Engineers in Action: Eswatini Suspended Bridge

A Technical Report submitted to the Department of Engineering Systems and Environment

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

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Spring, 2022

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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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Technical Report

Introduction

Maphoveleni, Eswatini is in high need of a footbridge over the Mtilane River due to long periods of flooding which occur throughout the year. In the past three years, six people have been injured attempting to cross the temporary log bridge currently in place. The log bridge is not an adequate height above the top of the river, has insufficient railings or other safety features, and becomes very slippery when wet. Crossing the river is necessary for the community to access numerous educational, health, and economic resources. Children must cross the river daily to attend school. During exam season, children are held at school for up to four weeks in order to ensure attendance, which puts a financial strain on the school and prevents the children from completing their chores at their homesteads. The community is primarily made up of agriculture and industrial workers, making it imperative that they cross the river to access local markets and work in the nearby city.

The bridge will benefit almost 2000 individuals including 1200 children who will have safe access to school all year round. This will not only increase overall education in the area, but also ensure students are able to return home during exam periods in order to help and be with their families. The bridge will indirectly serve the communities of Zombodze and Boyane. People coming from Manzini, the capital city of the department, will also be benefited. In addition, economic conditions for farmers and their families will be improved through more consistent market access.

Our team is tasked with developing a detailed design for a suspended cable footbridge to help provide year-round access to resources and services located across the Mtilane river from Zombodze and Boyane. There are seven desired objectives for the ultimate bridge design (listed in order of decreasing priority): safety, durability, serviceability, maintainability, constructability, economy, and aesthetics. Major components of the bridge design include a detailed drawing set (with plan, section, and profile views of the design), verified calculations of load capacity, geotechnical foundation analysis, hydrological erosion analysis, and more. In addition to the design of the bridge, our team is responsible for delivering an in-depth construction plan and schedule to provide guidance for the construction of the bridge in-country. This also includes materials sourcing as well as a safety plan which will provide important safety measures and information pertinent during the construction, operation, and maintenance of the bridge.

Site Information

This project will be located in the municipality of LudzeLudze & Zombodze Umphakatsi of the department of Manzini, Eswatini. This bridge will help the people from the Zombodze and Boyane community to cross the Mtilane River, and it will allow access for these communities to reach the city of Manzini, which is the closest city to the bridge with a travel time on foot of 30 minutes. The bridge is approximately 16 km away from the heart of the city of Manzini.

The proposed alignment is shown below in Figure 1. The abutment area is mostly clear with no signs of erosion and big rocks along the proposed centerline. The technical assessment completed on site shows that there are no obstructions within the horizontal or vertical clearance areas along the proposed center line for the suspended bridge. There appears to be some vegetation and tree cover located both downstream and upstream, but the proposed centerline is free of both, as it is located within open fields on both the right and left side of the bank. Some larger rocks are located in the river at the location of the proposed center line, but they do not appear to be large enough to interfere with the construction of the bridge.

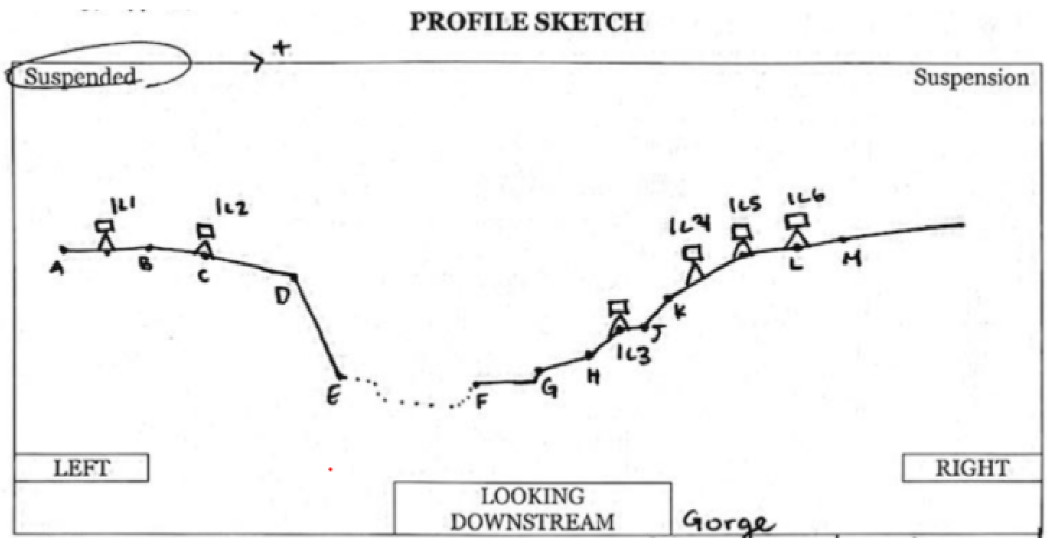


Figure 1. Surveying points provided in Technical Survey

There are no anticipated land ownership issues on the right embankment. A small amount of land on the left embankment belongs to the edge of a field owned by the Khumalo Homestead; however, the field is not cultivated and access issues are not anticipated. The proposed centerline exists downstream from the current crossing. This centerline has been proposed by the community members and avoids a significant amount of existing vegetation and erosion. No information has been provided to suggest that sewer, electrical, or potable water lines will need to be avoided in design or project construction. If any indication of such utilities become apparent to the team, this information will be promptly communicated to the Bridge Corps mentors to preserve the structural integrity of the design.

The proposed centerline of the Maphoveleni footbridge is downstream of the existing wooden structure crossing the Mtilane River. The channel shape can be seen in the survey provided by EIA which is roughly trapezoidal with a steep bank on the left hand side of the river. While the lower portion of the site on the right hand side of the river resembles a floodplain, the flow will be classified as a gorge due to the steepness of the bank on the opposite side. Designing to meet the specifications of a gorge will be a more conservative approach and the team will need three meters of available freeboard.

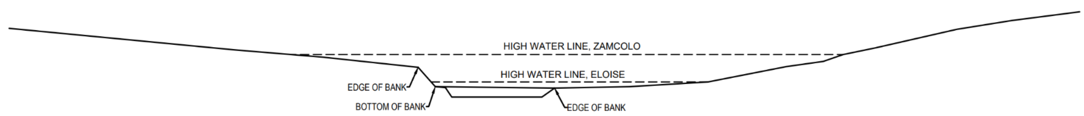


Figure 2. Elevation view of river, from survey provided by EIA

Additionally, two high water lines were provided in the technical report for Cyclones Zamcolo and Eloise. Cyclone Zamcolo, which occurred in 1984, caused record-breaking rainfall in Eswatini, resulting in 100-year flooding (Wikimedia Foundation, 2021). The Zamcolo high water line is the higher of the two water lines seen in Figure 2. More recently, Cyclone Eloise struck Eswatini in 2021, causing 20-year floods that again damaged much of the existing infrastructure (ReliefWeb, 2021). In order to maximize the longevity of the bridge and account for increase in water levels due to climate change, the team moved forward designing for the Zamcolo high water line.

Design Process

EIA outlines a number of requirements necessary for a standard design. These requirements may be viewed in the figure below. All of these standard design requirements were met. The decision was made to use a nonstandard abutment and anchor design in order to optimize design.

Design Requirements
Foundation must be 3.0m from edge of bank in soil
Foundation must be 1.5m from edge of bank in rock
Foundation must be placed behind an angle of internal friction (35 degrees in soil, 60 degrees in rock)
The ground profile slope in soil must be less than 10 degrees
The height difference between cable saddles shall not exceed 4% of the span [Delta(H) <= L/25]
The minimum walkway cable saddle elevation above the ground is 1.4m and the maximum elevation is 3.4m
Freeboard in floodplains >= 2.0m, in gorge 3.0m
Keep foundation out of floodplains

Figure 3. Design requirements from EIA

The team used the seven design objectives presented by EIA in Section 2.1 of the Bridge Builder Manual Volume 2a, these objectives are ordered by relative importance: Safety, Durability, Serviceability, Maintainability, Constructability, Economy, and Aesthetics. Our primary objective is to guarantee the safety of the bridge and those who use it. As such, our design must maintain structural integrity and incorporate features critical to the safety of users, such as the safety mesh. The second objective is durability, which includes proper weatherproofing of the bridge materials to maximize the structure's lifespan. Serviceability includes coordinating design features to reduce bridge sway and bounce and ensure adequate approach ramp angles. Maintainability includes ensuring that the structure can be maintained by the community at manageable rates and costs for years to come. Constructability involves focusing on materials that are feasible to acquire, prefabricate, and install. The sixth objective is economy, which involves making design decisions to reduce the overall cost of the bridge. The final design objective is aesthetics, which aims to create a structure that compliments the natural environment and surroundings of the communities. Our team followed the recommended progression of design laid out by Engineers in Action.

Design Progression

Our team participated in three review calls with alumni advisors as well as Engineers in Action staff to provide updates to our team's work on the project. Over the course of these review calls, our design changed dramatically.

Our design for review call one used standard design elements and only met standard design checks. These standard design checks, which are specified by EIA, include: cable tensile capacity, suspender force analysis, tower overturning, foundation bearing pressure, anchor sliding, and anchor uplift.This design was also created to meet freeboard requirements based upon the shorter of two high water lines provided from surveyors. The primary goal of our design process was to minimize the span of the bridge–this relates to the constructability of the bridge as well as the cost of the bridge's superstructure. The profile of that design is shown in the figure below:

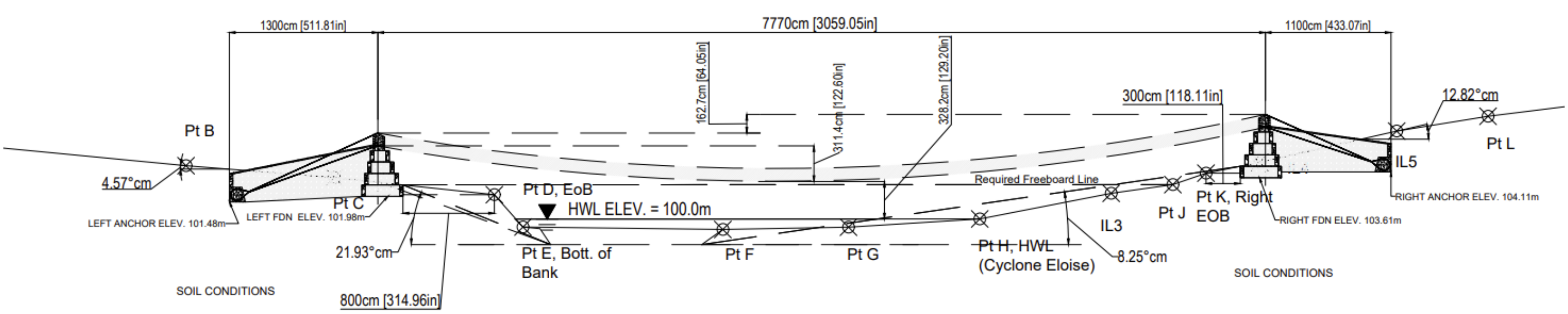


Figure 4. Preliminary design for Review Call #1

This design needed to be further analyzed structurally using the design checks that would later be outlined in EIA's advanced bridge design module. These advanced design checks include an advanced anchor sliding and uplift check, dead load calculation using bridge materials, component design checks for timber bridge decking and steel cross beams, soil shear analysis, tower eccentricity, tower moment capacity, biaxial loading capacity, tower minimum reinforcing requirements, and early-set concrete capacity. Additionally, our team recognized that we would likely need to develop nonstandard designs for certain bridge elements, such as the bridge abutments, in order to further optimize the design and reduce the amount of time and material required for the bridge's construction.

Comments from review call one as well as conversations with EIA personnel in January revealed that in addition to minimizing bridge span, reducing the amount of fill material and excavations required for bridge abutments should also govern design thinking. Our team took this into consideration before review call two. Our team created a design with a slightly longer bridge span than our previous one but it required smaller abutments. This reduction in abutment size was significant enough to make this new design more optimal than the previous one despite having a longer span length. A profile view of the design our team presented in review call two is shown below:

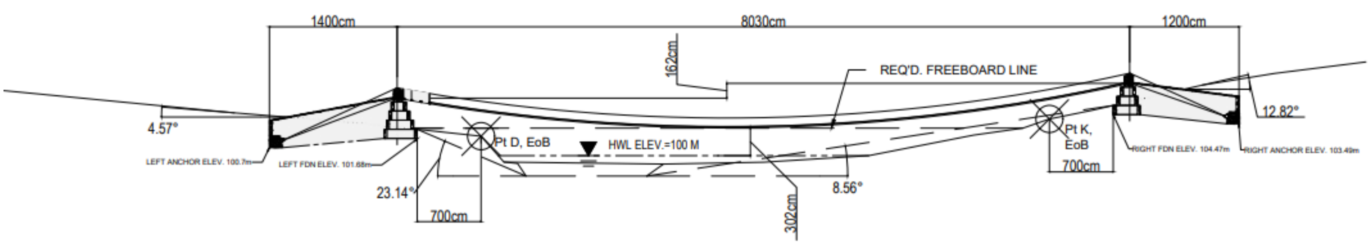


Figure 5. Design for Review Call #2

Comments and discussions from review call two prompted significant changes to the bridge design process. First was the recommendation to change which high water line our team was using for our bridge design. Citing climate change and also a desired increase in design robustness, EIA staff strongly encouraged our team to redesign our bridge for the higher storm mark that was provided to our team. This required new geometric layouts to be tested to ensure standard requirements were met. Our team was also presented with a call to further optimize the bridge abutments used in our design, mainly in terms of excavation depth reduction. With these changes in mind, our team set out to create a new design that was presented in review call three. A profile of that design is shown below and the final drawings for that design are also included in Appendix B:

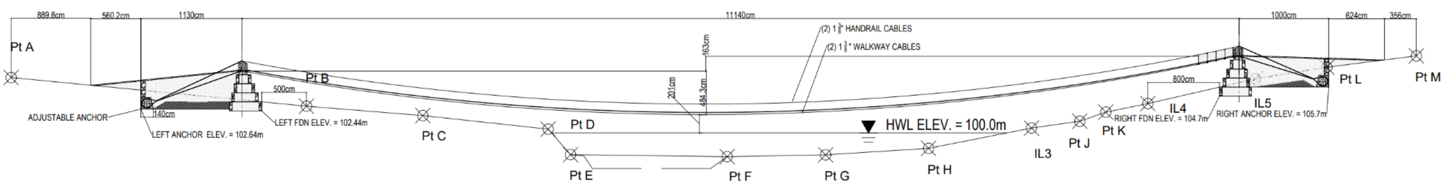


Figure 6. Design for Review Call #3

Slight adjustments were made to abutment design following review call three. These changes are shown in the full drawing set shown in the appendix.

Final Design Summary

Our final design is described in the table below:

Table 1. Final Design Geometric Conformance Summary

		Value	Units	Condition
Bridge Layout				
	Span, L	111.4	m	Sufficient
	Deck Width	1.04	m	

	River Type	Gorge	-	
	Left Foundation Elevation	102.44	m	
	Right Foundation Elevation	104.07	m	
	High Water Elev., HWL	100	m	
	Number of Tiers on Left	3.0		
	Number of Tiers on Right	3.0		
	Left Abutment Setback	5.0	m	Sufficient
	Right Abutment Setback	8.0	m	Sufficient
	Left Angle of Internal Friction	11.28	degrees	Sufficient
	Right Angle of Internal Friction	9.00	degrees	Sufficient
	Left Ground Slope Profile	5.49	degrees	Sufficient
	Right Ground Slope Profile	7.13	degrees	Sufficient
Height Difference				
	Maximum Allowable Height Difference	4.46	m	
	Actual Height Difference	1.63	m	Sufficient
Freeboard				
	Dead Load Sag	5.570	m	
	Distance from Lower Saddle to Lowest Point of Cable, f	4.78	m	

	Actual Freeboard	2.02	m	Sufficient

The achieved factors of safety for the various design checks on our bridge are shown below:

Table 2. Factors of Safety for Design Checks

Design Check	FS Required	High Side Achieved	Low Side Achieved
Cable Design	3.0	3.03	
Suspender Design	5.0	15.23	
Tower Overturning	1.5	4.78	4.30
Bearing Pressure	2.0	2.46	2.44
Tier 2 Anchor Sliding	1.5	1.76	2.02
Tier 2 Anchor Uplift	1.5	1.55	1.56
Calculated Dead Load less than Design?	-	Yes	
Timber Decking Check	-	Yes	
Steel Crossbeam Check	-	Yes	
Soil Shear Analysis	1.5	1.72	1.95
Tower Eccentricity within Range?	-	Yes	No
Tower Moment Capacity	-	Yes	Yes

Check?			
Tower Minimum Reinforcing Check?	-	Yes	Yes
Biaxial Loading Design Check?	-	Yes	Yes
3-day seat Early Concrete Moment Capacity/Reinforcement Check?	-	Yes	Yes
14-day set Early Concrete Moment Capacity/Reinforcement Check?	-	Yes	Yes
Construction Sag Requirement	=	2.968	meters

Our bridge design met all required factors of safety with the exception of the low side tower eccentricity. This value, only 2.2 cm away from the required 45 cm of allowable eccentricity, was deemed acceptable during meetings with alumni advisors and EIA staff for two main reasons. First is that EIA assumptions for calculating allowable eccentricity conservatively assume only reinforced concrete sections of the tower can resist biaxial loading, specifically bending, and not the masonry that is also part of the tower. This likely is not entirely true, meaning the allowable eccentricity is likely higher than 45 cm. Additionally, the value for belt friction used in calculating cable forces acting on the tower (following AASHTO's guidelines for belt friction) is conservatively valued at 0.2. If this value is reduced slightly to 0.18 , which is still within the AASHTO acceptable range of values, then the eccentricity requirements for the tower are met. Our team's calculations for all design checks can be seen in Appendix A as they correlate to the final design.

Construction and Safety Plans

With a finalized design, we moved forward with developing the construction and safety plans using EIA and Bridge EDU resources. OSHA safety standards and ISO material testing standards were considered and followed in preparing these plans.

Construction Schedule

Site Preparation

Site Preparation is the initial work that has to be done before the construction project starts. Site preparation increases productivity, safety, and reduces the unnecessary repetition of construction tasks. Several considerations have to be taken into account in order to have the site prepared for construction work: where the materials and tools should be stored, the exact location of the centerline so trees and rocks can be removed, how much space excavated soil will occupy, establishment of work areas, and safe pathway and river crossing to be used during the bridge construction.

Construction Phase 1

1. Material Collection:

a. 2-6 weeks: Exact amounts for each material can be found on the bill of quantities. Materials needed at the start of construction are the rocks, gravel, sand, and concrete. These materials are being transported to the site by tractors, trucks, and the people on-site (i.e., volunteers, laborers, students, etc.). Materials will be stored on site. Remember to maintain proper “housekeeping” to avoid having to move large amounts of materials and to ensure quantities and materials are organized. This eliminates many potential hazards in the workplace and helps get the job done safely and properly.

2. Foundation and Tiers:
    a. Construction Layout: 1-2 days: This step involves transferring the design from the drawings to the ground. It is necessary to establish the bridge centerline and mark where the foundations, abutments and anchors will be placed. It is necessary that the centerline is not moved throughout the entire construction process.
    b. Excavation for Abutments: 1-2 weeks: The time to complete this task varies depending on the manpower available, type of soil, and depth of foundation. See Appendix B for excavation drawings.
    c. Construct Tiers: 2-3 days per tier: The time to complete this task depends on the number of tiers per abutment, manpower available, and collection of rocks. This bridge has 6 total tiers, so construction will take approximately 3 weeks to complete.
3. The Towers:
    a. Construct Towers: 1 week: This step is composed of three major construction stages: the base level masonry perimeter, the towers, and the cast walkway hump,

with the installation of the T03 cable guide bars. Anchor and ramp excavations need to start while the towers are being built.

Construction Phase 2

4. Anchors:
    a. Install Anchors: 3-5 days: There are 7 steps involved in this process: assemble anchor reinforcing, unspool cable, drape cables over the abutments through walkway hump tubes, place the anchor cage in the designated location, clamp cables at fixed anchors, pour concrete at the fixed anchors, and install adjustable anchors. Rocks can be used to help place the anchor cage.
    b. Simultaneously, construction of ramp wall foundations should begin. It is important to have the ramp foundations completed before hoisting the cables.
5. Cable Hoisting:
    a. Position Cables to Hoist Sag: 3 days: This process is one of the most dangerous, so it must be done with a lot of precaution. There are 7 steps involved in this process: hand hoisting the cables, establishing and marking the f-value, placing the auto level, attaching winch to the hoisting loop in the main cable, hoisting cables again, and relaxing them. Cables need to be adjusted, clamped, and coated.
    b. Ramp Wall Construction: 1-2 weeks: The whole approach ramp, including the foundations, needs to be constructed and brought up to height.
6. Superstructure:
    a. Construct Walkway: 1-2 weeks: This step includes constructing the bridge deck and safety fencing with suspenders. Once the decking is installed, it is very important to grout the cables.

7. Bridge Celebration:
    a. We have to reserve a day to celebrate the finalization and inauguration of the bridge. It is the best part of the project when the whole community gathers to witness and use their new bridge, which they helped construct, for the first time.

Safety Protocol

Creating a culture of safety is of the utmost importance for any construction project. The safety system for this project is comprised of six elements:

1. <u>Leadership</u>

   A culture of safety is a function of leadership and operates in a trickle-down system. By having a safety manager on site to enforce safety at all levels, and rewarding workers for operating safely, a safety manager should inspire others on site to want to work safely. The enforcement of safety policies must be consistent and expectations should be set early on with the team. This can be done through the institution of a daily safety plan. The daily safety plan should identify team objectives and strategies for minimizing risks/ hazards for workers for daily on-site safety. Created by the safety manager, this planning should be completed daily and consider hazards related to the specific tasks to be completed that specific day. Frequent inspections of equipment, materials, and the job site should be completed by the safety manager daily. A safety review should be conducted at the conclusion of every work day to evaluate the project.
2. <u>Education</u>

   Educating worksite employees and volunteers is critical to preventing incidents. Safety is a team activity and cannot be achieved without the assistance of all participants. Each individual should be able to effectively identify hazards and implement strategies to mitigate risk. Project managers in conjunction with the safety manager should organize training sessions to ensure all workers on site understand the hazards associated with common tasks. Workers should be trained in personal protective equipment safety prior to beginning work. This includes wearing hard hats on site, safety glasses when dust is present or cutting metal, face shields when exposed to dust or cutting reinforcing bars/ cables and when using a grinder, hearing protection, foot protection, and hand protection. Hand and power tool safety should be reviewed and best practices such as inspecting tools prior to use, tying off tools to prevent falls, and ensuring guards are used when necessary. A meeting should be held with all workers on day 1 of construction to provide an overview of when PPE should be worn and best practices for operating hand and power tools.

3. <u>Communication</u>

   Communication is critical to creating a culture of safety. It is likely that a language barrier will exist between workers and the visiting volunteers, and miscommunication poses high risks of safety incidents. Signage in both the traveling teams and in-country language should be distributed/ posted throughout the site regarding proper use of PPE. The safety manager should organize safety briefing and discussions specific to the task at hand and communicate this in the local language to all participants. The safety manager is responsible for ensuring all workers are aware of the risks associated with each task and how to mitigate their risks.

4. <u>Planning</u>

Creating a safety plan that is project specific is essential to creating a safe work environment. The two goals of any safety plan should be to eliminate incidents and to increase efficiency through a safe work environment. Work Zone safety should be utilized and a work zone perimeter should be established. The perimeter will protect not only members of the construction team, but also members of the community. Personnel entering the perimeter should be trained in PPE as well as risk mitigation measures. Activity level safety planning should also be performed consistently in unison with the daily safety plan. Workers should never work alone and evaluating the hazards of each activity performed daily will prevent injury. Fall protection should be discussed with all workers and a rescue plan should be drafted for emergency situations.

5. Evaluation and Modification

Continually evaluating conditions and actions on a work site is essential to creating a culture of safety as well as creating a safe work environment. Daily site inspections should occur to evaluate any changed site conditions due to inclement weather or incident, as well as the quality of materials in storage and conditions of equipment should be inspected prior to every use. Daily excavation inspections should occur to mitigate any hazards and identify any changes in conditions from the prior work day. Fall protection inspection should be performed to prevent incidents and avoid implementing the rescue protocol. This includes evaluating the condition of harnesses, D-rings, and anchorage points. Creating a construction checklist with safety protocols for each stage of construction will help reduce oversight and ensure work site safety. Additionally, creating a photo inventory for comparing conditions throughout the project will provide essential information for safety and hazard reduction. By continually evaluating conditions, safety plans can be continually improved and modified to create a culture of safety.

6. Reinforcement

   Reinforcement is critical to ensuring individuals participate in creating a culture of safety. This is often through either positive reinforcement or consequences of actions. Workers should receive feedback from the safety manager and from other participants to cultivate this culture. An end of day review should be conducted to evaluate any safety incidents as well as any positive safety behavior that occurred on site. By encouraging workers who are operating safely, it is likely that these behaviors will continue and will be spread throughout the site. Additionally, incident reports should be completed for any safety hazards or incidents to document behaviors. Workers operating in unsafe manners should be disciplined and a zero-tolerance policy for non-safe behavior should be implemented.

Using this as a framework, we began to develop the safety plan starting with our plans for implementation. The safety manager of the traveling team will be in charge of safety. Safety concerns will be discussed with the community daily through safety briefings before and after the workday. All team members and community members should know about the elements of the culture of safety: commitment, communication, planning, education, evaluation, and reinforcement. All team members should exemplify good safety practices at all times: on site and away from site. Certain members of the team should be trained in wilderness first aid and be confident to act or communicate proper care when needed. Clear and frequent communication with all people involved in the project is essential in order to ensure safety is a top priority.

Each traveling team member is responsible for bringing their own safety glasses, work gloves, steel toe boots, hard hats, pants, and long sleeve shirts. These items are required at all times while on the construction site. The traveling team should decide if any of this PPE will be purchased in-country. Community volunteers will be responsible for their own shirts and pants along with work gloves. Other necessary PPE including hard hats and safety glasses will be provided as needed. Additional PPE will be required for certain activities. Safety harnesses, hearing protection, and face shields will be purchased in-country.

Next, we completed our Risk Management Plan which can be seen below:

Risk		**Monitoring Frequency**	**Scenario**	**Remedial Action**	**Responsible Party**
E	Saturated soil conditions	Daily	Grade 1: Standing water in excavation pits only following major rain event	No action needed; bridge design accounts for saturated condition once or twice per rainy season per B2P Manual	Bridge Engineer
			Grade 2: Standing water always in excavation pits,	Verify design capacity accounting for buoyant force. Consider installing	

			indicating high water table	drainage or possible redesign.	
F	Lack of community participation	Daily	Grade 1: Fewer workers than expected at job site	Convene Bridge Committee, adjust schedule	Construction Manager
			Grade 2: Insufficient workers during critical points in construction	Engage EIA mason or Project Manager for full evaluation of community's willingness and ability to contribute; Recruit workers from nearby towns; Suspend project	
G	Injury/loss of teammate	Continuous	Grade 1: Injury that cannot be treated on-site with first aid	Transport teammate to hospital in Diramba (see Table 8); Reorganization of team roles & responsibilities	Safety and Operations Manager
			Grade 2: Teammate can no longer work on	Permanent reorganization of	

			project/returns home	team roles & responsibilities	
H	Injury to community worker	Continuous	Injury that cannot be treated on-site with first aid	Transport community member to hospital in Diramba (see Table 8)	Safety and Operations Manager
I	Municipality fails to provide transportation for rocks	Weekly	Rocks are collected but municipality does not provide truck	Use community members with trucks (one identified over fall break); Depending on time-sensitivity, consider hiring Marvin or Fruto's truck	Safety and Operations Manager
J	Insufficient quantities of rock collected	Weekly	Grade 1: Sufficient quantities of river rock for structural work, insufficient quantities of rock for fill	Expand scope of collection zone; Contact local quarries to collect rock fragments and debris	Safety and Operations Manager
			Grade 2: Insufficient	Expand scope of collection zone; If	

			quantities of river rock for structural work, insufficient quantities of rock for fill	inadequate, purchase rock from regional supplier	
K	Severe weather	Continuous	Grade 1: Intermittent inclement weather	Cover excavated areas and curing concrete during heavy rains; inspect integrity of excavations	Construction Manager
			Grade 2: Ongoing or consistent inclement weather	For afternoon storms, adjust workday start; Optimize critical tasks for predicted breaks in weather; Inspect integrity of excavations – suspend work and shore if needed	

Conclusion

The final bridge design created by the team will be used in part or in full to construct a new bridge for the given site. The Maphoveleni bridge will greatly impact the lives of the surrounding community members and ensure new economic and educational opportunities to the people. More than just the bridge design, this capstone also focused heavily on other aspects of a bridge like construction, material acquisition, and instilling a culture of safety among team members. This document provides an outline for the process of the bridge design and many other important factors tied to building a bridge or any other structure.

One member of the team will be traveling this summer to a different bridge site with EIA to be part of the construction team. While no one from the team will be going to the Maphoveleni site in Eswatini, the final plan set for the bridge will instruct the team that will be traveling to this site on how to properly build the bridge. The efforts put in by the design team this year will have a tangible impact on real people which is ultimately why the team was so excited to be part of this project.

Appendix A: Design Calculations

Link to Google Sheets calculation workbook:

https://docs.google.com/spreadsheets/d/12u26Ku9BgBzJhr-iiyv7BY-783Rq6Ci9-ijBM_In9w0/edit?usp=sharing

Appendix B: Drawing Set

ESWATINI-MAPHOVELENI_VIRGINIA_SUSPENDED_BRIDGE

GPS COORDINATES	26°26'40"S,_31°17'21"E
COUNTRY	ESWATINI
REGION	MANZINI
INKHUNDLA	LUDZELUDZE/ZOMBODZE
COMMUNITY	ZOMBODZE/BOYANE
SPAN	80.3_METERS

GENERAL NOTES:

BRIDGE CONSTRUCTION SHALL BE EXECUTED BY THE MEANS AND METHODS STATED IN THE BRIDGES TO PROSPERITY, 2016 CABLE SUSPENDED BRIDGES, FIFTH EDITION BRIDGE BUILDER MANUAL.

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:

BRIDGES TO PROSPERITY, 2016 CABLE SUSPENDED BRIDGES, FIFTH EDITION BRIDGE BUILDER MANUAL

DESIGN LOADS:

DEAD LOAD	=	1.00	kN/m^2
LIVE LOAD$_{PRIMARY}$	=	3.14	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	fy	=	275 MPa	(40 ksi)
TIMBER	fb	=	3.96 MPa	(574 psi)
TIMBER	fv	=	1.44 MPa	(210 psi)
SOIL	qa	=	144 kPa	(3000 psf)
FRICTION ANGLE	Ø	=	30 degrees	

UNIT WEIGHTS:

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)
BROKEN ROCK	=	1900 kg/m^3	(119 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 METERS.

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:

ENGINEERS IN ACTION

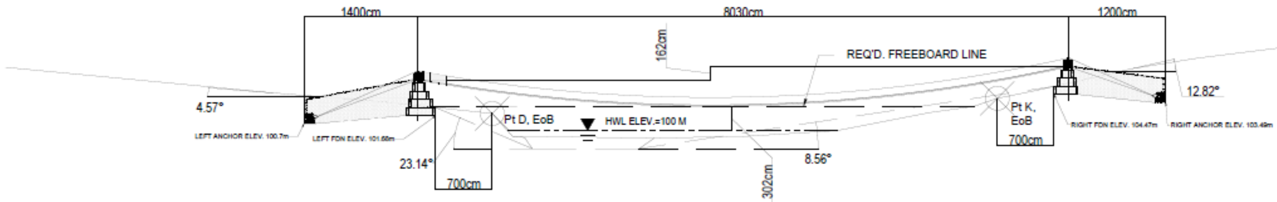
REV.	DESCRIPTION	DATE	ISSUED BY
R0	R0XXX	R0DDMMYY	R0XXX
1	XXX_1	DDMMYY	1_XXX
2	XXX_2	DDMMYY	2_XXX
3	XXX_3	DDMMYY	3_XXX
4	XXX_4	DDMMYY	4_XXX
5	XXX_5	DDMMYY	5_XXX

COUNTRY: ESWATINI
REGION: MANZINI
INKHUNDLA: LUDZELUDZE/ZOMBODZE
PROJECT: MAPHOVELENI
PROGRAM MANAGER: BRITTANY_MARGARITZ

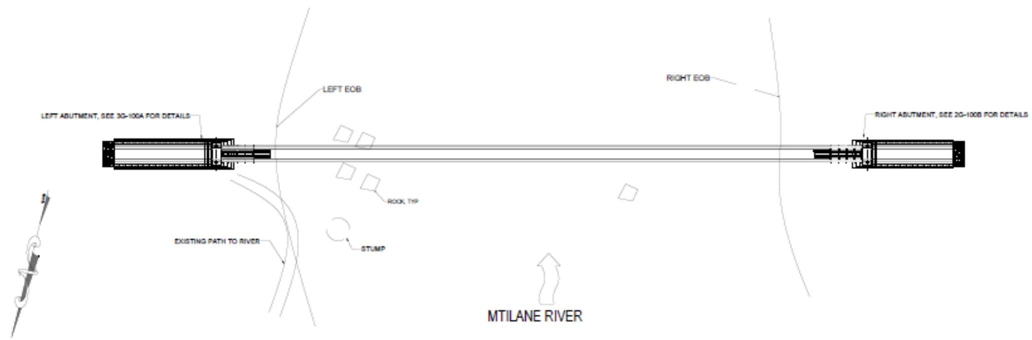
ENGINEERING RECORD
DATE: DD_MM_YYYY
DRAWN BY: DBXXX
CHECKED BY: CBXXX
APPROVED BY: ABXXX
REVIEWED BY: RBXXX

MAPHOVELENI SUSPENDED_FOOTBRIDGE TITLE

PROJECT NUMBER	DRAWING NUMBER
PROJECT_#	1



ELEVATION



PLAN

NOTES:
1. DESIGN SAG: 4.02m (5.00%)
2. HOISTING SAG: 3.69m (4.60%)
   f = 2.93m FROM LEFT ABUTMENT
   f = 4.55m FROM RIGHT ABUTMENT
3. SURVEY INFORMATION PROVIDED BY FIRST&LAST NAME ON DATE.
4. LANDMARKS INCLUDED IN PLAN VIEW ARE FOR

INFORMATION ONLY, ARE NOT DRAWN TO SCALE, AND IN APPROXIMATE LOCATIONS.

REV.	DESCRIPTION	DATE	ISSUED BY
R0	R0XXX	R0DDMMYY	R0XXX
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2	XXX_2	DDMMYY	2_XXX
3	XXX_3	DDMMYY	3_XXX
4	XXX_4	DDMMYY	4_XXX
5	XXX_5	DDMMYY	5_XXX

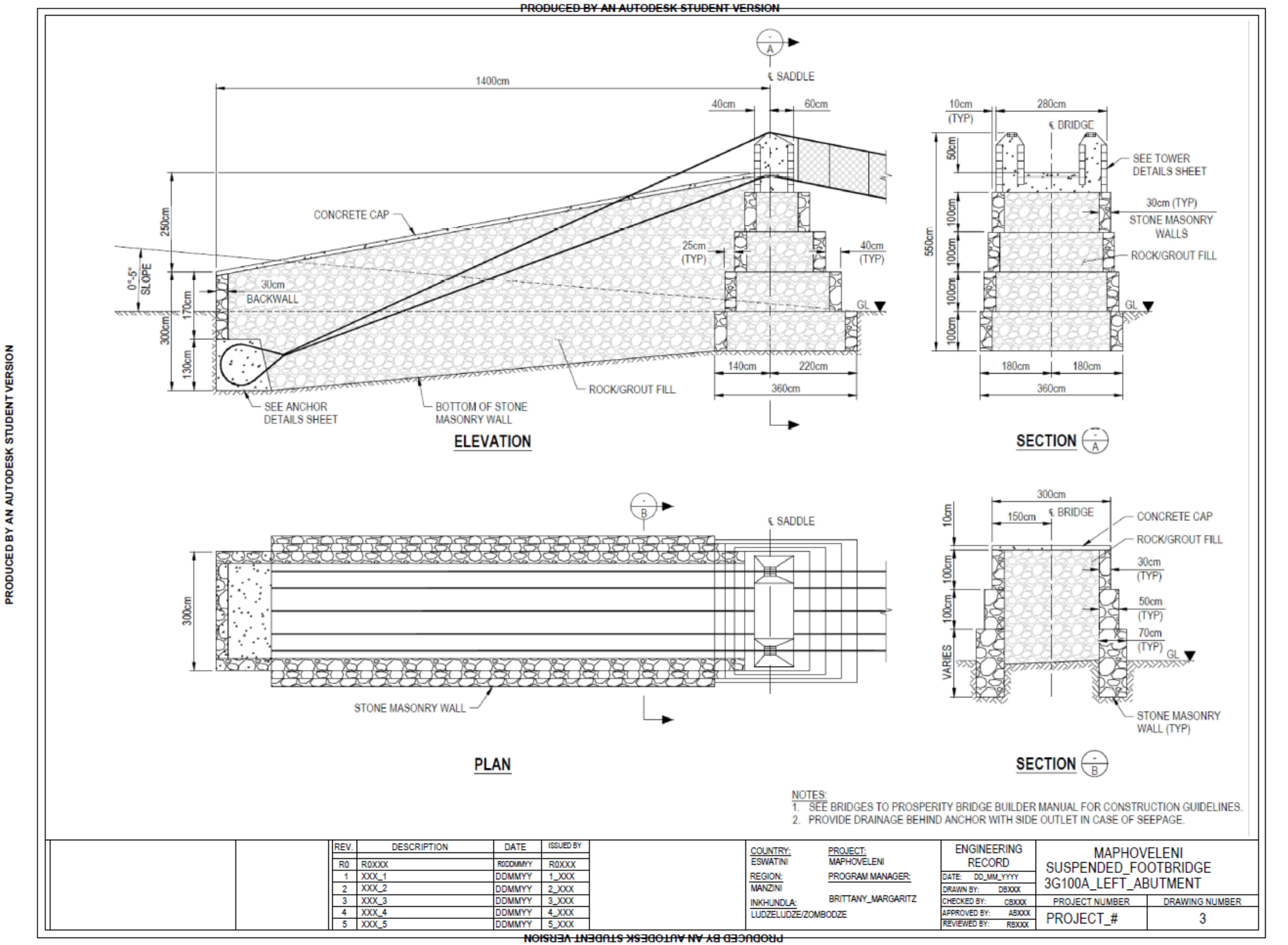
COUNTRY: ESWATINI
REGION: MANZINI
INKHUNDLA: LUDZELUDZE/ZOMBODZE
PROJECT: MAPHOVELENI
PROGRAM MANAGER: BRITTANY_MARGARITZ

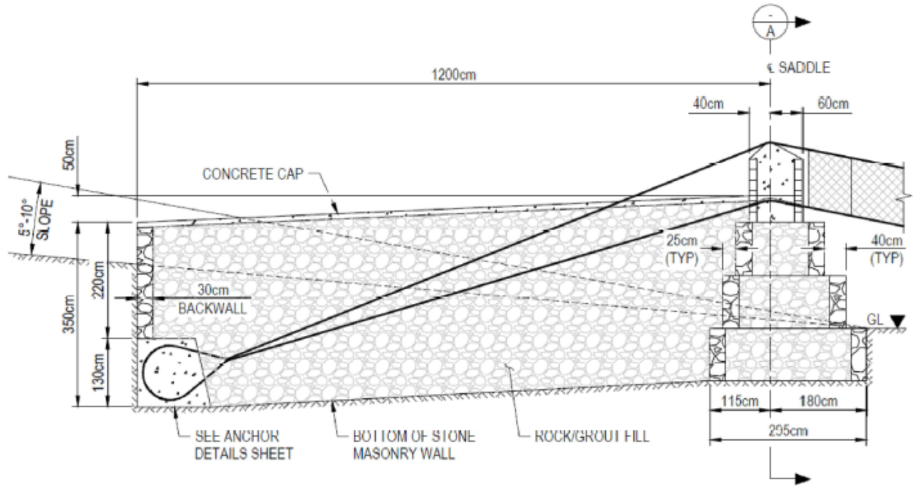
ENGINEERING RECORD
DATE: DD_MM_YYYY
DRAWN BY: DBXXX
CHECKED BY: CBXXX
APPROVED BY: ABXXX
REVIEWED BY: RBXXX

MAPHOVELENI SUSPENDED_FOOTBRIDGE LAYOUT

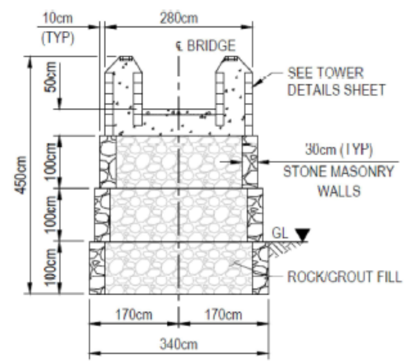
PROJECT NUMBER	DRAWING NUMBER
PROJECT_#	2

PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION

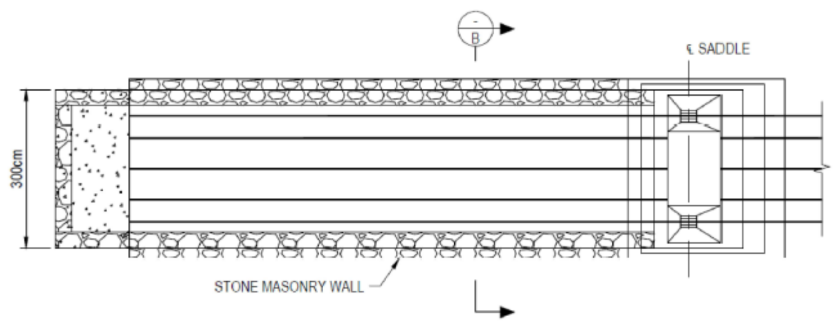

PRODUCED BY AN AUTODESK STUDENT VERSION
1400cm
℄ SADDLE
40cm
60cm
250cm
CONCRETE CAP
0°-5° SLOPE
30cm BACKWALL
170cm
300cm
130cm
25cm (TYP)
40cm (TYP)
GL
140cm
220cm
360cm
SEE ANCHOR DETAILS SHEET
BOTTOM OF STONE MASONRY WALL
ROCK/GROUT FILL
ELEVATION
10cm (TYP)
280cm
℄ BRIDGE
50cm
SEE TOWER DETAILS SHEET
30cm (TYP)
STONE MASONRY WALLS
ROCK/GROUT FILL
550cm
100cm
100cm
100cm
100cm
GL
180cm
180cm
360cm
SECTION A
℄ SADDLE
300cm
STONE MASONRY WALL
PLAN
300cm
150cm
℄ BRIDGE
10cm
CONCRETE CAP
ROCK/GROUT FILL
30cm (TYP)
100cm
100cm
50cm (TYP)
70cm (TYP)
VARIES
GL
STONE MASONRY WALL (TYP)
SECTION B
NOTES:
1. SEE BRIDGES TO PROSPERITY BRIDGE BUILDER MANUAL FOR CONSTRUCTION GUIDELINES.
2. PROVIDE DRAINAGE BEHIND ANCHOR WITH SIDE OUTLET IN CASE OF SEEPAGE.
REV. DESCRIPTION DATE ISSUED BY
R0 R0XXX R0DDMMYY R0XXX
1 XXX_1 DDMMYY 1_XXX
2 XXX_2 DDMMYY 2_XXX
3 XXX_3 DDMMYY 3_XXX
4 XXX_4 DDMMYY 4_XXX
5 XXX_5 DDMMYY 5_XXX
COUNTRY: ESWATINI
PROJECT: MAPHOVELENI
REGION: MANZINI
PROGRAM MANAGER: BRITTANY_MARGARITZ
INKHUNDLA: LUDZELUDZE/ZOMBODZE
ENGINEERING RECORD
DATE: DD_MM_YYYY
DRAWN BY: DBXXX
CHECKED BY: CBXXX
APPROVED BY: ABXXX
REVIEWED BY: RBXXX
MAPHOVELENI SUSPENDED_FOOTBRIDGE 3G100A_LEFT_ABUTMENT
PROJECT NUMBER
DRAWING NUMBER
PROJECT_#
3



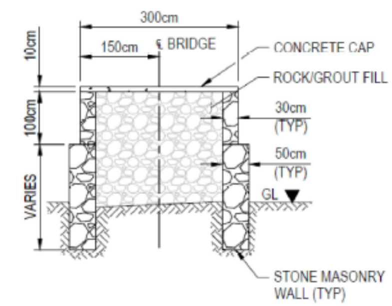
ELEVATION



SECTION A



PLAN



SECTION B

NOTES:
1. SEE BRIDGES TO PROSPERITY BRIDGE BUILDER MANUAL FOR CONSTRUCTION GUIDELINES.
2. PROVIDE DRAINAGE BEHIND ANCHOR WITH SIDE OUTLET IN CASE OF SEEPAGE.

REV.	DESCRIPTION	DATE	ISSUED BY
R0	R0XXX	R0DDMMYY	R0XXX
1	XXX_1	DDMMYY	1_XXX
2	XXX_2	DDMMYY	2_XXX
3	XXX_3	DDMMYY	3_XXX
4	XXX_4	DDMMYY	4_XXX
5	XXX_5	DDMMYY	5_XXX

COUNTRY: ESWATINI
REGION: MANZINI
INKHUNDLA: LUDZELUDZE/ZOMBODZE

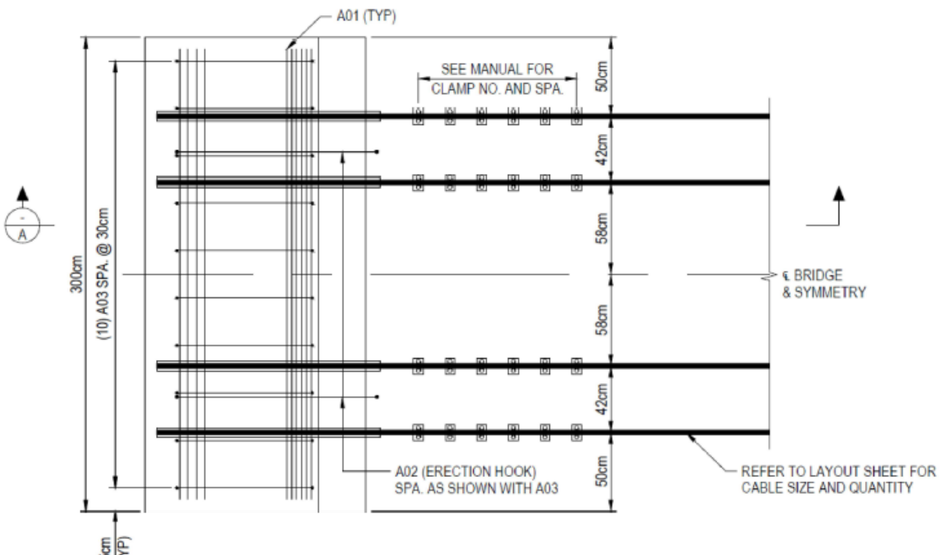
PROJECT: MAPHOVELENI
PROGRAM MANAGER: BRITTANY_MARGARITZ

ENGINEERING RECORD
DATE: DD_MM_YYYY
DRAWN BY: DBXXX
CHECKED BY: CBXXX
APPROVED BY: ABXXX
REVIEWED BY: RBXXX

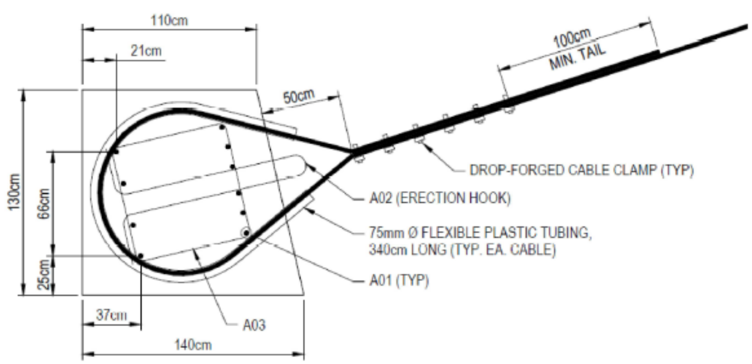
MAPHOVELENI SUSPENDED_FOOTBRIDGE 2G100B_RIGHT_ABUTMENT

PROJECT NUMBER	DRAWING NUMBER
PROJECT_#	4

PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION



PLAN



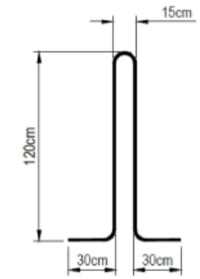
SECTION A

BILL OF MATERIALS

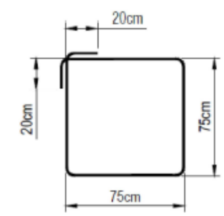
REINFORCING BARS (PER ANCHOR)

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



A02



A03

NOTES:

1. SEE BRIDGES TO PROSPERITY BRIDGE BUILDER MANUAL 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.

REV.	DESCRIPTION	DATE	ISSUED BY
R0	R0XXX	R0DDMMYY	R0XXX
1	XXX_1	DDMMYY	1_XXX
2	XXX_2	DDMMYY	2_XXX
3	XXX_3	DDMMYY	3_XXX
4	XXX_4	DDMMYY	4_XXX
5	XXX_5	DDMMYY	5_XXX

COUNTRY: ESWATINI
PROJECT: MAPHOVELENI
REGION: MANZINI
PROGRAM MANAGER: BRITTANY_MARGARITZ
INKHUNDLA: LUDZELUDZE/ZOMBODZE

ENGINEERING RECORD
DATE: DD_MM_YYYY
DRAWN BY: DBXXX
CHECKED BY: CBXXX
APPROVED BY: ABXXX
REVIEWED BY: RBXXX

MAPHOVELENI
SUSPENDED_FOOTBRIDGE
A5_ANCHOR_DETAILS

PROJECT NUMBER	DRAWING NUMBER
PROJECT_#	5

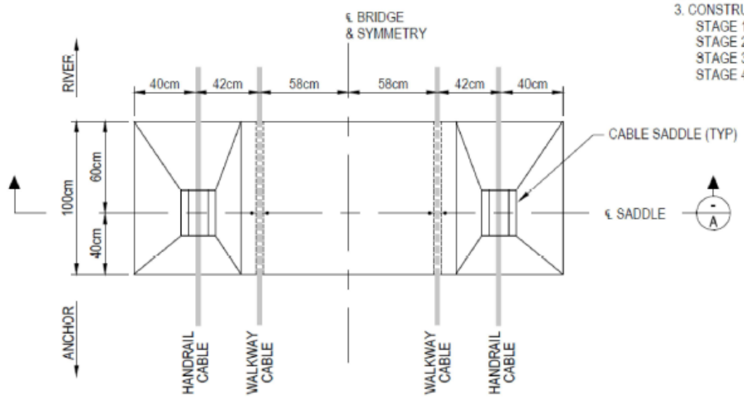
NOTES:
1. SEE BRIDGES TO PROSPERITY BRIDGE BUILDER MANUAL FOR CONSTRUCTION GUIDELINES.
2. 7.5cm CLEAR COVER SHALL BE PROVIDED FOR ALL REINFORCING.
3. CONSTRUCTION STAGES:
   - STAGE 1 - BASE LEVEL MASONRY PERIMETER FILLED WITH CONCRETE.
   - STAGE 2 - CONSTRUCT TOWERS IN LIFTS OF 20-40cm.
   - STAGE 3 - CAST WALKWAY HUMP AND STAB T03 CABLE GUIDE BARS.
   - STAGE 4 - CAST WALKWAY TOPPING SLAB OVER SLEEVED CABLES.

BILL OF MATERIALS

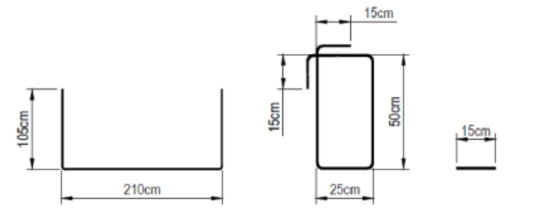
REINFORCING BARS (PER TOWER)

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	0.6

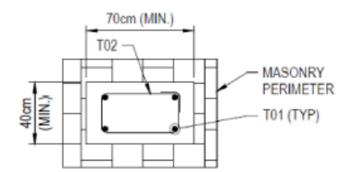
ITEM	QUANTITY
CONCRETE	1.08m³
PLASTIC HOSE x 110cm	3



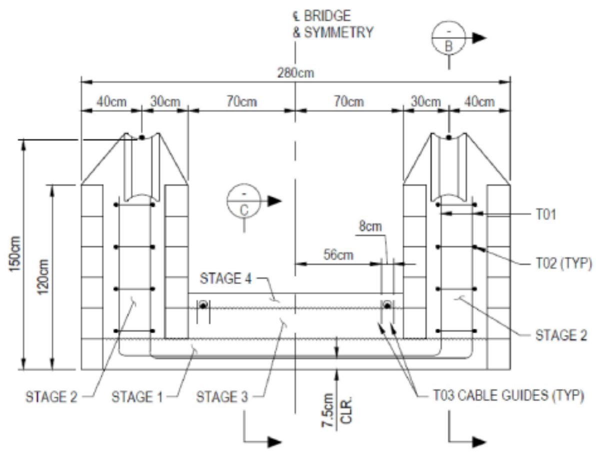
PLAN



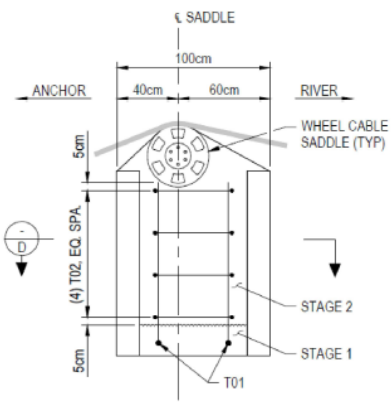
T01 T02 T03



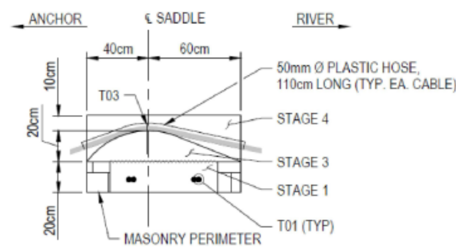
SECTION D



SECTION A



SECTION B



SECTION C

REV.	DESCRIPTION	DATE	ISSUED BY
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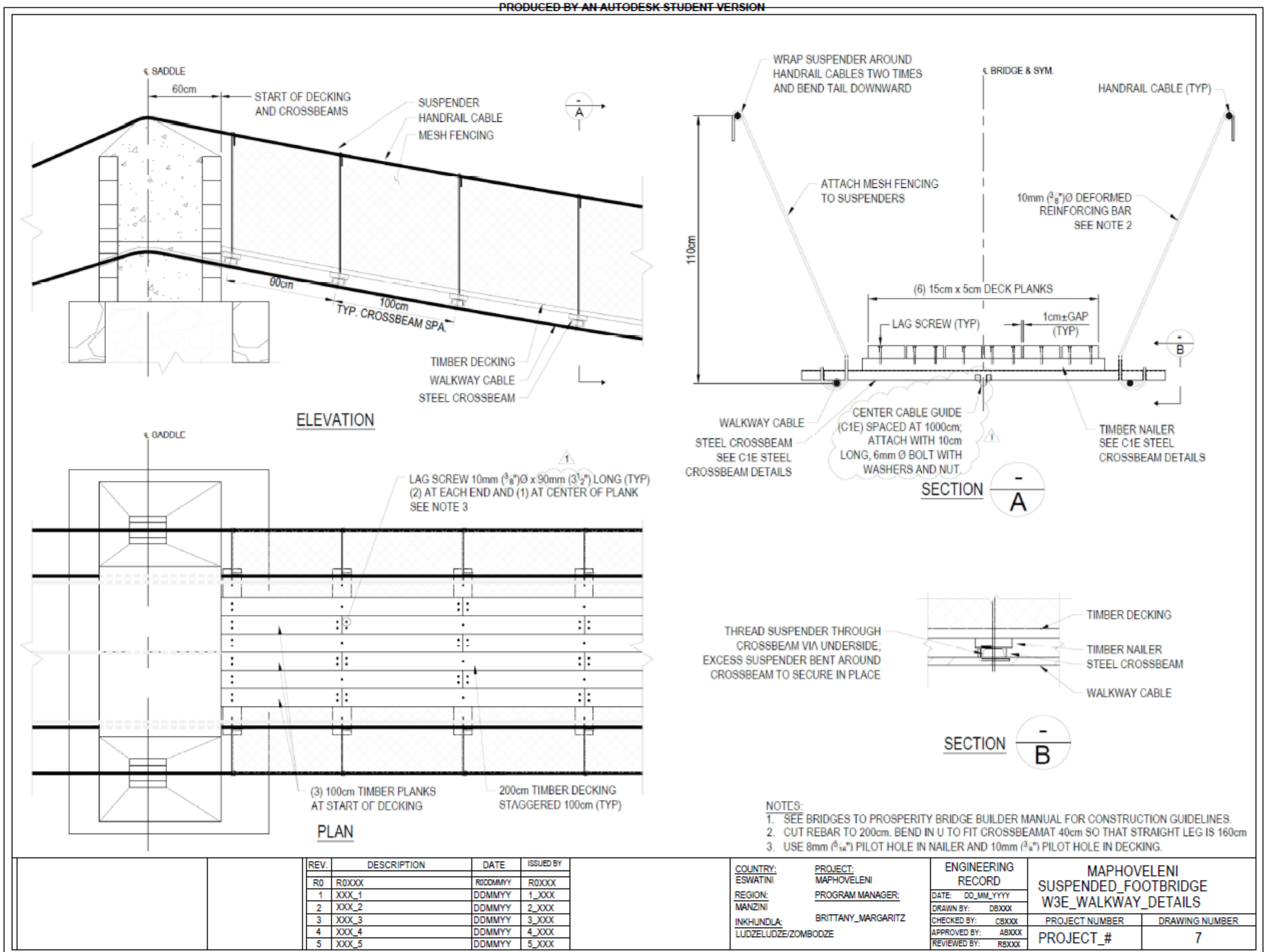
3	XXX_3	DDMMYY	3_XXX
4	XXX_4	DDMMYY	4_XXX
5	XXX_5	DDMMYY	5_XXX

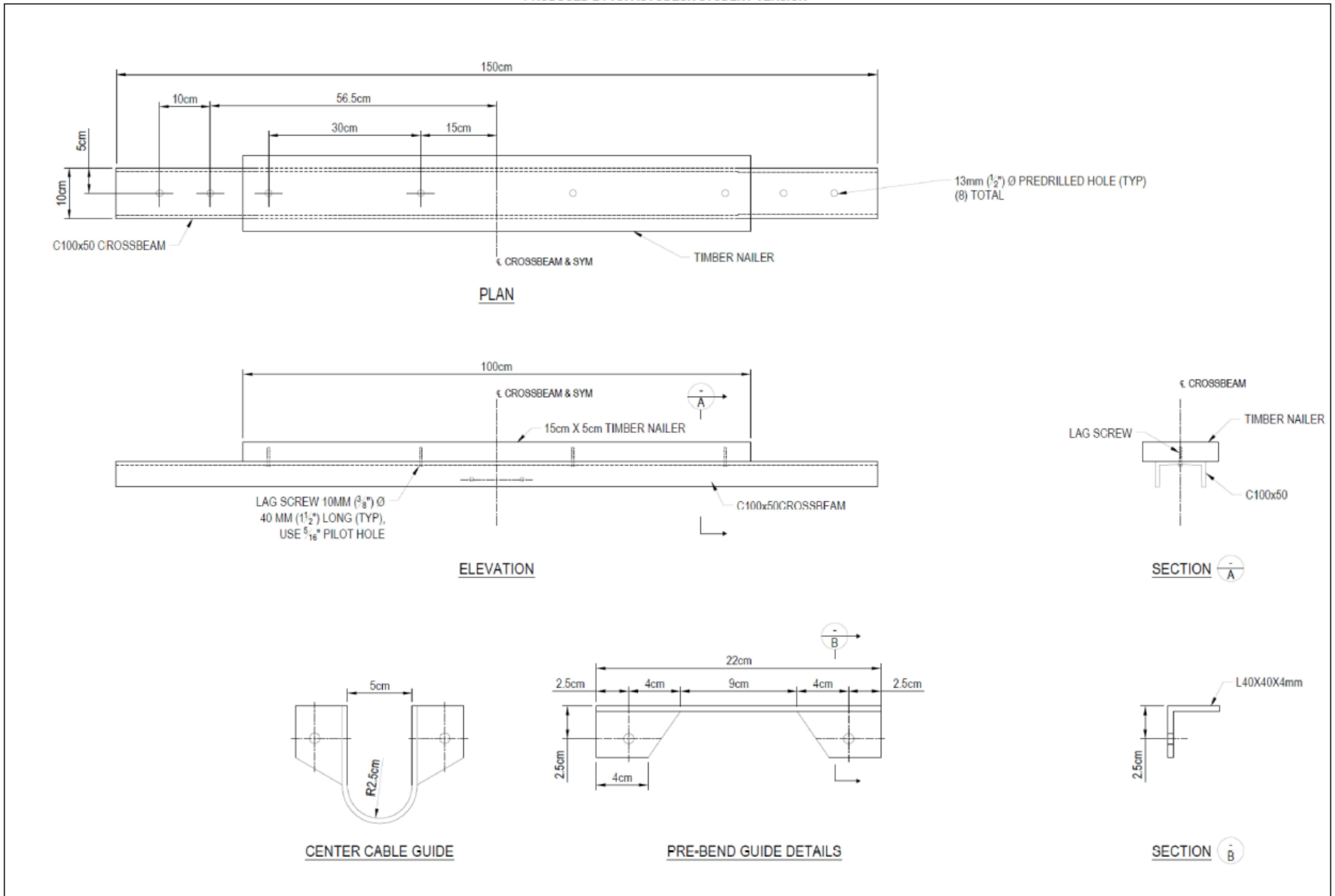
COUNTRY: ESWATINI
PROJECT: MAPHOVELENI
REGION: MANZINI
PROGRAM MANAGER: BRITTANY_MARGARITZ
INKHUNDLA: LUDZELUDZE/ZOMBODZE

ENGINEERING RECORD
DATE: DD_MM_YYYY
DRAWN BY: DBXXX
CHECKED BY: CBXXX
APPROVED BY: ABXXX
REVIEWED BY: RBXXX

MAPHOVELENI
SUSPENDED_FOOTBRIDGE
T4_TOWER_DETAILS

PROJECT NUMBER	DRAWING NUMBER
PROJECT_#	6


PRODUCED BY AN AUTODESK STUDENT VERSION
℄ SADDLE
60cm
START OF DECKING AND CROSSBEAMS
SUSPENDER
HANDRAIL CABLE
MESH FENCING
90cm
100cm
TYP. CROSSBEAM SPA.
TIMBER DECKING
WALKWAY CABLE
STEEL CROSSBEAM
ELEVATION
WRAP SUSPENDER AROUND HANDRAIL CABLES TWO TIMES AND BEND TAIL DOWNWARD
℄ BRIDGE & SYM.
HANDRAIL CABLE (TYP)
ATTACH MESH FENCING TO SUSPENDERS
10mm (3/8")Ø DEFORMED REINFORCING BAR SEE NOTE 2
110cm
(6) 15cm x 5cm DECK PLANKS
LAG SCREW (TYP)
1cm±GAP (TYP)
WALKWAY CABLE
STEEL CROSSBEAM SEE C1E STEEL CROSSBEAM DETAILS
CENTER CABLE GUIDE (C1E) SPACED AT 1000cm; ATTACH WITH 10cm LONG, 6mm Ø BOLT WITH WASHERS AND NUT.
TIMBER NAILER SEE C1E STEEL CROSSBEAM DETAILS
SECTION A
LAG SCREW 10mm (3/8")Ø x 90mm (3½") LONG (TYP) (2) AT EACH END AND (1) AT CENTER OF PLANK SEE NOTE 3
(3) 100cm TIMBER PLANKS AT START OF DECKING
200cm TIMBER DECKING STAGGERED 100cm (TYP)
PLAN
THREAD SUSPENDER THROUGH CROSSBEAM VIA UNDERSIDE; EXCESS SUSPENDER BENT AROUND CROSSBEAM TO SECURE IN PLACE
TIMBER DECKING
TIMBER NAILER
STEEL CROSSBEAM
WALKWAY CABLE
SECTION B
NOTES:
1. SEE BRIDGES TO PROSPERITY BRIDGE BUILDER MANUAL FOR CONSTRUCTION GUIDELINES.
2. CUT REBAR TO 200cm. BEND IN U TO FIT CROSSBEAMAT 40cm SO THAT STRAIGHT LEG IS 160cm
3. USE 8mm (5/16") PILOT HOLE IN NAILER AND 10mm (3/8") PILOT HOLE IN DECKING.
REV. | DESCRIPTION | DATE | ISSUED BY
R0 | R0XXX | R0DDMMYY | R0XXX
1 | XXX_1 | DDMMYY | 1_XXX
2 | XXX_2 | DDMMYY | 2_XXX
3 | XXX_3 | DDMMYY | 3_XXX
4 | XXX_4 | DDMMYY | 4_XXX
5 | XXX_5 | DDMMYY | 5_XXX
COUNTRY: ESWATINI
PROJECT: MAPHOVELENI
REGION: MANZINI
PROGRAM MANAGER: BRITTANY_MARGARITZ
INKHUNDLA: LUDZELUDZE/ZOMBODZE
ENGINEERING RECORD
DATE: DD_MM_YYYY
DRAWN BY: DBXXX
CHECKED BY: CBXXX
APPROVED BY: ABXXX
REVIEWED BY: RBXXX
MAPHOVELENI SUSPENDED_FOOTBRIDGE W3E_WALKWAY_DETAILS
PROJECT NUMBER: PROJECT_#
DRAWING NUMBER: 7



REV.	DESCRIPTION	DATE	ISSUED BY
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2	XXX_2	DDMMYY	2_XXX
3	XXX_3	DDMMYY	3_XXX
4	XXX_4	DDMMYY	4_XXX
5	XXX_5	DDMMYY	5_XXX

COUNTRY: ESWATINI
PROJECT: MAPHOVELENI
REGION: MANZINI
PROGRAM MANAGER: BRITTANY_MARGARITZ
INKHUNDLA: LUDZELUDZE/ZOMBODZE

ENGINEERING RECORD
DATE: DD_MM_YYYY
DRAWN BY: DBXXX
CHECKED BY: CBXXX
APPROVED BY: ABXXX
REVIEWED BY: RBXXX

MAPHOVELENI
SUSPENDED_FOOTBRIDGE
C5E_CROSSBEAM_DETAILS

PROJECT NUMBER	DRAWING NUMBER
PROJECT_#	8

PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION