Bridges to Prosperity

Changing Lives One Bridge at a Time

Volume 3: Suspended Pedestrian Bridge
Part 1: Design and Analysis

First Edition 2009

Foreword

Bridges to Prosperity Suspended Bridge Manual

Dear User:

The creation of this manual has been over 32 years in the making. In 1977 Engineer Robert Groeli made an official trip to the Baglung District in Nepal to view the incredible chain suspended bridges being built by the locals there. His report that followed launched a program operated by the Nepalese Government and supported by Helvetas of Zurich, Switzerland to enhance and replicate this amazing technology elsewhere in Nepal. By the late 1990's, the BBLL (Building Bridges at the Local Level) had become one of the most successful development infrastructure programs in the world. Their early success was followed by publishing the "Suspended Short Span Trail Bridge Standard Technical Handbook and Drawings" in 2002 which was followed by the completion of 2,500 bridge in Nepal by 2008.

The publishing of this manual coincided with Helvetas agreeing to train our first in-country managers in 2003: Zoe Pacciani and Chris Rollins. As we expanded the Helvetas community footbridge program into Africa and Latin American, it became apparent that the original Helvetas drawings needed to be converted into AutoCAD, and the manuals converted into a visual format. These changes are effective not only for ease of training, but also to allow the manualsand drawings to be easily adapted to each new country, allowing for changes in topography, available resources, and culture. Like Helvetas found, one cannot publish a manual like this overnight. Even with the generous jumpstart training received from Helvetas Nepal, it took us 8 years to gain the experience necessary to do so and as any text, these manuals will always be a work in progress, leading to annual review and revision.

The volunteer, donors, and sponsors that made this all possible are too many to name. But, I would like to specifically thank Parsons Brinckerhoff (PB) of NYC for converting the Claris Draw documents into AutoCAD, the Rotary Club of Newport News, 35 other Rotary Clubs and the Rotary Foundation, and the volunteers and staff on the Bridges to Prosperity design team (Jeremy Johannesen, Avery Bang, Zoe Pacciani, and Chris Rollins) that contributed so many hours to make this possible.

In the same spirit that allowed us to freely use the Helvetas manuals, we hereby do the same. This manual is a gift and can be freely copied and distributed. We would ask, however, that any changes made to the manual are not only shared with Helvetas and Bridges to Prosperity so that we all might benefit, but that you also make any new manuals or changes free and available to all as well.

Sincerely,

Kenneth R. Frantz, Rotarian &
Founder, Bridges to Prosperity, Inc.
5007 C-126 Victory Blvd.
Yorktown, VA 23693
www.bridgestoprosperity.org

Rotary Club of Newport News

Introduction

In 2003, Bridges to Prosperity (B2P) staff traveled to Nepal to train with the Swiss organization Helvetas to learn about their cable-suspended bridge technology. Design and construction of the suspended bridge were taught in addition to Helvetas' approach to participatory bridge building at the community level. Over the past 6 years, Bridges to Prosperity has introduced the highly efficient and economical Suspended Bridge design to countries in need of the technology all around the world.

The designs included in the Volume 3 Suspended Pedestrian Bridge Manual originated with the Helvetas Nepal Short Span Trail Bridge Technical Handbook that was created with over 30 years of experience in the mountainous regions of Nepal. Bridges to Prosperity has encountered new technical and cultural challenges as we have taken the technology from Ethiopia to Peru. The designs have been modified and adapted to better suit the given area of work. Bridges to Prosperity has modified construction practices and expanded flexibility in design alternatives and design process materials to ensure the suspended pedestrian bridge remains a locally sustainable option for communities in varying topographic and geographic regions of the world.

There are four components to Volume 3: Suspended Pedestrian Bridge Manual, structured as follows:

Part 1: ***Design and Material Quantities***

Part 2: ***Construction Plans***

Part 3: ***Construction Guide & Quality Control***

Part 4: ***Operations & Maintenance***

As with any modulated design, usage assumptions must be made by the original designer. The following manual will attempt to provide both modulated drawings for use without additional engineering and design guides for those interested in bridge uses not covered within these manuals. For further design and loading assumptions reference the Helvetas Nepal Short Span Trail Bridge Technical Handbook, internationally accepted design standards as well as locally pertinent design codes and standards.

Volume 3 Suspended Pedestrian Bridge
Part 1: Design and Analysis
Table of Contents

Section 1: Suspended Bridge Design Background

1.1 Design Loadings & Assumptions

The following section details basic load assumptions used by Bridges to Prosperity when modifying and extrapolating upon the original bridge design. They need not be referenced for non-engineer designers, as all designs are already complete using the following codes and assumptions. Skip to Section 2 for design process.

1.1.1 Liveloads

Before starting on the bridge design, verify with local structural loading codes and regulations. The Bridges to Prosperity standard for liveload is 3.11 kN/m² (65 lb/ft²). As noted in AASHTO (1997), the live load reduction from 4.07 kN/m² (85 lb/ft²) for decking areas exceeding 400 square feet is consistent with ASCE 7-95, "Minimum Design Loads for Buildings and Other Structures." The reduction accounts for the reduced probability of the large loading area of the structure being fully loaded at any given time and is consistent with the loadings expected for a typical pedestrian bridge.

Total LL = 3.11 kN/m, assuming 1.0 meter width

1.1.2 Dead Loads

The deadload is the sum of all self-weights of the bridge materials. Below is a table of assumed sizes and weights, used in B2P design efforts.

	Assumptions/Conversions	Loading
Suspenders	8 mm diameter x 1.7 m steel rebar = 8.5e-5 m³ per rod Unit weight steel = 490 lb/ft³ = 7847.3 kg/m³ 0.67 kg per suspender 0.0098 kN/kg Suspender spacing 1 meter on center per side	0.007 kN/ m
Cross beams	10 cm x 10 cm x 1.4 m Assume 600 kg/ m³ Cross beams 1 meter on center	0.082 kN/m
Decking	5 cm x 20 cm x 2 m = 0.02 m³ per 2 meter member Assume 400 kg/ m³ 8 kg per decking panel 5 decking panels across	0.196 kN/m
Cable	Assume 6x19 IWRC galvanized steel cable Assume 32 mm cable (1 ¼") : 2.89 lb/ft Assume 6 cables 1 lb/ft = 1.288 kg/m	0.036 kN/m

Total DL = 0.321 kN/m, assuming 1.0 meter width

1.1.3 Wind Loads (Overturning)

A wind load applied horizontally at a right angle to the longitudinal axis of the bridge shall be applied at 1.676 kN/m² (35 lb/ft²). The specified wind pressures are for a wind velocity of 100 miles per hour. In such case a site has higher wind-velocity requirements: AASHTO Article 3.15 (1997) may be referenced or another local code. Given the projected profile of the bridge is 1.1 meters in height: the resulting wind overturn force is 1.843 kN/m.

Total WL = 1.843 kN/m, assuming 1.1 meter railing height

1.1.4 Load Combinations

To calculate the accumulative effective load, each possible load combination must be checked to find the maximum controlling case. The following load combinations will be used, extracted from Table 3.22.1A in AASHTO (1997):

$$\text{Group I: } DL + LL = 0.321\frac{\text{kN}}{\text{m2}} + 3.11\frac{kN}{m^2} = 3.43kN/m^2 \rightarrow \text{directs}$$

$$\text{Group II: } \frac{(DL+WL)}{1.25} = \frac{(0.321+1.843\ )}{1.25} = 1.73kN/m^2$$

$$\text{Group III: } \frac{(DL+LL+0.3*WL)}{1.25} = \frac{(0.321+3.11+0.3*1.843)}{1.25} = 3.18\ kN/m^2$$

Further details of design assumptions may be referenced in Section 5.

1.2 Limitations

The suspended bridge is intended for pedestrians, livestock and any small cart capable of crossing on the 1.0 meter wide deck width. Widening the deck up to 1.5 meters is possible as well, but requires an engineer evaluate the anchor, tower and decking plans. It is recommended that any bicycles, animals or motorbikes be walked across, but all are considered acceptable for crossing.

Although the lateral wind loadings proportionally increase with increased span, there is a design limit of 120 meters without additional wind guy structures. The longitudinal rigidity of the bridge is compromised beyond 120 meters without the additional lateral support. Wind guys significantly increase the overall cost of the structure as two (2) additional cables and four (4) additional anchors are required.

The design guide is also limited to 1.0 meter deck widths. Increasing the deck width thereby increases both the dead and liveload and therefore requires an engineer to complete calculations. Future editions of this manual may include a greater number of alternatives Furthermore, if a steel deck is chosen, the corresponding deadload is increased. Note that the original Helvetas Nepal design included the steel deck loadings and therefore if steel deck is chosen, no design loading modifications are necessary.

Section 2: Design Procedure

2.1 Overview

Designing the suspended cable bridge requires very little technical background. The following section will provide a step by step guide to designing a bridge following the completion of the site survey as outlined in *Volume 2 Feasibility & Topographic Survey*.

2.2 Abney Level Survey

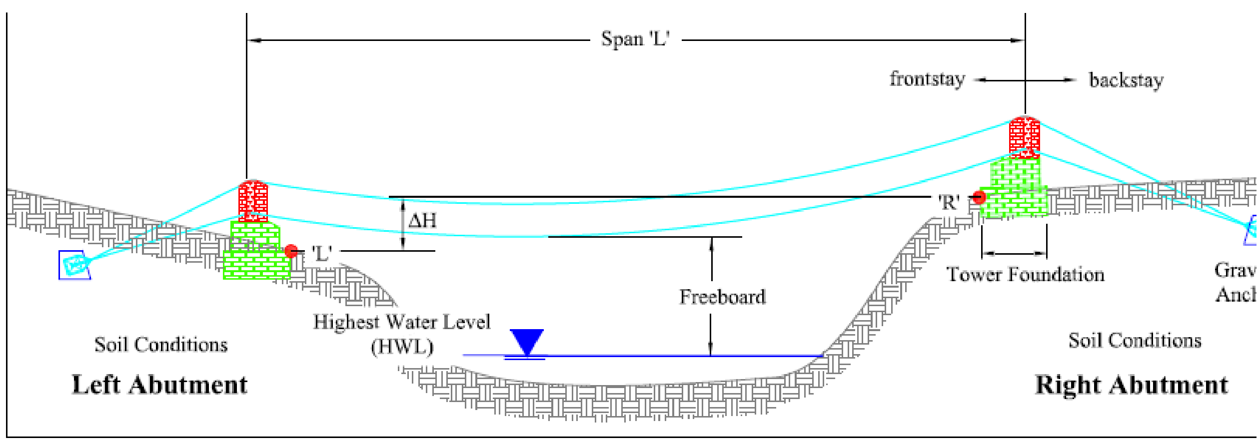
If not done so already, complete a bridge profile survey using an Abney level. Reference *Volume 2 Feasibility & Topographic Survey* for complete details.

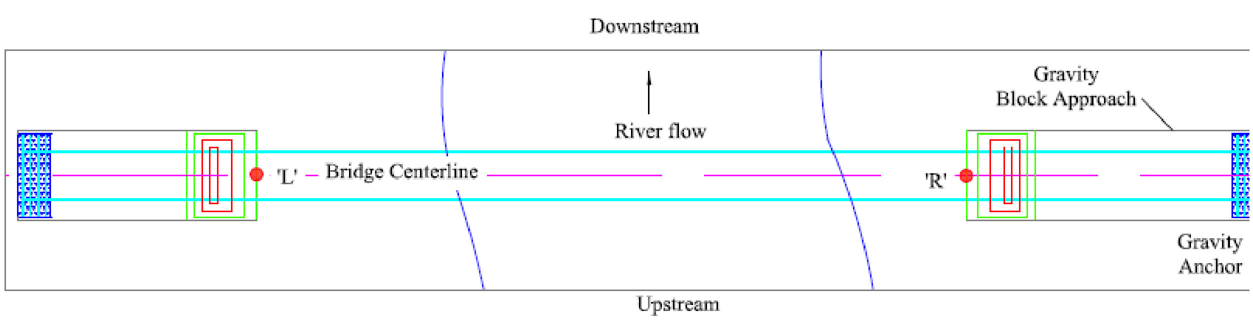
2.3 Bridge Profile & Fix Foundation Locations

Create a profile sketch from the site survey. Use points 'L' and 'R' from the survey to mark the preliminary location of the towers for the left and right side respectively. Verify that the left abutment is the left side of the bank when facing down stream, water to one's back.

Define critical components:

- Span in meters. Note if measured between 'L' and 'R' or if intended mid-tower span
- Height difference between 'L' and 'R', from elevation data on survey sheet
- Note soil or rock type on either side





2.4 Calculate Required Number of Tiers

A minimum clearance is required between the lowest point in the cable and the highest point that the water has ever reached (HWL). Furthermore, the maximum height difference between the two towers must be no more than the span (L) divided by 25, or four percent of the span. If ΔH (the height difference between points 'L' and 'R')) exceeds this amount, one or more of the towers needs to be raised. To provide adequate clearance and to equalize differences in elevation between two sides, one must calculate the required number of tiers; each tier is 1.0 meter tall as the elevation of the bridge towers dictate the elevation of the cables.

In order to calculate the required height, the following information must be known;

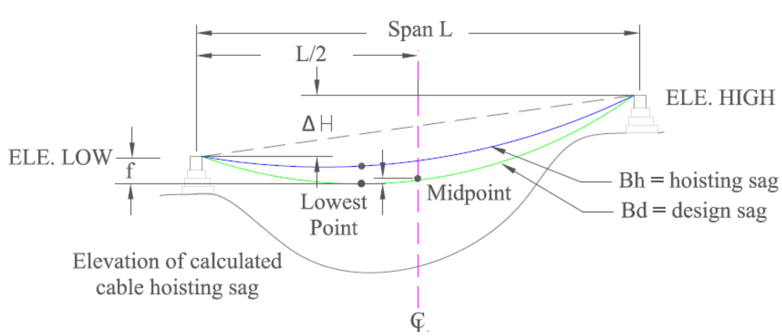
- **Span (L)** in meters (must be less than 120 meters)
  As the survey points 'L' and 'R' are relative to the front of foundation to front of foundation, start by assuming an addtional 1.40 meters on either side to include walkway saddle to walkway saddle span. Once drawings selected, verify the dimension.

- **Height difference (ΔH)** = Elevation 'L' – Elevation 'R'
  Start by assuming that each side has one tier, so the elevation of the walkway towers is 1.40 meters above 'R' and 'L' respectively (1.0 meter for one tier, 40 cm for saddle placement, per the tower drawing T1). Use the same elevation assumptions and nomiclature as used in the survey: low side foundation elevation = 100.00.

- **Cable Design Sag (Bd) and Hoisting sag (Bh)** (for Non-Prestreched Cable)
  The cable sag is the vertical drop that the cable will dip below the walkway saddles. The cable is hoisted to a lesser sag than is designed because once the cable is set, the self-weight of the bridge in addition to the loading will slightly stretch the cable. As such, the final lowest point is the design sag, but the actual low point takes both into consideration.

	Less than 80 m	***Greater than 80 m***
$B_d = Design\ Sag$	5.00% x L	4.55% x L
$B_h = Hoist\ Sag$	4.00% x L	3.64% x L

- **Low point 'f'**
  If both sides are equal height (ΔH = 0), then the low point is directly in the middle. If not, the Calculate using the following equation or use the low point matrix on the following page.



$$f = \frac{(4B_d - \Delta H)^2}{16B_d}$$

Design Sag Elevation

Relative to low side Abutment

Span (m)

Height Differential ΔH between abutments (m)	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.00	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.00	4.09	4.32	4.55	4.77	5.00	5.23
0.25	1.63	1.88	2.13	2.38	2.63	2.88	3.13	3.38	3.63	3.88	3.88	3.97	4.19	4.42	4.65	4.88	5.10
0.50	1.51	1.76	2.01	2.26	2.51	2.76	3.00	3.25	3.50	3.75	3.75	3.84	4.07	4.30	4.53	4.75	4.98
0.75	1.40	1.64	1.89	2.14	2.39	2.64	2.89	3.14	3.38	3.63	3.63	3.72	3.95	4.18	4.41	4.63	4.86
1.00	1.29	1.53	1.78	2.03	2.27	2.52	2.77	3.02	3.27	3.52	3.52	3.61	3.83	4.06	4.29	4.51	4.74
1.25	1.18	1.42	1.67	1.91	2.16	2.41	2.66	2.90	3.15	3.40	3.40	3.49	3.72	3.94	4.17	4.39	4.62
1.50	1.08	1.32	1.56	1.81	2.05	2.30	2.54	2.79	3.04	3.29	3.29	3.38	3.60	3.83	4.05	4.28	4.50
1.75	0.98	1.22	1.46	1.70	1.94	2.19	2.43	2.68	2.93	3.17	3.17	3.26	3.49	3.71	3.94	4.16	4.39
2.00	0.89	1.13	1.36	1.60	1.84	2.08	2.33	2.57	2.82	3.06	3.06	3.15	3.38	3.60	3.83	4.05	4.28
2.25	0.81	1.03	1.27	1.50	1.74	1.98	2.22	2.47	2.71	2.95	2.95	3.04	3.27	3.49	3.71	3.94	4.16
2.50	0.72	0.95	1.17	1.41	1.64	1.88	2.12	2.36	2.60	2.85	2.85	2.94	3.16	3.38	3.60	3.83	4.05
2.75	0.65	0.86	1.09	1.31	1.55	1.78	2.02	2.26	2.50	2.74	2.74	2.83	3.05	3.27	3.50	3.72	3.94
3.00	0.57	0.78	1.00	1.23	1.45	1.69	1.92	2.16	2.40	2.64	2.64	2.73	2.95	3.17	3.39	3.61	3.83
3.25	0.50	0.71	0.92	1.14	1.37	1.60	1.83	2.06	2.30	2.54	2.54	2.63	2.85	3.07	3.29	3.51	3.73
3.50	0.44	0.63	0.84	1.06	1.28	1.51	1.74	1.97	2.20	2.44	2.44	2.53	2.75	2.96	3.18	3.40	3.62
3.75	0.38	0.56	0.77	0.98	1.19	1.42	1.65	1.88	2.11	2.34	2.34	2.43	2.65	2.86	3.08	3.30	3.52
4.00	0.32	0.50	0.69	0.90	1.11	1.33	1.56	1.79	2.02	2.25	2.25	2.34	2.55	2.77	2.98	3.20	3.42
4.25	0.27	0.44	0.63	0.83	1.04	1.25	1.47	1.70	1.93	2.16	2.16	2.24	2.45	2.67	2.88	3.10	3.32
4.50	0.22	0.38	0.56	0.76	0.96	1.17	1.39	1.61	1.84	2.07	2.07	2.15	2.36	2.57	2.79	3.00	3.22
4.75	0.18	0.33	0.50	0.69	0.89	1.10	1.31	1.53	1.75	1.98	1.98	2.06	2.27	2.48	2.69	2.91	3.12
5.00	0.14	0.28	0.44	0.63	0.82	1.02	1.23	1.45	1.67	1.89	1.89	1.97	2.18	2.39	2.60	2.81	3.03
5.25	0.11	0.24	0.39	0.56	0.75	0.95	1.16	1.37	1.58	1.81	1.81	1.89	2.09	2.30	2.51	2.72	2.93
5.50	0.08	0.20	0.34	0.51	0.69	0.88	1.08	1.29	1.50	1.72	1.72	1.80	2.01	2.21	2.42	2.63	2.84
5.75	0.06	0.16	0.29	0.45	0.63	0.81	1.01	1.22	1.43	1.64	1.64	1.72	1.92	2.13	2.33	2.54	2.75
6.00	0.04	0.13	0.25	0.40	0.57	0.75	0.94	1.14	1.35	1.56	1.56	1.64	1.84	2.04	2.24	2.45	2.66

- **Verify adequate Freeboard (Fb)**

Freeboard is the clearance required between the lowest point in the cable and the highest point of the water. An engineer may reduce or increase the suggested freeboard values in accordance with site topographic conditions, but for general purposes, minimum freeboard clearance required is as follows;

- Mountainous gorges: 4.0 -5.0 meters
- Flood Plains: 2.0 meters

Freeboard is verified by taking the low side 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 number of tiers on either one or both foundations.

$$F_b = Low\ Ele. - f - HWL$$

Example:

A flat valley surveyed with a span of 60 meters, point 'L' 2.0 meters lower than point 'R', and a High Water Level (HWL) at elevation 96.5 meters from the survey;

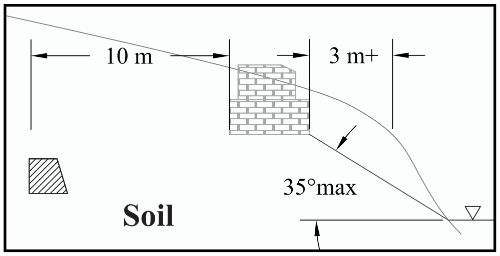
Low side elevation = 101.40 meters
Low point in cable (relative to low side) 'f' = 2.08 meters
High Water Level (HWL) = 96.5 meters

$$F_b = Low\ Ele. - f - HWL = 101.40 - 2.08 - 96.5 = 2.82 > 2.0$$ **Okay**

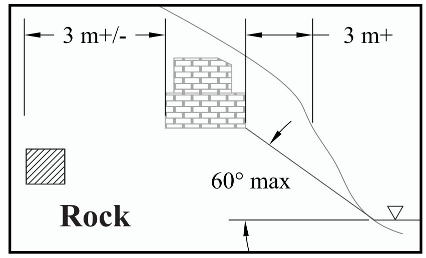
Finalize Position of Foundations

After selecting the number of tiers required, the size of the foundation footprint is known. This step will verify the layout and design. If front of foundation survey points 'L' and 'R' must be moved, take care to note on survey and at field site.

- Verify adequate slope angle or distance from slope (*Volume 2 Topographic Survey*)



Maximum 35 degree slope in soil
<u>or</u> minimum 3.0 meters from edge



Maximum 60 degree slope in rock
<u>or</u> minimum 1.5 meters from edge

- Verify span less than 120 meters between saddles
- Verify final height difference from top of tiers (ΔH) < L / 25
- Take final span and recalculate Design Sag, Bd. Verify low point 'f'

$$f = \frac{(4B_d - \Delta H)^2}{16B_d}$$

- Calculate Freeboard

$$F_b = Low\ Ele. - f - HWL$$

- Verify clearance greater than minimum allowance

Flood Plains: 2.0 meters

Mountainous gorge: 3.0 meters

2.6 Select Tier & Anchor Designs

There are two types of anchor designs; Gravity Anchors and Drum Anchors. Gravity Anchors may be used in any soil or rock conditions and they rely on 'deadweight', or material placed over the anchor. As such, the excavation required is considerable.

Drum Anchors require rock conditions as they rely on friction between the rock face and the poured concrete drum. As such, only hard or fractured rock conditions are acceptable. See *Volume 2: Feasibility & Topographic Survey* for more information.

Gravity Anchor plans are split into two main subcategories; 0 - 60 meter spans, and 61 - 120 meter spans. Each classification includes one (1), two (2), and three (3) tier alternatives. A summary of Gravity Anchor Plans found in *Volume 3 Part 2: Suspended Bridge Drawings* are as follows:

0 - 60 m	1 Tier Gravity Anchor	1G60
0 - 60 m	2 Tier Gravity Anchor	2G60
0 - 60 m	3 Tier Gravity Anchor	3G60
61 - 120 m	1 Tier Gravity Anchor	1G120
61 - 120 m	2 Tier Gravity Anchor	2G120
61 - 120 m	3 Tier Gravity Anchor	3G120

Drum Anchor plans are also split into two main subcategories; 0 - 60 meter spans, and 61 - 120 meter spans. No further classification is needed as rock anchors do not lend themselves to more than one tier. This is due to the short distance between the anchor and the saddles, required due to sloped rock conditions. To raise the number of tiers would require to set anchor proportionally further back into the rock, thus increasing difficulty. There are three sizes of drum anchors; small, medium and large. Small (0 - 40 meters) and Medium (41 - 60 meters) anchors are included in 1D60, Large (60 -120 meters) may be found in 1D120. A summary of Drum Anchor Plans found in *Volume 3 Part 2: Suspended Bridge Drawings* are as follows:

0 - 60 m	1 Tier Drum Anchor in Rock	1D60
61 - 120 m	2 Tier Drum Anchor in Rock	1D120

2.7 Select Cable Sizes: Cable Look-Up Tool

Bridges to Prosperity created a Microsoft Excel Cable Look-up Tool, available at their website at www.bridgestoprosperity.org/resources.

The Cable Look-up Tool requires the user to input the breaking strength (often referred to as breaking force) of available cable in pounds, and based on any number of cable number combinations, outputs the maximum span allowable for a given deck width. Before using the tool, research available steel cable and request a Proforma Invoice stating breaking strengths for given cables.

The Cable Look-up Tool assumes that the cable has a liveload elongation of 0.325% and is intended for use with non-prestretched cable.

Step 1

Research available cable breaking strengths. If reported in metric tons or kilonewtons (kN), convert into pounds using the following relationships:

$$Metric\ Tons\ x\ 2204.62\ \frac{pounds}{Metric\ Ton} = value\ in\ pounds$$

$$kN\ x\ 224.81\ \frac{pounds}{kN} = value\ in\ pounds$$

Step 2

Input Breaking Strength values (in pounds) and desired number of cables (red text).

Step 3

Modify combinations until desired deck width has value at least as long as bridge span (yellow).

Example:

Input 2 walkway cables and 2 handrail cables. Try again with 4 walkway cables and 2 handrail cables.

CABLE SELECTION - BRIDGES TO PROSPERITY

SUSPENDED BRIDGES: 20 - 120 meters

LOOKUP TOOL FOR CABLE CAPACITY

ENTER BREAKING FORCE OF CABLES (lbs.)

Available Honduras Cable		
size	Breaking Strength	
26 mm	90000	pounds
30 mm	108000	pounds
32 mm	130000	pounds

USER NOTICE:

1. This spreadsheet is intended for use with NON-prestretched cable.
   Cable design is in conjunction with the Helvitas Short Span Trail Bridge Manual
   Suspended Type - Volume 1.
2. Hoisting sag = 80% x the Sag specified below.
3. Assumed Live Load elongation = 0.325%.
4. Contact Bridges to Prosperity with questions: www.bridgestoprosperity.org

DECK CABLES:	2	@	130,000	pounds
HAND CABLES:	2	@	90,000	pounds
TOTAL BREAKING FORCE =			440,000	pounds

MAXIMUM SPAN LENGTH FOR 440000 lb. CABLE CAPACITY (FS=3)

Deck:	70cm	75cm	80cm	85cm	90cm
Max Span:	100m	92m	85m	82m	79m
Sag (m):	4.55	4.18	4.00	4.00	3.95

Step 4

Calculate quantity of cable. Consider the costs of several combinations of cable before moving on. Often cable is sold by the reel of 500 meters, so if one combination requires slightly more than 500 meters, it may be worth the additional cost to increase the size of the cable to reduce the number of cables and thus the total required length.

Calculate the quantity of cable to order; where the distance between anchors, with an additional 14 meters and a 4 percent contingency to account for cable sag and wrap-back within the anchors. Find the distance values from the Construction Drawings.

$$L_{cable} = 1.04(L + 14 + d_{left\ tower\ to\ anchor} + d_{right\ tower\ to\ anchor})$$

2.8 Select Construction Drawings

For a given span, geologic conditions and number of tiers, two (2) Abutment Tier & Anchor drawings must be selected, one for each side of the river. The Tower drawing details the 1.0 meter deck width tower and is required. Three (3) Decking drawings must be selected for either 2 or 4 walkway cables, with alternatives between crossbeam nailers and no nailers respectively.

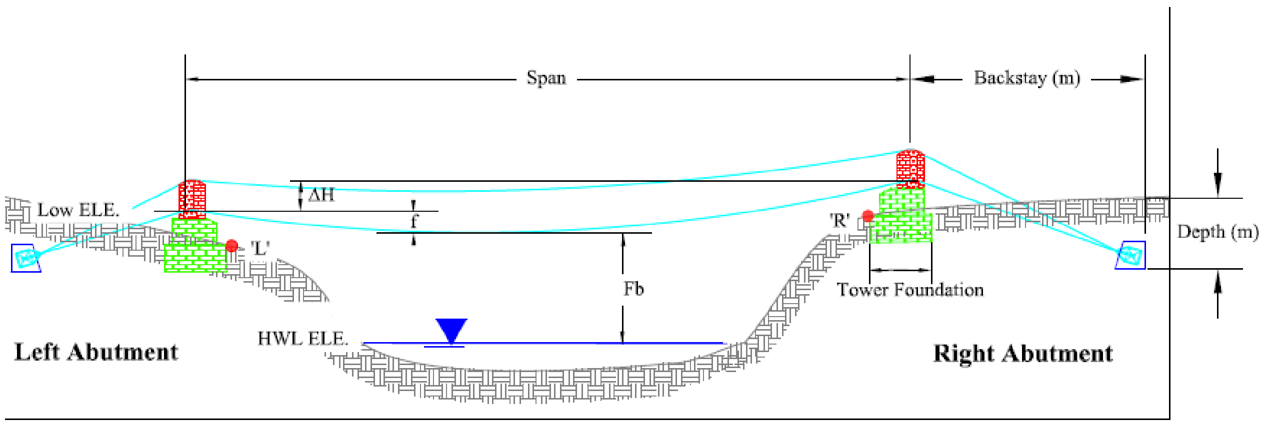
☐ Abutment Tier & Anchor (Right and Left side required)			
Gravity Anchors			
	0 - 60 m	1 Tier	1G60
	0 - 60 m	2 Tier	2G60
	0 - 60 m	3 Tier	3G60
	61 - 120 m	1 Tier	1G120
	61 - 120 m	2 Tier	2G120
	61 - 120 m	3 Tier	3G120
Rock Drum Anchors			
	0 - 60 m	1 Tier	1D60
	61 - 120 m	2 Tier	1D120

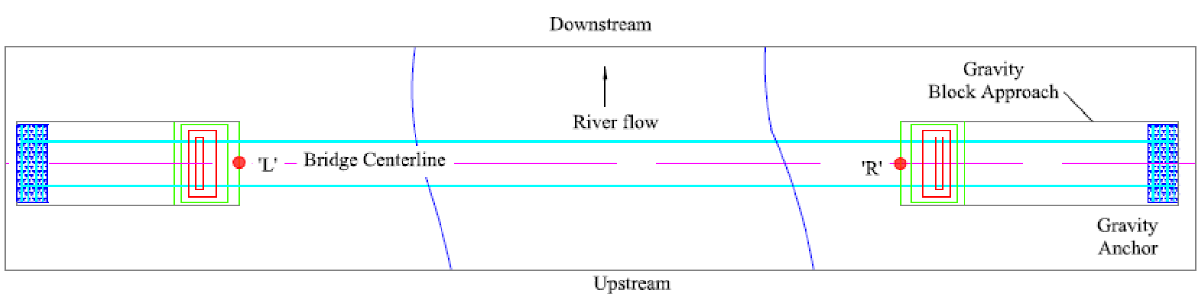
☐ Tower	1.0 m deck width	T1
☐ Decking Plan	2 walkway cables	W21
	4 walkway cables	W41
☐ Decking Section	2 walkway cables	W22
	4 walkway cables	W42
☐ Decking Detail		
With Nailer		
	2 walkway cables	W23
	4 walkway cables with Nailer	W43
No Nailer		
	2 walkway cables No Nailer	W24
	4 walkway cables No Nailer	W44

2.9 Compile into Final Drawings

Complete the bridge design by compiling all required bridge drawings and creating a bridge profile for the project. Include critical dimensions including span, depth of anchor, distance to the back of the anchor. Select the following drawings;

Gravity Anchor Right Side	1G60
Gravity Anchor Left Side	1G60
Tower 1.0 m deck width	T1
Decking Plan	W21
Decking Section	W22
Decking Detail With Nailer	W23





2.10 Design Example

A flood plain valley with a 60 meter span was surveyed. Critical points of the survey as follows:

- Point 'L' Elevation (low side) = 100.0 meters
- Point 'R' Elevation (high side) = 102.0 meters
- HWL = 96.5 meters

To calculate the minimum number of tiers, modify until freeboard (Fb) is greater than 2.0 meter minimum as specified for a valley. Start by assuming one tier (1.0 meter height plus 0.4 meter saddle coverage height).

Span (L) = 60 meters $100.0\ m + 1.40\ m = 101.4\ meters$

Elevation low side walkway saddle = $102.0\ m + 1.40\ m = 103.4\ meters$

Elevation high side walkway saddle = $\Delta H = 103.4\ m - 101.4\ m = 2.0\ meters$

Height difference (ΔH) = $\Delta H < \frac{L}{25} ==> 60/25 = 2.4\ m > 2.0\ m\ OKAY$

Verify:

Cable Design Sag (Bd)

$$B_d = 5.0\% * \ L\ (Design\ sag, less\ than\ 80\ meter\ span) = \ 0.05 * 60.0 = 3.0\ meters$$

Low point 'f'

Cross reference span and ΔH on Design Sag Elevation Chart = 2.08 meters

Design Sag Elevation

Relative to low side Abutment

Height Differential ΔH between abutments (m)	Span (m)																
	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.00	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.00	4.09	4.32	4.55	4.77	5.00	5.23
0.25	1.63	1.88	2.13	2.38	2.63	2.88	3.13	3.38	3.63	3.88	3.88	3.97	4.19	4.42	4.65	4.88	5.10
0.50	1.51	1.76	2.01	2.26	2.51	2.76	3.00	3.25	3.50	3.75	3.75	3.84	4.07	4.30	4.53	4.75	4.98
0.75	1.40	1.64	1.89	2.14	2.39	2.64	2.89	3.14	3.38	3.63	3.63	3.72	3.95	4.18	4.41	4.63	4.86
1.00	1.29	1.53	1.78	2.03	2.27	2.52	2.77	3.02	3.27	3.52	3.52	3.61	3.83	4.06	4.29	4.51	4.74
1.25	1.18	1.42	1.67	1.91	2.16	2.41	2.66	2.90	3.15	3.40	3.40	3.49	3.72	3.94	4.17	4.39	4.62
1.50	1.08	1.32	1.56	1.81	2.05	2.30	2.54	2.79	3.04	3.29	3.29	3.38	3.60	3.83	4.05	4.28	4.50
1.75	0.98	1.22	1.46	1.70	1.94	2.19	2.43	2.68	2.93	3.17	3.17	3.26	3.49	3.71	3.94	4.16	4.39
2.00	0.89	1.13	1.36	1.60	1.84	2.08	2.33	2.57	2.82	3.06	3.06	3.15	3.38	3.60	3.83	4.05	4.28
2.25	0.81	1.03	1.27	1.50	1.74	1.98	2.22	2.47	2.71	2.95	2.95	3.04	3.27	3.49	3.71	3.94	4.16
2.50	0.72	0.95	1.17	1.41	1.64	1.88	2.12	2.36	2.60	2.85	2.85	2.94	3.16	3.38	3.60	3.83	4.05
2.75	0.65	0.86	1.09	1.31	1.55	1.78	2.02	2.26	2.50	2.74	2.74	2.83	3.05	3.27	3.50	3.72	3.94
3.00	0.57	0.78	1.00	1.23	1.45	1.69	1.92	2.16	2.40	2.64	2.64	2.73	2.95	3.17	3.39	3.61	3.83
3.25	0.50	0.71	0.92	1.14	1.37	1.60	1.83	2.06	2.30	2.54	2.54	2.63	2.85	3.07	3.29	3.51	3.73
3.50	0.44	0.63	0.84	1.06	1.28	1.51	1.74	1.97	2.20	2.44	2.44	2.53	2.75	2.96	3.18	3.40	3.62
3.75	0.38	0.56	0.77	0.98	1.19	1.42	1.65	1.88	2.11	2.34	2.34	2.43	2.65	2.86	3.08	3.30	3.52
4.00	0.32	0.50	0.69	0.90	1.11	1.33	1.56	1.79	2.02	2.25	2.25	2.34	2.55	2.77	2.98	3.20	3.42
4.25	0.27	0.44	0.63	0.83	1.04	1.25	1.47	1.70	1.93	2.16	2.16	2.24	2.45	2.67	2.88	3.10	3.32
4.50	0.22	0.38	0.56	0.76	0.96	1.17	1.39	1.61	1.84	2.07	2.07	2.15	2.36	2.57	2.79	3.00	3.22
4.75	0.18	0.33	0.50	0.69	0.89	1.10	1.31	1.53	1.75	1.98	1.98	2.06	2.27	2.48	2.69	2.91	3.12
5.00	0.14	0.28	0.44	0.63	0.82	1.02	1.23	1.45	1.67	1.89	1.89	1.97	2.18	2.39	2.60	2.81	3.03
5.25	0.11	0.24	0.39	0.56	0.75	0.95	1.16	1.37	1.58	1.81	1.81	1.89	2.09	2.30	2.51	2.72	2.93
5.50	0.08	0.20	0.34	0.51	0.69	0.88	1.08	1.29	1.50	1.72	1.72	1.80	2.01	2.21	2.42	2.63	2.84
5.75	0.06	0.16	0.29	0.45	0.63	0.81	1.01	1.22	1.43	1.64	1.64	1.72	1.92	2.13	2.33	2.54	2.75
6.00	0.04	0.13	0.25	0.40	0.57	0.75	0.94	1.14	1.35	1.56	1.56	1.64	1.84	2.04	2.24	2.45	2.66

Verify Freeboard 'Fb'

$$F_b = Low\ Ele. - f - HWL = 101.40 - 2.08 - 96.5 = 2.82 > 2.0\ meters\ OKAY$$

Select Cable

The cable supplier provided specifications for a 26 mm IWRC cable with breaking strength of 30.0 metric tons (68,343 pounds). Using the Cable Look-up Tool, 4 walkway deck cables and 2 hand cables are required, as they are sufficient to a 64 meter span.

LOOKUP TOOL FOR CABLE CAPACITY
ENTER BREAKING FORCE OF CABLES (lbs.)

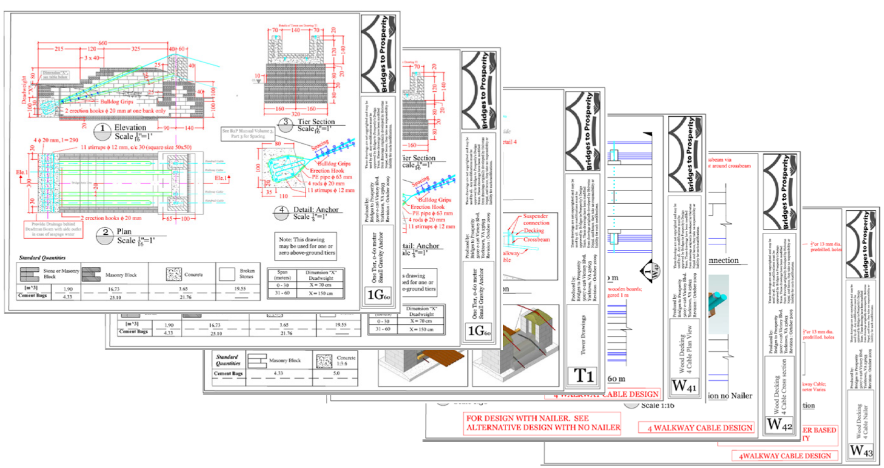
DECK CABLES:	4	@	68,343	pounds
HAND CABLES:	2	@	68,343	pounds
TOTAL BREAKING FORCE =			410,059	pounds

MAXIMUM SPAN LENGTH FOR 410059.20488 lb. CABLE CAPACITY (FS=3)

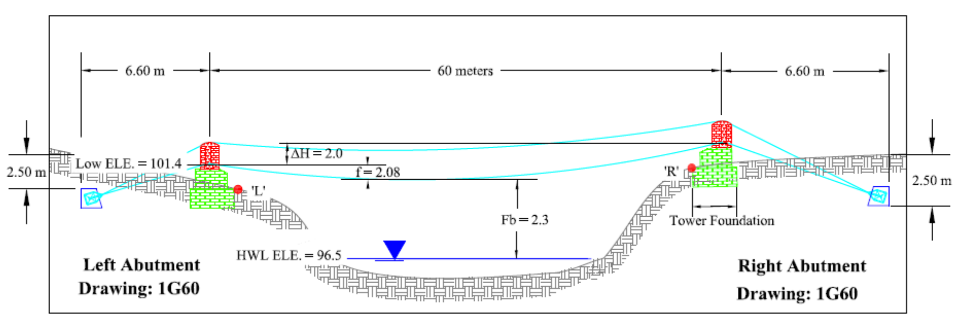
Deck:	70cm	75cm	80cm	85cm	90cm	100cm	106cm
Max Span:	92m	86m	81m	77m	72m	64m	60m
Sag (m):	4.18	4.00	4.00	3.85	3.60	3.20	3.00

Select Drawings

- One tier, 60 meters or less Right abutment = 1G60
- One tier, 60 meters or less Left abutment = 1G60
- Tower Drawing= T1
- Decking Plan, 4 cable = W41
- Decking Section, 4 cable = W42
- Decking Details, 4 cable Nailer = W43



Compile into Final Drawing



Section 3: Material Estimate

3.1 Cable & Clamps

Select steel cable based on the material breaking strengths, using the Cable Look-up Tool on www.bridgestoprosperity.org/resources. After selecting the optimum combination, calculate the quantity to order by multiplying the number of cables by the following equation:

$$L_{cable} = 1.04(L + 14 + d_{left\ tower\ to\ anchor} + d_{right\ tower\ to\ anchor})$$

The quantity of clamps per cable is dependant on the size of the cable and the type of clamp selected. The table below is the Bridges to Prosperity standard for torque requirements for drop-forged and malleable cable clamps at given cable and clamp diameters. Cable clamp manufacturer provide specifications that must be verified as this chart is only given as a guideline.

Drop-forged clamps are of superior quality and must be purchased whenever possible.

Cable diameter (mm)	Cable diameter (inches)	Spacing (cm)	Drop-Forged Clamps		NOT RECOMMENDED Malleable Clamps	
			Minimum # of	Torque in ft lbs.	Minimum # of clips	Torque in ft lbs.
3.2	1/8	19.2	2	4.5	4	3
4.8	3/16	28.8	2	7.5	4	4.5
6.4	1/4	38.4	2	15	4	15
7.9	5/16	47.4	2	30	4	15
9.5	3/8	57	2	45	4	30
11.1	7/16	66.6	2	65	5	40
12.7	1/2	76.2	3	65	5	45
11.1	9/16	66.6	3	95	5	50
15.9	5/8	95.4	3	95	5	75
19.1	3/4	114.6	4	130	6	75
22.2	7/8	133.2	4	225	6	130
25.4	1	152.4	5	225	7	130
28.6	1 1/8	171.6	6	225	7	200
31.8	1 1/4	190.8	7	360	8	200
34.9	1 3/8	209.4	7	360	10	200
38.1	1 1/2	228.6	8	360	--	--
41.3	1 5/8	247.8	8	430	--	--
44.5	1 3/4	267	8	590	--	--
50.8	2	304.8	8	750	--	--
57.2	2 1/4	343.2	8	750	--	--
63.5	2 1/2	381	9	750	--	--
69.9	2 3/4	419.4	10	750	--	--
76.2	3	457.2	10	1,200	--	--
88.9	3 1/2	533.4	12	1,200	--	--

3.2 Steel Reinforcement Bar

Towers

- 4 pieces steel rebar, 16 mm x 4.50 meters in length
- (# of walkway cables + 2) pieces, 16 mm x 20 cm

Decking Suspenders

- (Twice the (Span + 1) pieces), 8 mm smooth, cut to 1.80 m

Gravity Anchors

- Spans 60 meters or less (Small or Medium)
  - 4 pieces steel rebar, 20 mm, 2.90 m in length;
  - 11 square rings, 10 mm, cut to 2.20 m each, bent into squares 0.50 m per side

- Spans 61 -120 meters (Large)
  - 8 straight bars, 20 mm, 2.90 m in length;
  - 11 square rings, 10 mm, cut to 3.35 m each, bent into squares 0.80 m per side

Rock Drum Anchors

- Spans 40 meters or less**
  - Anchor rods, 16 pieces, 25 mm, cut at 1.50 meters
  - Inner drum: 8 pieces, 10 mm, cut at 3.40 meters, bent into 0.90 m diameter circle
  - Outer drum: 8 pieces, 10 mm, cut at 5.25 meters, bent into 1.50 m diameter circle

- Spans 41 - 60 meters
  - Anchor rods, 20 pieces, 25 mm, cut at 1.50 meters
  - Inner drum: 8 pieces, 10 mm, cut at 4.15 meters, bent into circle 1.15 meter diameter
  - Outer drum: 8 pieces, 10 mm, cut at 5.90 meters, bent into circle 1.70 meter diameter

- Spans 61 - 120 meters
  - Anchor rods, 40 pieces, 25 mm, cut at 1.50 meters
  - Inner drum: 8 pieces, 10 mm, cut at 4.15 meters, bent into circle 1.15 meter diameter
  - Outer drum: 8 pieces, 10 mm, cut at 5.90 meters, bent into circle 1.70 meter diameter

3.3 Cement

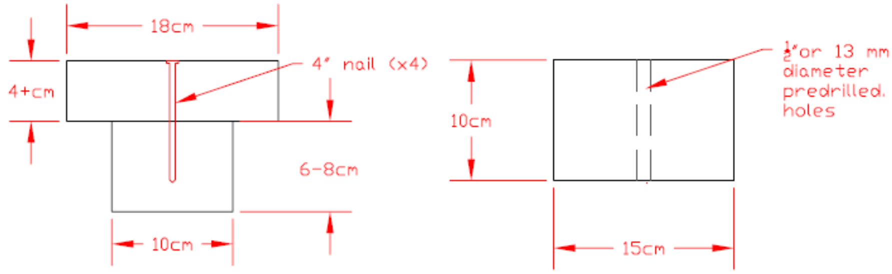
Quantities are given on drawings. Sum together the quantities of Tier & Anchor drawings for both Left and Right abutment and the additional quantity from the Towers.

If accelerant is to be used to expedite the curing time, take care to note the affective 28 day strength minimum time. It is recommended to err on the side of time for anchor pours. The quantity required is specified on the product.

3.4 Decking

Bridges to Prosperity chooses to use wood decking where ever wood is a viable option. There are two types of wood decking alternatives: with or without a 'nailer'. The 'nailer' is the same width as the decking panels, and is attached to the top of the narrower cross-beam to increase the amount of surface area available for nailing the decking panels. The 'nailer' improves constructability and allows for a smaller crossbeam size but increases the total length of decking panels required. It is up to the design engineer to decide if the added cost is warranted.

Nailer (Recommended) | No Nailer



Decking panels are cut to 3.0 meters for any span over 60 meters and preferably all spans. If the bridge is shorter than 60 meter span, 2.0 meter decking panels are allowable. The total number of decking panels is equal to [span divided by length of each board (either 2.0 or 3.0)] multiplied by five (5), as there will be five decking panels across, each 15 - 25 cm wide. If 'nailers' are to be used, an additional (Span plus one) meters of decking panels will be required, cut at 1.0 meters.

- ☐ Crossbeams: (Span + 1)
- ☐ Decking: (Span / length of each board (either 2.0 or 3.0) x 5)
- ☐ Nailers (optional): (Span + 1)

3.5 Other Materials

• Flexible Plastic tubing: 5 cm diameter*	3.5 meter per cable (Anchor)
• Flexible Plastic tubing: 5 cm diameter*	2.0 meter per cable (Tower)
• Tying Wire	10 kg
• Nails: 5"	1 kg per linear meter
• U-nails	1 kg per 10 linear meters
• Screws: 5/16 x 10 cm (4")	1 per deck panel
• Anti-corrosive paint	1 gallon (3.8 L) per 50 linear meters
• Fencing: 1.50 m high	Bridge span x 2
• Roofing Tar	4 gallons
• Handrail Saddles	4 pieces
• Paint for towers	6 gallons
• Sand/Gravel	
• Masonry Block	

** The best product for this purpose is reinforced suction tube used by water trucks.*

3.6 Material Quantities Example

Bridge Location: Cahuac District, Huanuco **Span: 60m**		
Item	Unit	Units required
Cable and clamps		
Cable 26mm	m	391.04
Clamps 26mm	piece	64.00
Construction Materials		
Cement	bags of 40kg	173.66
Concrete Blocks = 40 x 20 x 15 (cm)	unit	180.00
Rebar 10mm (3/8")	(9m)	6.00
Rebar 16mm (5/8")	(9m)	11.00
Rebar 20mm (3/4")	(9m)	4.00
Handrail saddles	unit	4.00
Walkway saddles - 2 cable	unit	4.00
Tying wire	kg	10.00
Plastic suction tube 3"	mts	20.00
Roofing Tar	gal	8.00
Deck		
Wood crossbeams - (10cm x 20cm) x 140cm	piece	62.00
Wood platform - (5cm x 20cm) x 200cm	piece	155.00
Screw - 8mm x 10cm(nailing panel to crossbeam connection)	unit	62.00
Nails - 15cm	kg	26.00
Smooth iron bar 10mm (3/8") (suspenders)	(9m)	32.00
Anti-rust paint (suspenders)	gal	1.00
Safety fencing = 1.5m in height	mts	76.00
U-Nails	kg	6.00
Tying wire	kg	20.00
Local Materials		
Sand	m^3	40.00
Gravel	m^3	10.00
River rock	m^3	80.00
Dressed Stone	m^3	40.00
Transportation		
Transportation of materials	per trip	6.00
Labor and Technical Support		
Mason	daily	180.00
Supervision	daily	90.00
Logistical Support	per visit	12.00

BRIDGE NAME:

Bridge Location:

Span:

Material List

All prices are estimations, prices can change at moment of purchase, always verify

Item	Unit	Units required	Estimated Unit Price	
Cable and clamps				
Cable 26mm	m			
Clamps 26mm	piece			
Cable 32mm	m			
Clamps 32mm	piece			
				$ -
Construction Materials				
Cement (6.4 x volume for concrete, 1.1 x area for mortar)	bags of 40kg			
Concrete Blocks = 40 x 20 x 15 (cm)	unit			
Rebar 12mm (1/2")	(9m)			
Rebar 16mm (5/8")	(9m)			
Rebar 20mm (3/4")	(9m)			
Rebar 25mm (1")	(9m)			
Handrail saddles	unit			
Walkway saddles - 2 cable	unit			
Walkway saddles- 4 cables	unit			
Tying wire	kg			
Plastic suction tube 3"	mts			
Roofing Tar	gal			
				$ -
Deck				
Wood crossbeams - (10cm x 10cm) x 140cm	piece			
Wood nailing panels - (5cm x 20cm) x 100cm	piece			
Wood crossbeams - (10cm x 20cm) x 140cm	piece			
Wood platform - (5cm x 20cm) x 200cm	piece			
Screw - 8mm x 10cm(nailing panel to crossbeam connection)	unit			
Nails - 15cm	kg			
Smooth iron bar 10mm (5/16") (suspenders)	(9m)			
Smooth iron bar 12mm (1/2") (j-bolts)	unit			
Anti-rust paint (suspenders)	0.5gal			
Anti-rust paint (j-bolts)	0.5gal			
Safety fencing = 1.5m in height	mts			
U-shaped nails	kg			
Tying wire	kg			
				$ -
Local Materials				
Sand	m³			
Gravel	m³			
River rock	m³			
Dressed Stone	m³			
				$ -
Transportation				
Transportation of materials (City - City)	per trip			
Transportation of materials (City - Village)	per trip			
Transportation of materials (Village to site)	per trip			
				$ -
Misc. Tools and Tool Rental				
Misc. Tools* (listed below)				
Tool rental (winch and/or drill)				
				$ -
Labor and Technical Support				
Mason	daily			
Carpenter	daily			
Supervision	daily			
Logistical Support	per visit			
Logistical Support	per visit			
			Estimated Sub-total for Labor	$ -
			Total	$ -
			Contingency 10%	$ -
			Total with 10% Contingency	$ -