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
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
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
Site Location

- 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
Delineate Watershed

- **Process DEM**
  - Flow direction
  - Flow accumulation
  - Watershed boundary

- **Max elevation**
  - 2,290 ft
Watershed Characteristics

- Delineate Watershed
  - 6.99 mi²
  - 67% forested
  - 33% open
  - RCN = 74.28
    - Based on soil type and land usage

Contour interval = 65 ft
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
Found slope for each cross section
Calculated weighted average for all 5 paths

\[
Percent \ slope = \frac{\text{Point}_2 - \text{Point}_1}{\text{Length \ of \ segment}} \times 100
\]

<table>
<thead>
<tr>
<th>Cross section</th>
<th>Elevation at bridge</th>
<th>Elevation at peak</th>
<th>Distance from bridge</th>
<th>Point 2-Point 1</th>
<th>Slope</th>
<th>Average</th>
<th>Weighted Average</th>
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<td>1</td>
<td>358</td>
<td>1520</td>
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<td>1010</td>
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<td>4118</td>
<td>543</td>
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</table>
HEC-HMS Design Storm Model

- NRCS Curve Number method
  - Have
    - Length = 4.52 mi
    - Area = 6.99 mi²
    - 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

\[ I_A = 0.2 \times \text{Soil Retention} \]
\[ S = \frac{1000}{CN} - 10 \]
\[ L_t = L^{0.08} \left( \frac{1000 - 9 \times CN^{0.7}}{1900 \times CN^{0.07} \times \sqrt{Y}} \right) \]

\( I_A \) = Initial Abstraction
\( L_t \) = Lag time
\( S \) = Max Soil Retention
HEC-HMS hydrologic simulation model
HEC-HMS hydrologic simulation model

Summary Results for Reservoir "Bridge site"

**Project**: Senior Design
**Simulation Run**: Run 2
**Reservoir**: Bridge site

- **Start of Run**: 01Dec2013, 00:00
- **End of Run**: 03Dec2013, 00:00
- **Compute Time**: 12Dec2017, 16:36:22

**Basin Model**: Bridge
**Meteorologic Model**: Dec 7-8 Panama Storm Event
**Control Specifications**: Control 1

**Volume Units**: IN

**Computed Results**
- **Peak Inflow**: 7990.8 (CFS)
- **Date/Time of Peak Inflow**: 01Dec2013, 14:00
- **Peak Discharge**: 7990.8 (CFS)
- **Date/Time of Peak Discharge**: 01Dec2013, 14:00
- **Inflow Volume**: 7.76 (IN)
- **Peak Storage**: (AC-FT)
- **Discharge Volume**: 7.76 (IN)
Main Channel

- Summary
  - Peak flow
    - 7990 CFS
  - Time of peak
    - 14 hours
Manning's Equation

Manings equation = \( Q = \frac{C_m}{n} \times A \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} = S^{\frac{1}{2}} \times k \)

Manings equation = \( Q = \frac{1.49}{0.45} \times 772.4 \times 9.28^{\frac{2}{3}} \times 0.005^{\frac{1}{2}} = 0.005^{\frac{1}{2}} \times 96711 = 7990 \text{ cfs} \)

- \( C_m = 1.49 \) 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
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
Bridge Design – Plan
Bridge Design – Profile

Main Elements
- Towers
- Cables
- Deck/Walkway
- Anchors
- Foundation
Bridge Design – Towers

- Designed with Bridges to Prosperity standards
- Tower Load: 101 kips
Bridge Design – Cables

- Main Span: 1\(\frac{5}{8}\)” diameter, 264 kip breaking strength
- Suspender: 3\(\frac{5}{8}\)” 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
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
Bridge Design – Anchors

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

Goal?

**Minimize dimensions** for appropriate safety factors to reduce costs of materials.
Structural Analysis – Anchors

SPAN (L)
10′

ΔH = 1.8′

SAO = 12

FREEBOARD
36.0′

36.0′

36.0′

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
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

3. Forces from soil

4. Weight of Anchor

---

**1. Tension from cable**

**2. Friction**

**3. Forces from soil**

**4. Weight of Anchor**

---

**Belle**
Anchor Forces

1. Anchor Sliding Check
   Step 1: Identify Horizontal Forces

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!

\[ FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = 2 \]
Anchor Forces

1. Anchor Sliding Check

Step 2: Sum Horizontal Driving Forces

\[ R_S = P_{Active} + T_H \]

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

\[ K_a = \frac{(1 - \sin \phi)}{(1 + \sin \phi)} = 0.361 \]

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

Where:
- \( K_a \) = active earth pressure coefficient
- \( \gamma \) = soil density = 115 lb/ft^3
- \( h \) = anchor height = 8 ft
- \( w \) = anchor width = 10 ft
- \( \phi \) = angle of internal friction = 28 deg
1. Anchor Sliding Check

Step 2: Sum Horizontal *Driving* Forces

\[ R_S = P_{Active} + T_H \]

\[ R_S = 13.3 \text{ lbs} + 77.6 \text{ kips} = 91 \text{ kips} \]
1. Anchor Sliding Check

Step 3: Sum Horizontal Resisting Forces

\[ R_R = R_{friction} + R_{passive} \]

\[ R_{friction} = \mu \cdot (T_H + W_{soil}) = 36.3 \text{ kips} \]

\[ R_{passive} = \frac{1}{2} K_p Y \left( \frac{3}{4} h \right)^2 w(H_2 - H_1) = 230 \text{ kips} \]

\[ K_p = \frac{1 + \sin(28^\circ)}{1 - \sin(28^\circ)} = 2.77 \]
1. Anchor Sliding Check

Step 3: Sum Horizontal Resisting Forces

\[ R_R = R_{friction} + R_{passive} \]

\[ R_R = 36.3 \text{ kips} + 230 \text{ kips} = \textbf{266.3 kips} \]
Anchor Forces

1. Anchor Sliding Check

Step 4: Verify Horizontal Forces

\[ FS = \frac{R_R}{R_s} = \frac{266.3 \text{ kips}}{91 \text{ kips}} = 2.9 \]

\[ \therefore \text{Acceptable} \]
Anchor Forces

2. Anchor Uplift Check

Step 1: Identify Vertical Forces

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

\[ FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = 2 \]
Anchor Forces

2. Anchor Uplift Check
   Step 2: Sum Vertical *Driving* Forces

\[ T_{BS_v} = \text{Vertical Driving Force} = 38.8 \text{ kips} \]
Anchor Forces

2. Anchor Uplift Check

Step 3: Sum Vertical Resisting Forces

\[ V_R = R_{friction} + W_{Anchor} + W_{soil} \]

\[ = 36.3 \text{ kips} + 51.3 \text{ kips} + 17 \text{ kips} = 104.6 \text{ kips} \]
2. Anchor Uplift Check

Step 4: Verify Vertical Forces

\[ FS = \frac{V_R}{T_{BS_v}} = \frac{104.6 \text{ kips}}{38.8 \text{ kips}} = 2.7 \]

\[ \therefore \text{Acceptable} \]
Foundation Calculations

Span (L) 180°

ΔH = 1'-0"

SAG=12'

FREEBOARD 35'-8"

35.0'

36.0'
Foundation Calculations

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

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

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

Belle
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

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

$$= 25,350\, lbs$$

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

$$= 93,990\, lbs$$

Vertical Load at Towers from Cable

Weight of Towers

Weight of concrete

Bearing Capacity of Soil, $q$

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Foundation Calculations

Design Area:

$$6.5 \text{ ft} \times 6.5\text{ft} = 42 \text{ ft}^2$$

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

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

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

Assume bearing capacity = $3,500 \text{ lbs/ft}^3$

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

$\therefore \text{ Acceptable}$
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
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

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<tr>
<th>Item</th>
<th>Material Cost</th>
<th>Labor Cost</th>
<th>Equipment</th>
<th>Total</th>
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<tbody>
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<td>Clear and Grub</td>
<td>$2,391.37</td>
<td>$2,391.37</td>
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<td>Tower Foundations</td>
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<td>Erosion Control</td>
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<td>Superintendent</td>
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<tr>
<td>Misc Tools/Operations</td>
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<td>$36,826.14</td>
<td>$3,800.00</td>
<td>$87,099.16</td>
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Total: $88,000
Cost Estimate Breakdown

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

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

<table>
<thead>
<tr>
<th>Task Mode</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Predecessors</th>
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<tr>
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<td>Mobilization</td>
<td>3 days</td>
<td>Jan 1/3/18</td>
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<td></td>
<td>Clear and Grub East Bank</td>
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<td>Jan 1/1/18</td>
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<td>Clear and Grub West Bank</td>
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<td></td>
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<td>Form and Pour East Anchor</td>
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<td>Set Cables</td>
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<td>Jan 2/1/18</td>
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*Figures are illustrative and may not reflect actual dates.*
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
Thank you!