July 17, 2013

# Cable Engineering for Nik Wallenda

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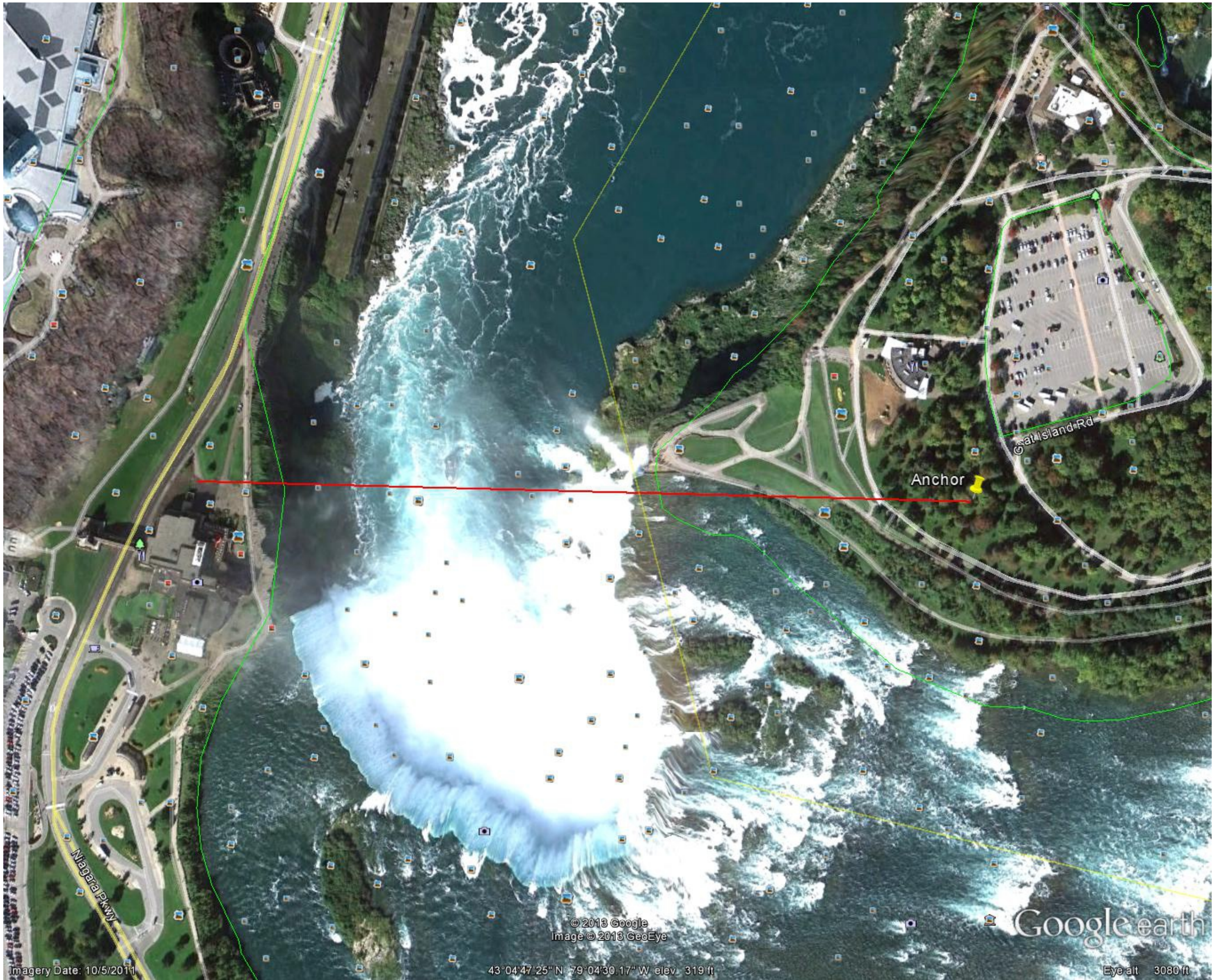
# What Matters to Nik

- In our first conversation, we agreed that:
  - Our job was to give Nik a cable that would not surprise him (never go bump in the night, no unexpected or random motions)
- He can walk up or down fairly steep slopes but the preferred maximum slope is 5° off horizontal
- We "did" Niagara Falls in 2012 (event June 15)
- We "did" the Grand Canyon in 2013 (event June 23)

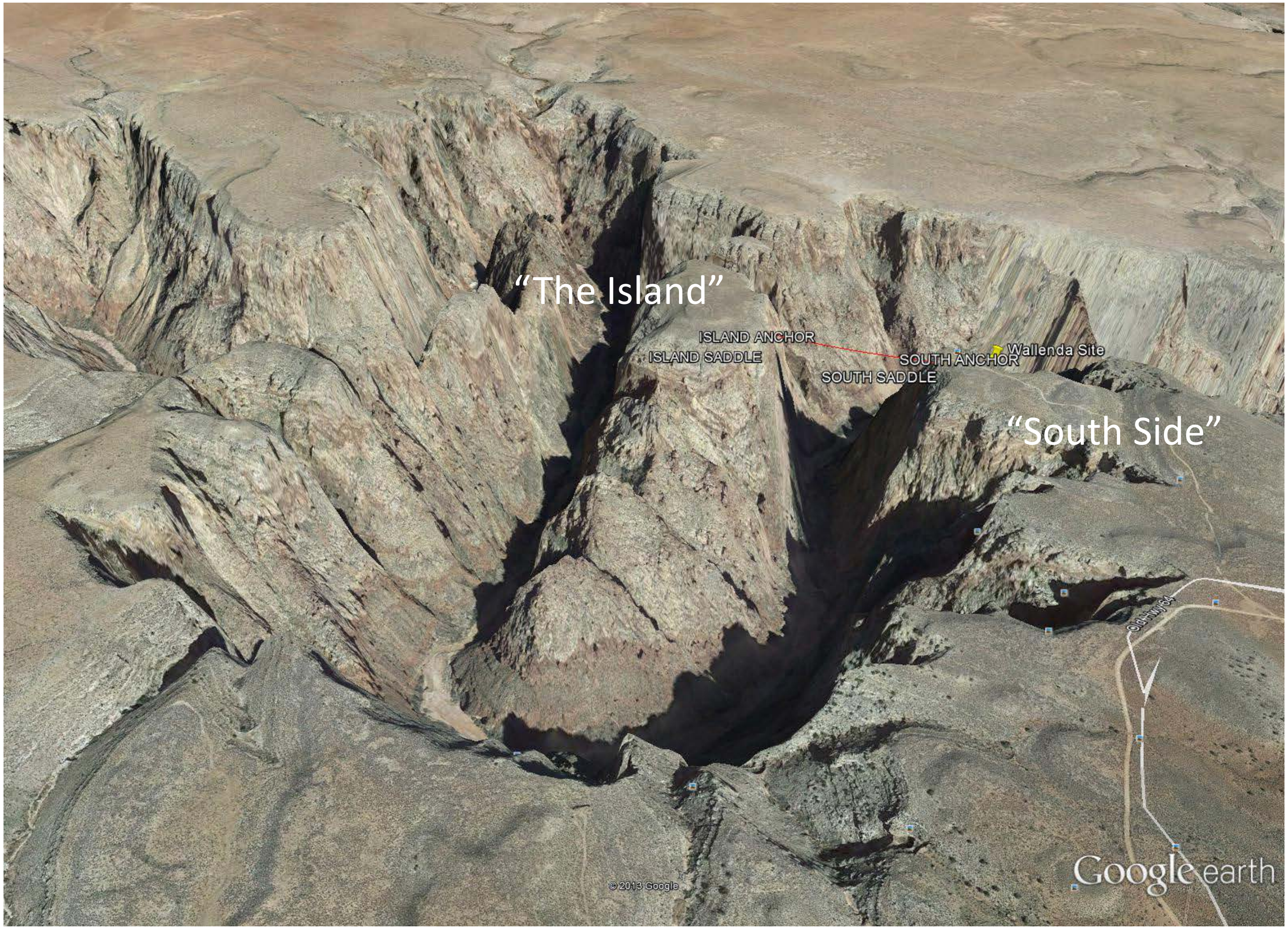
# Our Niagara Falls Location

Ontario

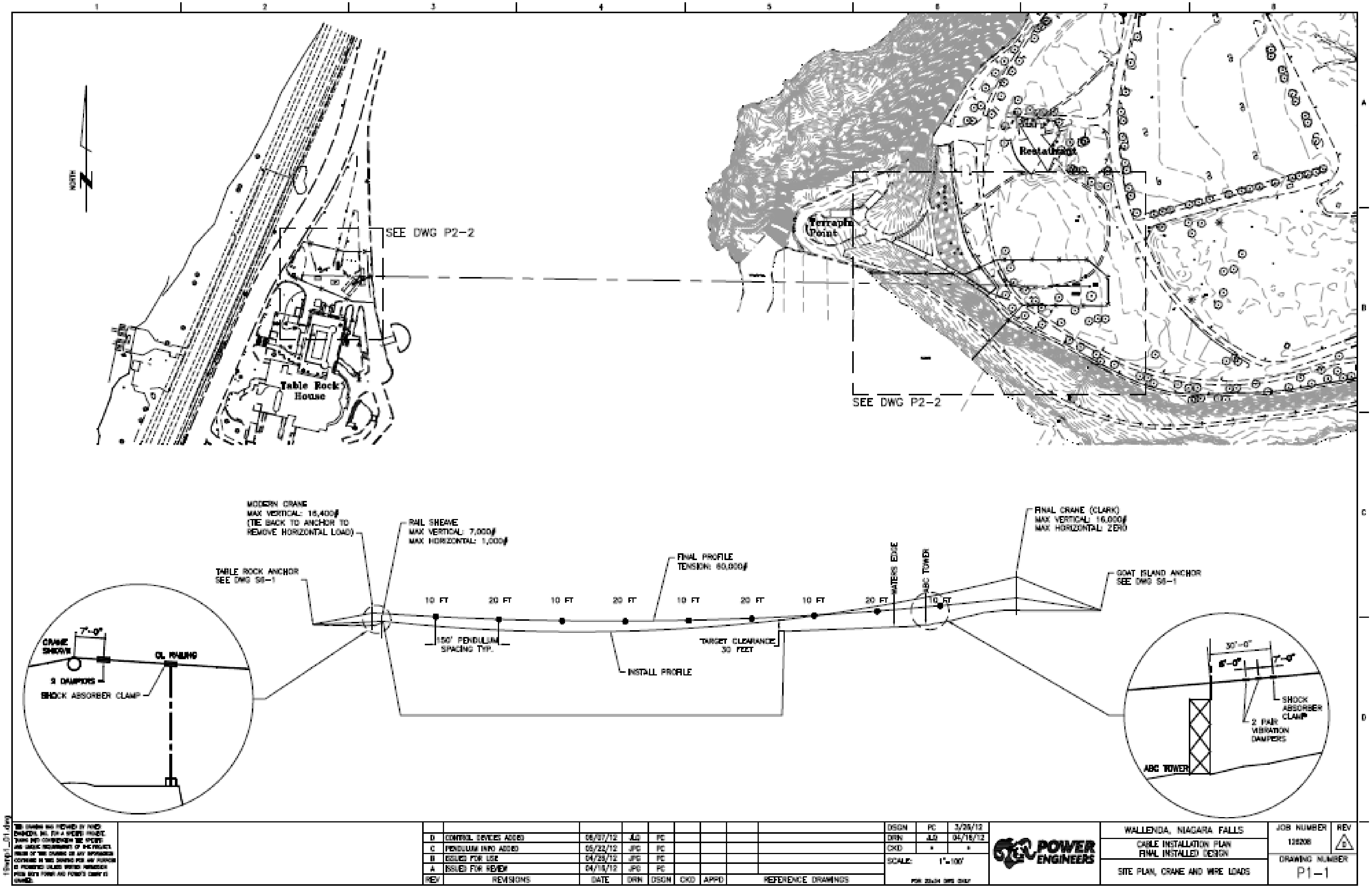



New York

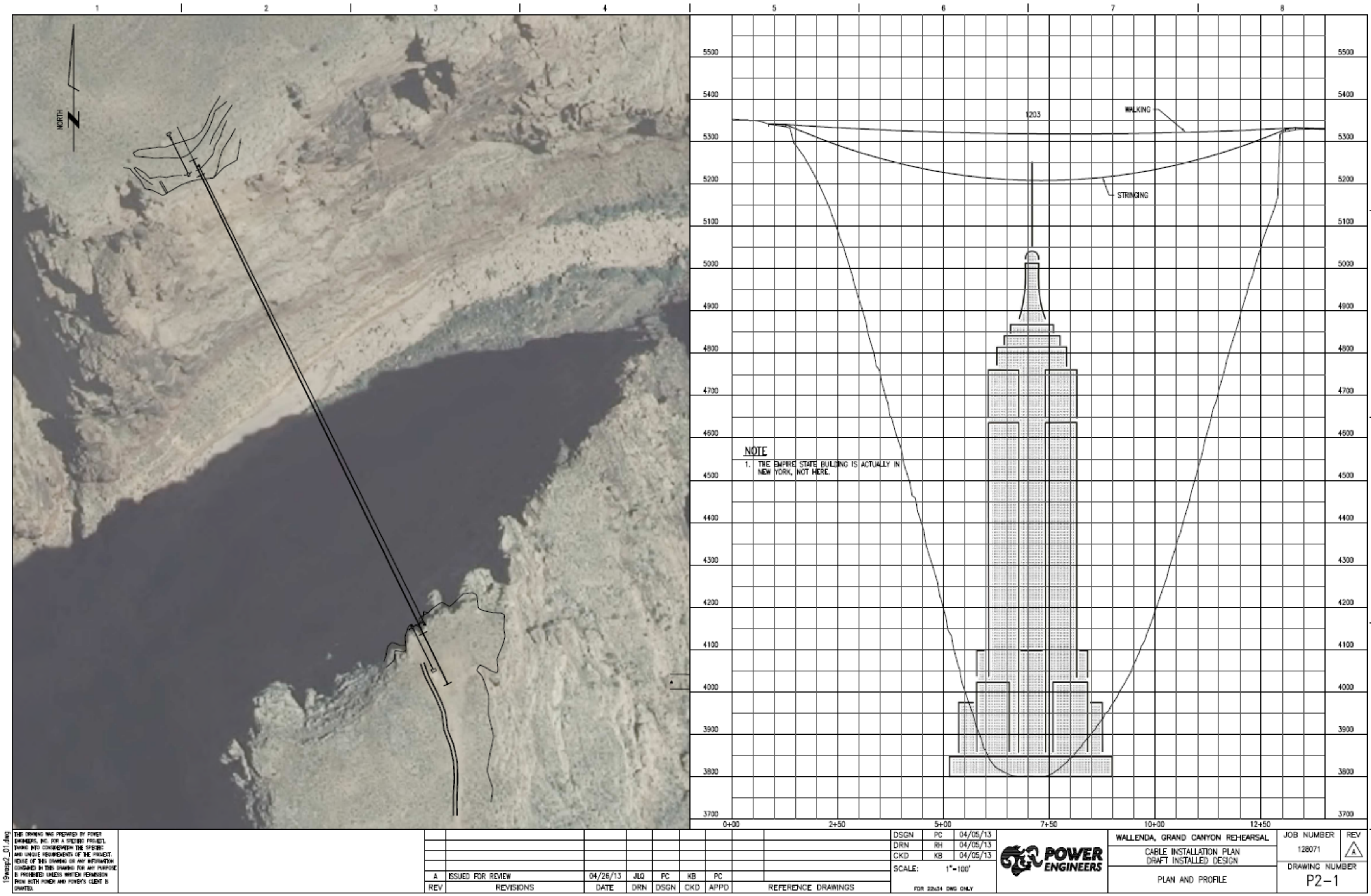
# Our Grand Canyon Location



# Our Niagara Falls Plan and Profile



# Our Grand Canyon Plan & Profile



# Our Constraints

## Niagara Falls

- Desired tension was decided to be 30 tons
  - RBS is 198 tons (15%)
  - Tested anchors to 60 tons
  - Rock at unknown depth (hollow core micropiles)
- Land on both sides of span was fully accessible but owned by State/Provincial government agencies (Parks).
  - Fully occupied by tourists
  - Two countries (National Border)
  - Lots of rules and permissions required
  - Review of engineering and installation plan required by both Parks and TV (ABC) engineers.

- No damage or permanent marks
- Cable will be in place for 3 days (June)
- No sway guys, developed pendulums idea
- Modest temperature range day-night
- Modest wind expectations
- Cable pulling work limited to night time

## Grand Canyon

- Desired tension was decided to be 32.5 tons
  - RBS is 198 tons (16.5%) SAME cable!
  - Tested anchors to 48 tons
  - Rock at the surface (grouted cable slings)
- Land on north end of span was completely inaccessible except by helicopter
  - No Tourists (closed site)
  - Navajo Nation
  - Less rules and permissions required
  - No Review of engineering and installation plan required.

- No damage or permanent marks
- Cable will be in place for 3 days (June)
- No sway guys, modified pendulums idea
- Greater temperature range day-night (40F°)
  - Tension change is 600 lbs / 10F°
- Greater wind expectations, hotter
- Cable pulling work limited to day time with limited wind.

# Our Installation Plan

## Niagara Falls

- Install and test anchors a month ahead
  - Cluster of 4 hollow core rods (one ft apart)
  - 23 ft deep in Ontario (15 ft into rock), 30° off vertical
  - 70 ft deep in NY (barely reaching the rock)
- Place Cable Reel truck and Tensioner on the US side
  - Set back 200 ft from Big Crane
  - Big Crane holds cable 60 ft above ground to clear high ground to the Gorge wall
- Place Puller on the CDN side
- Fly 2-purchase sock line from Canada to US, through block on the end of the cable, back to CDN-side anchor
  - Make a double purchase pull across the Gorge at night.
  - Pulling tension 12 tons on the cable
- Cable length is predetermined.
- Pin cable at both ends
- Lift cable at both ends with cranes to generate final tension and positioning
  - System tension is fully adjustable by crane hook movements
- Installed 9 pendulums at 150 ft spacing

## Grand Canyon

- Install and test anchors a month ahead
  - Cluster of 4 cable slings (6 ft apart)
  - 18 ft deep, 45° off vertical
  - Two extra anchors on south side for equipment
- Place Cable Reel truck, Tensioner AND Puller on the South side
  - Pulling line turning block placed on the Island
  - Set 6 ft high timber saddle 25 ft from the Brink on both sides
- Fly sock line from South side to Island, through a turning block and back to the South Side. Attach to the cable's lead end.
  - Make a single purchase pull to the Island
  - Pulling tension 5.5 tons on the cable
- Cable length is NOT predetermined
- Pin cable on Island
- Suck tension up on South side with 6-purchase system and Puller.
  - Target tension is function of temperature
- When tension is reached (dyno reading), clamp cable tail creating the required cable length
  - System tension is fixed unless we execute a redo.
- Installed 20 pendulums at 58 ft spacing

# PLS-CADD Usage

## Niagara Falls

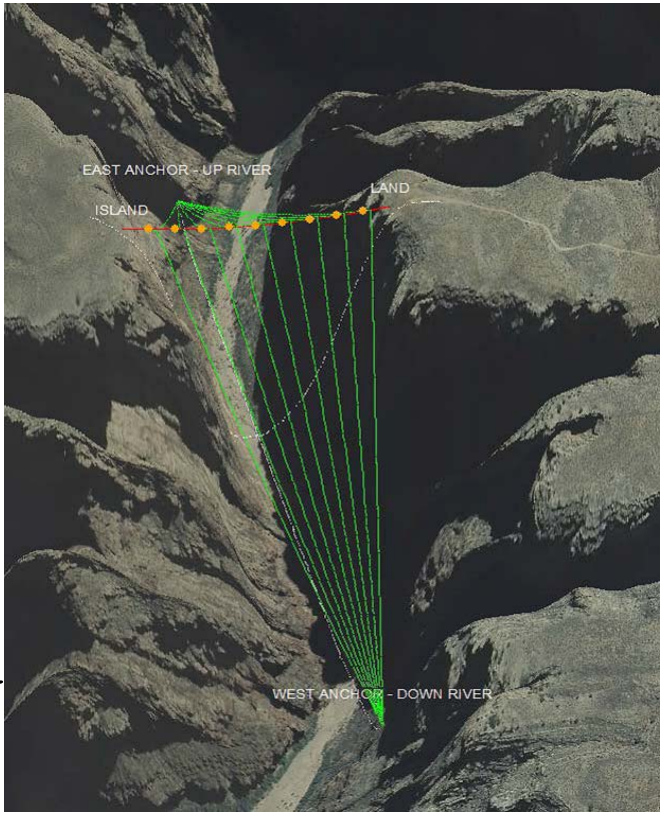
- 3 day duration (no creep)
- No need for temperature considerations because the system was full adjustable
- The ONLY characteristic of the cable that needed consideration but was not calculable in PLS-CADD any better than by hand was its initial elongation upon first tensioning.
  - The cable was NOT factory pre-tensioned. On first loading, it elongated 13 ft on 1,500 ft (0.85%) more or less
  - This was a half-educated guess that turned out to be about right.
- It was most important to create the desired tension at the expense of proper positioning.
  - If we got the length and stretch values pretty close, the cranes could fine tune the system.
- We did NOT use PLS-CADD at Niagara

## Grand Canyon

- 3 day duration (no creep)
  - SAME Cable, second use, same tensions
- Temperature needed consideration

Also:

First plan was for a stayed cable system. We modeled this in PLS-TOWER




This plan was vacated because it required the purchase and installation ($$$) of about 10-12 miles of small stay cables are were likely too long to be effective and loaded the big cable excessively.

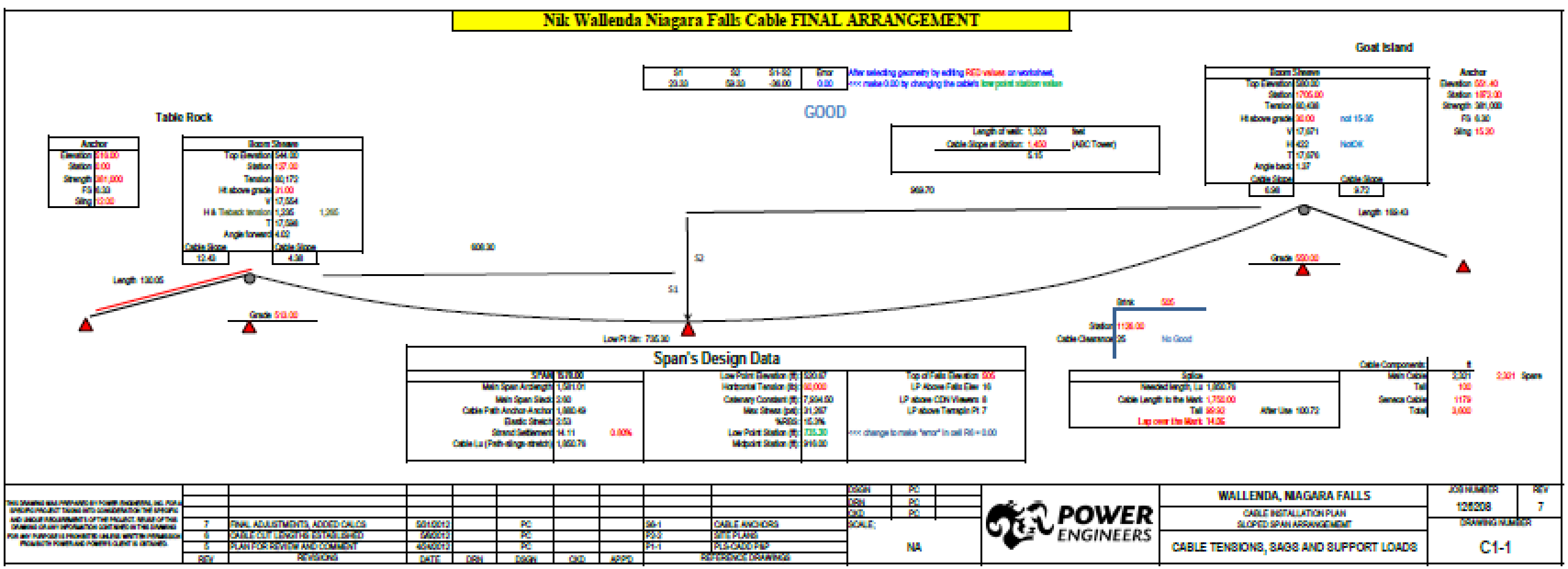
# The PLS-TOWER model

- This is a PLS-TOWER model.
- The Red Line is segments of “structure” (cable elements) between the nodes
- The green lines are guy cables attached to the Nodes and running to anchor points on the canyon floor.
- The Yellow dots are marker ball point loads for the pendulums (only 9 at the time)

- The nodes on the cable “structure” had to be placed by coordinates in space that represented the eventual shape/position of the cable in order to converge. It’s a trick!
  - The convergence of the very flexible cable element structure has trouble translating through large displacements to converge to the solution.

# Niagara Falls Calculation Platform

- All the cable calculations were done on this Excel spreadsheet
  - No need for thermal or creep calculations
  - Much need for cable length adjustments and crane location/height adjustments
  - IE: no need for PLS-CADD’s capabilities or complexities
  - Spreadsheet became a project drawing



# Grand Canyon Calculation Platform: PLS-CADD

- The PLS model is a single cable deadended to two “zero height” deadend structures at the anchor locations with 7 ft tall suspension towers at the timber saddle locations set about 25 ft back of the canyon wall brinks.
- The Design process
  1. Uses two line edits: one with pendulums attached to the cable as marker balls and the other without.
  2. In RS mode, set the pendulum  model to 65,000 lbs tension at 80°F
  3. Convert to FE mode and note the length of cable in the main span
  4. In the “no pendulum” model, in FE mode, set the cable length equal to that just determined in the other model
  5. Run the “no pendulum” model through a range of temperatures and create a sagging table: tension vs. temperature.

- The Installation process
  1. Pull the cable to tension reading a dynamometer at the Island Anchor end. Tension choice is a function of the temperature at the time.
  2. Test the “tension – slack” relationship.
  3. Pull slack out of the Tail Cable and clamp it to the main cable. This engaged a second dyno in the Tail Cable assembly.
  4. Following day, add the pendulums expecting the tension to approach 65,000 lbs barring temperature differences from 80°F.

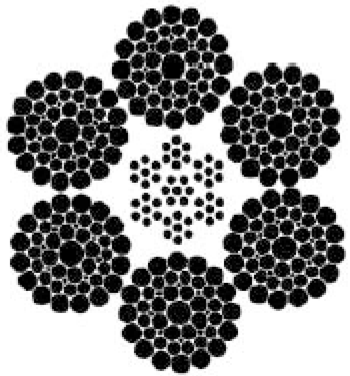
# Here's What Really Happened!

- Pulled the cable up to the calculated tension (62,000 lbs) according to the sagging table as readable on the Island dyno.
  - The target sag was about 23 ft in the 1,229 ft span, Catenary Constant is about 8,500 ft – pretty tight!
- Explored the tension-slack relationship
  - Marked the cable at the timber saddle and pulled ONE MORE INCH of cable out of the span
  - The tension rose 2,500 lbs. Interesting!
  - Relaxed the cable back to the 62,000 lb reading on the dyno
  - The digital dyno readout bounced around constantly by several hundred pounds.
- Tensioned the tail cable to remove slack and clamped it to the main cable to create an anchor-to-anchor cable system at tension.
- The second dyno placed in the system at the Tail Cable anchorage could now also read the tension in the cable.
  - While the Island dyno reading remained at 62,000 lbs (more or less), the Tail Dyno read 55,000 lbs more or less. (10+% different!)
  - **Rule** (that I broke on this project): NEVER sag conductors with a dynamometer. They are not reliable!
- We chose through convenience to go with the Island Dyno reading and ignore the Tail dyno
- Started placing pendulums
  - The tension rose but not as much as expected
  - Why? Did the cable stretch even an inch or two during that day? Did the anchors give back even a fraction of an inch?
- Nik walked on the cable when the Island dyno read 62,500 lbs and claimed it felt soft.
  - He wanted 65,000 lbs and claimed to feel the difference from 62,500 lbs based on that comment.
  - I think the Island Dyno was wrong and the actual tension was closer to the ignored tail dyno (55,000 lbs). That, he would feel!

# The “6x37 Class” Steel Wire Rope Cable

<u>Central Bundle</u>:
made of 7 sub-bundles of 7 equal diameter strands each.
<u>6 Outer Bundles</u>:
Unequal diameters in various layers. 49 strands in each. See embedded small wires forcing layers above an below to lay in same direction.

- Greased (sticky), no galvanizing.
- Total of 343strands
- RBS 198 tons
- <u>Not</u> factory pre-stressed.



# The Event Features Compared.

## Niagara Falls

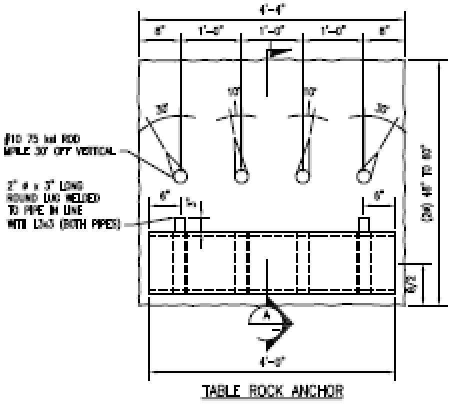
- Anchor to Anchor: 1,872 ft
- Crane to Crane Span: 1,578 ft
- Nik walked about 1,400 ft
- Crane hook heights: 30-32 ft
- Cable height above Falls brink: 15 ft
- Cable height above the lower river: 180 ft
- Cable tension during the walk: 62,500 lbs (31.2 tons) *maybe!*
- 9 Pendulums 10 ft and 20 ft long alternating at 150 ft
- Cable vibration: None. No dampers applied
- C = 8,500 ft !

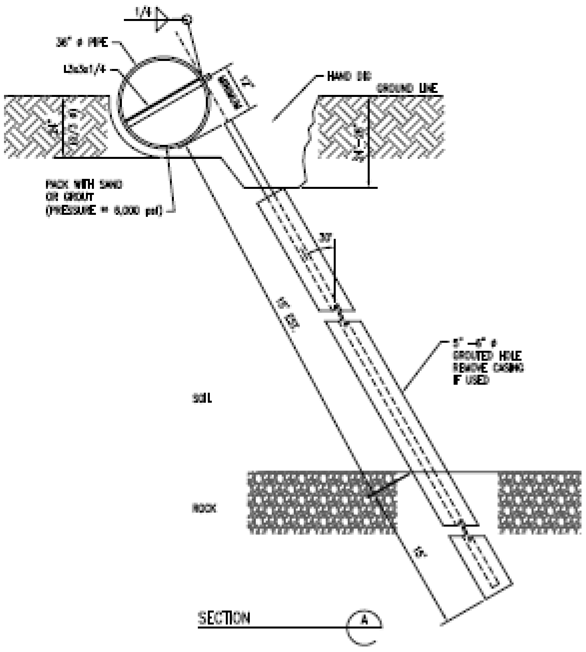
## Grand Canyon

- Anchor to Anchor: 1,400 ft
- Saddle to Saddle Span: 1,219 ft
- Nik walked about 1,219 ft
- Saddle heights: 6 ft
- Cable height above Canyon brinks: 6 ft
- Cable height above the lower river: 1,500 ft
- Cable tension during the walk: 62,500 lbs (31.2 tons) *maybe!*
- 20 Pendulums 10 ft and 20 ft long alternating at 58 ft
- Cable vibration: None. Dampers used as pendulum weights
- C = 8,500 ft !

# Niagara Falls Design Features

- Ultimate design capacity of each anchorage is 5 times cable tension
- Made up of 4 micropiles each tension tested to 60K (the tension of the cable)
  - Ontario: 15 ft into rock at 8 ft depth
  - NY: 3-5 ft into rock at 65-70 ft depth
- A sling on each anchor rod runs over a steel pipe saddle to manage load alignment (prevent anchor rod bending)
- Pipe saddle embedded in earth to prevent forward movement.
- Excavation: 5 ft x 4 ft x 1.5 ft deep



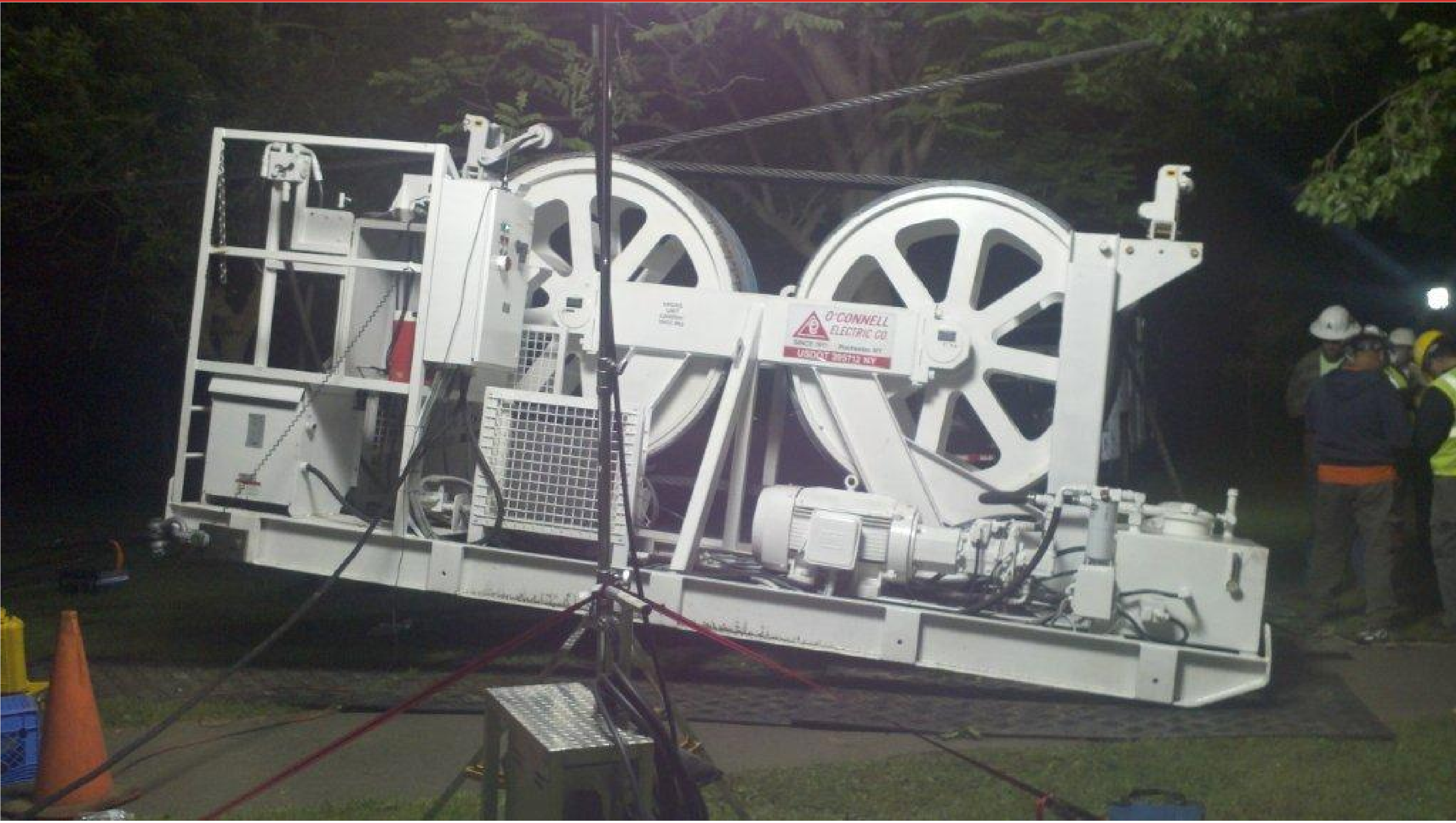



# Micropile Foundations

# Cable Pull: Tensioner on the US side

# Pulling Line Flown across

# Woops!



# Pulling Line (3/4”, 75,000# RBS)

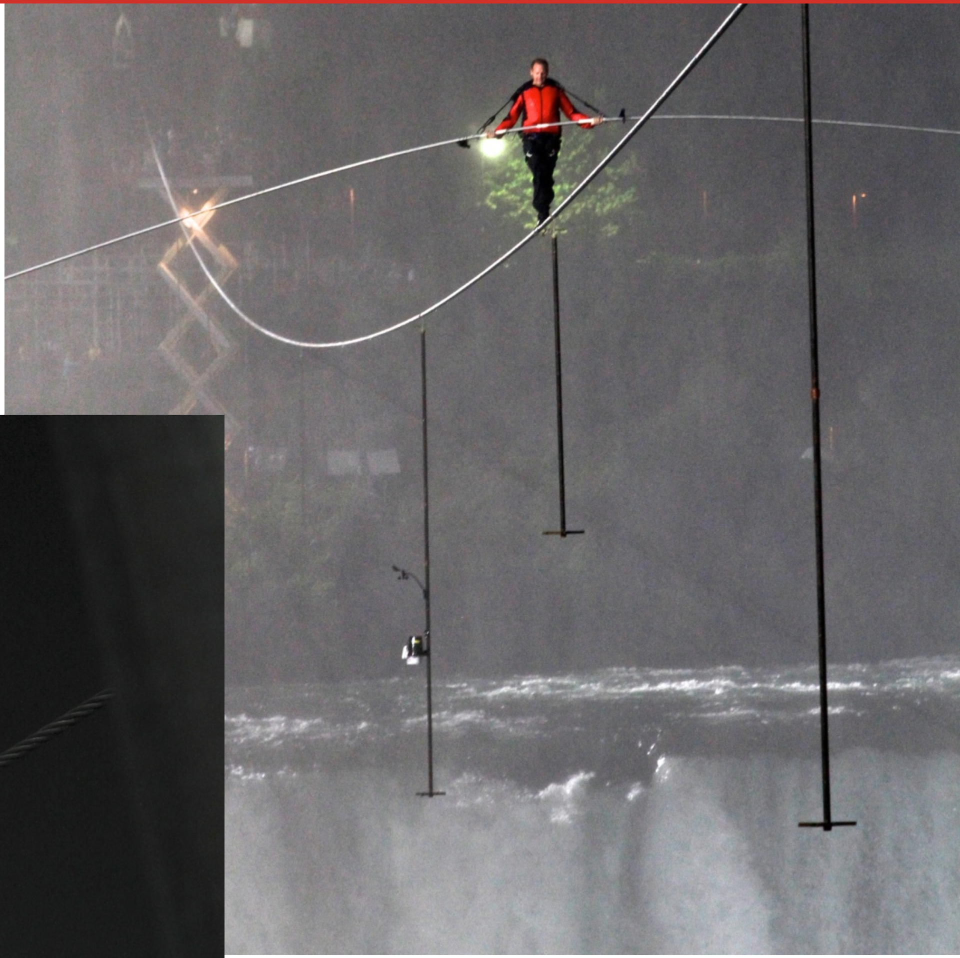
# By sunrise…

# Details…

# Details…

# Ready for Showtime

# SHOWTIME!



# Outa Here!

- After the show's end at 11 PM, the ABC TV people removed the staging by 1 AM, and we ran the install plan in reverse.
- The cable was removed and reeled up by 4:30 AM
- By 7 AM, we were out of there
- By 10 AM, Nik (himself) had backfilled the anchor holes
  - Like it didn't even happen
- Except the crowd of 120,000+ left a terrible mess of junk everywhere. Not our problem. Google "Nik Wallenda Niagara Falls"

# The Grand Canyon Design Features

- Anchors
  - Set of four 1.125” steel cable sling tails grouted directly into rock
  - 18 ft deep at 45° angle
  - 12 T capacity each (60 T ultimate)
  - Yoke with the same NF big steel plate assembly
  - Small saddle provided at the surface to allow the anchor cable to direct itself without harm
- Saddles
  - No big cranes to generate cable tension
  - Cable sitting on low timber stack saddles with sheave mounted on top
    - Less than 7 ft high

# The south side anchorage with Tail cable and dyno ready for use.

# Starting the Big Cable Pull

# Pulling Rope and installed cable

# The Main Cable : Tail Cable Joint

16 large Crosby Clamps transfer the 32 ton tension between the main cable and tail cable behind the South side Saddle.

6-purchase B&T,
4 - 10 ton Morgan grips and 16 Crosbys

# Prepping for Showtime

# Nik Wallenda: doing his thing

# Discussion