El Hatillo Bridge Project

December 14, 2017

MTU iDesign

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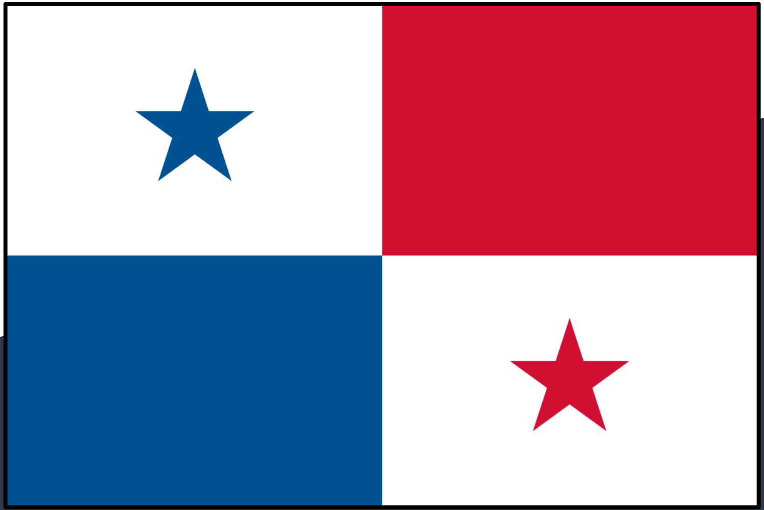
Outline

- Project Location
- Problem Description
- Hydraulic Analysis
- Bridge Design
- Cost and Schedule Estimate
- Conclusion/Questions



Andrew

Project Location

Better Bridges

- El Hatillo is in **Central Panama**
- West of Panama City in the Coclé Province
- Penonomé is the largest surrounding city
- El Hatillo is home to 27 permanent residents
- Mainly farmers or part time laborers

Andrew

Problem Description

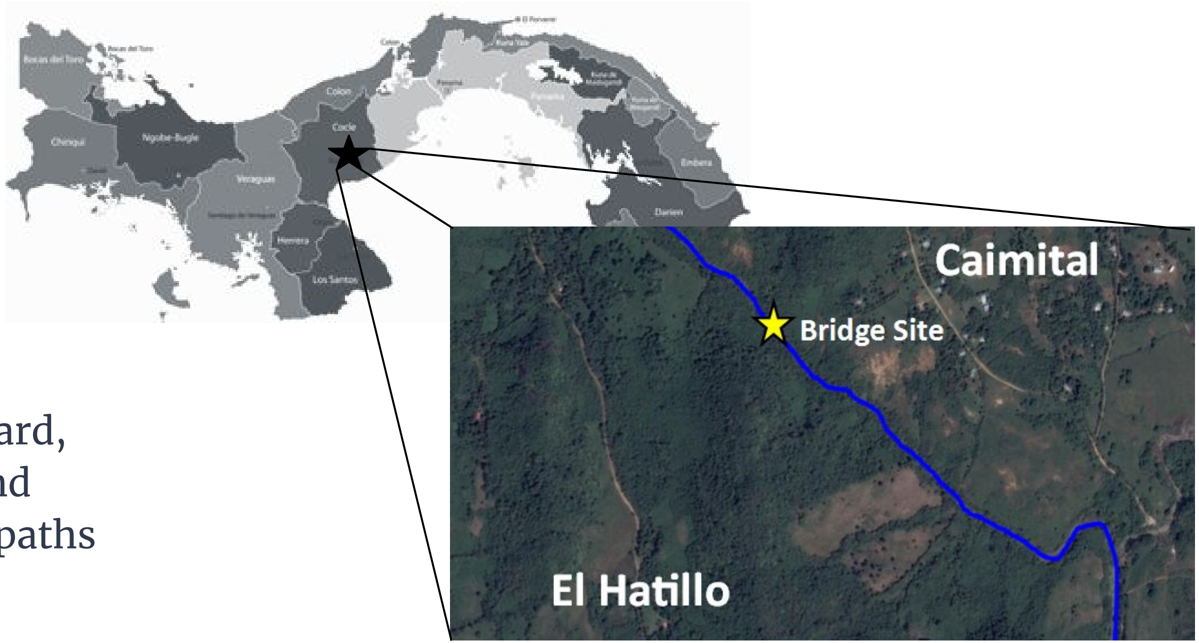
- The Rio Cabuya floods to nearly 18 feet above its usual water level
- El Hatillo can be stranded for days several times each year
- Access to neighboring communities is a necessity
- Work, education, and supplies are all in Caimital

Andrew

Site Location

Better Bridges

- Four sites were surveyed while in Panama
- The chosen site was named DHH
- Best choice for freeboard, material efficiency, and proximity to existing paths

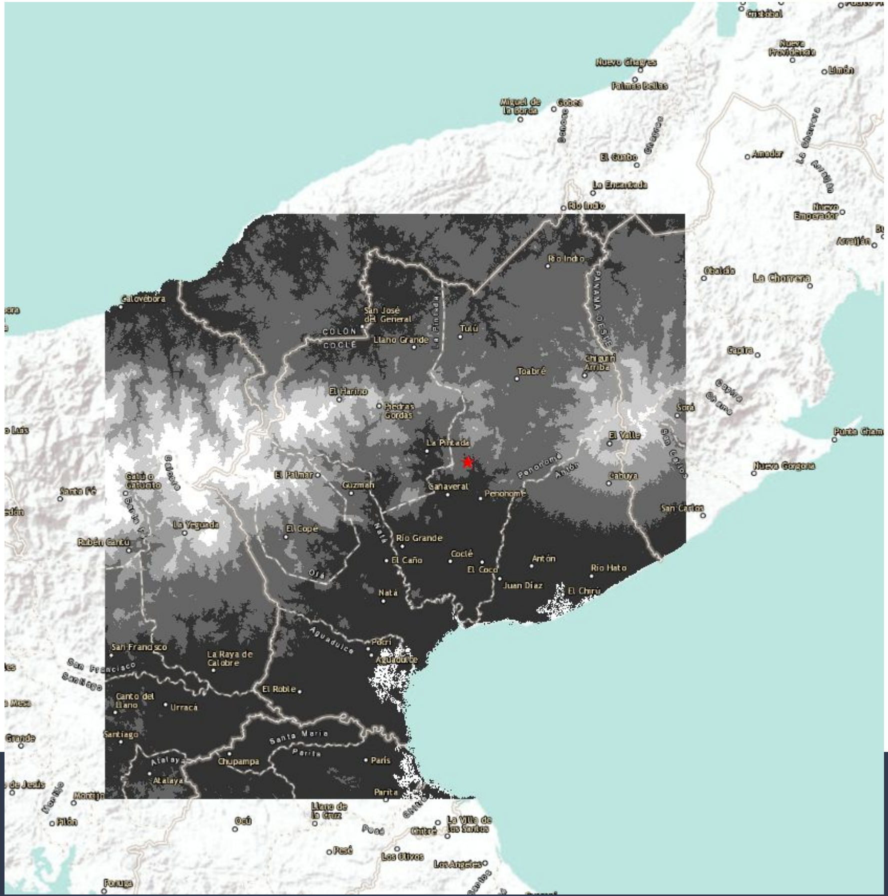


Hydraulic Analysis

- ArcGIS
  - Watershed characteristics
  - Main channel
- Google Maps Pro
  - Slope
- HEC-HMS
  - Design Storm
  - Flood hydrograph
  - Estimate flow rates
- Manning Equation
  - Determine max water height

Digital Elevation Model (DEM)

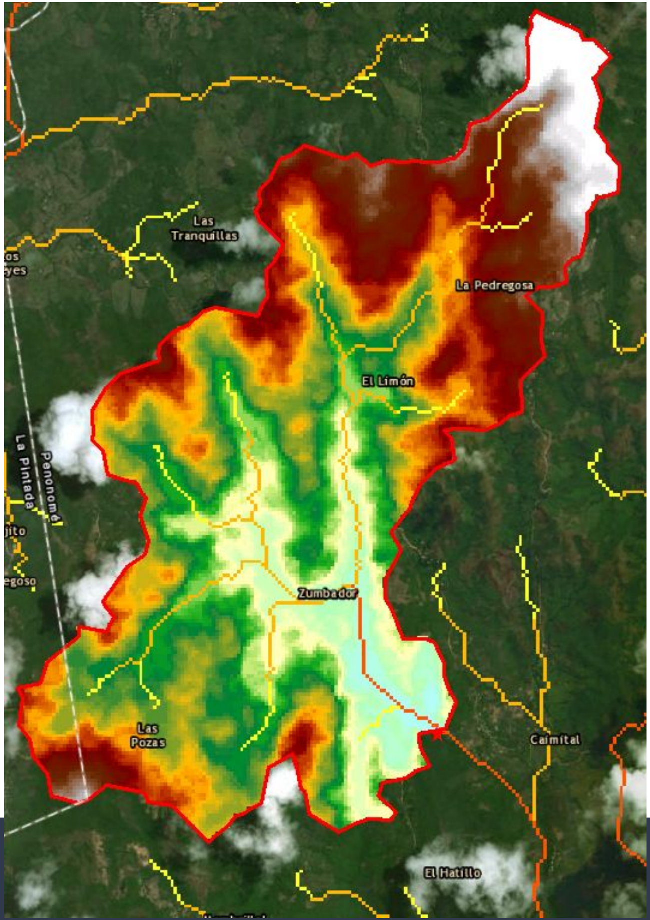
- United States Geological Survey (USGS)
  - Earth Explorer
- DEM data over terrain base map
- Red Star: GPS coordinates for bridge site
  - N 08.57754
  - W -80.37422

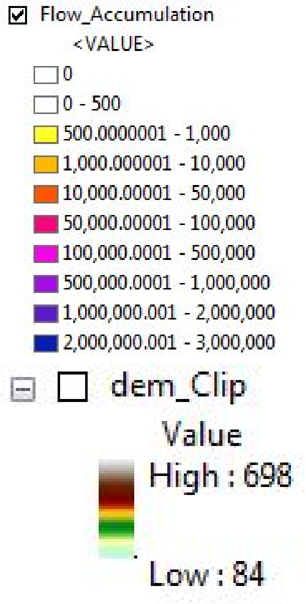


Madison

Delineate Watershed

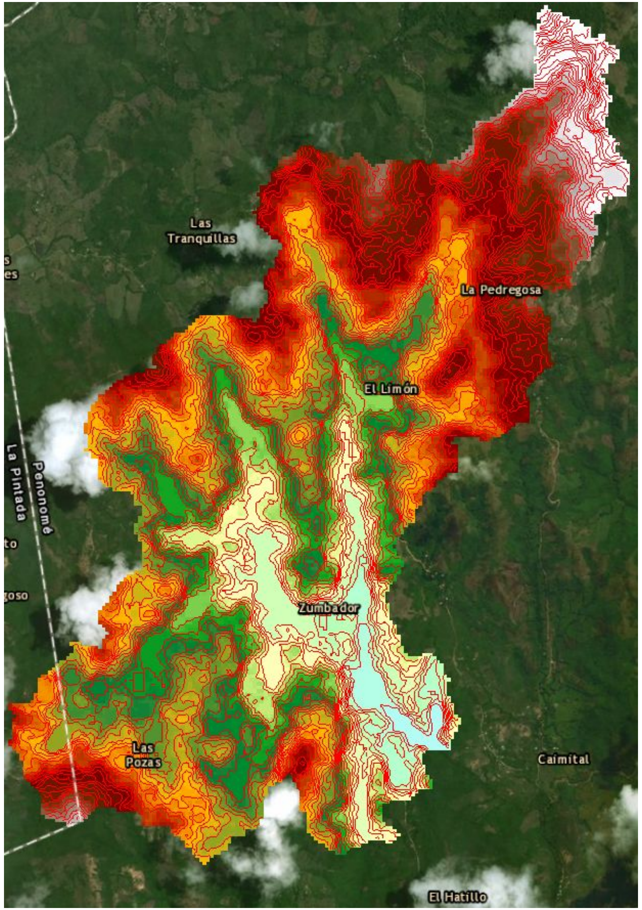
- Process DEM
  - Flow direction
  - Flow accumulation
  - Watershed boundary
- Max elevation
  - 2,290 ft





Watershed Characteristics

- Delineate Watershed
  - 6.99 mi^2
  - 67% forested
  - 33% open
  - RCN = 74.28
    - Based on soil type and land usage

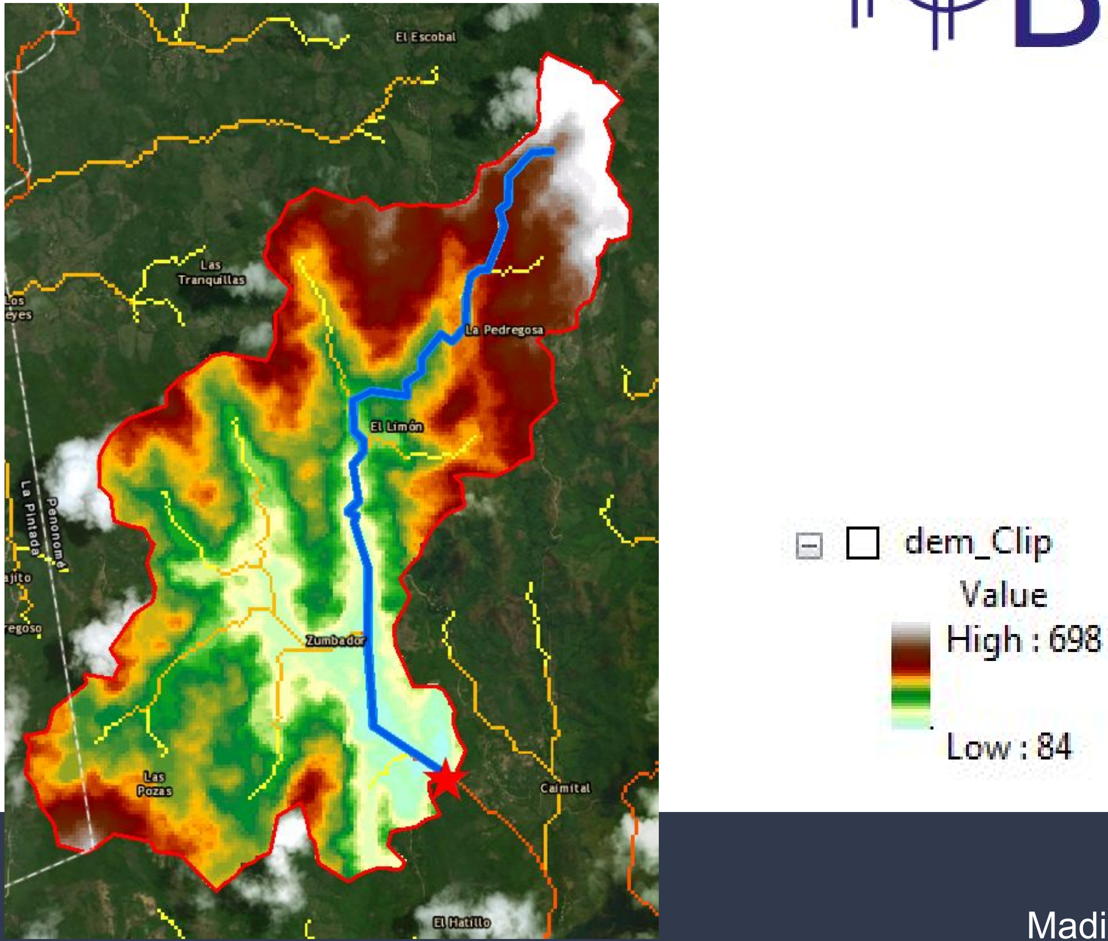


Contour interval = 65 ft

Madison

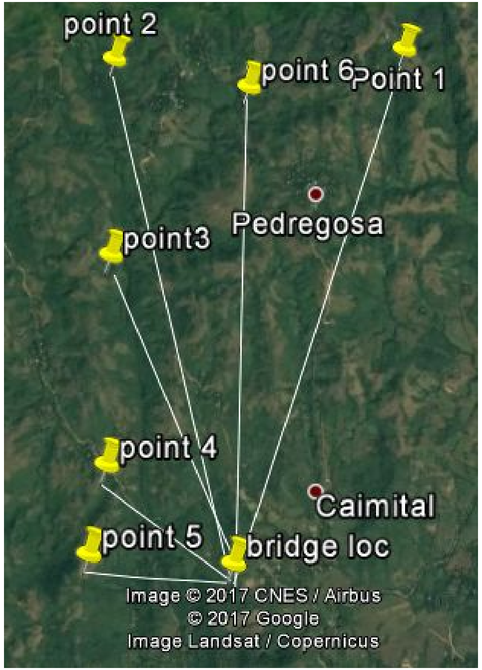
Main Channel

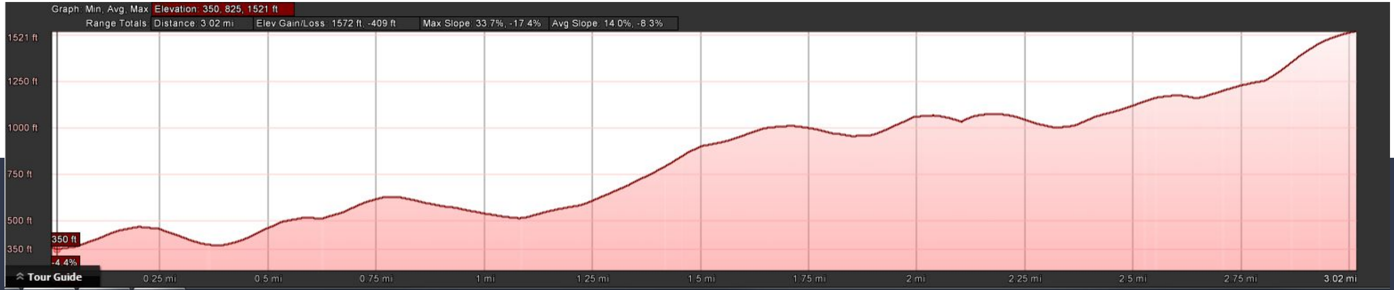
- Length
  - 4.52 miles



Watershed Slope
Google Maps Pro

- Points on the high and low areas across the watershed
- Elevation profile for each path





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Watershed Slope Google Maps Pro

- Found slope for each cross section
- Calculated weighted average for all 5 paths

$$Percent\ slope = \frac{Point_2 - Point_1}{Length\ of\ segment} * 100$$

Cross section	Elevation at bridge	Elevation at peak	Distance from bridge	Point 2-Point 1	Slope	Average	Weighted Average
1	358	1520	15889	1162	7%	6%	5.5%
2	358	1010	15206	652	4%		
3	358	553	9293	195	2%		
4	358	510	4540	152	3%		
5	358	901	4118	543	13%		

HEC-HMS Design Storm Model

- NRCS Curve Number method
  - Have
    - Length = 4.52 mi
    - Area =6.99 mi^2
    - Watershed Slope = 3.8%
    - Curve Number = 75.28
  - Find
    - Lag time value = 143 minutes (2.3 hours)
    - Max Soil Retention = 3.28 inches
    - Initial abstraction value = 0.66 inches

$$I_A = 0.2 * Soil\ Retention$$

$$S = \frac{1000}{CN} - 10$$

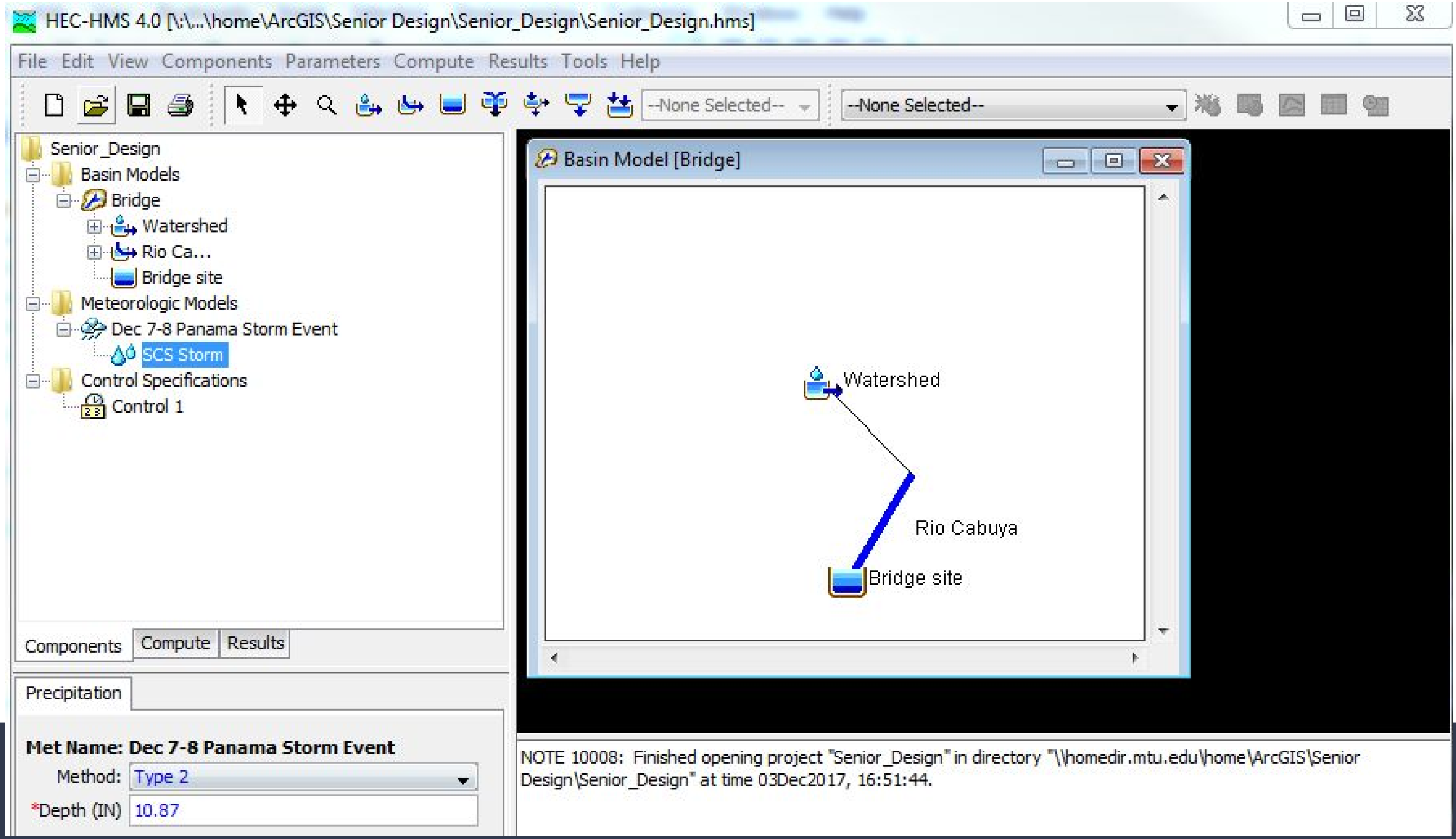
$$L_t = L^{.08} \frac{(1000 - 9 * CN)^{0.7}}{1900 * CN^{.07} * \sqrt{Y}}$$

I_A = Initial Abstraction

L_t= Lag time

S = Max Soil Retention

HEC-HMS hydrologic simulation model



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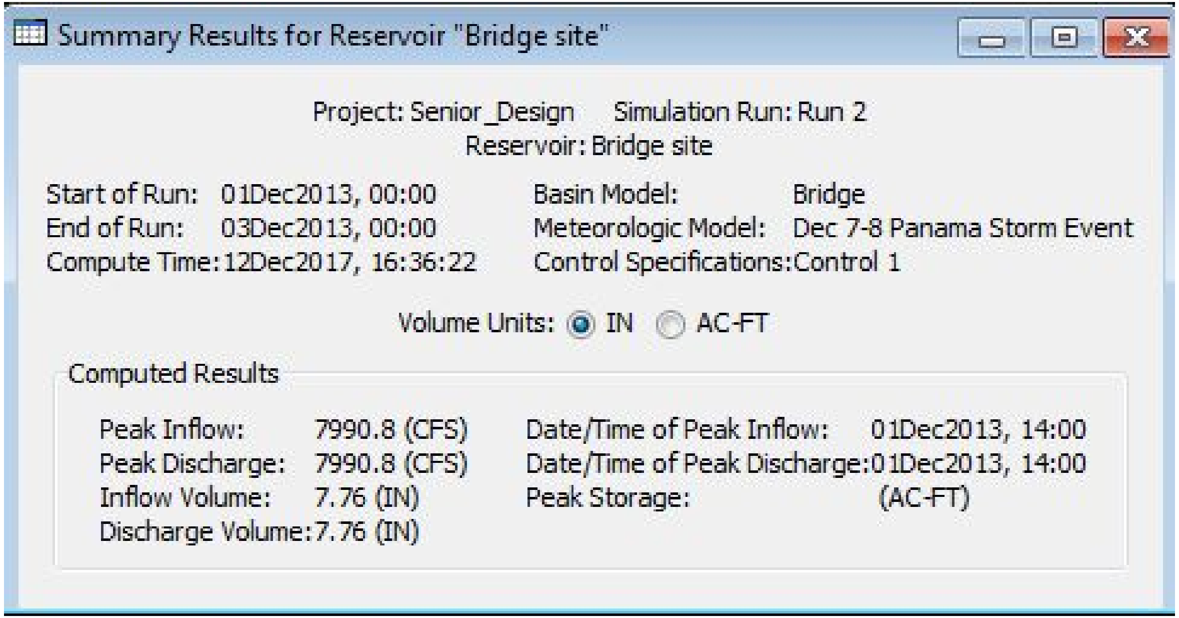
HEC-HMS hydrologic simulation model



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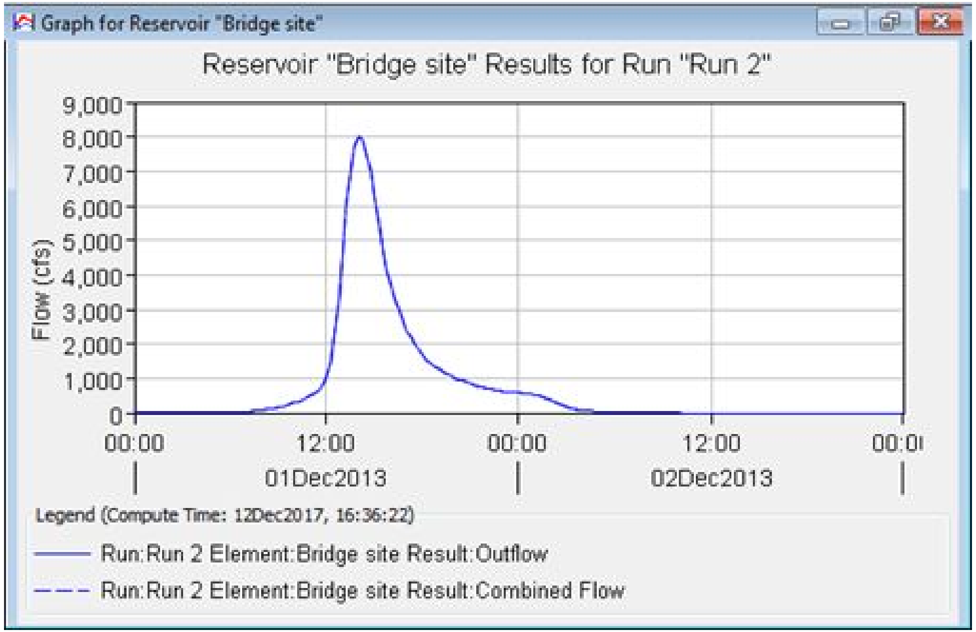
Main Channel

- Summary
  - Peak flow
    - 7990 CFS
  - Time of peak
    - 14 hours



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Manning’s Equation

$$Manings\ equation = \ Q = \frac{C_m}{n} * A * R^{\frac{2}{3}} * S^{\frac{1}{2}} = S^{\frac{1}{2}} * k$$

$$Manings\ equation = \ Q = \frac{1.49}{.045} * 772.4 \ * 9.28^{\ \frac{2}{3}} * 0.005^{\ \frac{1}{2}} = 0.005^{\frac{1}{2}} * 96711 = 7990\ \text{cfs}$$

C_m = 1.49 for US Standard Units

A = Cross Sectional Area (ft^2)

R = hydraulic Radius = $\frac{A}{wp}$ (ft)

WP = Wetted Perimeter = Perimeter-width of channel (ft)

S = Slope = .005 ft/ft (or 0.5%)

n = Manning’s Coefficient = 0.045 for 49% cobble, and 51% brush and vegetation

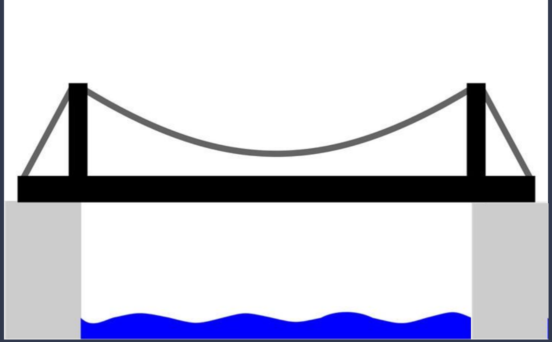
Q = Discharge =7990 $\frac{ft^3}{s}$

Max Depth = 17.3 ft

Madison

Bridge Design

- Suspension bridge
- Two 280 ft galvanized steel cables
- 20ft tall towers
- 160ft deck span
- Concrete anchors and foundation
- Wooden deck with steel supports



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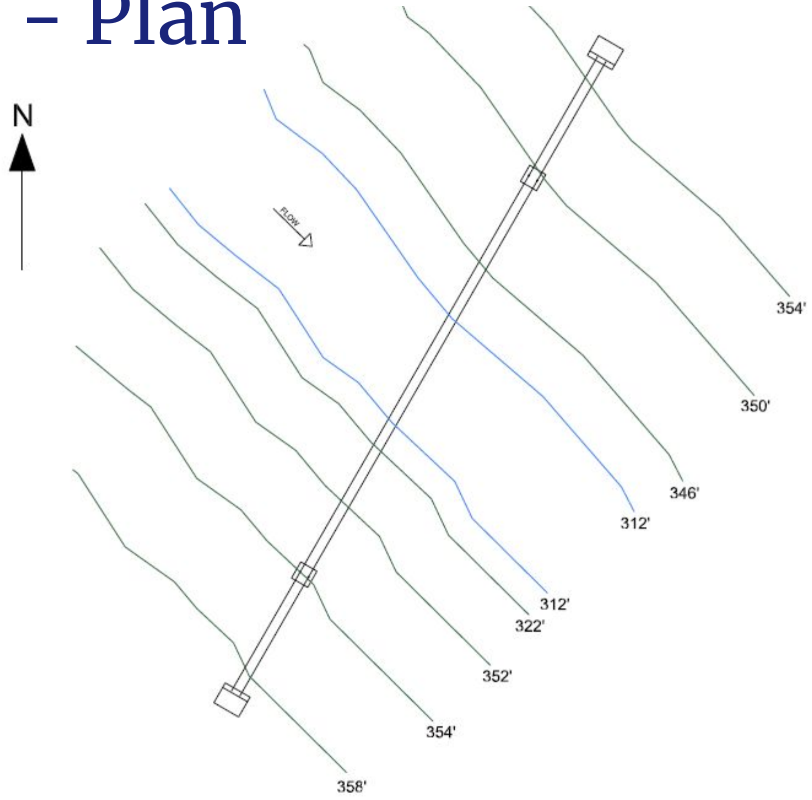
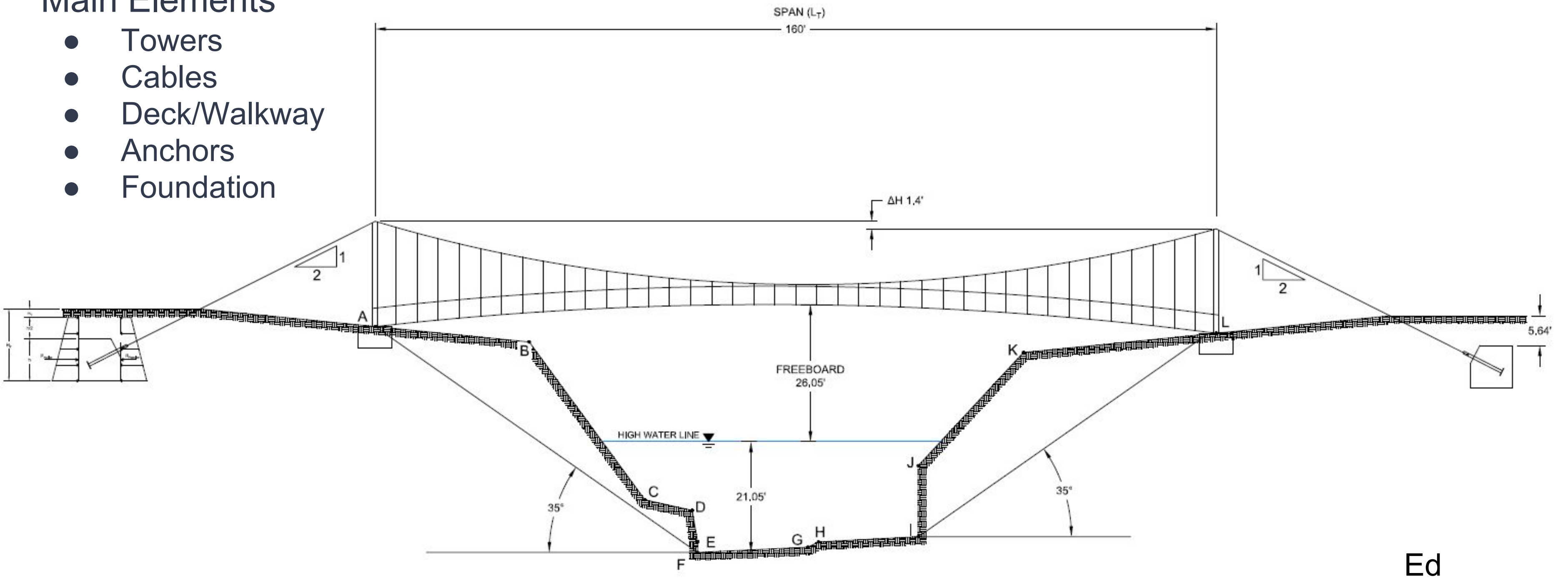
Bridge Design - Plan



Bridge Design – Profile

Main Elements

- Towers
- Cables
- Deck/Walkway
- Anchors
- Foundation



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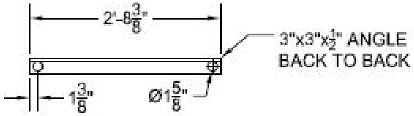
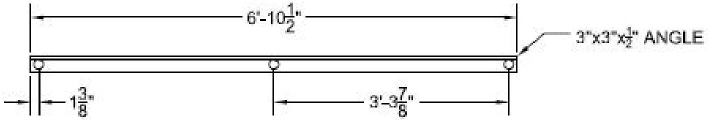
Bridge Design – Towers

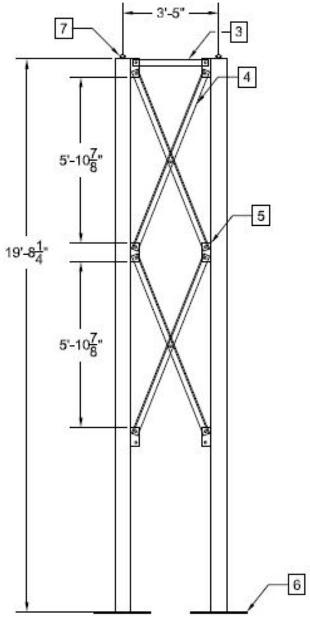
- Designed with Bridges to Prosperity standards
- Tower Load: 101 kips



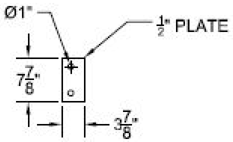
3 TOWER CROSS-BRACING
SCALE: 1" = 1'-0"



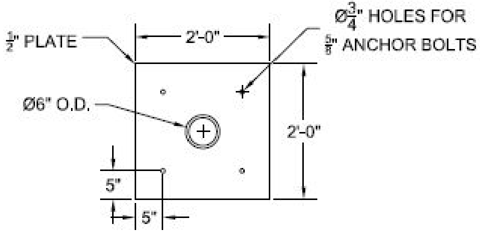
4 TOWER CROSS-BRACING
SCALE: 1" = 1'-0"



2 TOWER DETAIL
SCALE: 1/2" = 1'-0"



5 CONNECTOR PLATE
SCALE: 1" = 1'-0"



6 BASEPLATE
SCALE: 1" = 1'-0"

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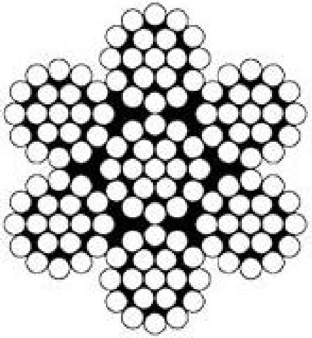
Bridge Design – Cables

- Main Span: 1⅝” diameter, 264 kip breaking strength
- Suspender: ⅜” diameter, 15.1 kip breaking strength
- Max Tension in cable 130 kips
- FS very high for suspender cables due to cost indifference and corrosion defense



$$1\frac{5}{8}\text{" } Cable\ Ultimate\ Strength = 132\ tons = 264{,}000 lbs$$

$$Cable\ Factor\ of\ Safety\ (FS_c) = 5.0$$

$$Number\ of\ 1\frac{5}{8}\text{" } Cables\ (N_c) = \frac{T_{total} \cdot 5.0}{264{,}000 lbs} = 1.56 \rightarrow 2\ cables\ total$$

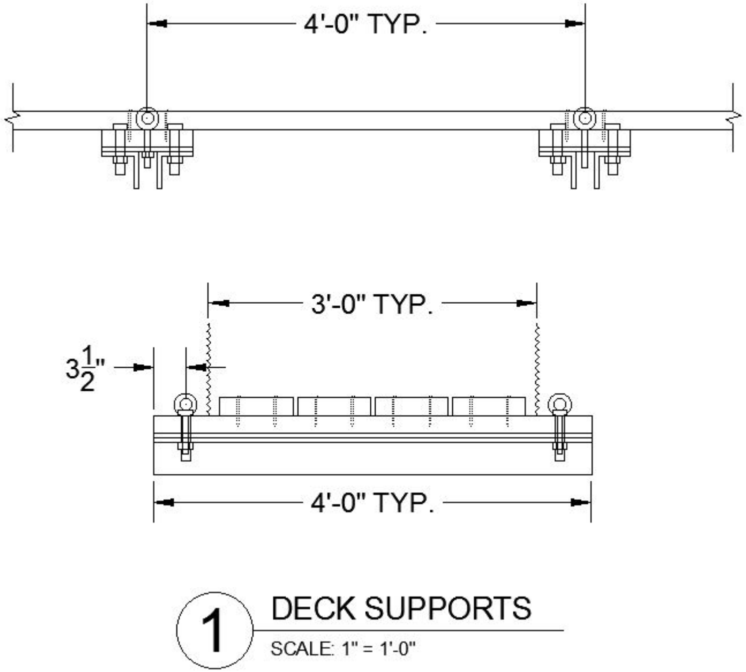
$$\frac{3}{8}\text{" } Suspender\ Cable\ Breaking\ Strength = 7.55\ tons = 15{,}100 lbs$$

$$Suspender\ Cable\ Factor\ of\ Safety = \frac{15{,}100 lbs}{750 lbs} = 20.1 > 5.0$$

Ed

Bridge Design – Deck/Walkway

- Dead Load: 13,200 lbs
- Live Load (90 psf): 43,200 lbs
- Wind Load (20 psf): 1,800 lbs
- 2”x8”x8’ Pressure Treated Lumber
- 4’ chainlink fence
- Designed for simple and easy maintenance



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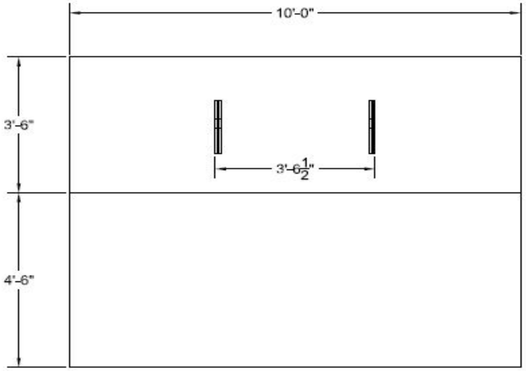
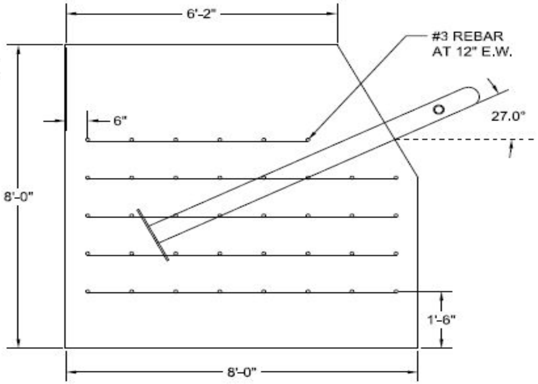
Bridge Design – Anchors

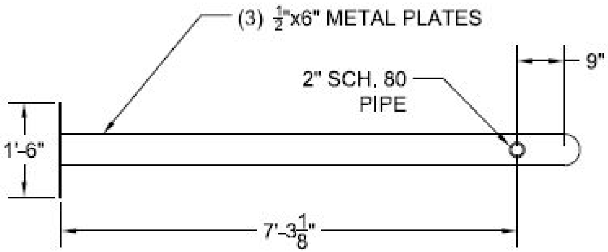
- 22.5 CY of concrete each
- Reinforced with #3 rebar



9 ANCHOR DETAIL
SCALE: 3/4" = 1'-0"



10 ANCHOR DETAIL
SCALE: 3/4" = 1'-0"



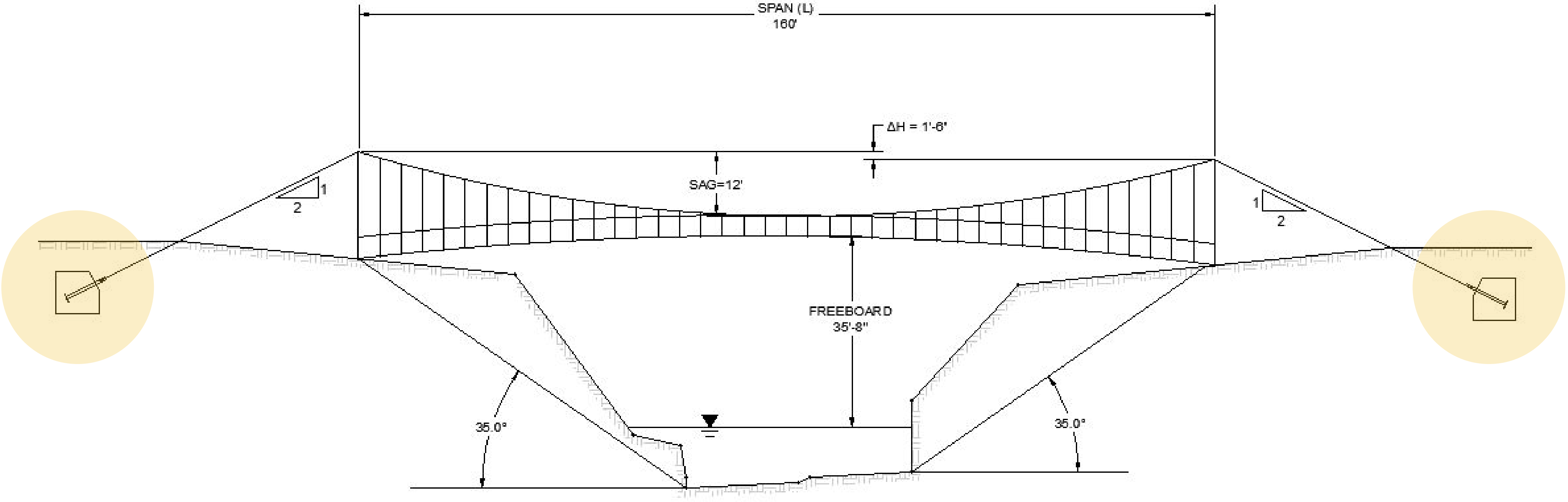
11 CABLE CONNECTOR
SCALE: 3/4" = 1'-0"

Structural Analysis

Goal?

Minimize dimensions for appropriate safety factors to reduce costs of materials.

Structural Analysis – Anchors



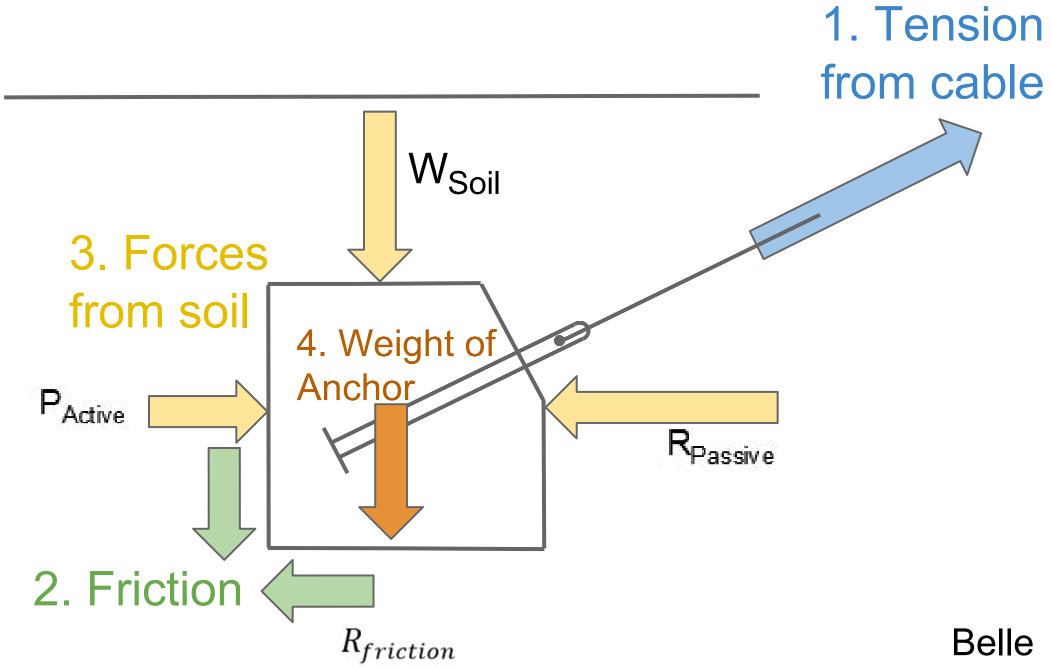
Belle

Anchor Forces

Free Body Diagram

Identify Forces Acting on Anchor

1. Tension from Cable
2. Friction
3. Forces from Soil
4. Weight of Anchor



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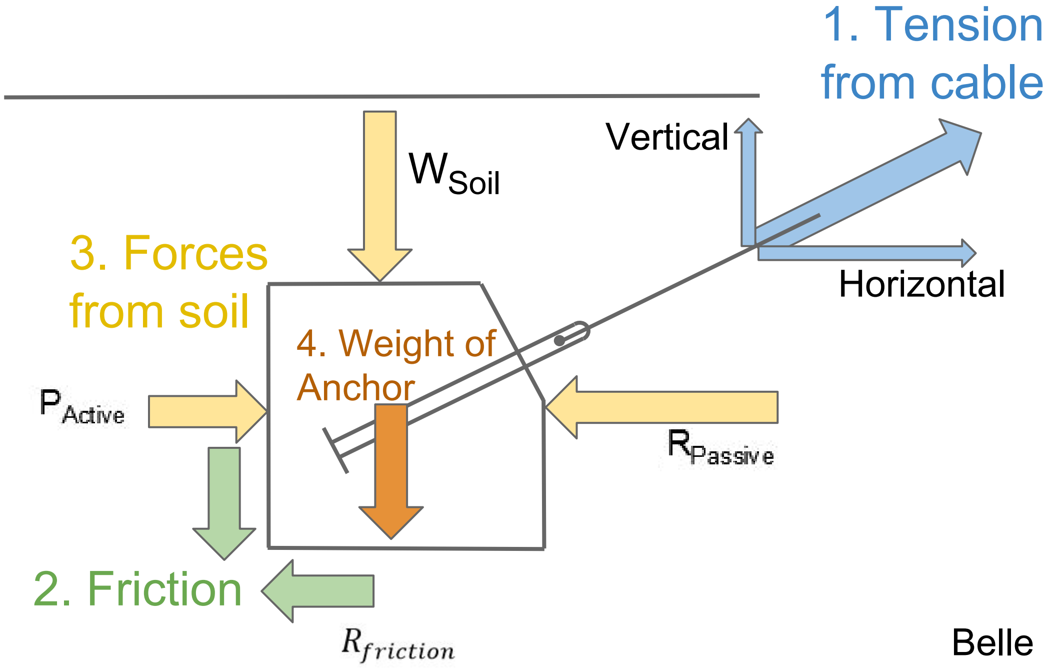
Anchor Forces

Free Body Diagram

Identify Forces Acting on Anchor

1. **Sliding Check (horizontal)**
   a. Driving Forces
   b. Resisting Forces

2. **Uplift Check (vertical)**
   a. Driving Forces
   b. Resisting Forces



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Anchor Forces

1. Anchor Sliding Check

Step 1: Identify Horizontal Forces

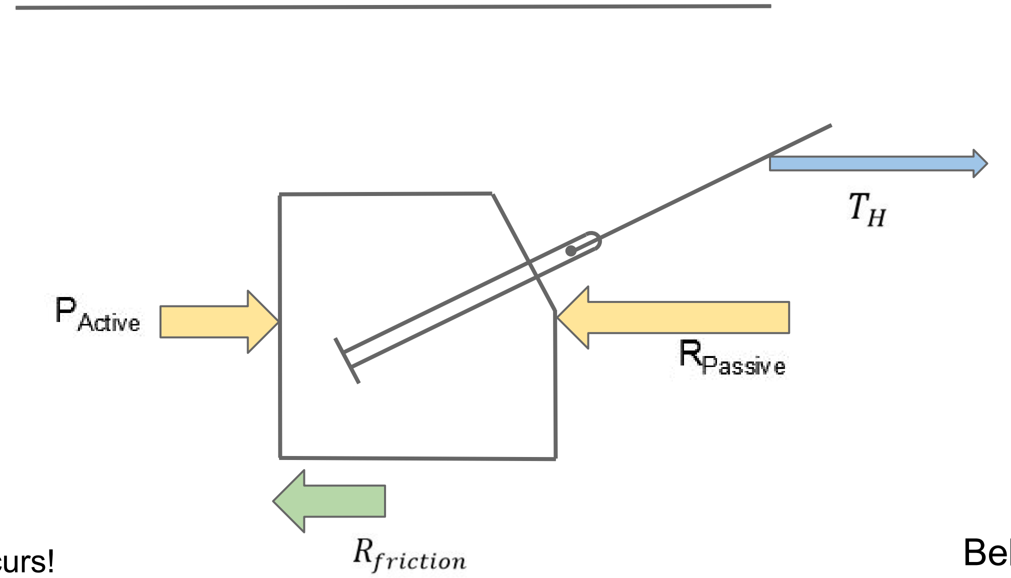
$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = 2$$

Driving Forces

$$R_S = P_{Active} + T_H$$

Resisting Forces

$$R_R = R_{friction} + R_{Passive}$$



Driving forces need to be smaller so no sliding occurs!

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Anchor Forces

1. Anchor Sliding Check

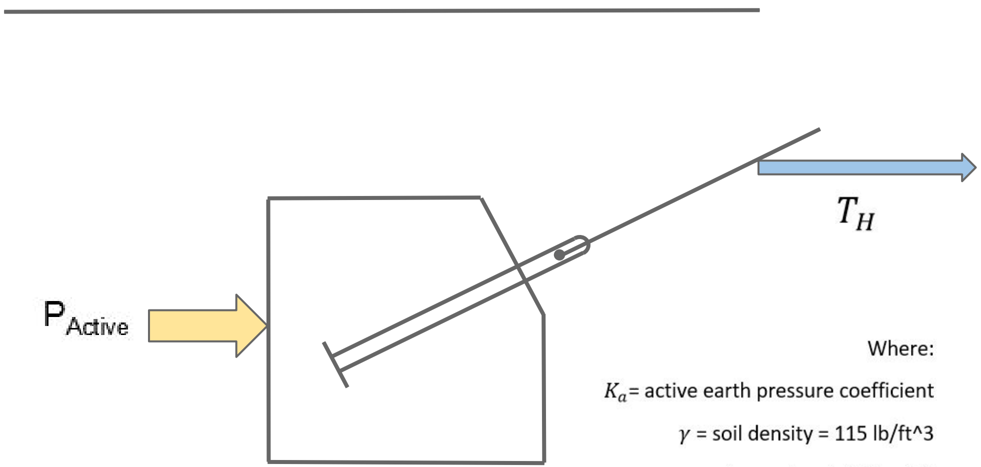
Step 2: Sum Horizontal *Driving* Forces

$$R_S = P_{Active} + T_H$$

$$P_{Active} = \frac{1}{2}(K_a)(\gamma)(h^2)(w) = 13.3 \text{ kips}$$

$$K_a = \frac{(1 - \sin\emptyset)}{(1 + \sin\emptyset)} = 0.361$$

$$Horizontal\ Tension\ (T_H) = \frac{Working\ Load \cdot L}{8 \cdot Sag} = 77.6\ kips$$



Where:

K_a = active earth pressure coefficient

γ = soil density = 115 lb/ft^3

h = anchor height = 8 ft

w = anchor width = 10 ft

$\emptyset$ = angle of internal friction = 28 deg

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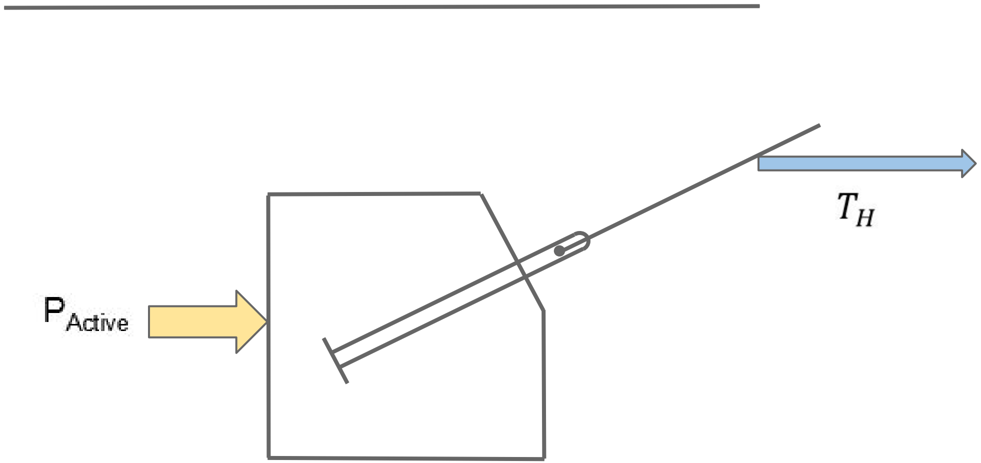
Anchor Forces

1. Anchor Sliding Check

Step 2: Sum Horizontal *Driving* Forces

$$R_S = P_{Active} + T_H$$

$$R_S = 13.3\ lbs + 77.6\ kips = \mathbf{91\ kips}$$



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Anchor Forces

1. Anchor Sliding Check

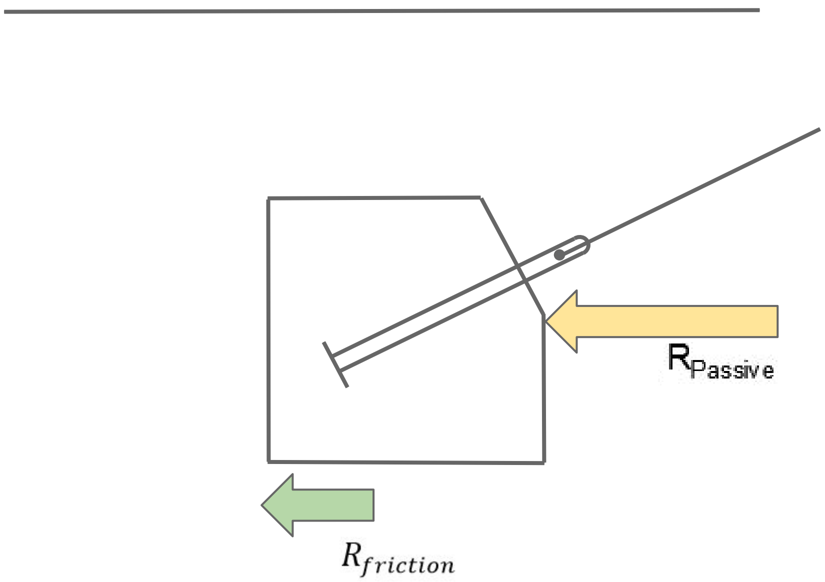
Step 3: Sum Horizontal *Resisting* Forces

$$R_R = R_{friction} + R_{Passive}$$

$$R_{friction} = \mu * (T_H + W_{soil}) = 36.3\ kips$$

$$R_{Passive} = \frac{1}{2} K_p \gamma \left(\frac{3}{2} h\right)^2 w(H_2 - H_1) = 230\ kips$$

$$K_p = \frac{1 + \sin(28°)}{1 - \sin(28°)} = 2.77$$



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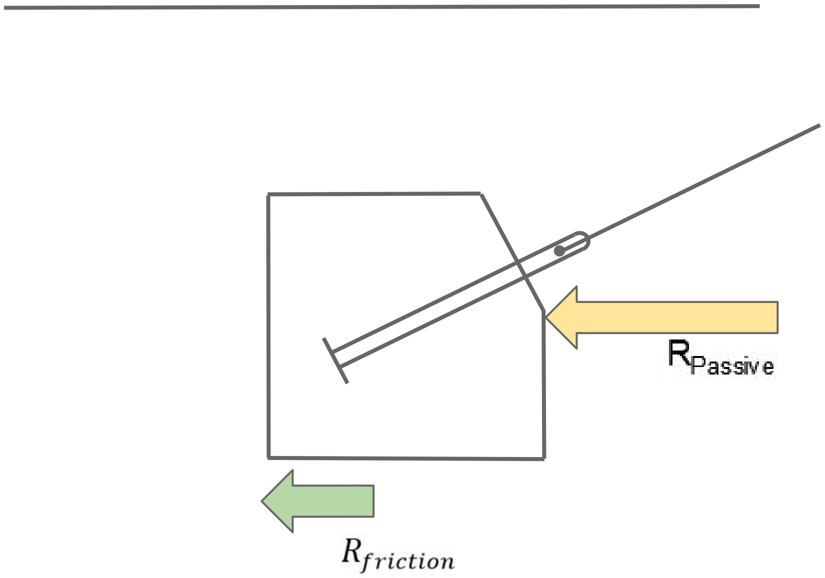
Anchor Forces

1. Anchor Sliding Check

Step 3: Sum Horizontal *Resisting* Forces

$$R_R = R_{friction} + R_{Passive}$$

$$R_R = 36.3\ kips + 230\ kips = \mathbf{266.3\ kips}$$



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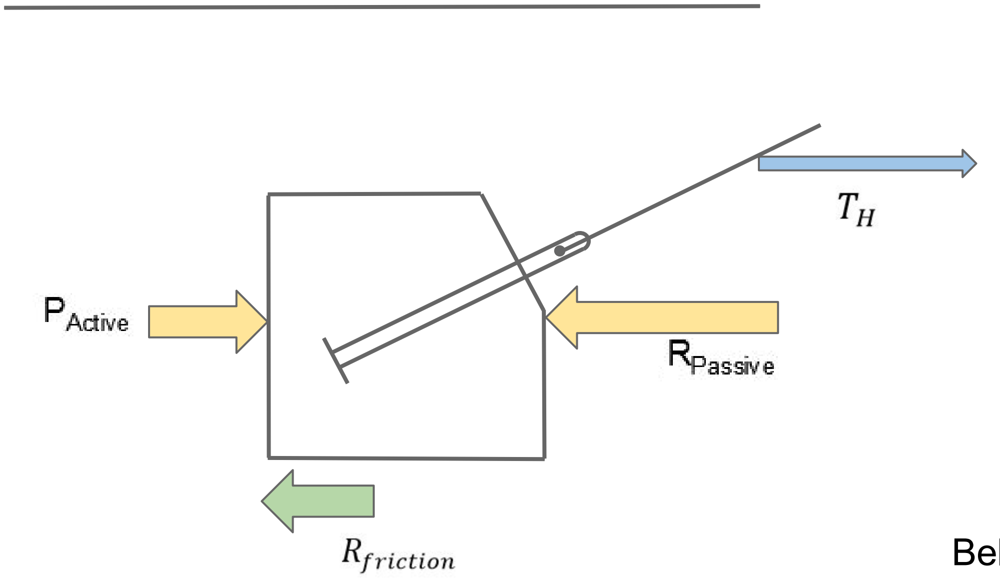
Anchor Forces

1. Anchor Sliding Check

Step 4: Verify Horizontal Forces

$$FS = \frac{R_R}{R_S} = \frac{266.3\ kips}{91\ kips} = 2.9$$

$$\therefore\ Acceptable$$



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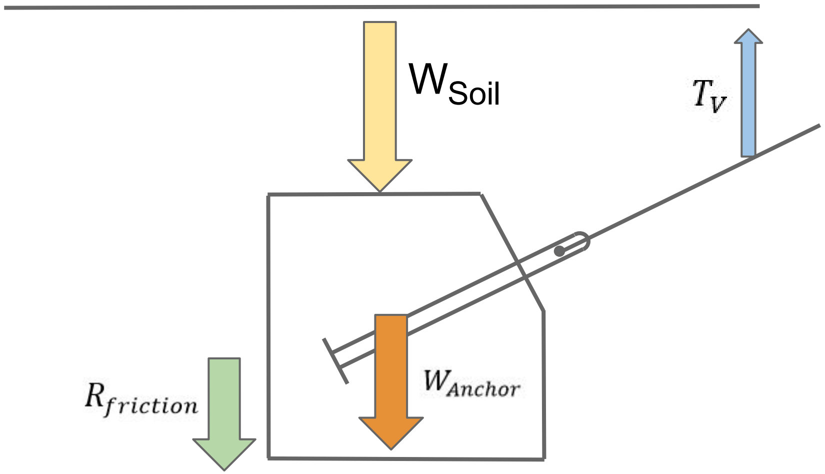
Anchor Forces

2. Anchor Uplift Check

Step 1: Identify Vertical Forces

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = 2$$

1. Uplift from tension in cable
2. Friction
3. Weight of soil
4. Weight of anchor



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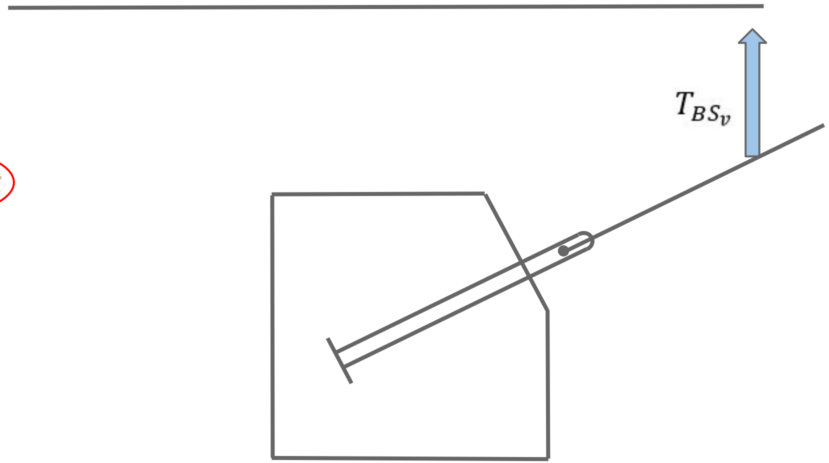
Anchor Forces

2. Anchor Uplift Check

Step 2: Sum Vertical *Driving* Forces

$$T_{BS_v} = Vertical\ Driving\ Force = 38.8\ kips$$



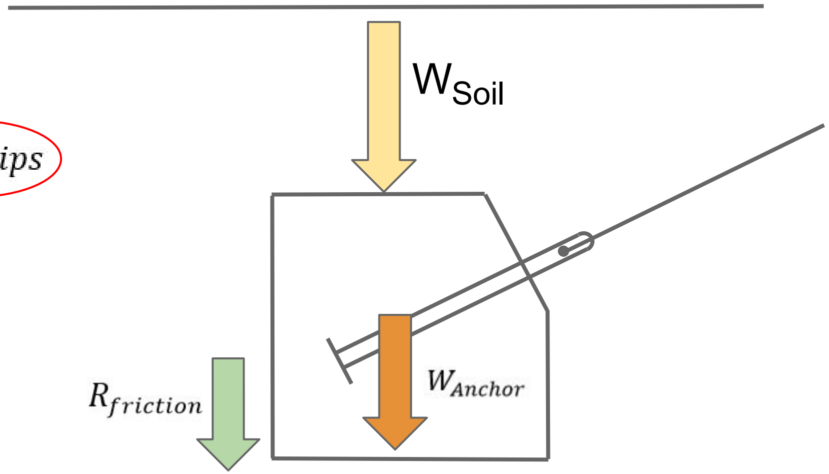
Anchor Forces

2. Anchor Uplift Check

Step 3: Sum Vertical *Resisting* Forces

$$V_R = R_{friction} + W_{Anchor} + W_{soil}$$

$$= 36.3\ kips + 51.3\ kips + 17\ kips = 104.6\ kips$$



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Anchor Forces

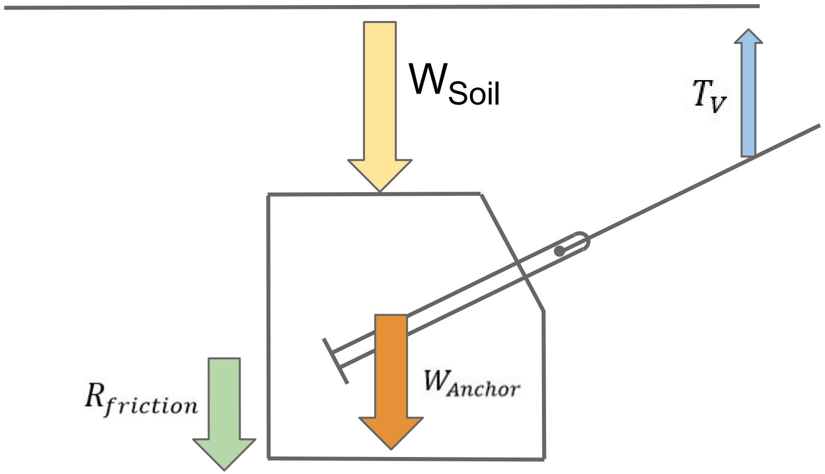
2. Anchor Uplift Check

Step 4: Verify Vertical Forces

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = 2$$

$$FS = \frac{V_R}{T_{BS_v}} = \frac{\mathbf{104.6\ kips}}{\mathbf{38.8\ kips}} = \mathbf{2.7}$$

$$\therefore \textit{Acceptable}$$



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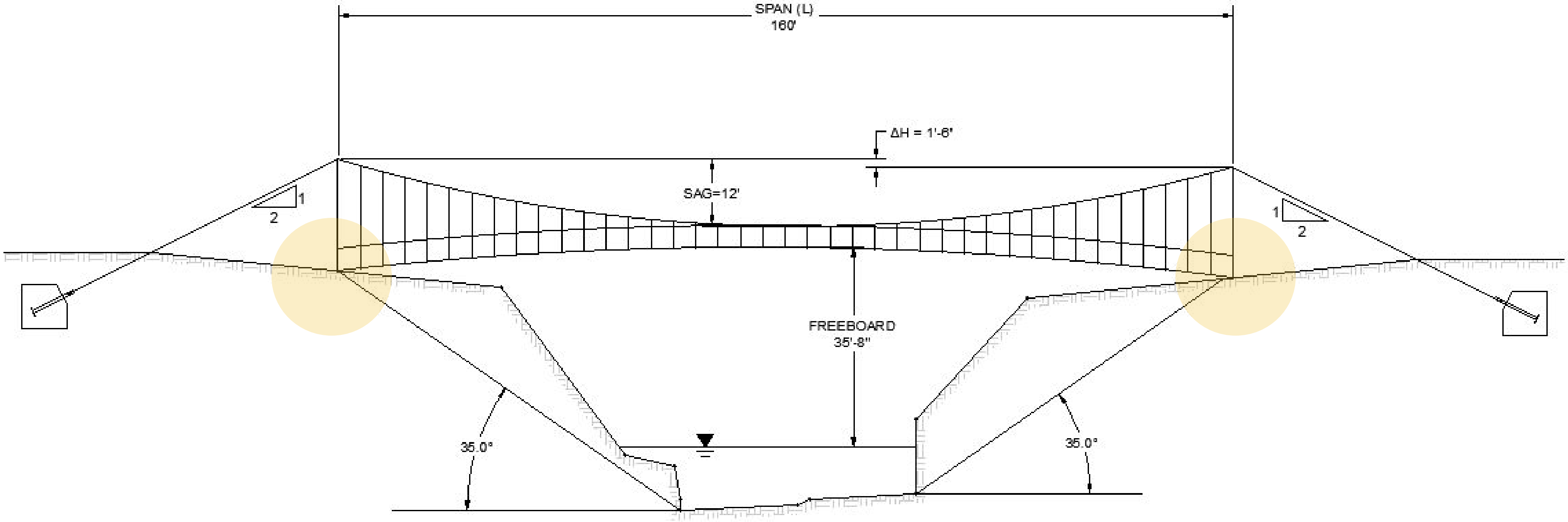
Foundation Calculations



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Foundation Calculations

Confirm total forces acting on soil do not exceed its bearing capacity, *q*

$$P = \frac{F}{A}$$

$$SF = \frac{q}{P} = 1.5$$

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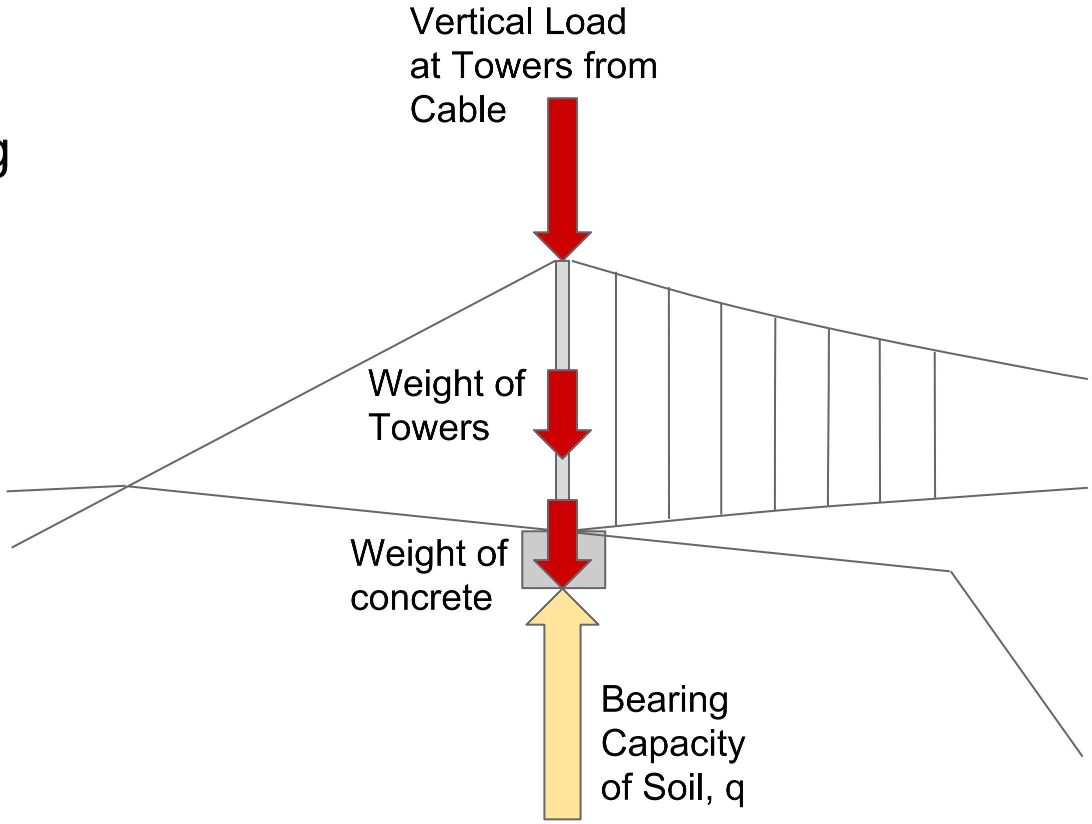


Foundation Calculations

Working Vertical Load at Towers $F_{wv} = 67{,}000\ lbs$

Weight of towers = 1630 lbs

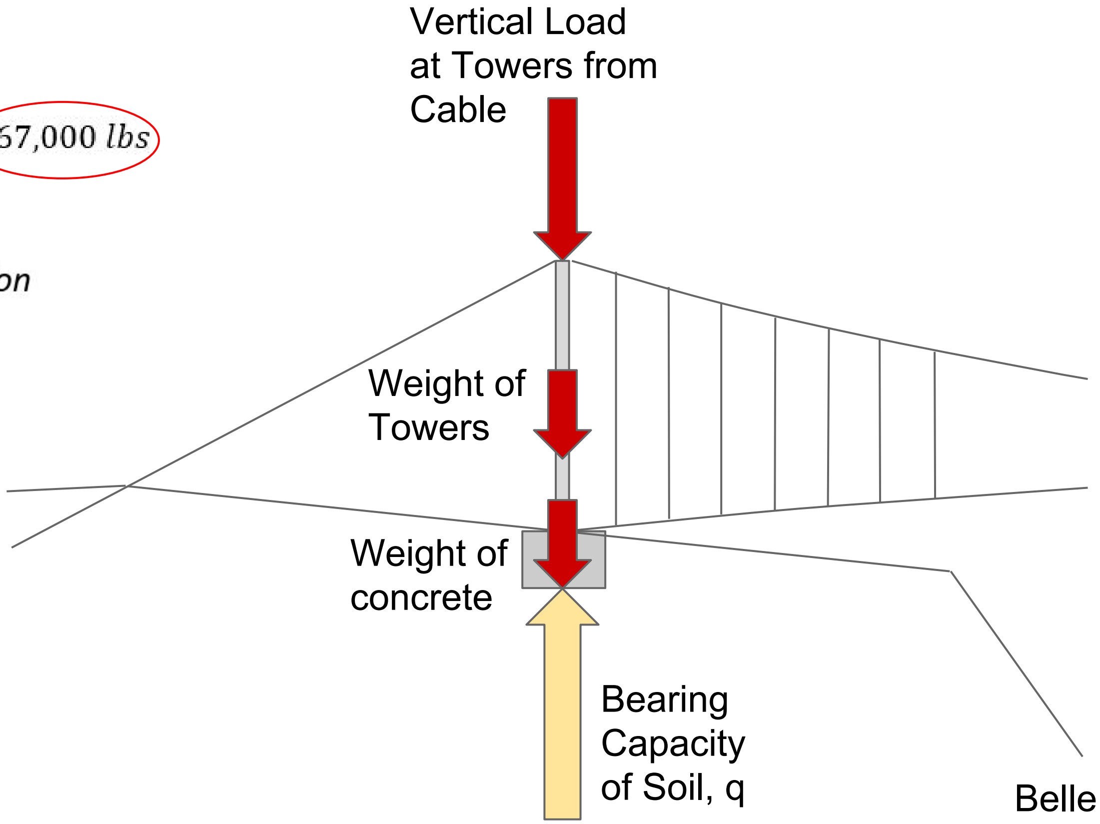
Weight of concrete for 6.5' x 6.5' foundation

$$W_f = 150\,\frac{lb}{ft^3} * 6.5\ ft * 6.5\ ft * 4\ ft$$

$$= 25{,}350\ lbs$$

Forces on soil $F = W_f + W_t + F_{wv}$

$$= \boxed{93{,}990 lbs}$$



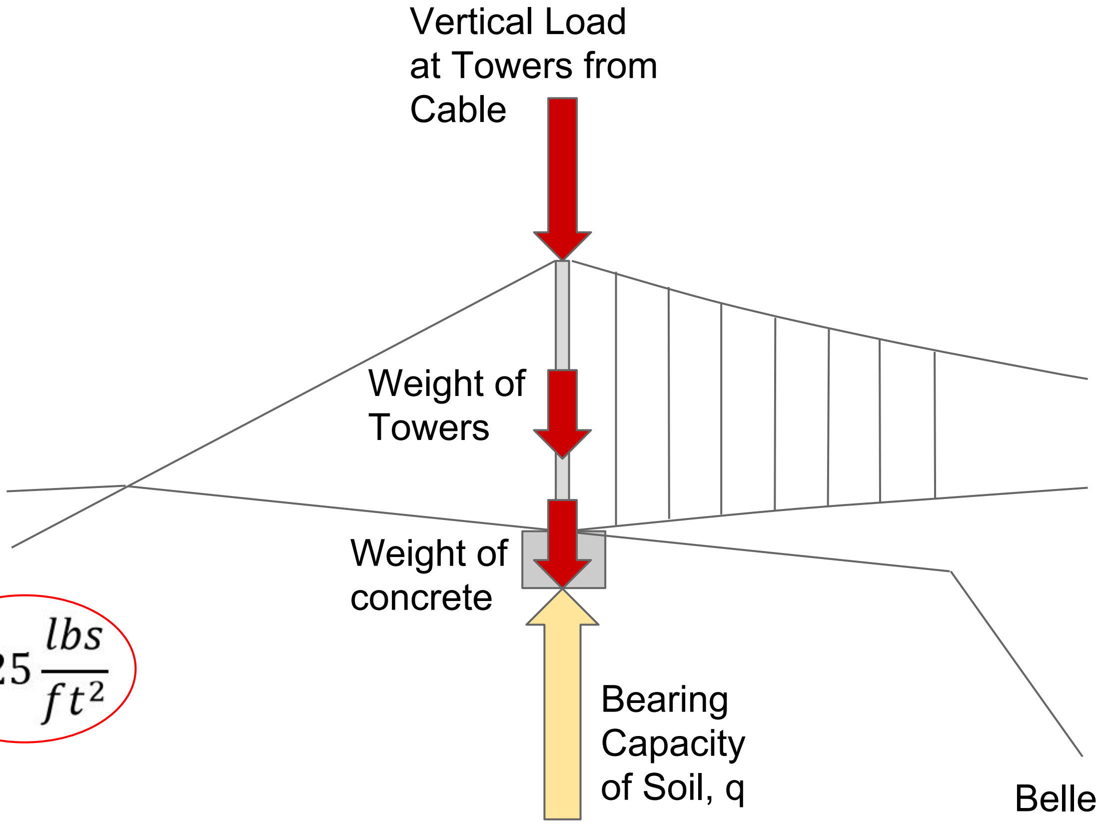
Foundation Calculations

Design Area:

6.5 ft x 6.5ft = 42 ft^2

$$P = \frac{F}{A}$$

$$P = \frac{F}{A} = \frac{94{,}000\ lbs}{42\ ft^2} = 2{,}225\,\frac{lbs}{ft^2}$$



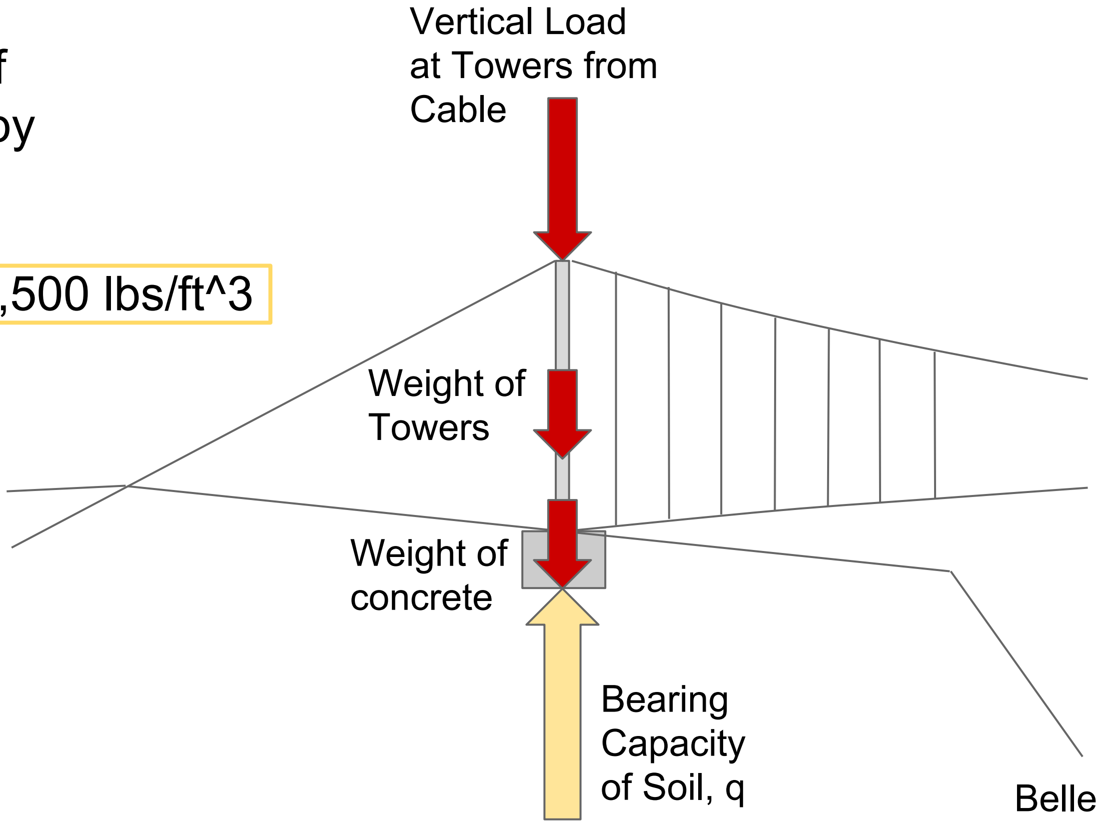
Foundation Calculations

Compare bearing capacity of soil to the pressure exerted by the foundation onto the soil

Assume bearing capacity = 3,500 lbs/ft^3

$$SF = \frac{3{,}500\,\frac{lbs}{ft^2}}{2{,}225\,\frac{lb}{ft^2}} = \mathbf{1.57}$$

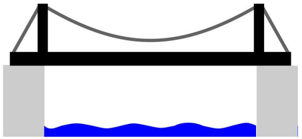
$$\therefore \boldsymbol{Acceptable}$$



Structural Analysis

Summary

- **Anchors-Buried**
  - Dimensions
    - 8’ x 8’ x 10’
    - Safety factor of 2 for horizontal and vertical components
  - Assumptions
    - Water table negligible



- **Foundation-Buried**
  - Dimensions
    - 6.5’ x 6.5’ x 4’
    - Safety Factor of 1.5
  - Assumptions
    - Soil Properties

Belle

Cost Estimate

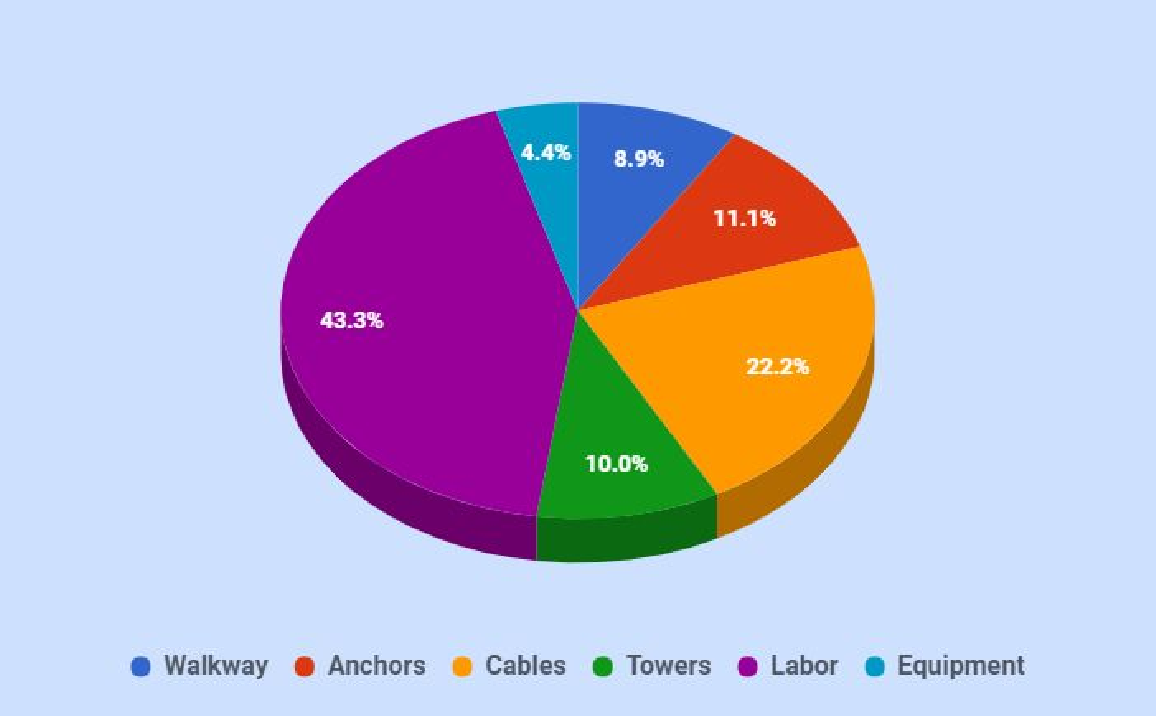
- Using RS Means and MDOT construction rates
- Material costs estimated using various suppliers across continental US
- Labor costs in Panama are expected to be significantly less
- Donated labor and materials would greatly reduce cost

Item	Material Cost	Labor Cost	Equipment	Total
Clear and Grub		$2,391.37	$800.00	$3,191.37
Excavation		$1,888.70		$1,888.70
Anchors	$9,401.16	$12,569.77		$21,970.93
Tower Foundations	$1,290.12	$4,189.92		$5,480.04
Towers	$7,508.02	$1,224.15		$8,732.17
Cables	$19,578.98	$597.66	$200.00	$20,376.64
Walkway	$7,488.74	$4,317.02		$11,805.76
Erosion Control	$1,206.00	$647.55		$1,853.55
SuperIntendant		$9,000.00		$9,000.00
Misc Tools/Operations			$2,800.00	$2,800.00
Totals	$46,473.02	$36,826.14	$3,800.00	$87,099.16
				$88,000

Andrew

Cost Estimate Breakdown

Walkway:	$8,000
Anchors:	$10,000
Cables:	$20,000
Towers:	$9,000
Labor:	$39,000
Equipment:	$4,000
Total:	**$90,000**



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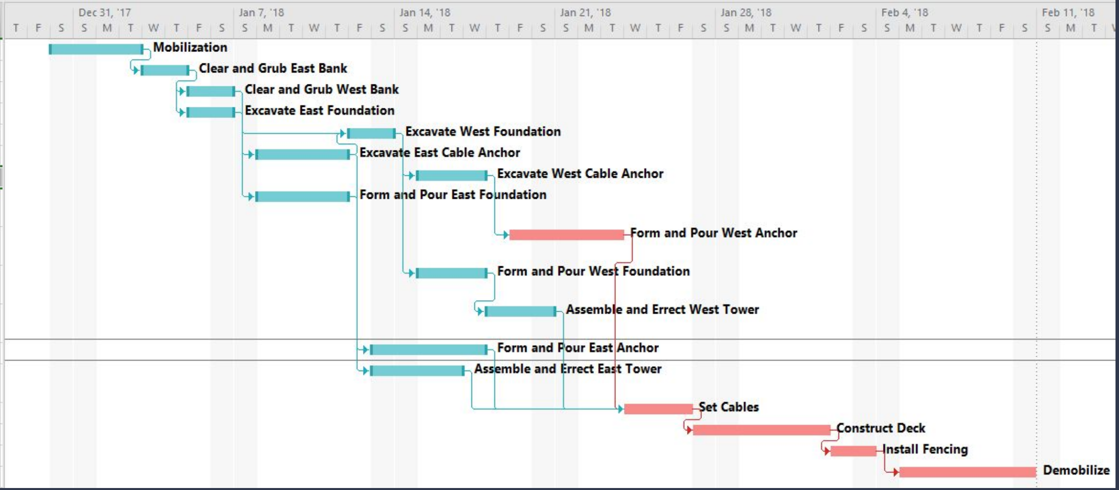
Schedule

Better Bridges

- Start: End of wet season
- End: During dry season (dry season is January-May)
- 40 day duration
- Optimal schedule excluding major delays

Task Mode	Task Name	Duration	Start	Finish	Predecessors
	Mobilization	3 days	Sat 12/30/17	Tue 1/2/18	
	Clear and Grub East Bank	2 days	Wed 1/3/18	Thu 1/4/18	1
	Clear and Grub West Bank	2 days	Fri 1/5/18	Sat 1/6/18	2
	Excavate East Foundation	2 days	Fri 1/5/18	Sat 1/6/18	2
	Excavate West Foundation	2 days	Fri 1/12/18	Sat 1/13/18	6,3
	Excavate East Cable Anchor	3 days	Mon 1/8/18	Thu 1/11/18	4
	Excavate West Cable Anchor	3 days	Mon 1/15/18	Wed 1/17/18	5
	Form and Pour East Foundation	3 days	Mon 1/8/18	Thu 1/11/18	4
	Form and Pour West Anchor	4 days	Fri 1/19/18	Tue 1/23/18	7
	Form and Pour West Foundation	3 days	Mon 1/15/18	Wed 1/17/18	5
	Assemble and Errect West Tower	3 days	Thu 1/18/18	Sat 1/20/18	10
	Form and Pour East Anchor	4 days	Sat 1/13/18	Wed 1/17/18	6
	Assemble and Errect East Tower	3 days	Sat 1/13/18	Tue 1/16/18	8
	Set Cables	3 days	Wed 1/24/18	Fri 1/26/18	12,9,13,11
	Construct Deck	5 days	Sat 1/27/18	Thu 2/1/18	14
	Install Fencing	2 days	Fri 2/2/18	Sat 2/3/18	15
	Demobilize	6 days	Mon 2/5/18	Sat 2/10/18	16



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Conclusion

- El Hatillo Footbridge
  - Better Bridges has designed a bridge with sustainability and economic efficiency as a focus
  - Easy repairs and maintenance are important design factors
  - The danger and inconvenience of wading through the Cabuya River will be eliminated with the construction of this bridge

- Team Experience
  - iDesign provided great design experience and cultural learning opportunities

Andrew

Thank you!