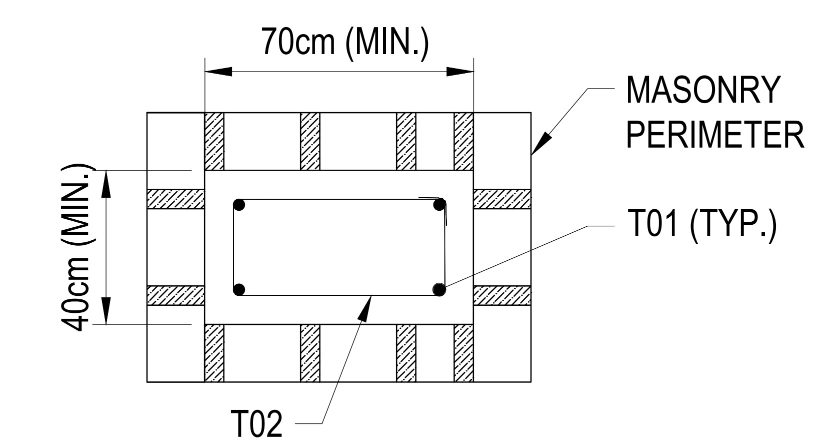
NAME	BAR SIZE (mm)	LENGTH (cm)	QUANTITY	LENGTH (m)
T01	16 (#5)	413	4	16.5
T02	10 (#3)	170	8	13.6
T03	10 (#3)	15	4	0.9

ITEM	QUANTITY
CONCRETE	1.08m^3
FLEXIBLE PLASTIC TUBING x 110cm	2

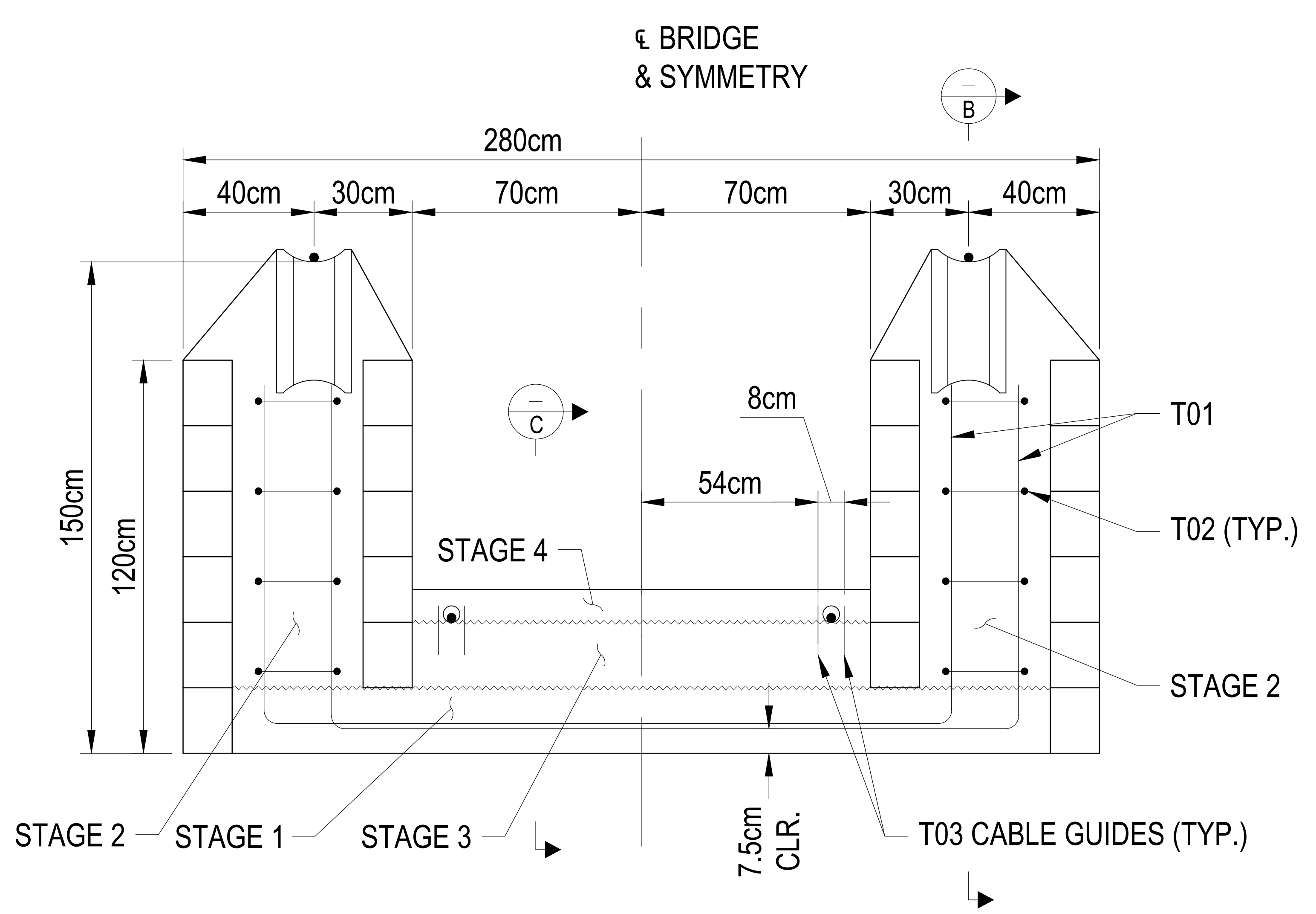


PLAN

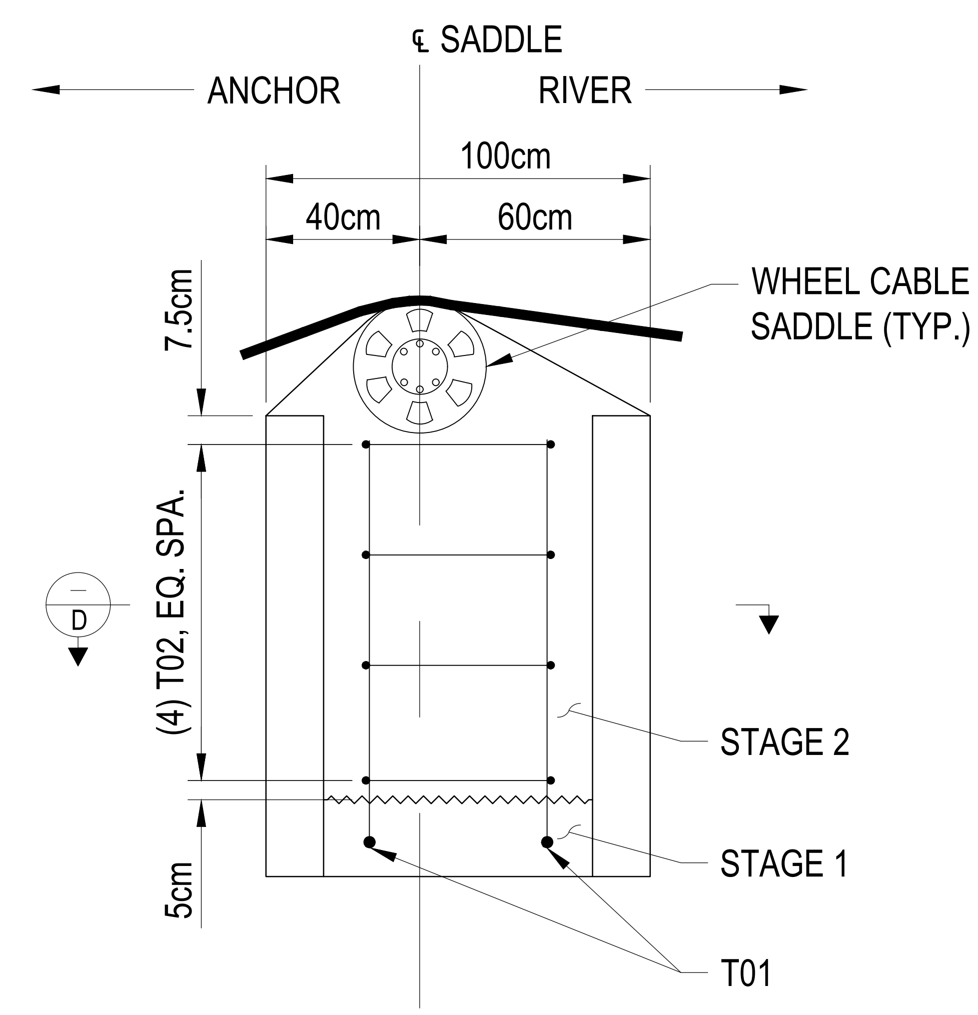




SECTION D



SECTION A



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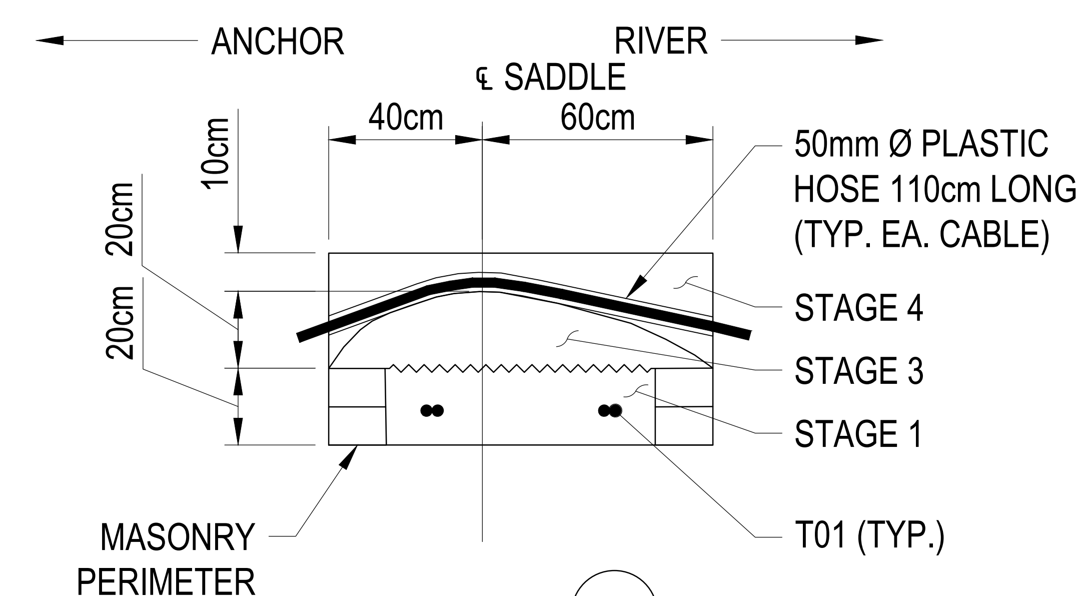


SECTION C

HOOS BUILDING BRIDGES

ENGINEERS IN ACTION

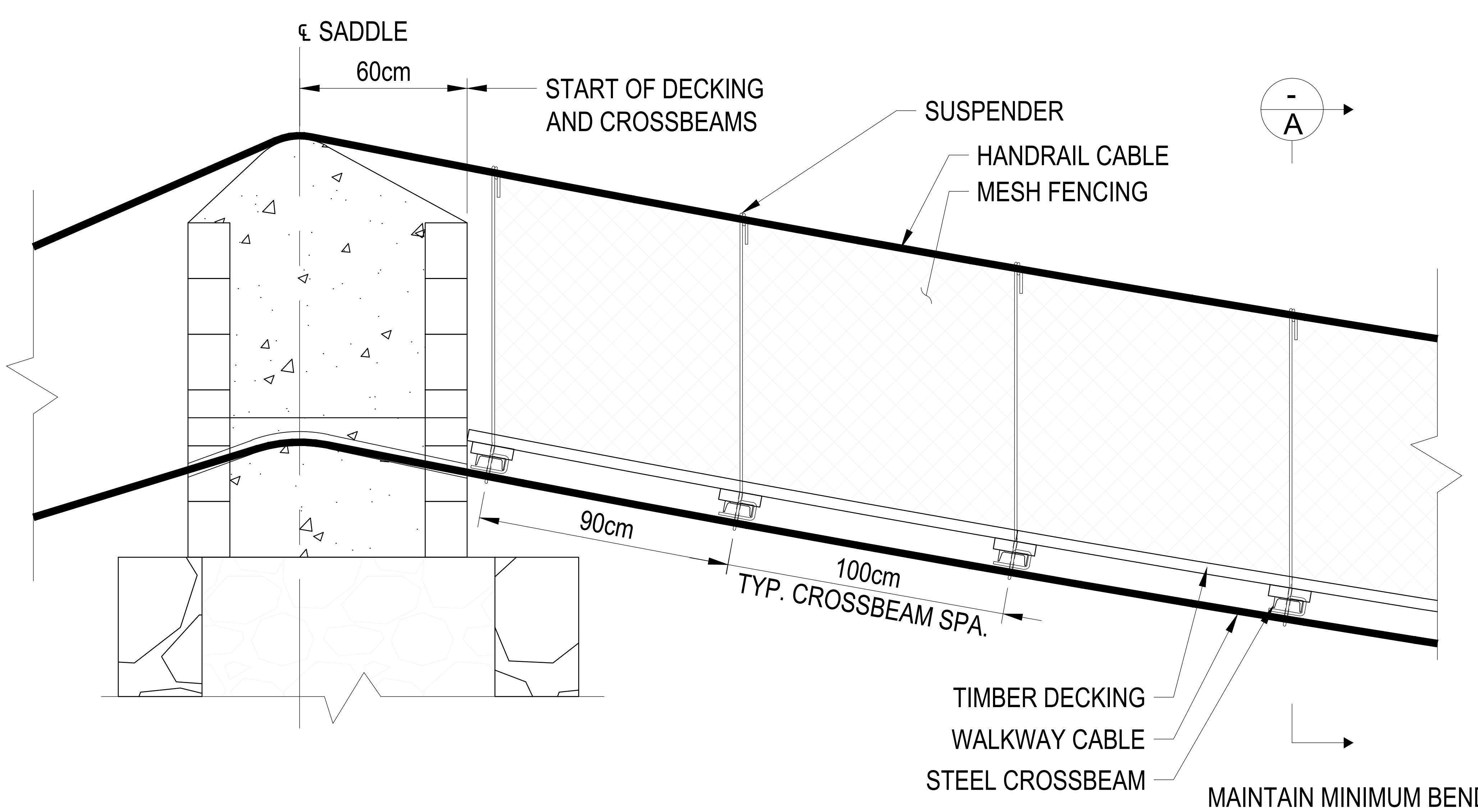
REV.	DESCRIPTION	DATE	ISSUED BY
0	ISSUED FOR CONSTRUCTION	04/11/2022	BKK
1	UPDATED BEND DIM.	10/7/2023	BKK

COUNTRY: BOLIVIA
DEPARTMENT: COCHABAMBA
MUNICIPALITY: POCONA
PROJECT: RÍO K'ELLU MAYU
PROGRAM MANAGER: ETHAN GINGERICH

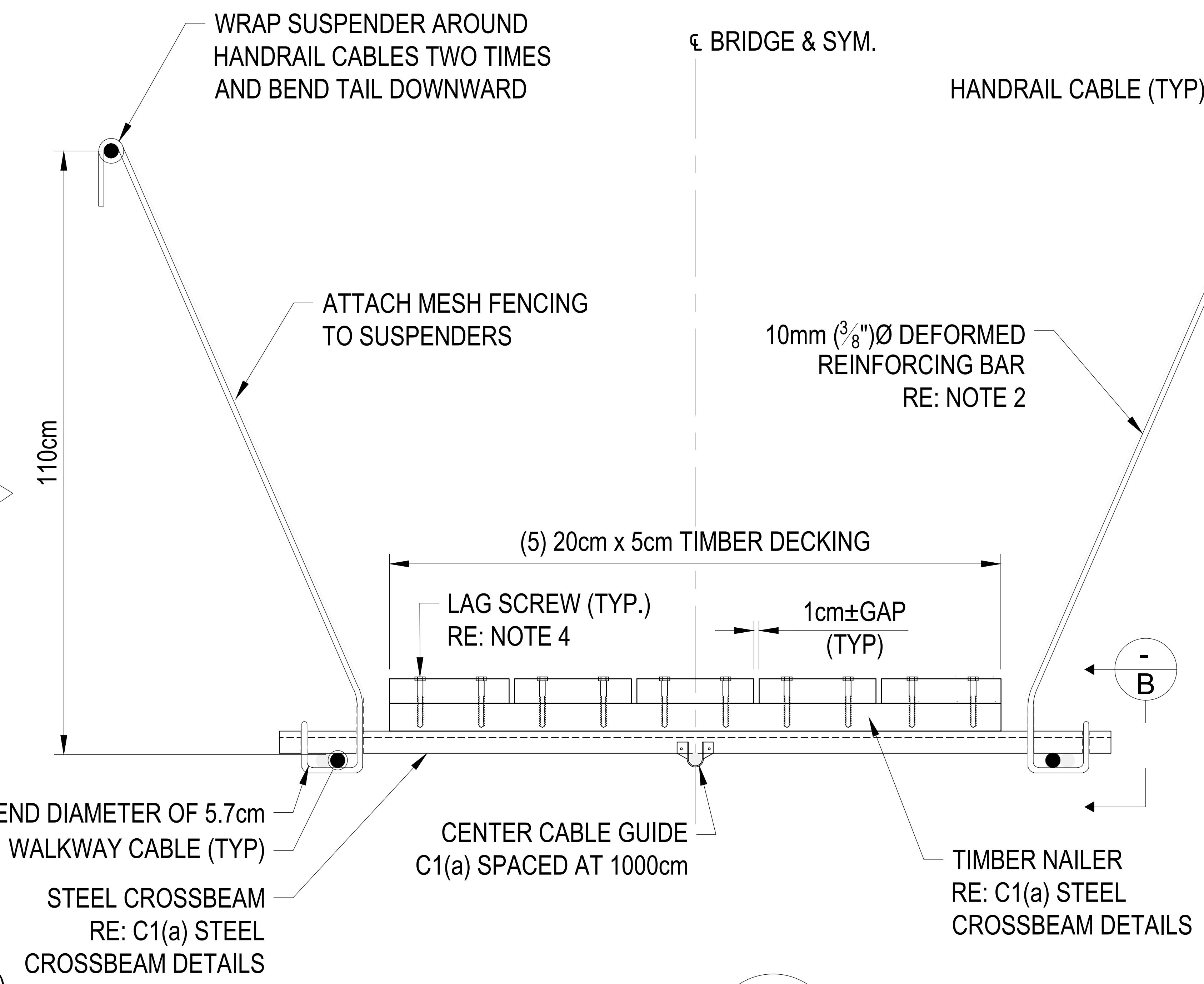
ENGINEERING RECORD
DATE: 10/7/2023
DRAWN BY: BKK
CHECKED BY:
APPROVED BY:
REVIEWED BY:

TOWER DETAILS
TWO WALKWAY CABLES

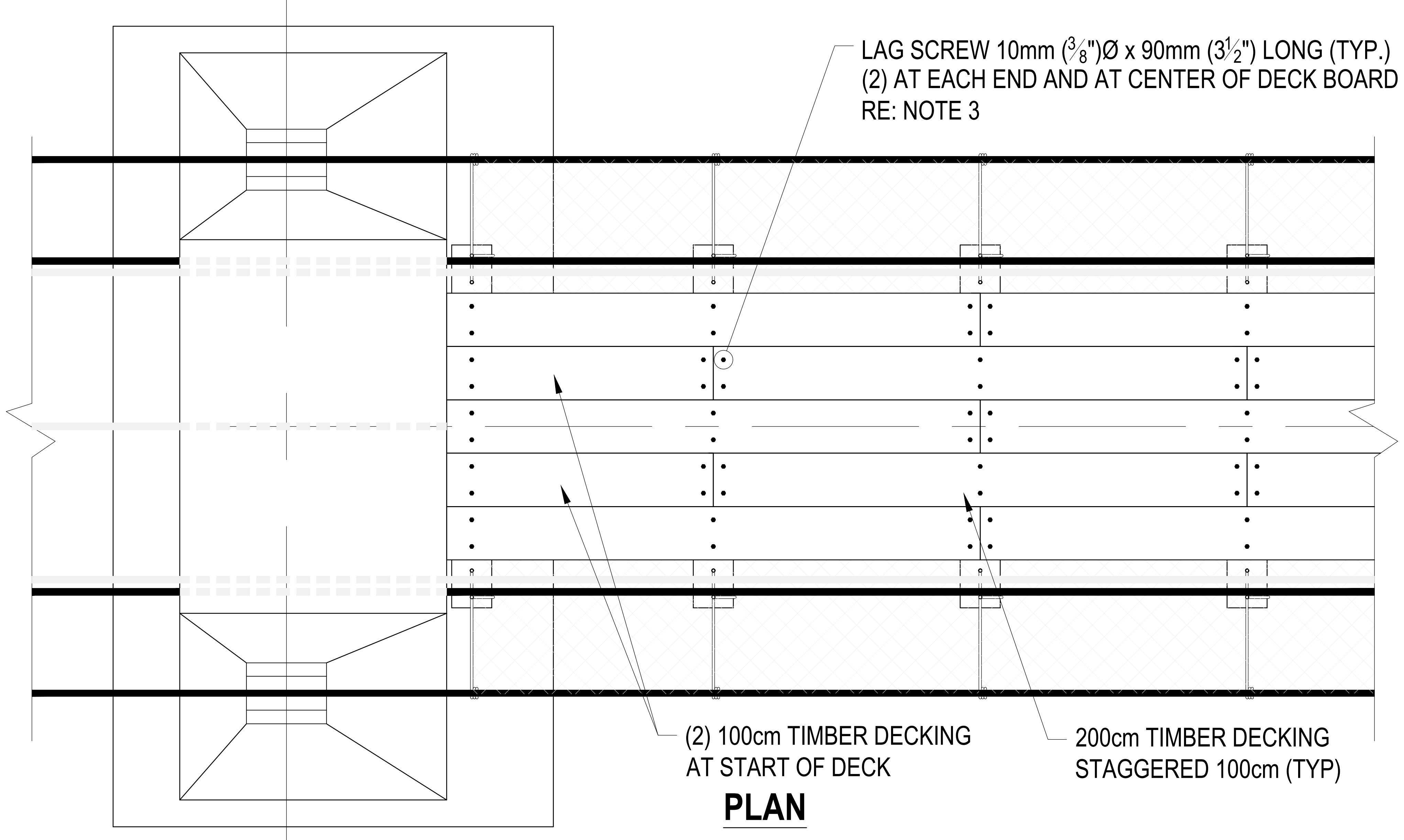
PROJECT	DRAWING NUMBER
23-001	T4



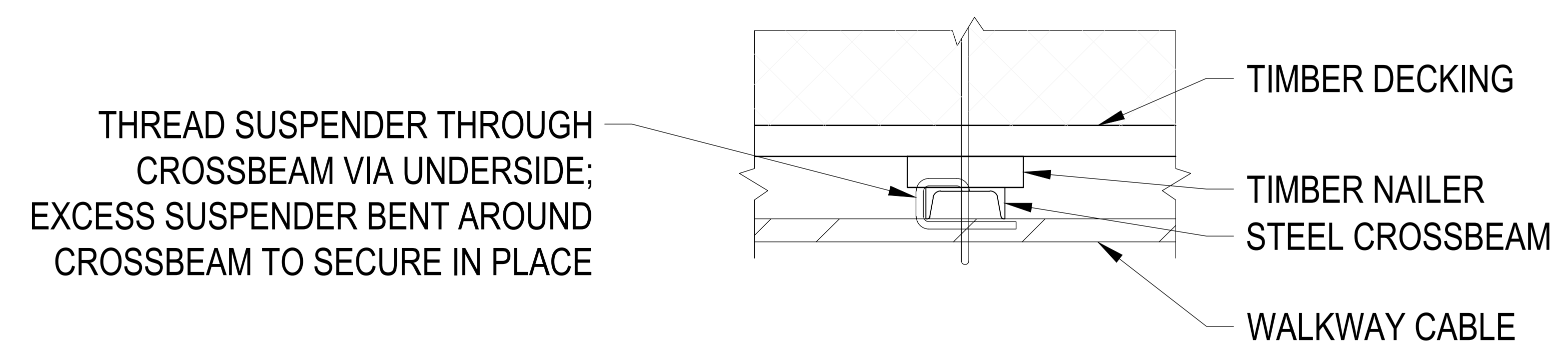
ELEVATION



SECTION A



PLAN



SECTION B

NOTES:

1. SEE ENGINEERS IN ACTION BRIDGE BINDER FOR CONSTRUCTION GUIDELINES.
2. CUT REBAR TO 200cm. BEND IN U TO FIT CROSSBEAM AT 40cm SO THAT STRAIGHT LEG IS 160cm.
3. USE 8mm (5/16") PILOT HOLE IN NAILER AND 10mm (3/8") PILOT HOLE IN DECKING.
4. LEAVE LAG SCREW HEAD PARTIALLY EXPOSED FOR REPLACEMENT AND MOISTURE ISSUES.

HOOS BUILDING BRIDGES

ENGINEERS IN ACTION

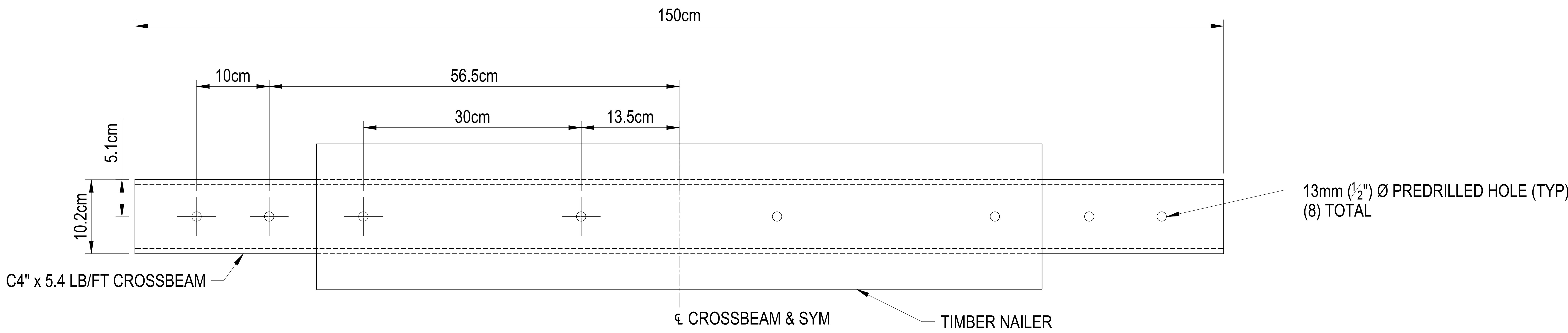
REV.	DESCRIPTION	DATE	ISSUED BY
0	ISSUED FOR CONSTRUCTION	22/11/2022	KNW
1	UPDATED MINIMUM BEND DIM.	9/7/2023	BKK

COUNTRY: BOLIVIA
PROJECT: RÍO K'ELLU MAYU
DEPARTMENT: COCHABAMBA
PROGRAM MANAGER: ETHAN GINGERICH
MUNICIPALITY: POCONA

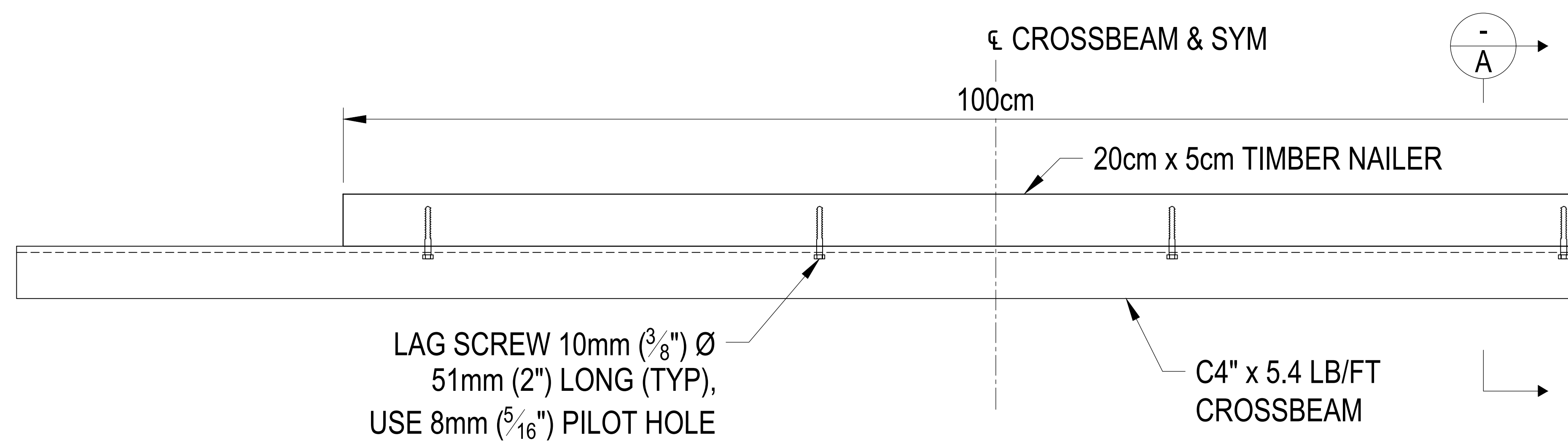
ENGINEERING RECORD
DATE: 9/7/2023
DRAWN BY: KNW
CHECKED BY: KNW
APPROVED BY: KNW
REVIEWED BY: BKK

WALKWAY DETAILS STEEL CROSSBEAMS WITH NAILER

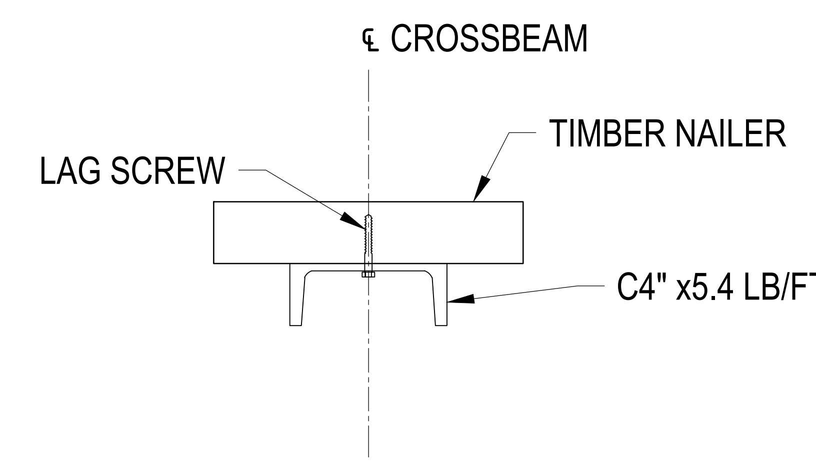
PROJECT NUMBER	DRAWING NUMBER
23-001	W3



PLAN



ELEVATION



SECTION - A

HOOS BUILDING BRIDGES

ENGINEERS IN ACTION

REV.	DESCRIPTION	DATE	ISSUED BY
0	ISSUED FOR CONSTRUCTION	22/11/2022	KNW

COUNTRY: BOLIVIA

DEPARTMENT: COCHABAMBA

MUNICIPALITY: POCONA

PROJECT: RÍO K'ELLU MAYU

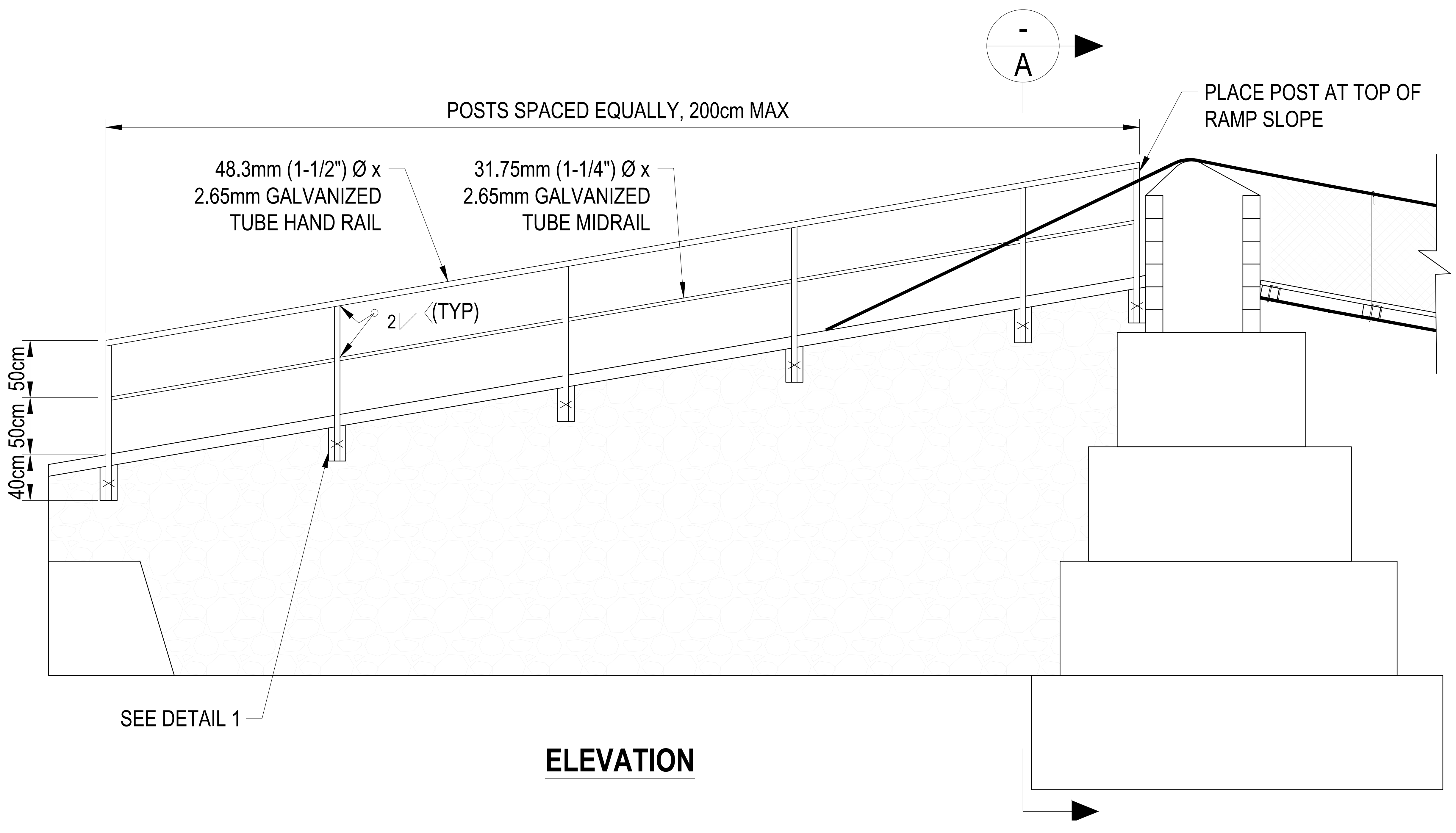
PROGRAM MANAGER: ETHAN GINGERICH

ENGINEERING RECORD

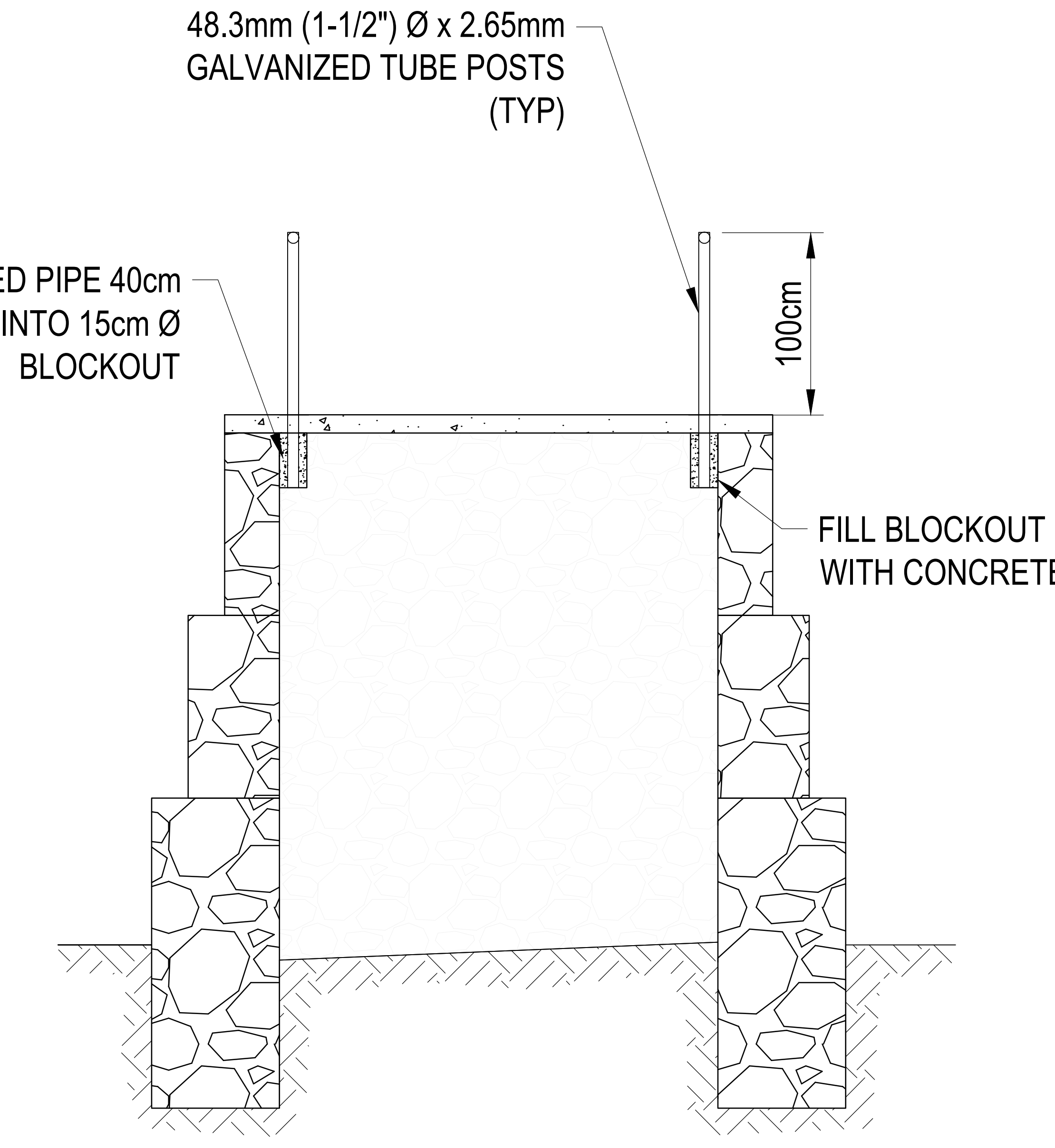
DATE: 22/11/2022
DRAWN BY: KNW
CHECKED BY: KNW
APPROVED BY: KNW
REVIEWED BY: KNW

STEEL CROSSBEAM DETAILS
C4" x 5.4 LB/FT

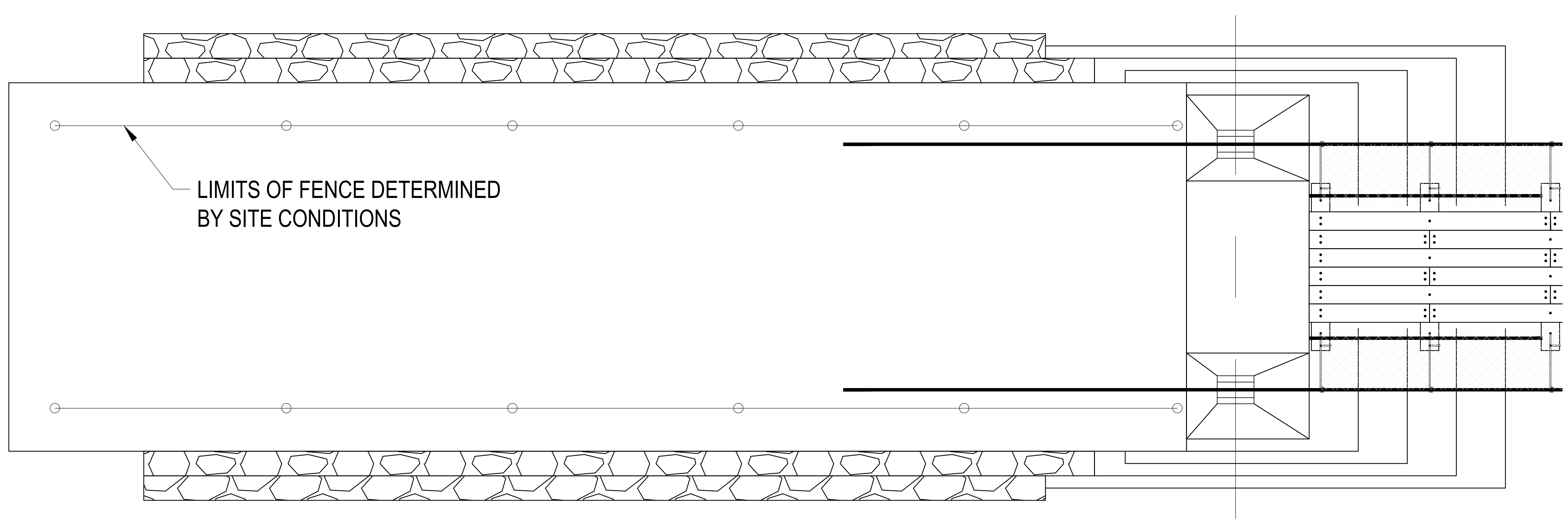
PROJECT NUMBER	DRAWING NUMBER
23-001	C1



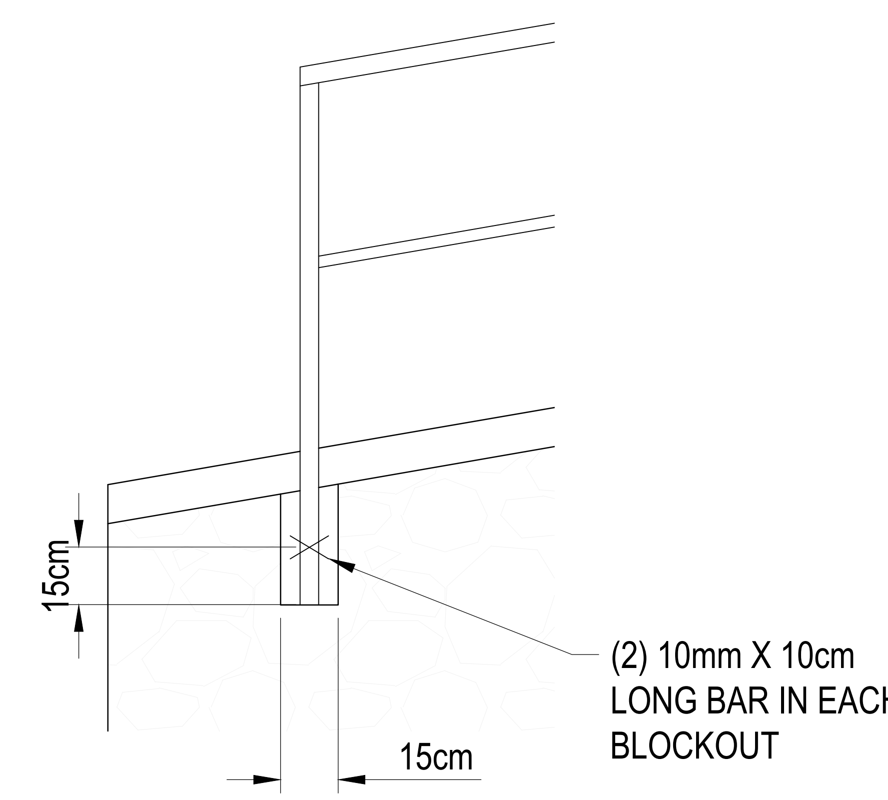
ELEVATION



SECTION A



PLAN



DETAIL 1

NOTES:

1. PROVIDE APPROACH RAMP RAIL SYSTEM WHEN THE DISTANCE FROM GRADE TO THE TOP OF THE RAMP CAP EXCEEDS 1.8m (6ft).
2. APPROACH RAMP RAIL SYSTEM IS NOT REQUIRED WHERE THE VERTICAL DISTANCE IS LESS THAN 1.8m, SUBJECT TO THE PREFERENCE OF COUNTRY MANAGER AND/OR COMMUNITY.
3. WELD THROAT SIZE IS mm.

HOOS BUILDING BRIDGES

ENGINEERS IN ACTION

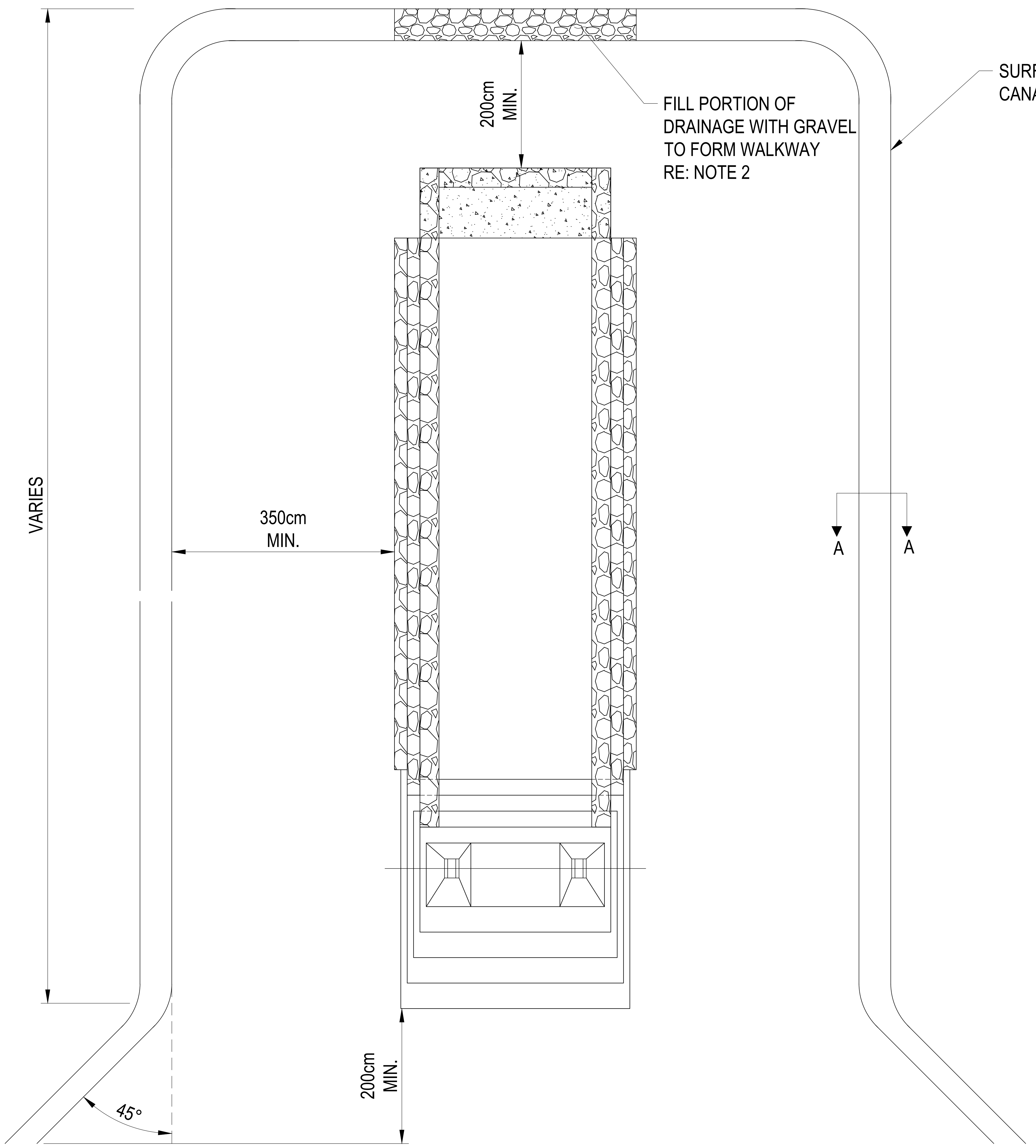
REV.	DESCRIPTION	DATE	ISSUED BY
0	ISSUED FOR CONSTRUCTION	18/10/2022	KNW

COUNTRY: BOLIVIA
PROJECT: RÍO K'ELLU MAYU
DEPARTMENT: COCHABAMBA
PROGRAM MANAGER: ETHAN GINGERICH
MUNICIPALITY: POCONA

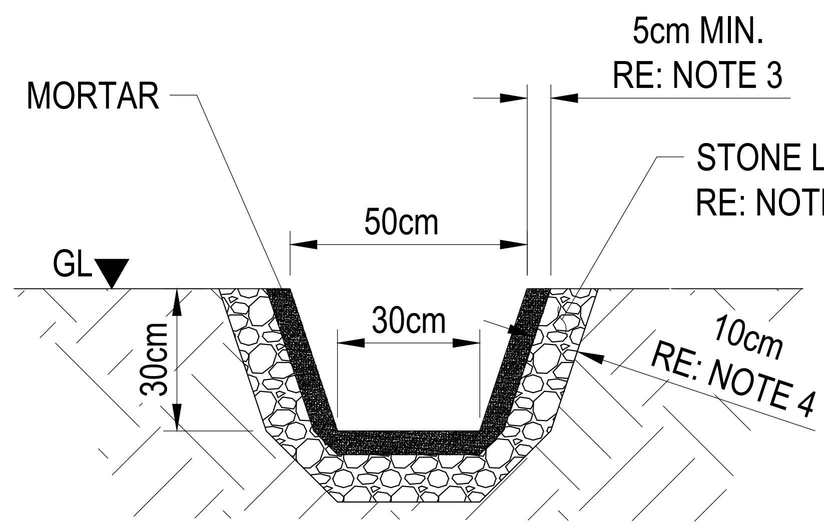
ENGINEERING RECORD
DATE: 28/03/2022
DRAWN BY: KNW
CHECKED BY: KNW
APPROVED BY: KNW
REVIEWED BY: KNW

APPROACH RAMP DETAILS
WELDED TUBES
BOLIVIA PROJECTS

PROJECT	DRAWING NUMBER
23-001	F3



PLAN



SECTION A-A

NOTES:

1. DRAINAGE CONSTRUCTION SHOULD BE COMPLETED WITH LEFTOVER MATERIALS WHEN POSSIBLE.
2. DO NOT FILL DRAINAGE WITH SOIL.
3. DRAINAGE THICKNESS SHOULD BE A MINIMUM OF 5cm.
4. LINE CHANNEL WITH SMALL STONES APPROXIMATELY 10cm THICK.
5. THIS DETAIL IS FOR PLANNING PURPOSES AND USES STANDARD, MINIMUM DIMENSIONS. FIELD CHANGES ARE ACCEPTABLE TO BETTER FIT SITE TOPOGRAPHY.

HOOS BUILDING BRIDGES

ENGINEERS IN ACTION

REV.	DESCRIPTION	DATE	ISSUED BY
0	ISSUED FOR CONSTRUCTION	11/12/2023	BKK

COUNTRY: BOLIVIA
DEPARTMENT: COCHABAMBA
MUNICIPALITY: POCONA

PROJECT: RÍO K'ELLU MAYU
PROGRAM MANAGER: ETHAN GINGERICH

ENGINEERING RECORD
DATE: 01/11/2023
DRAWN BY: BKK
CHECKED BY: BEM
APPROVED BY: BEM
REVIEWED BY: BKK

SURFACE DRAINAGE STEEP BACKSLOPES >10°

PROJECT NUMBER	DRAWING NUMBER
23-001	D4

Tier 1 Calculations

Load and Materials

Width	1.04	m	3.412073496	ft
DL	1	kN/m^2	20.89	psf
w_DL	1.04	kN/m	0.07	kip/ft
L	40.20	m	131.89	ft
A	41.81	m^2	0.92	ft^2
LL (reduced)	3.89	kN/m^2	81.33	psf
w_LL (reduced)	4.05	kN/m	0.27	kip/ft

Cable Analysis

Sag				
h_hoist	1.64	m	5.38	ft
h_deadload	1.83	m	6.00	ft
h_liveload	2.22	m	7.27	ft
h_construction	1.21	m	3.96	ft
Tension Force P				
P_h_hoist	123.16	kN	27.69	kips
P_h_deadload	110.44	kN	24.83	kips
P_h_total_load_reduced	464.19	kN	104.35	kips
P_h_liveload	355.13	kN	79.84	kips
P_h_total_load_nonreduced	462.37	kN	103.95	kips
Theta				
Theta_high (Right)	0.23			
Theta_low (Left)	0.20			
Mainstay Forces at Tower				
P_v,main,right	109.81	kN	24.69	kips
P_T,main,right	477.00	kN	107.23	kips
P_v,main,left	94.80	kN	21.31	kips
P_T,main,left	473.77	kN	106.51	kips
BackStory Cable Forces				
Left side				
P_T,back,left	517.60	kN	116.36	kips
P_v,back,left	229.01	kN	51.48	kips
P_T,main,left	473.77	kN	106.51	kips
P_v,main,left	94.80	kN	21.31	kips
R_Tower_left	323.81	kN	72.80	kips
Right side				
P_T,back,right	487.03	kN	109.4897365	kips
P_v,back,right	147.43	kN	33.14	kips
P_T,main,right	477.00	kN	107.23	kips
P_v,main,right	109.81	kN	24.69	kips
R_Tower_right	257.24	kN	57.83	kips
Maximum Vertical Tower Forces	517.60	kN	116.36	kips

Maximum Tower Rx	323.81	kN	72.79597295	kips

Cable Design

Number of Cables	3.28			
Rounded Number of Cables	4.00			
Rounded Number in case less than 4	4.00			
Factor of Safety	3.66			

Bearing Pressure

<u>Left side</u>

P_Total	1092.76	kN	245.66	kips
B*	3.23	m	10.59	ft
q_s	94.01	kPa	1963.92	lb/ft^2
q_u	286.00		5974.54	lb/ft^2
FSmin	3.00	kN	0.67	kips
FS	3.04	kPa	63.55	lb/ft^2

<u>Right side</u>

P_Total	278.98	kN	62.72	kips
B*	4.12	m	13.52	ft
q_s	21.16	kPa	441.96	lb/ft^2
q_u	286.00	kPa	5974.54	lb/ft^2
FSmin	3.00			
FS	13.52			

Suspender Analysis

Number of Cables	4			
Tributary Width	1.00	m	3.28	ft
P_beam	4.89	kN	1.00	kips
P_suspender	1.22	kN	0.17	kips
Rebar	#10			
Bar Area	71.00	mm^2	0.11	in^2
Yield Strength	275.00	Mpa	39885.38	psi
	275000.00	kN/m^2	5743494.43	psf
FS	15.96			
FS _req	5.00			

Tower Overturning

Overturning Moment

<u>Left side</u>

P_back,low	441.75	kN	99.31	kips
P_h,saddle,low	68.03	kN	15.29	kips
P_v,saddle,low	290.25	kN	65.25	kips
P_h,hand,low	34.01	kN	7.65	kips
P_h,walk,low	34.01	kN	7.65	kips

Y_hand,low	6.00	m	19.69	ft
Y_walk,low	4.90	m	16.08	ft
M_o,low	370.76	kN-m	273.46	kip-ft
Right side				
P_back,high	450.13	kN	101.19	kips
P_h,saddle,high	35.18	kN	7.91	kips
P_v,saddle,high	246.07	kN	55.32	kips
P_h,hand,high	17.59	kN	3.95	kips
P_h,walk,high	17.59	kN	3.95	kips
Y_hand,high	3.51	m	11.52	ft
Y_walk,high	2.41	m	7.91	ft
M_o,high	104.12	kN-m	76.80	kip-ft
Restorative Moment				
Left side				
P_Tower	39.00	kN	8.77	kip
P_Foundation	374.00	kN	84.08	kip
P_Tier3 (bottom)	193.72	kN	43.55	kip
P_Tier2	142.95	kN		
P_Tier1 (top)	97.03	kN		
P_v,saddle,low	246.07	kN	55.32	kip
M_r	2134.90	kN-m	1574.62	kip-ft
FS	5.76			
FR_req	1.50			
Right side				
P_Tower	39.00	kN	8.77	kip
P_Foundation	142.95	kN	32.14	kip
P_Tier1	97.03	kN	21.81	kip
P_v,saddle,high	246.07	kN	55.32	kip
M_r	678.93	kN-m	500.76	kip-ft
FS	6.52			
FR_req	1.50			

Anchor Uplift

Self Weight Calculations				
Right and Left				
V_anch,20-60m	2.85	m^3	9.35	ft
P_anch,20-60m	67.10	kN	15.08	kips
Anchor Dimensions				
b1	1.10	m	3.61	ft
b2	0.80	m	2.62	ft
H	1.00	m	3.28	ft
w	3.00	m	9.84	ft
Material Weights				

Concrete	2400.00	kg/m^3	149.83	lb/ft^3
Masonry	2100.00	kg/m^3	131.10	lb/ft^3
Fill	1900.00	kg/m^3	118.61	lb/ft^3
Soil	1800.00	kg/m^3	112.37	lb/ft^3
Concrete	23.54	kN/m^3	1.47	lb/ft^3
Masonry	20.60	kN/m^3	1.29	lb/ft^3
Fill	18.64	kN/m^3	1.16	lb/ft^3
Soil	17.66	kN/m^3	1.10	lb/ft^3
Uplift				
Left side				
H	2.00	m	6.56	ft
Phi	0.52	rad	30.00	deg
B1	2.25	m	7.40	ft
A_anchor	1.50	m^2	16.15	ft^2
P_overb	103.71	kN	23.31	kips
P_v,back	254.58	kN	57.23	kips
Vn	170.81	kN	38.40	kips
Vs	254.58	kN	57.23	kips
FS_req	1.50			
FSl	0.67			
Right side				
H	2.50	m	8.20	ft
Phi	0.52	rad	30.00	deg
B1	2.54	m	8.34	ft
A_anchor	1.50	m^2	16.15	ft^2
P_overb	170.78	kN	38.39	kips
P_v,back	210.86	kN	47.40	kips
Vn	237.88	kN	53.48	kips
Vs	210.86	kN	47.40	kips
FS_req	1.50			
FS	1.13			

Anchor Sliding

Left side				
theta	0.20	rad		
Alpha	0.46	rad		
P_main,high	473.77	kN	106.51	kips
P_back, high	517.60	kN	116.36	kips
P_h,anchor	464.19	kN	104.35	kips
P_h,tower	0.00	kN	0.00	kips
mu	0.15			
ϕ	0.52	rad		
k_a	0.33			
H	2.50	m	8.20	ft

P_active	55.18	kN	12.41	kips
R_s	519.37	kN	116.76	kips
R_n, min	779.05	kN	175.14	kips
P_ramp, req	325.75	kN	73.23	kips
V_ramp, min	17.48	m^3	617.18	ft^3
A_ramp, min	5.83	m^2	62.71	ft^2
A_ramp3G60A	38.96	m^2	419.38	ft^2
Does it Check	OK			
V_ramp1G60B	116.89	m^3	4127.79	ft^3
P_ramp1g60B	2178.64	kN	489.78	kips
P_wall	441.77	kN	99.31	kips
R_n	2266.44	kN	509.51	kips
FS Req	1.50			
FS	4.36			
<u>Right side</u>				
Theta	0.23	rad	13.31	degrees
Alpha	0.31	rad	17.62	degrees
P_main,high	477.00	kN	107.23	kips
P_back, high	487.03	kN	109.49	kips
P_h,anchor	464.19	kN	104.35	kips
P_h,tower	0.00	kN	0.00	kips
mu	0.15			
ϕ (phi)	0.52	rad		
k_a	0.33			
H	3.00	m	9.84	ft
P_active	79.46	kN	17.86	kips
R_s	543.65	kN	122.22	kips
R_n, min	815.47	kN	183.32	kips
P_ramp, req	956.54	kN	215.04	kips
V_ramp, min	51.32	m^3	1812.32	ft^3
A_ramp, min	17.11	m^2	184.13	ft^2
A_ramp1G60B	26.00	m^2	279.81	ft^2
Does it Check?	OK			
V_ramp1G60B	77.99	m^3	2754.01	ft^3
P_ramp1g60B	1453.56	kN	326.77	kips
P_wall	969.88	kN	218.04	kips
R_n	2264.99	kN	509.19	kips
FS Req	1.50			
FS	4.17			

Tier 2 Calculations

Loads

Deck

w_deck	1.04	m	3.41	ft

t_deck	0.05	m	0.16	ft
ρ_timber	900.00	kg/m^3	0.06	kips/ft^3
γ_timber	8.83	kN/m^3	0.06	kips/ft^3
ω_deck	0.46	kN/m	0.03	kips/ft
Crossbeam				
A_nailor	0.01	m^2	0.11	ft^2
A_steel	10.20	cm^2	0.01	ft^2
s	1.00	m	3.28	ft
l_nailor	1.05	m	3.44	ft
l_steel	1.50	m	4.92	ft
ρ_timber	900.00	kg/m^3	0.06	kips/ft^3
γ_timber	8.83	kN/m^3	0.06	kips/ft^3
ρ_steel	7850.00	kg/m^3	0.49	kips/ft^3
γ_steel	77.01	kN/m^3	0.49	kips/ft^3
V_nailor	0.01	m^3	0.37	ft^3
V_steel	0.00	m^3	0.05	ft^3
ω_crossbeam	0.21	kN/m	0.01	kips/ft
Cables				
ρ_ cable	5.21	kg/m	0.00	kips/ft^3
γ_cable	0.05	kN/m	0.00	kips/ft^3
#	4.00			
ω_cables	0.20	kN/m	0.01	kips/ft
ω_fence				
h_fence	1.20	m	3.94	ft
ρ_ fence	2.20	kg/m^2	0.00	kips/ft^2
γ_fence	0.02	kN/m^2	0.00	kips/ft^2
ω_fence	0.05	kN/m	0.00	kips/ft
Suspenders				
l_susp	2.00	m	6.56	ft
A_steel	71.00	mm^2	0.00	ft^2
V_susp	0.00	m^3	0.01	ft^3
ρ_steel	7850.00	kg/m^3	0.49	kips/ft^3
γ_steel	77.01	kN/m^3	0.49	kips/ft^3
s	1.00			
ω_susp	0.02	kN/m	0.00	kips/ft
Total Dead Load				
ω_DL	0.95	kN/m	0.06	kips/ft

Tower Checks

Overturning				
Left side				
h_tower	1.50	m	4.92	ft
h_walk	0.50	m	1.64	ft
x_cable	0.60	m	1.97	ft

x_tower	0.50	m	1.64	ft
Deff	0.70	m	2.30	ft
E_saddle	0.10	m	0.33	ft
P_h,hand	35.47	kN	7.97	kips
P_h,walk	23.49	kN	5.28	kips
alpha	0.46	rad		
P_v,hand	104.16	kN	23.42	kips
P_v,walk	95.08	kN	21.37	kips
P_tower	39.00	kN	8.77	kips
OM	115.81	kN-m	85.42	kip-ft
RM	150.18	kN-m	110.77	kip-ft
FS	1.30			
FS_req	1.50			
Right Side	1.50	m	4.92	ft
h_tower	1.50	m	4.92	ft
h_walk	0.41	m	1.35	ft
x_cable	0.60	m	1.97	ft
x_tower	0.50	m	1.64	ft
Deff	0.70	m	2.30	ft
E_saddle	0.10	m	0.33	ft
P_h,hand	29.04	kN	6.53	kips
P_h,walk	19.89	kN	4.47	kips
alpha	0.32	rad		
P_v,hand	106.10	kN	23.85	kips
P_v,walk	87.59	kN	19.69	kips
P_tower	39.00	kN	8.77	kips
OM	93.27	kN	68.80	kip-ft
RM	148.55	kN	109.57	kip-ft
FS	1.59			
FS_req	1.50			
Eccentricity				
Left side				
P_h,hand	35.47	kN	7.97	kips
P_v,hand	104.16	kN	23.42	kips
H_col	1.30	m	4.27	ft
delta	0.33	rad		
E_calc	0.44	m	1.45	ft
E_max	0.45	m	1.48	ft
Right Side				
P_h,hand	29.04	kN	6.53	kips
P_v,hand	106.10	kN	23.85	kips
H_col	1.30	m	4.27	ft
delta	0.27	rad		
E_calc	0.36	m	1.17	ft

E_max	0.45	m	1.48	ft
Flexural Capacity				
Left and Right				
As	400.00	mm^2	0.004	ft^2
fy	275.00	MPa	5743.29	kips/ft^2
d	62.50	cm	2.05	ft
	625.00	mm	2.05	ft
f'c	10.00	MPa	208.85	kips/ft^2
w_eff	40.00	cm	1.31	ft
	400.00	mm	1.31	ft
a	31.24	mm	0.10	ft
Mn	67031800.00	N-mm	49.44	kip-ft
	67.03	kN-m	49.44	kip-ft
M_design	60.33	kN-m	44.50	kip-ft
Left side				
P_h,hand	35.47	kN	7.97	kips
H_col	1.30	m	4.27	ft
P_v,hand	104.16	kN	23.42	kips
offset	0.10	m	0.33	ft
P_tower	39.00	kN	8.77	kips
x_tower	0.50	m	1.64	ft
M_service	16.19	kN-m	11.95	kip-ft
FS	3.73			
FS_req	1.5			
Right side				
P_h,hand	29.04	kN	6.53	kips
H_col	1.30	m	4.27	ft
P_v,hand	106.10	kN	23.85	kips
offset	0.10	m	0.33	ft
P_tower	39.00	kN	8.77	kips
x_tower	0.50	m	1.64	ft
M_service	7.64	kN-m	5.63	kip-ft
FS	7.90			
FS_req	1.5			
Serviceability (cracking)				
lambda	1.00			
f_r	2002.82	kN/m^2	290.47	psi
S	0.03	m	0.11	ft
M_cr	65.43	kN-m	48.26	kip-ft
M_service	14.35	kN-m	10.59	kip-ft
Sectional req.				
gamma3	1.60			
gamma1	0.62			
f_r	2002.82	kN/m^2	290.47	psi

S	0.03	m	0.11	ft
our section	64.90	kN-m	47.87	kip-ft
M_design	60.33	kN-m	44.50	kip-ft

Anchor Uplift

Overburden

Left side

width	3.00	m	9.84	ft
width_fill,backwall	2.40	m	7.87	ft
A_fill	2.61	m^2	28.14	ft^2
V_fill	6.27	m^3	221.59	ft^3
ρ_fill	1900.00	kg/m^3	0.12	kips/ft^3
γ_fill	18.64	kN/m^3	0.12	kips/ft^3
P_fill	116.96	kN	26.29	kips
A_concrete	0.27	m^2	2.88	ft^2
V_concrete	0.80	m^3	28.31	ft^3
ρ_concrete	2400.00	kg/m^3	0.15	kips/ft^3
γ_concrete	23.54	kN/m^3	0.15	kips/ft^3
P_concrete	18.87	kN	4.24	kips
A_backwall	0.28	m^2	3.00	ft^2
V_backwall	0.67	m^3	23.65	ft^3
ρ_masonry	2100.00	kg/m^3	0.13	kips/ft^3
γ_masonry	20.60	kN/m^3	0.13	kips/ft^3
P_backwall	13.79	kN	3.10	kips
A_sidewall	3.18	m^2	34.20	ft^2
t_sidewalls	0.60	m	1.97	ft
V_sidewalls	1.91	m^3	67.33	ft^3
P_sidewalls	39.28	kN	8.83	kips
P_anch	67.10	kN	15.08	kips
Vn	256.00	kN	57.55	kips
Vs	254.58	kN	57.23	kips
FS	1.01			
FS_req	1.50			

Right side

width_concrete	3.00		9.84	ft
width_fill,backwall	2.40	m	7.87	ft
A_fill	5.88	m^2	63.30	ft^2
V_fill	14.11	m^3	498.45	ft^3
ρ_fill	1900.00	kg/m^3	0.12	kips/ft^3
γ_fill	18.64	kN/m^3	0.12	kips/ft^3
P_fill	263.08	kN	59.14	kips
A_concrete	0.34	m^2	3.67	ft^2
V_concrete	1.02	m^3	36.16	ft^3
ρ_concrete	2400.00	kg/m^3	0.15	kips/ft^3

γ_concrete	23.54	kN/m^3	0.15	kips/ft^3
P_concrete	24.11	kN	5.42	kips
A_backwall	0.63	m^2	6.78	ft^2
V_backwall	1.51	m^3	53.39	ft^3
ρ_masonry	2100.00	kg/m^3	0.13	kips/ft^3
γ_masonry	20.60	kN/m^3	0.13	kips/ft^3
P_backwall	31.14	kN	7.00	kips
A_sidewall	6.85	m^2	73.76	ft^2
t_sidewalls	0.60	m	1.97	ft
V_sidewalls	4.11	m^3	145.19	ft^3
P_sidewalls	84.70	kN	19.04	kips
P_anch	67.10	kN	15.08	kips
Vn	470.13	kN	105.69	kips
Vs	210.86	kN	47.40	kips
FS	2.23			
FS_req	1.50			

Abutment Sliding

Additional Abutment Weight

Left side

A_base	1.78	m^2	19.17	ft^2
t_base	0.40	m	1.31	ft
V_base	1.42	m^3	50.32	ft^3
A_second	5.39	m^2	57.97	ft^2
t_second	0.60	m	1.97	ft
V_second	6.46	m^3	228.24	ft^3
A_third	27.99	m^2	301.33	ft^2
t_third	0.70	m	2.30	ft
V_third	39.19	m^3	1384.03	ft^3
ρ_masonry	2100.00	kg/m^3	0.13	kips/ft^3
γ_masonry	20.60	kN/m^3	0.13	kips/ft^3
P_wall	969.88	kN	218.04	kips

Right side

A_base	9.15	m^2	98.49	ft^2
t_base	0.40	m	1.31	ft
V_base	7.32	m^3	258.50	ft^3
A_second	11.77	m^2	126.69	ft^2
t_second	0.60	m	1.97	ft
V_second	14.12	m^3	498.78	ft^3
ρ_masonry	2100.00	kg/m^3	0.13	kips/ft^3
γ_masonry	20.60	kN/m^3	0.13	kips/ft^3
P_wall	441.77	kN	99.31	kips

Concrete Mix Design

f'c	10.00	MPa	208.85	kips/ft^2
B	0.79			
A	2.67			
f'c(3)	3.72	MPa	77.79	kips/ft^2
f'c(7)	5.99	MPa	125.02	kips/ft^2
f'c(14)	7.84	MPa	163.66	kips/ft^2
f'c(28)	9.69	MPa	202.30	kips/ft^2

Cable Geometry

Custom Sag Values Bolivia				
Construction Sag	3.00%			
Hoist Sag	4.08%			
Dead Load Sag	4.55%			
Live Load Sag	5.51%			
h1	1.21	m	3.96	ft
h2	1.64	m	5.38	ft
h3	1.83	m	6.00	ft
h4	2.22	m	7.28	ft
Span	40.20	m	131.90	ft
Delta H	0.65	m	2.13	ft
Construction Sag Geometry				
X_low	17.39	m	57.05	ft
Y_low	0.90	m	2.95	ft
Theta_low	0.10	radians		
X_high	22.81	m	74.84	ft
Y_high	1.55	m	5.09	ft
Theta_high	0.14	radians		
f_hoist_c_low	0.90	m	2.95	ft
f_hoist_c_high	1.55	m	5.09	ft
Hoisting Sag Geometry				
X_low	18.11	m	59.42	ft
Y_low	1.33	m	4.37	ft
Theta_low	0.15	radians		
X_high	22.09	m	72.48	ft
Y_high	1.98	m	6.50	ft
Theta_high	0.18	radians		
f_hoist_h_low	1.33	m	4.37	ft
f_hoist_h_high	1.98	m	6.50	ft
Dead Load Sag Geometry				
X_low	18.32	m	60.09	ft
Y_low	1.52	m	4.98	ft
Theta_low	0.17	radians		
X_high	21.89	m	71.81	ft
Y_high	2.17	m	7.12	ft

Theta_high	0.20	radians		
f_hoist_DL_low	1.52	m	4.98	ft
f_hoist_DL_high	2.17	m	7.12	ft
LL/Fully Loaded Sag Geometry				
X_low	18.63	m	61.11	ft
Y_low	1.90	m	6.24	ft
Theta_low	0.20	radians		
X_high	21.58	m	70.79	ft
Y_high	2.55	m	8.37	ft
Theta_high	0.24	radians		
f_hoist_LL_low	1.90	m	6.24	ft
f_hoist_LL_high	2.55	m	8.37	ft

Split Cable Analysis

<u>Left side</u>				
Details				
Number of Handrail Cables	2.00			
Number of Walkway Cables	2.00			
Mu_walkway	0.23	kN-m	0.17	kip-ft
Mu_tower_column saddles	0.20	kN-m	0.15	kip-ft
Mu_anchor_analysis	0.15	kN-m	0.11	kip-ft
alpha_hand	26.26	rad		
alpha_walk	21.48	rad		
Theta Left Dead	9.50	rad		
Theta Left Live	11.70	rad		
Theta Left Total	11.70	rad		
w_d	1.00	kN/m	1.36	kips/m
w_l	5.09	kN/m	6.90	kips/m
w_t	9.34	kN/m	12.67	kips/m
L	40.20	m	131.90	ft
h_sag_dead	1.83	m	6.00	ft
h_sag_live	2.22	m	7.27	ft
h_sag_total	2.22	m	7.27	ft
P_h_dead	110.45	kN	24.83	kips
P_h_live	464.24	kN	104.37	kips
P_h_total	852.24	kN	191.59	kips
Cable Analysis Dead left				
P_t,left,hand,back	55.99	kN	12.59	kips
P_t,left,main	111.99	kN	25.18	kips
P_t,left,walk,back	55.99	kN	12.59	kips
Tower Analysis Dead				
P_back	98.06	kN	22.04	kips
P_main	111.99	kN	25.18	kips
Tower Columns (handrail only)				

P_v,hand	15.47	kN	3.48	kips
P_h,hand	5.63	kN	1.27	kips
P_v,hand,back	21.69	kN	4.88	kips
P_v,hand,main	9.24	kN	2.08	kips
P_h,hand,back	43.97	kN	9.88	kips
P_h,hand,main	55.23	kN	12.42	kips
Walkway Hump				
P_back	97.98	kN	22.03	kips
P_main	111.99	kN	25.18	kips
P_v,walk	13.59	kN	3.06	kips
P_h,walk	4.82	kN	1.08	kips
P_v,walk,back	17.94	kN	4.03	kips
P_v,walk,main	9.24	kN	2.08	kips
P_h,walk,back	45.59	kN	10.25	kips
P_h,walk,main	55.23	kN	12.42	kips
Abutment Analysis				
Vertical	44.53	kN	10.01	kips
Horizontal	16.07	kN	3.61	kips
Anchor Analysis				
P_h,tower	20.89	kN	4.70	kips
Total Horizontal Driving Force				
R_s	110.45	kN	24.83	kips
Cable Analysis Live				
P_t,left,hand,back	237.05	kN	53.29	kips
P_t,left,main	474.10	kN	106.58	kips
P_t,left,walk,back	237.05	kN	53.29	kips
Tower Analysis Live				
P_back	415.12	kN	93.32	kips
P_main	474.10	kN	106.58	kips
Tower Columns (handrail only)				
P_v,hand	69.96	kN	15.73	kips
P_h,hand	22.99	kN	5.17	kips
P_v,hand,back	91.83	kN	20.65	kips
P_v,hand,main	48.08	kN	10.81	kips
P_h,hand,back	186.14	kN	41.85	kips
P_h,hand,main	232.12	kN	52.18	kips
Walkway Hump				
P_back	411.17	kN	92.44	kips
P_main	474.10	kN	106.58	kips
P_v,walk	61.68	kN	13.87	kips
P_h,walk	20.41	kN	4.59	kips
P_v,walk,back	75.28	kN	16.92	kips
P_v,walk,main	48.08	kN	10.81	kips
P_h,walk,back	191.31	kN	43.01	kips

P_h,walk,main	232.12	kN	52.18	kips
Abutment Analysis				
Vertical	201.59	kN	45.32	kips
Horizontal	66.39	kN	14.92	kips
Anchor Analysis				
P_h,tower	86.80	kN	19.51	kips
Total Horizontal Driving Force				
R_s	464.24	kN	104.37	kips
Cable Analysis Total				
P_t,left,hand,back	435.16	kN	97.83	kips
P_t,left,main	870.33	kN	195.66	kips
P_t,left,walk,back	435.16	kN	97.83	kips
Tower Analysis Total				
P_back	756.24	kN	170.01	kips
P_main	870.33	kN	195.66	kips
Tower Columns (handrail only)				
P_v,hand	127.78	kN	28.73	kips
P_h,hand	43.51	kN	9.78	kips
P_v,hand,back	167.30	kN	37.61	kips
P_v,hand,main	88.26	kN	19.84	kips
P_h,hand,back	339.10	kN	76.23	kips
P_h,hand,main	426.12	kN	95.80	kips
Walkway Hump				
P_back	791.99	kN	178.05	kips
P_main	870.33	kN	195.66	kips
P_v,walk	116.63	kN	26.22	kips
P_h,walk	28.81	kN	6.48	kips
P_v,walk,back	145.00	kN	32.60	kips
P_v,walk,main	88.26	kN	19.84	kips
P_h,walk,back	368.49	kN	82.84	kips
P_h,walk,main	426.12	kN	95.80	kips
Abutment Analysis				
Vertical	372.19	kN	83.67	kips
Horizontal	115.84	kN	26.04	kips
Anchor Analysis				
P_h,tower	144.65	kN	32.52	kips
Total Horizontal Driving Force				
R_s	852.24	kN	191.59	kips
Right side				
Details Right				
Number of Handrail Cables	2.00			
Number of Walkway Cables	2.00			
Mu_walkway	0.23	kN-m	0.17	kip-ft
Mu_tower_column saddles	0.20	kN-m	0.15	kip-ft

Mu_anchor_analysis	0.15	kN-m	0.11	kip-ft
alpha_hand	18.61	rad		
alpha_walk	12.68	rad		
Theta Left Dead	9.50	rad		
Theta Left Live	11.70	rad		
Theta Left Total	11.70	rad		
w_d	1.00	kN/m	1.36	kips/m
w_l	5.09	kN/m	6.90	kips/m
w_t	9.34	kN/m	12.67	kips/m
L	40.20	m	131.90	ft
h_sag_dead	1.83	m	6.00	ft
h_sag_live	2.22	m	7.27	ft
h_sag_total	2.22	m	7.27	ft
P_h_dead	110.45	kN	24.83	kips
P_h_live	464.24	kN	104.37	kips
P_h_total	852.24	kN	191.59	kips
Cable Analysis Dead				
P_t,right,hand,back	55.99	kN	12.59	kips
P_t,right,main	111.99	kN	25.18	kips
P_t,right,walk,back	55.99	kN	12.59	kips
Tower Analysis Dead				
P_back	100.71	kN	22.64	kips
P_main	111.99	kN	25.18	kips
Tower Columns (handrail only)				
P_v,hand	12.66	kN	2.85	kips
P_h,hand	3.75	kN	0.84	kips
P_v,hand,back	16.07	kN	3.61	kips
P_v,hand,main	9.24	kN	2.08	kips
P_h,hand,back	47.72	kN	10.73	kips
P_h,hand,main	55.23	kN	12.42	kips
Walkway Hump				
P_back	101.51	kN	22.82	kips
P_main	111.99	kN	25.18	kips
P_v,walk	10.19	kN	2.29	kips
P_h,walk	2.85	kN	0.64	kips
P_v,walk,back	11.14	kN	2.50	kips
P_v,walk,main	9.24	kN	2.08	kips
P_h,walk,back	49.52	kN	11.13	kips
P_h,walk,main	55.23	kN	12.42	kips
Abutment Analysis				
Vertical	35.50	kN	7.98	kips
Horizontal	10.36	kN	2.33	kips
Anchor Analysis				
P_h,tower	13.21	kN	2.97	kips

Total Horizontal Driving Force				
R_s	110.45	kN	24.83	kips
Cable Analysis Live				
P_t,right,hand,back	237.05	kN	53.29	kips
P_t,right,main	474.10	kN	106.58	kips
P_t,right,walk,back	237.05	kN	53.29	kips
Tower Analysis Live				
P_back	426.36	kN	95.85	kips
P_main	474.10	kN	106.58	kips
Tower Columns (handrail only)				
P_v,hand	58.05	kN	13.05	kips
P_h,hand	15.04	kN	3.38	kips
P_v,hand,back	68.03	kN	15.29	kips
P_v,hand,main	48.08	kN	10.81	kips
P_h,hand,back	202.03	kN	45.42	kips
P_h,hand,main	232.12	kN	52.18	kips
Walkway Hump				
P_back	425.96	kN	95.76	kips
P_main	474.10	kN	106.58	kips
P_v,walk	47.41	kN	10.66	kips
P_h,walk	12.17	kN	2.74	kips
P_v,walk,back	46.75	kN	10.51	kips
P_v,walk,main	48.08	kN	10.81	kips
P_h,walk,back	207.78	kN	46.71	kips
P_h,walk,main	232.12	kN	52.18	kips
Abutment Analysis				
Vertical	163.52	kN	36.76	kips
Horizontal	42.26	kN	9.50	kips
Anchor Analysis				
P_h,tower	54.43	kN	12.24	kips
Total Horizontal Driving Force				
R_s	464.24	kN	104.37	kips
Cable Analysis Total				
P_t,right,hand,back	435.16	kN	97.83	kips
P_t,right,main	870.33	kN	195.66	kips
P_t,right,walk,back	435.16	kN	97.83	kips
Tower Analysis Total				
P_back	776.70	kN	174.61	kips
P_main	870.33	kN	195.66	kips
Tower Columns (handrail only)				
P_v,hand	106.10	kN	23.85	kips
P_h,hand	29.04	kN	6.53	kips
P_v,hand,back	123.93	kN	27.86	kips
P_v,hand,main	88.26	kN	19.84	kips

P_h,hand,back	368.05	kN	82.74	kips
P_h,hand,main	426.12	kN	95.80	kips
Walkway Hump				
P_back	791.99	kN	178.05	kips
P_main	870.33	kN	195.66	kips
P_v,walk	87.59	kN	19.69	kips
P_h,walk	19.89	kN	4.47	kips
P_v,walk,back	86.92	kN	19.54	kips
P_v,walk,main	88.26	kN	19.84	kips
P_h,walk,back	386.34	kN	86.85	kips
P_h,walk,main	426.12	kN	95.80	kips
Abutment Analysis				
Vertical	299.78	kN	67.39	kips
Horizontal	77.96	kN	17.53	kips
Anchor Analysis				
P_h,tower	97.85	kN	22.00	kips
Total Horizontal Driving Force				
R_s	852.24	kN	191.59	kips

Construction Sag

Based on h_1	0.03			
Number of Handrails	2.00			
Total number of cables	4.00			
mu	0.15			
Alpha_hand_left	0.46	rad		
Alpha_hand_right	0.31	rad		
P_h1	33.50	kN	7.53	kips
Theta Construction Sag Low Side	0.10	rad		
Theta Construction Sag High Side	0.14	rad		
<u>Right side</u>				
P_t_back,hand	15.54	kN	3.49	kips
P_v,back,hand	4.96	kN	1.12	kips
Winch Capacity	29.40	kN	6.61	kips
P_max	7.77	kN	1.75	kips
<u>Left side</u>				
P_t_back,hand	15.30	kN	3.44	kips
P_v,back,hand	6.77	kN	1.52	kips
Winch Capacity	29.40	kN	6.61	kips
P_max	7.65	kN	1.72	kips
Erection Hook	110.00	MPa	2297.32	kips/ft^2
FS_req	3.00			
FS Right	4.03			
FS Left	4.11			

Anchor Analysis Construction

wc	0.20	kN/m	13.70	lbs/ft
L	40.20	m	131.90	ft
hsag	1.64	m	5.38	ft
theta left construction	0.10	radians		
theta right construction	0.14	radians		
alphawalkleft	0.37	radians		
alphahandleft	0.46	radians		
alphawalkright	0.22	radians		
alphahandright	0.32	radians		
handarea	2.00	cables		
walkwarea	2.00	cables		
totalarea	4.00	cables		
muconservative	0.15			
<u>Right Abutment</u>				
ptmain	24.64	kN	5.54	kips
ptbackhand	22.85	kN	5.14	kips
ptbackwalk	22.48	kN	5.05	kips
panchor	67.10	kN	15.08	kips
pwalls	969.88	kN	218.04	kips
pvcables	9.26	kN	2.08	kips
pvhandback	2.62	kN	0.59	kips
pvwalkback	3.29	kN	0.74	kips
pvhandmain	1.11	kN	0.25	kips
pvwalkmain	2.23	kN	0.50	kips
pvanchor	5.91	kN	1.33	kips
ptower	315.07	kN	70.83	kips
phanchor	21.84	kN	4.91	kips
phhandback	7.22	kN	1.62	kips
phwalkback	14.62	kN	3.29	kips
pactive	79.46	kN	17.86	kips
phtower	2.57	kN	0.58	kips
phhandmain	8.14	kN	1.83	kips
phwalkmain	16.27	kN	3.66	kips
calculated fos	1.54			
FoS Required	1.50			
<u>Left Abutment</u>				
ptmain	24.64	kN	5.54	kips
ptbackhand	22.51	kN	5.06	kips
ptbackwalk	21.87	kN	4.92	kips
panchor	67.10	kN	15.08	kips
pwalls	441.77	kN	99.31	kips
pvcables	11.52	kN	2.59	kips
pvhandback	3.63	kN	0.82	kips

pvwalkback	5.34	kN	1.20	kips
pvhandmain	0.85	kN	0.19	kips
pvwalkmain	1.70	kN	0.38	kips
pvanchor	8.97	kN	2.02	kips
ptower	882.79	kN	198.46	kips
phanchor	20.29	kN	4.56	kips
phhandback	6.73	kN	1.51	kips
phwalkback	13.57	kN	3.05	kips
pactive	55.18	kN	12.41	kips
phtower	4.21	kN	0.95	kips
phhandmain	8.17	kN	1.84	kips
phwalkmain	16.34	kN	3.67	kips
calculated fos	1.88			
FoS Required	1.50			

Anchor Uplift Construction

Right side				
panchor	67.10	kN	15.08	kips
pvanchor	5.91	kN	1.33	kips
calculated fos	11.35			
FoS Required	1.50			
Left side				
panchor	67.10	kN	15.08	kips
pvanchor	8.97	kN	2.02	kips
calculated fos	7.48			
FoS Required	1.50			

E.2 Construction Schedule

WEEKLY CONSTRUCTION SCHEDULE: TERRERO SUR SUSPENDED BRIDGE								
	Project Week #:	1 (May 13-19, 2024)	**Primary Tasks:**	**Site preparation and excavation**			***Led by EIA**	
	Key Equipment:	-Spray paint; string/stakes; shovels; hammer; plumb bob; nails						
		MON May 13	**TUES May 14**	**WED May 15**	**THURS May 16**	**FRI May 17**	**SAT May 18**	**SUN May 19**
TASKS	Site Clearing/Preparation							
	Mark Excavations							
	Excavation: R. Foundation							
	Right Foundation Masonry							
PERSONNEL	# EIA Masons	0	0	0	0	0	2	
	EIA Project Manager	✓	✓	✓	✓	✓	✓	
	EIA Sign Off Needed?	✗	✓	✓	✓	✓	✓	
	# Municipal Masons	0	0	0	0	0	4	
	AM: Community Foreman	✗	✓	✓	✓	✓	✓	
	PM: Community Foreman	✗	✓	✓	✓	✓	✓	
	AM: # Community Laborers	6	6	6	6	6	8	
	PM: # Community Laborers	3	6	6	6	6	8	
	Total Hours Worked	5	9	9	9	9	8	
ROLES	Project Manager	✓	✓	✓	✓	✓	✓	
	Safety & Operations	✓	✓	✓	✓	✓	✓	
	Bridge Engineer							
	Construction Mgr.	✓	✓	✓	✓	✓	✓	
	Construction Mgr. Asst.						✓	
	Quality Control Engineer	✓	✓	✓	✓	✓	✓	
	In-Country Logistics Mgr.	✓	✓	✓	✓	✓	✓	
	Research Director							
	Bridge Corps Member	✓	✓	✓	✓	✓	✓	
	Material Order							
	Material Delivery	✓						

WEEKLY CONSTRUCTION SCHEDULE: RIO K'ELLU MAYU SUSPENDED BRIDGE				
Project Week #:	2 (May 20-26, 2024)	**Primary Tasks:**	**Site preparation, excavation**	***Led by EIA**
Key Equipment:	-Spray paint; string/stakes; shovels; hammer; plumb bob; nails			

ENGINEERS IN ACTION

		MON	TUES	WED	THURS	FRI	SAT	SUN
		May 20	**May 21**	**May 22**	**May 23**	**May 24**	**May 25**	**May 26**
TASKS	Right Foundation Masonry							
	Right Foundation Fill/Cap							
	Prep Right Tier (assemble mat.)							
	Right Tier 1 Masonry							
	Right Tier 1 Fill/Cap							
PERSONNEL	# EIA Masons	2	2	0	2	2	0	
	EIA Project Manager	✓	✓	✓	✓	✓	✓	
	EIA Sign Off Needed?	✓	✓	✓	✓	✓	✓	
	# Municipal Masons	4	4	0	4	4	0	
	AM: Community Foreman	✓	✓	✓	✓	✓	✓	
	PM: Community Foreman	✓	✓	✓	✓	✓	✓	
	AM: # Community Laborers	8	8	8	8	8	8	
	PM: # Community Laborers	8	8	8	8	8	8	
	Total Hours Worked	8	8	8	8	8	8	
ROLES	Project Manager	✓	✓	✓	✓	✓	✓	
	Safety & Operations	✓	✓	✓	✓	✓	✓	
	Bridge Engineer							
	Construction Mgr.	✓	✓	✓	✓	✓	✓	
	Construction Mgr. Asst.	✓	✓	✓	✓	✓	✓	
	Quality Control Engineer	✓	✓	✓	✓	✓	✓	
	In-Country Logistics Mgr.	✓	✓	✓	✓	✓	✓	
	Research Director							
	Bridge Corps Member	✓	✓	✓	✓	✓	✓	
	Material Order							
	Material Delivery			✓				

ENGINEERS IN ACTION

WEEKLY CONSTRUCTION SCHEDULE: RIO K'ELLU MAYU SUSPENDED BRIDGE					
Project Week #:	3 (May 27-June 2, 2024)	**Primary Tasks:**	**Foundations/Tiers**		
Key Equipment:	-Truck, drum mixer, generator; string, plumb bob, water level -shovels, wheelbarrow buckets; masonry tools Materials: cement, gravel, sand, ro				
	MON	**TUES**	**WED**	**THURS**	**FRI**
	May 27	**May 28**	**May 29**	**May 30**	**May 31**
TASKS					
Right Tower Base					
Place CMU					
Left Foundation Excavation					
Left Foundation Fill/Cap					
Left Tier 1 Masonry					
Left Tier 1 Fill/Cap					
PERSONNEL					
# EIA Masons	0	✓	0	2	2
EIA Project Manager	✓	✓	✓	✓	✓
EIA Sign Off Needed?	✗	✗	✓	✓	✓
# Municipal Masons	4	4	0	4	4
AM: Community Foreman	✓	✓	✓	✓	✓
PM: Community Foreman	✓	✓	✓	✓	✓
AM: # Community Laborers	8	8	6	8	8
PM: # Community Laborers			6	8	8
Total Hours Worked	4	4	9	8	8
ROLES					
Project Manager	✓	✓	✓	✓	✓
Safety & Operations	✓	✓	✓	✓	✓
Bridge Engineer					
Construction Mgr.	✓	✓	✓	✓	✓
Construction Mgr. Asst.	✓	✓		✓	✓
Quality Control Engineer	✓	✓	✓	✓	✓
In-Country Logistics Mgr.	✓	✓	✓	✓	✓

	Research Director					
	Bridge Corps Member	✓	✓	✓	✓	✓
	Material Order					
	Material Delivery					

WEEKLY CONSTRUCTION SCHEDULE: RIO K'ELLU MAYU SUSPENDED BRIDGE						
	Project Week #:	4 (June 3-9, 2024)	**Primary Tasks:**	**Tiers (cont.); Towers**		
	Key Equipment:	-**Truck,** drum mixer, generator; string, plumb bob, water level -shovels, wheelbarrow b Materials: cement, gravel, sand, rock fill, CMU; *Angle grinder, welder (hump/rim)				
		MON	**TUES**	**WED**	**THURS**	**FRI**
		June 3	**June 4**	**June 5**	**June 6**	**June 7**
TASKS	Left Tier 2 Masonry					

Left Tier 2 Fill/Cap						
Left Tier 3 Masonry						
Left Tier 3 Fill/Cap						
PERSONNEL	# EIa Masons	2	2	2	2	2
EIA Project Manager		✓	✓	✓	✓	✓
EIA Sign Off Needed?			✓	✓	✓	✓
# Municipal Masons		4	4	4	4	4
AM: Community Foreman		✓	✓	✓	✓	✓
PM: Community Foreman		✓	✓	✓	✓	✓
AM: # Community Laborers		4	4	4	4	4
PM: # Community Laborers		0	0	0	0	0
Total Hours Worked		4	4	4	4	4
ROLES	Project Manager	✓	✓	✓	✓	✓
Safety & Operations		✓	✓	✓	✓	✓
Bridge Engineer						
Construction Mgr.		✓	✓	✓	✓	✓
Construction Mgr. Asst.		✓	✓	✓	✓	✓
Quality Control Engineer		✓	✓	✓	✓	✓
In-Country Logistics Mgr.		✓	✓	✓	✓	✓
Research Director						
Bridge Corps Member		✓	✓	✓	✓	✓
	Material Order					
Material Delivery						

WEEKLY CONSTRUCTION SCHEDULE: RIO K'ELLU MAYU SUSPENDED BRIDGE						
	Project Week #:	5 (June 10-16, 2024)	**Primary Tasks:**		**Anchor/Cables**	
	Key Equipment:	Tools: wire cutters; angle grinder, jig, pipe shovel, string, plumb bob, level Materials: sand tubing, tie wire (anchor cage) **Anchor Pour:** mixer, truck, slump cone, tamping rod, bu				
		MON	**TUES**	**WED**	**THURS**	**FRI**
	June 10		**June 11**	**June 12**	**June 13**	**June 14**
TASKS	Left Tower Base					
	Left Anchor Excavation					
	Right Anchor Excavation					
	Drainage System					
	Tie Anchor Cages					
PERSONNEL	# EIA Masons	0	0	0	0	0

	EIA Project Manager	✓	✓	✓	✓	✓
	EIA Sign Off Needed?	✗	✓	✓	✓	✓
	# Municipal Masons	4	0	0	0	0
	AM: Community Foreman	✓	✓	✓	✓	✓
	PM: Community Foreman	✓	✓	✓	✓	✓
	AM: # Community Laborers	8	6	6	6	6
	PM: # Community Laborers		6	6	6	6
	Total Hours Worked	4	9	9	9	9
ROLES	Project Manager	✓	✓	✓	✓	✓
	Safety & Operations	✓	✓	✓	✓	✓
	Bridge Engineer					
	Construction Mgr.	✓	✓	✓	✓	✓
	Construction Mgr. Asst.	✓				
	Quality Control Engineer	✓	✓	✓	✓	✓
	In-Country Logistics Mgr.	✓	✓	✓	✓	✓
	Research Director					
	Bridge Corps Member	✓	✓	✓	✓	✓
	Material Order					
	Material Delivery					

WEEKLY CONSTRUCTION SCHEDULE: RIO K'ELLU MAYU SUSPENDED BRIDGE						
	Project Week #:	6 (June 17-23, 2024)	**Primary Tasks:**	**Anchor; Approaches**		
	Key Equipment:	Cable: angle grinder, generator; wrench or breaker bar w/ cheater bar, cable, clamps, tubin Sag Set: -cable hoist/winch; T-level stick; abney level; 1m stick; torque wrench; metal bar; Approaches: mixer/truck/generator; string, plumb bob, shovels, buckets, cement/sand/gra				
		MON	**TUES**	**WED**	**THURS**	**FRI**
		June 17	**June 18**	**June 19**	**June 20**	**June 21**
TASKS	Move Cables across River					
	Anchor Pour					

ENGINEERS IN ACTION

Decking Prep						
Construct Approach Walls						
Set Sag						
Install Cables						
PERSONNEL	# EIA Masons	0	0	0	0	0
EIA Project Manager		✓	✓	✓	✓	✓
EIA Sign Off Needed?		✓	✓	✓	✓	✓
# Municipal Masons		0	0	0	0	0
AM: Community Foreman		✓	✓	✓	✓	✓
PM: Community Foreman		✓	✓	✓	✓	✓
AM: # Community Laborers		4	4	4	4	4
PM: # Community Laborers		6	6	2	2	2
Total Hours Worked		8	8	6	6	6
ROLES	Project Manager	✓	✓	✓	✓	✓
Safety & Operations		✓	✓	✓	✓	✓
Bridge Engineer		✓	✓	✓	✓	✓
Construction Mgr.		✓	✓			
Construction Mgr. Asst.		✓	✓			
Quality Control Engineer		✓	✓	✓	✓	✓
In-Country Logistics Mgr.		✓	✓	✓	✓	✓
Research Director						
Bridge Corps Member		✓	✓	✓	✓	✓
	Material Order					
Material Delivery						

ENGINEERS IN ACTION

WEEKLY CONSTRUCTION SCHEDULE: RIO K'ELLU MAYU SUSPENDED BRIDGE						
Project Week #:		7 (June 24-30)	**Primary Tasks:**		**Decking**	
Key Equipment:		Tools: hammers, wrenches, wood saw, hack saw/blades; harness, fall protection -Materials:2 cm diameter pipe (bending suspenders), crossbeams, galvanized screws, deck -Connecting Deck to approach: deck panels, 1 bag cement Fencing: wire cutters, pliers, galvanized fencing mesh, U-nails, galvanized tie wire				
		MON	**TUES**	**WED**	**THURS**	**FRI**
		June 24	**June 25**	**June 26**	**June 27**	**June 28**
TASKS	Install Cables					
Fill Walls						
Pour Concrete						
PERSONNEL	# EIA Masons	0	0	0	0	0
EIA Project Manager		✓	✓	✓	✓	✓
EIA Sign Off Needed?		✓	✓	✓	✓	✓
# Municipal Masons		0	0	0	0	0
AM: Community Foreman		✓	✓	✓	✓	✓
PM: Community Foreman		✓	✓	✓	✓	✓

	AM: # Community Laborers		4	4	4	4	4
	PM: # Community Laborers		0	2	2	2	2
	Total Hours Worked		3	6	6	6	6
ROLES		Project Manager	✓	✓	✓	✓	✓
	Safety & Operations		✓	✓	✓	✓	✓
	Bridge Engineer		✓	✓	✓	✓	✓
	Construction Mgr.						
	Construction Mgr. Asst.						
	Quality Control Engineer		✓	✓	✓	✓	✓
	In-Country Logistics Mgr.		✓	✓	✓	✓	✓
	Research Director						
	Bridge Corps Member		✓	✓	✓	✓	✓
		Material Order					
	Material Delivery						

ENGINEERS IN ACTION

WEEKLY CONSTRUCTION SCHEDULE: RIO K'ELLU MAYU SUSPENDED BRIDGE						
Project Week #:		8 (July 1-7, 2024)	**Primary Tasks:**	**Decking/Finishing**		
Key Equipment:		-Fencing materials				
		MON	**TUES**	**WED**	**THURS**	**FRI**
		July 1	**July 2**	**July 3**	**July 4**	**July 5**
TASKS	Concrete Cures	Concrete Cures through July 1				
Prep Materials						
Installation of Cross Beams						
Installation of Fencing						
PERSONNEL	# EIA Masons	0	0	0	0	0
EIA Project Manager		✗	✗	✓	✓	✓
EIA Sign Off Needed?		✗	✗	✓	✓	✓
# Municipal Masons		0	0	0	0	0
AM: Community Foreman		1	1	✓	✓	✓
PM: Community Foreman		0	0	✓	✓	✓
AM: # Community Laborers		2	2	4	4	4
PM: # Community Laborers		0	0	2	2	2
Total Hours Worked		2	2	6	6	6
ROLES	Project Manager			✓	✓	✓

Safety & Operations			✓	✓	✓
Bridge Engineer			✓	✓	✓
Construction Mgr.					
Construction Mgr. Asst.					
Quality Control Engineer			✓	✓	✓
In-Country Logistics Mgr.	✓	✓	✓	✓	✓
Research Director					
Bridge Corps Member			✓	✓	✓
Material Order					
Material Delivery					

WEEKLY CONSTRUCTION SCHEDULE: RIO K'ELLU MAYU SUSPENDED BRIDGE						
	Project Week #:	9 (July 8-14, 2024)	**Primary Tasks:**	**Decking/Finishing**		
	Key Equipment:	-Fencing materials				
		MON	**TUES**	**WED**	**THURS**	**FRI**
		July 8	**July 9**	**July 10**	**July 11**	**July 12**
TASKS	Fencing					
	Open Bridge					
	Research Assessment					
PERSONNEL	# EIA Masons	0	0			
	EIA Project Manager	✓	✓			
	EIA Sign Off Needed?	✓	✓			
	# Municipal Masons	0	0			
	AM: Community Foreman	✓	✓			
	PM: Community Foreman	✓	✓			
	AM: # Community Laborers	4	4			
	PM: # Community Laborers	2	2			
	Total Hours Worked	6	6			
ROLES	Project Manager	✓	✓	✓		
	Safety & Operations	✓	✓			
	Bridge Engineer	✓	✓			
	Construction Mgr.					
	Construction Mgr. Asst.					
	Quality Control Engineer	✓	✓	✓		
	In-Country Logistics Mgr.	✓	✓			✓
	Research Director					
	Bridge Corps Member	✓	✓			
	Material Order					
	Material Delivery					