



The 2013-2014 Survey of the Washington Monument

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NOAA's National Geodetic Survey

Why?



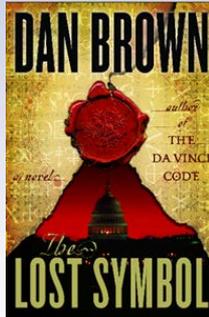
Construction of the Washington Monument

Construction

- 1799-1833 – Congressional promises for a monument fail to yield material action
- 1833: The *Washington National Monument Society* is formed by private citizens upset at Congressional inaction
- 1833-1848: Fundraising by the Society

Construction

- 1848 – Construction begins
 - Foundation first
 - Cornerstone with time capsule set in foundation
- 1854 – Construction ceases
 - Funds depleted and pre-war tensions
 - 152 feet high
 - *Two* doors: East & West
 - Today there is only an East door



1854-1878: Unfinished



Construction

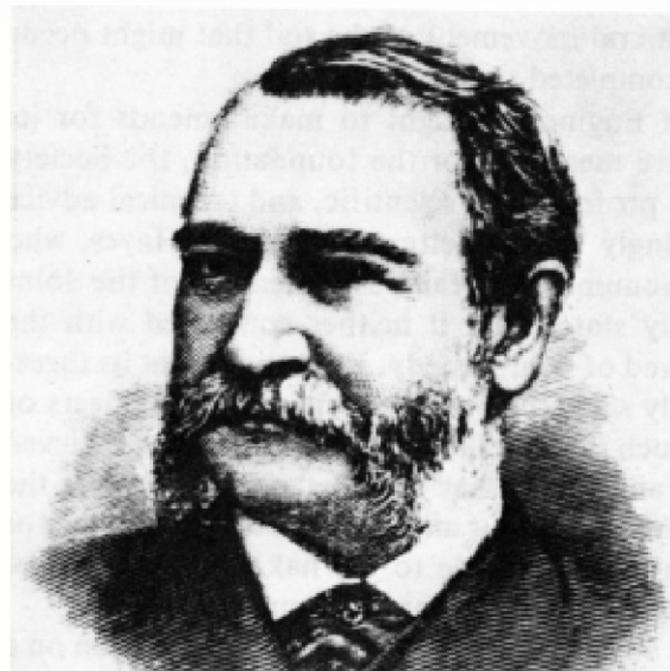
- 1854-1876 – The embarrassing pause
 - Politics within the Society
 - Civil War
 - Repeated inquiries about **the foundation's strength**
 - All claim that no serious issues exist
- 1876 – Congress appropriates re-start funds
 - First time that **taxpayer** funds were used

Construction

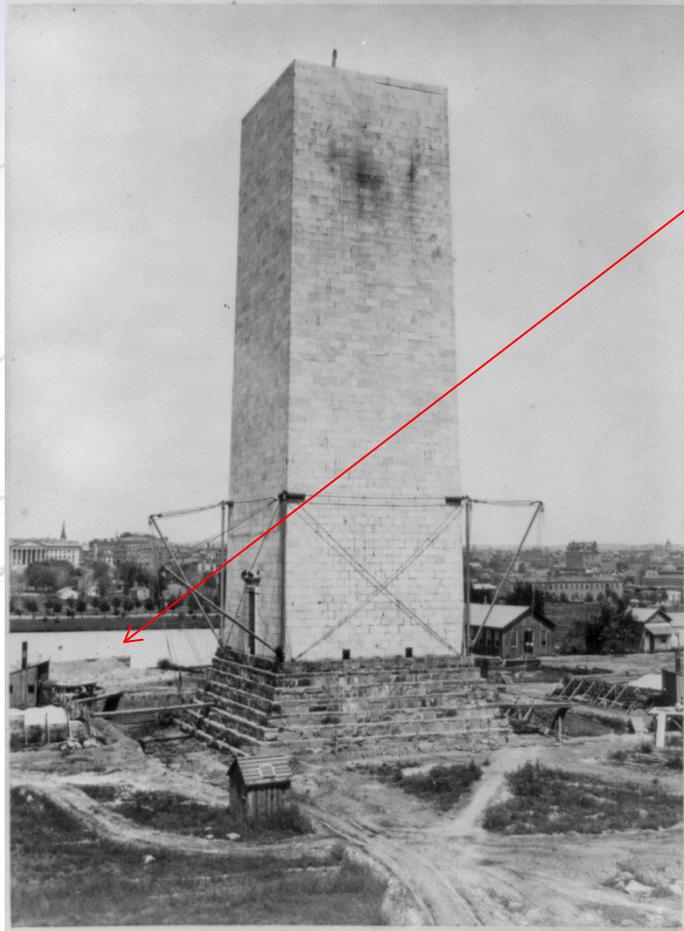
- 1876 – Re-studying the foundation
 - All previous reports of the foundation being “safe” are **rejected**
 - Nine inches of settlement had been overlooked in previous reports because of “*using the wrong stone as a bench mark for measuring the settlement of the structure*”
 - Decision: Strengthen the foundation
 - 1878 – Additional Congressional Appropriation

Construction

- 1878 – Lt Col Thomas Casey takes charge
 - First step: Strengthen foundation

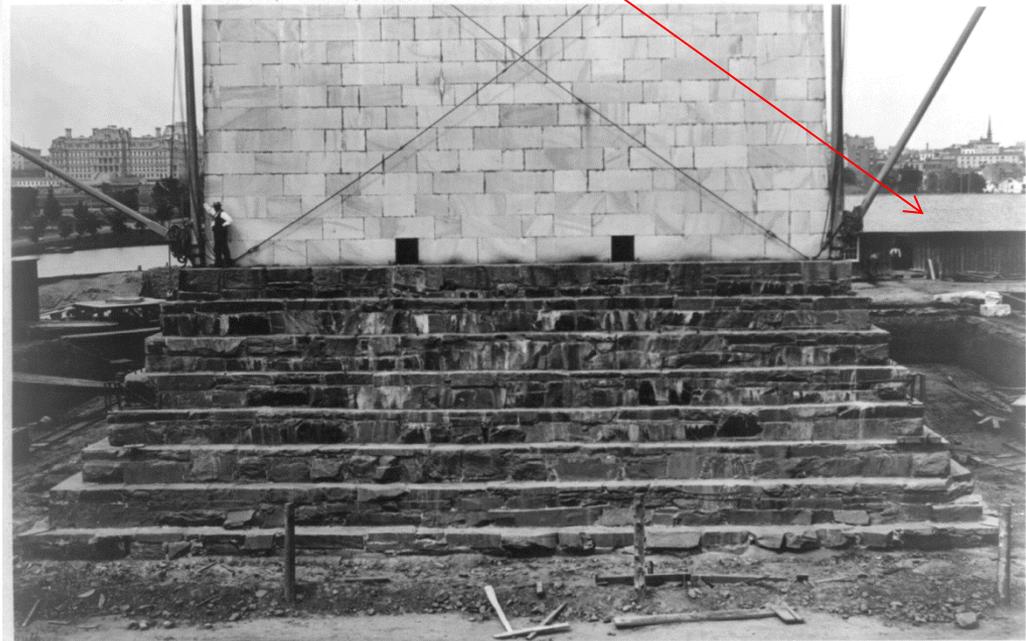


Strengthening the Foundation



“Babcock Lake”
North of the WM
(since drained)

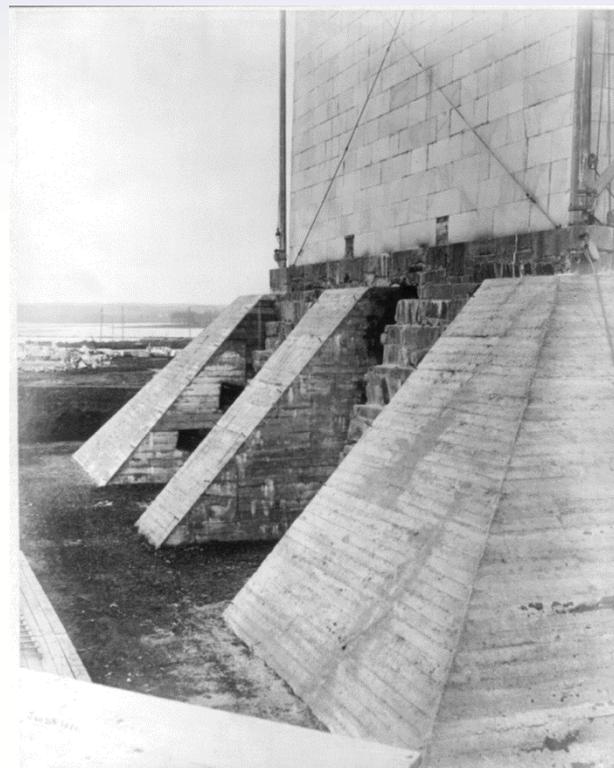
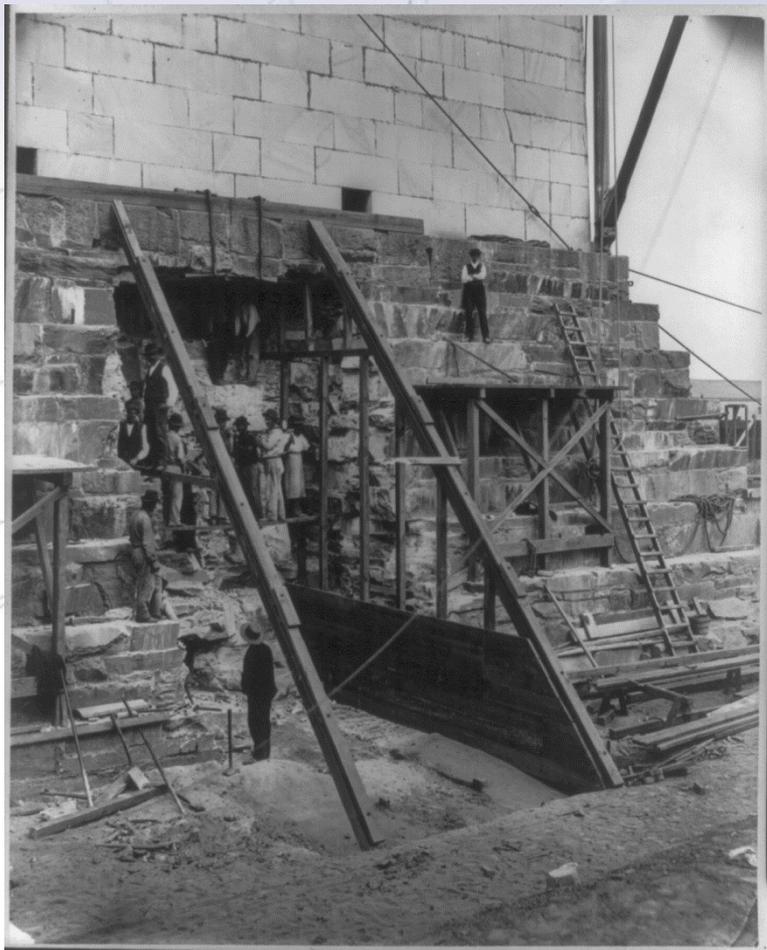
From the South
August 14, 1879



*Foundation of Washington Monument.
From the South.
August 14, 1879.*

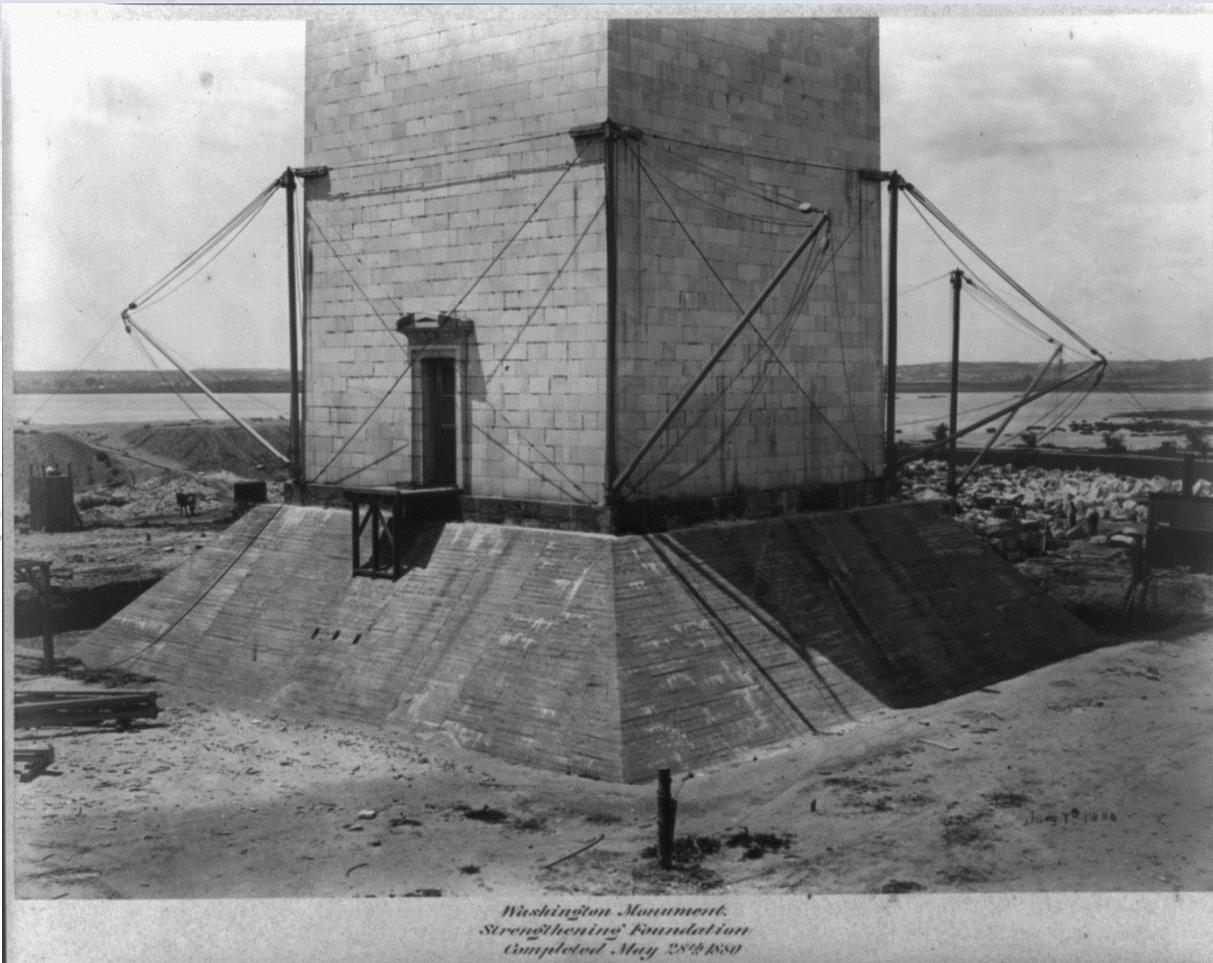
Strengthening the Foundation

From the South East
January 20th, 1880



*Reinforcing of Foundation, Washington Monument
from the South East
January 20th 1880*

Strengthening the Foundation

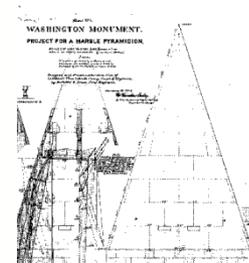
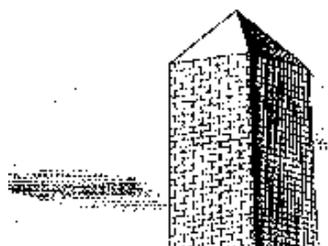


“Completed
May 28th, 1880”

*Washington Monument.
Strengthening Foundation
Completed May 28th 1880*

Construction

- 1880 – Work on the main obelisk resumes
 - Significant loss of plans since 1854
- 1884 – Decision to make pyramidion *stone*, rather than *metal* and change its shape



The aluminum apex

- Dec 6, 1884 – Finished!*
 - Casey sets the aluminum apex.
- Aluminum apex
 - To be a lightning rod

* Windows still not installed,
plus other finishing touches



“As finished the Monument is 555 feet 5 1/8 inches in height”

The work of building the Obelisk was commenced August 7th 1880, the old shaft having first been reduced to a height of 150 feet, and, as before stated the masonry of the Obelisk was completed Dec: 6th 1884.

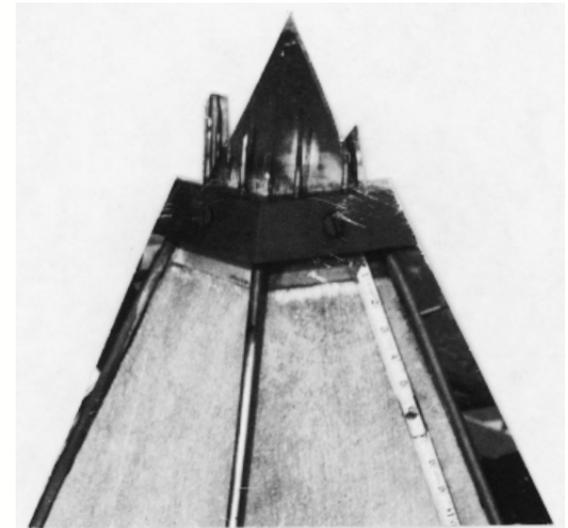
As finished the Monument is 555 feet 5/8 inches in height, the shaft being 500 ft 5/8 inches, and the pyramidion or apex 55 feet.

The topmost point is 597 feet 3 inches above mean low water in the Potomac. The shaft as completed is 55 feet 1 1/2 inches square at the base and 34 feet 5 1/2 inches square at the top. The batter of the sides is .247# of an inch to one foot in rise. The height

- Lt Col Thomas L. Casey

Immediate Changes

- Jun 8, 1885: Lightning strike damaged stones in pyramidion
 - Installation of lightning “band” sitting directly on aluminum apex
 - Luckily the platform was still in place from Dec 1884!



Accessing the top



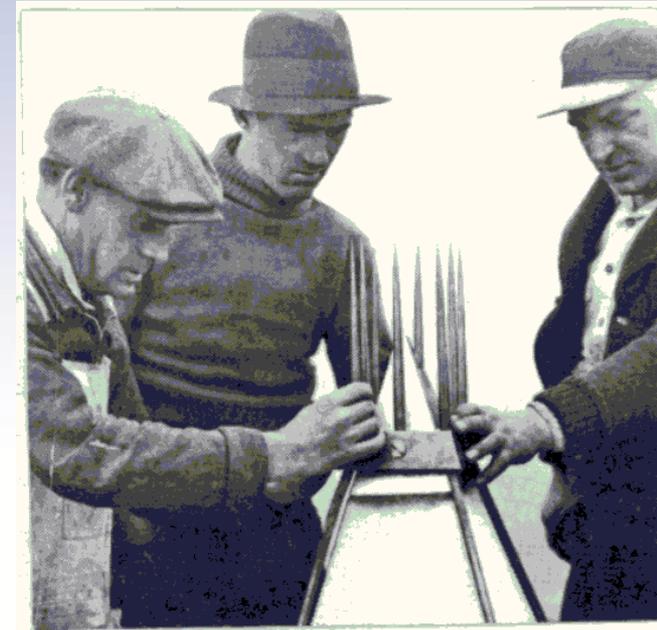
Surveying

1885-1934: USC&GS

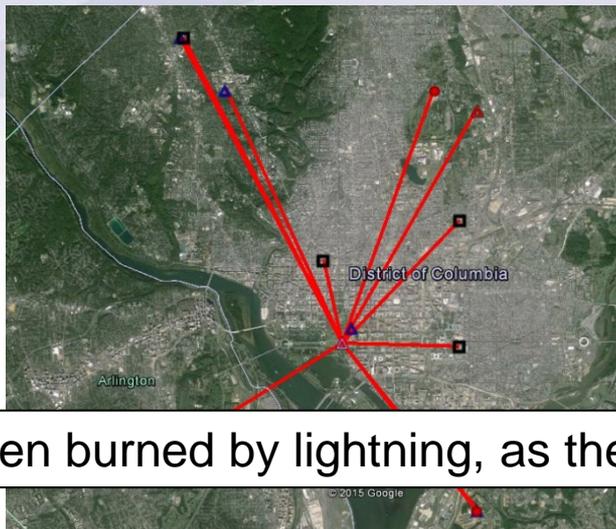
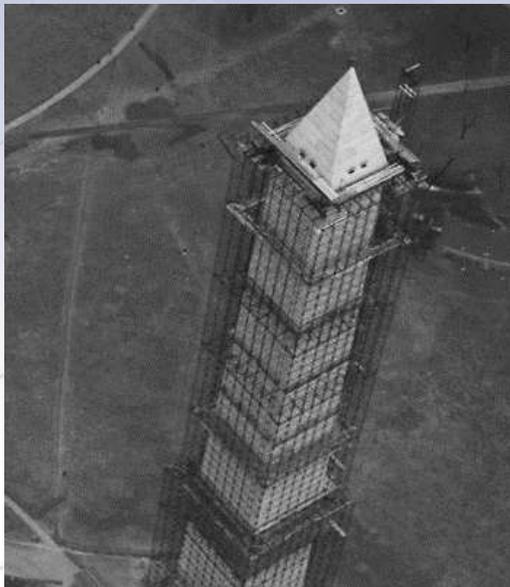
- The US Coast and Geodetic Survey
 - Leveling (height difference surveys) around the base and grounds of the WM since 1885. Useful for detecting subsidence.
 - The peak of the WM, *sighted from the ground*, was a prominent landmark, useful for traverse (latitude and longitude) surveys around the DC area, but a survey instrument had never been used atop the WM itself

1934

- Monument in disrepair
 - “Public Works Act”
 - Scaffolding
 - Lightning Protection System
 - Same band as 1885, but added new rods
 - Aluminum Apex:
 - New engraving, “quietly” done
 - With scaffolding up, C&GS is granted approval to occupy the WM peak for a triangulation survey



1934



“...tip has apparently been burned by lightning, as the top is about 1/2 inch square...”



...and somewhere, a young man named Don Breidenbach was born.

1934-1999

- USC&GS (becoming the National Geodetic Survey in the 1970s) continues **leveling surveys** on and around the WMM grounds
- 1999 – A **new round of renovations** are proposed, and NGS seeks a chance to position the peak again, this time with **GPS**

1999



May 21, 2015

NOAA Brown Bag Seminar

1999: Geodetic forensics (2014)

- GPS
 - Bad environment, but **lots** of data helped!
- Leveling
 - Nothing published about floor connections
- Vertical angles
 - Non-reciprocal, no metadata
- Architectural Height
 - Never finalized

2011 - August 23 at 1:51:04 p.m



Earthquake Damage

Federal Funds: \$7.5 M
David M. Rubenstein: \$7.5 M



2013: Request

- Post-Earthquake repairs: **Same scaffolding as 1999**. NGS reaches out to NPS to request a new geodetic survey of the peak
- Goal: More accuracy in latitude, longitude, elevation of the WM peak than before
- **By-product:** Architectural height determination

Reconnaissance



Don Breidenbach!



Lightning collar off for the first time in 128 years!

Reconnaissance



Up-view from peak.
Bad for GPS!



Rare down-view over peak



Hole for
cords!

Preparation



Adapter from NIST, ca: 1999
Unavailable ca: 2013

Also, the lightning collar is off
and staying off! What to do?



Ask Don Breidenbach (and his
son Steve!) to design and build a new
one. Turnaround: 5 days!

GPS

- Despite expected difficulties, decided to begin with GPS



Meridian Stone



USFS Commemorative Mark



Zero Milestone



W M WEST



W M SOUTH



WASHINGTON MONUMENT

Traverse

- *Simultaneous Reciprocal* vertical angles and distances
 - Measure vertical angles and slope distances from peak-to-ground and ground-to-peak at almost the same time
- Horizontal angles (triangulation)
 - Between ground marks and from ground marks to peak, and from peak to ground marks

Traverse

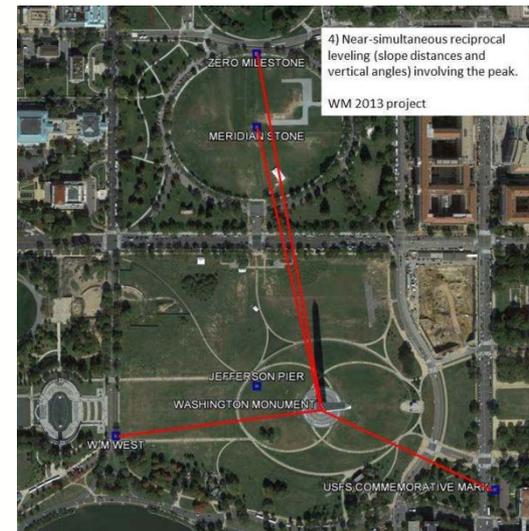
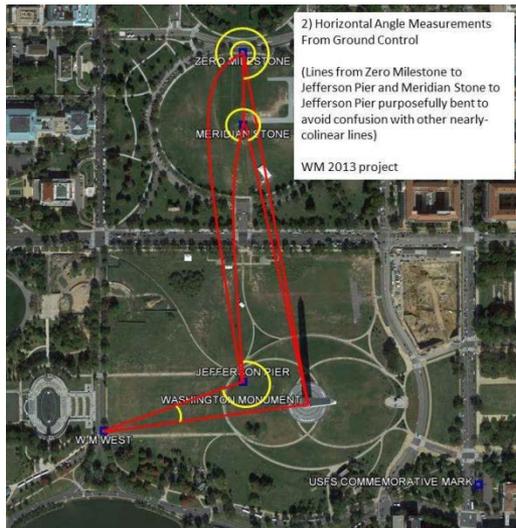
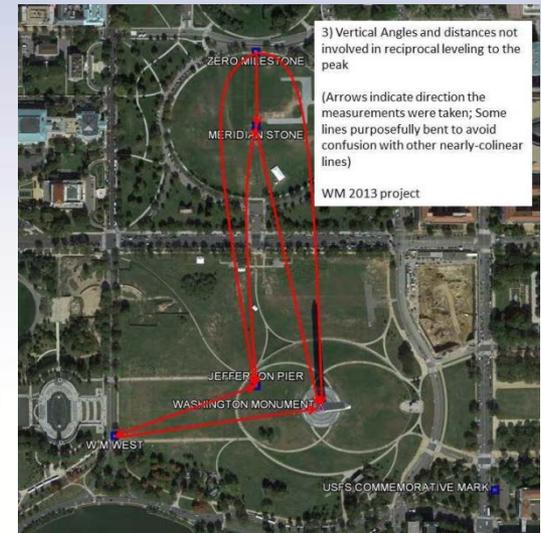
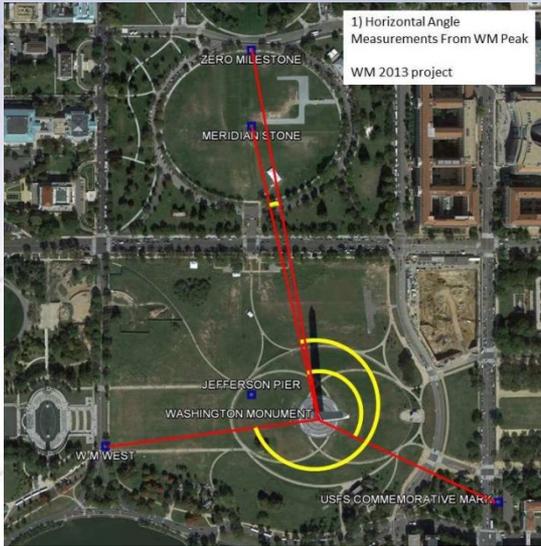


Simultaneous
within minutes

Reciprocal
peak → ground
and
ground → peak



Traverse

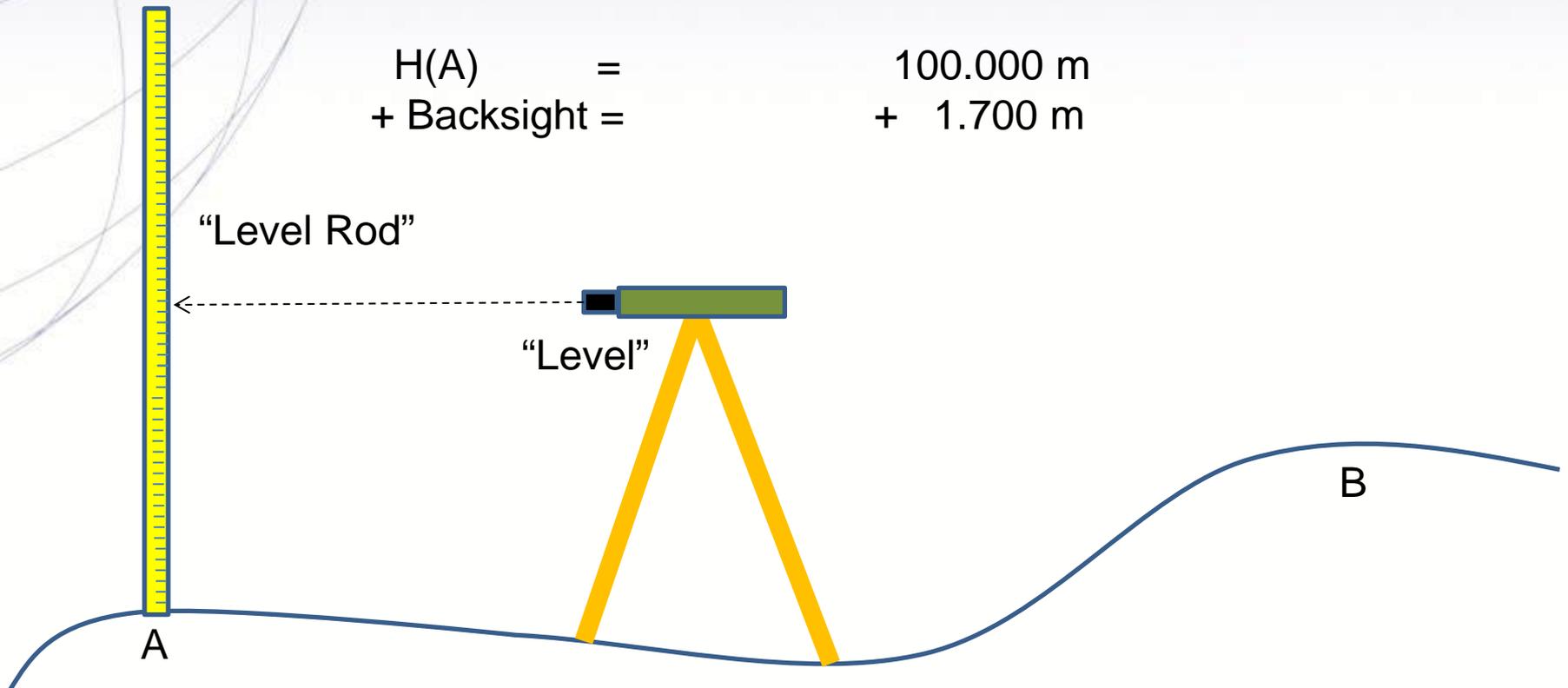


Traverse



Leveling

- Height difference calculator

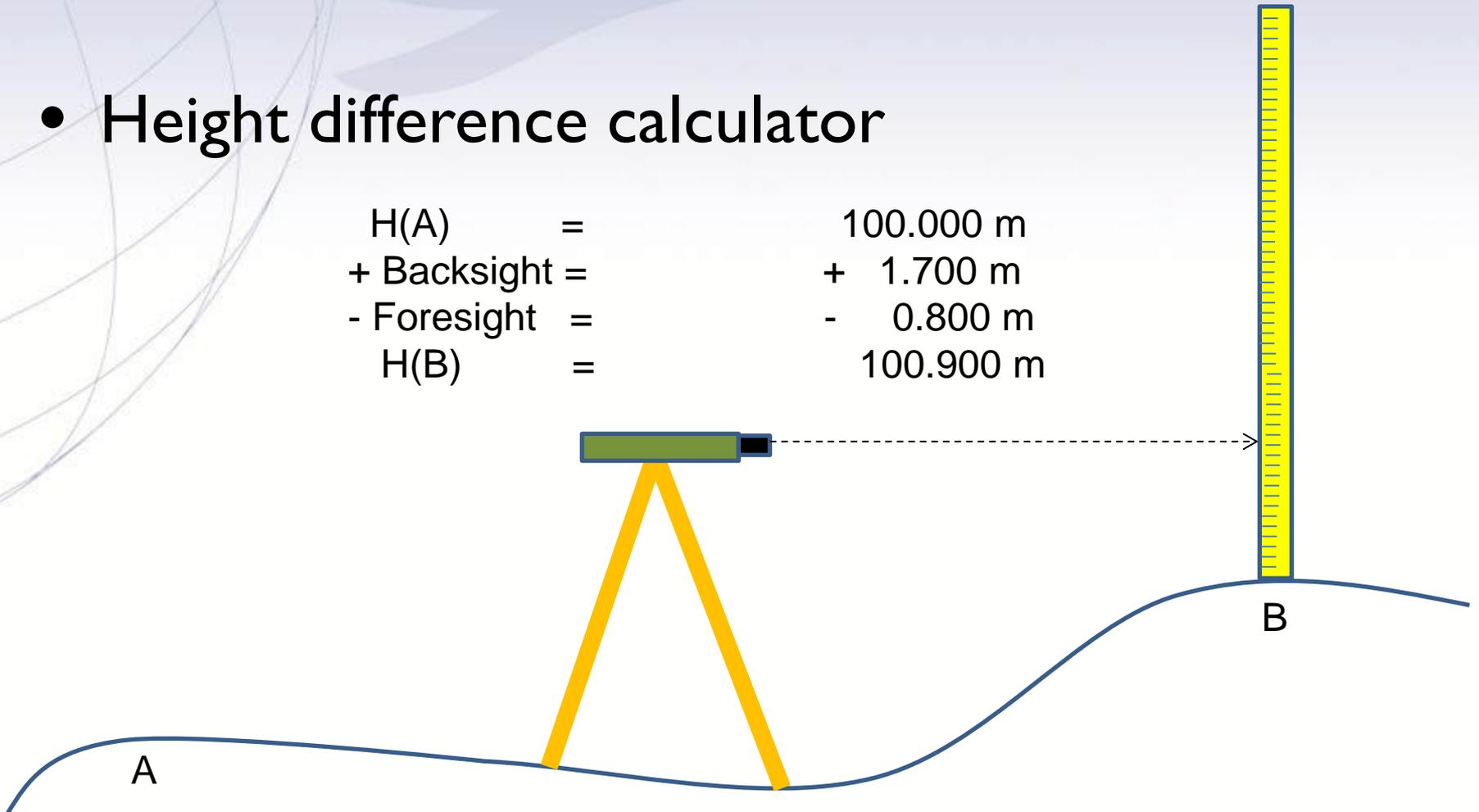


$$\begin{aligned}
 H(A) &= 100.000 \text{ m} \\
 + \text{ Backsight} &= + 1.700 \text{ m}
 \end{aligned}$$

Leveling

- Height difference calculator

H(A)	=	100.000 m
+ Backsight	=	+ 1.700 m
- Foresight	=	- 0.800 m
H(B)	=	100.900 m



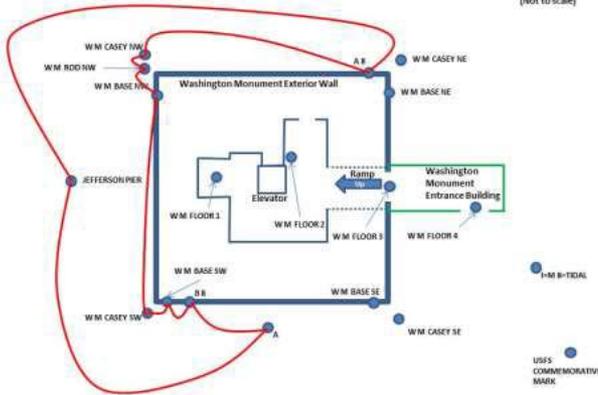
Leveling

4 days to compute/confirm NAVD 88 heights on points

1 day to connect to "floor level" to determine architectural height

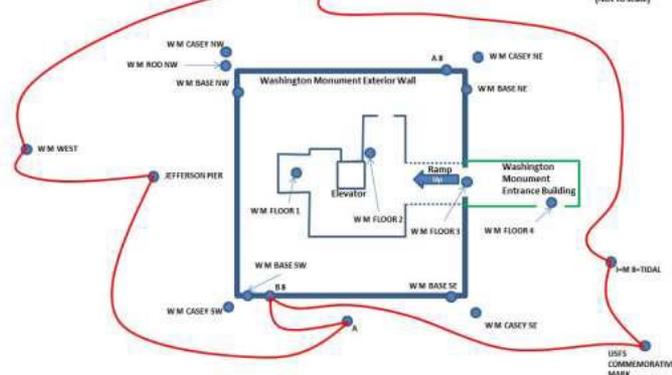
W M 2014 Leveling Loop 1 (4/8/2014)

- ZERO MILESTONE
- MERIDIAN STONE



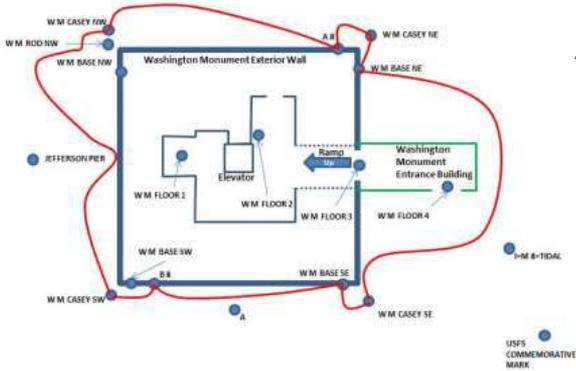
W M 2014 Leveling Loop 3 (4/10 & 14/2014)

- ZERO MILESTONE
- MERIDIAN STONE



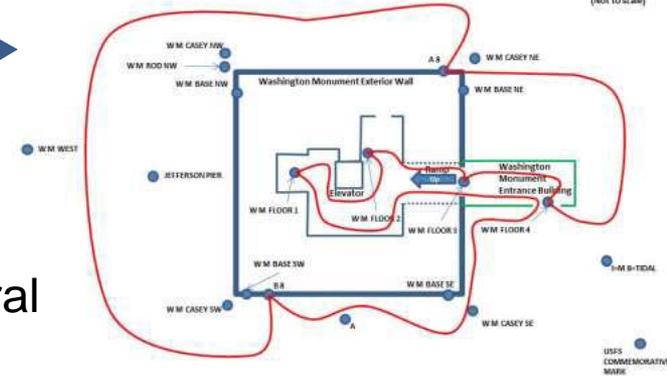
W M 2014 Leveling Loop 2 (4/9/2014)

- ZERO MILESTONE
- MERIDIAN STONE

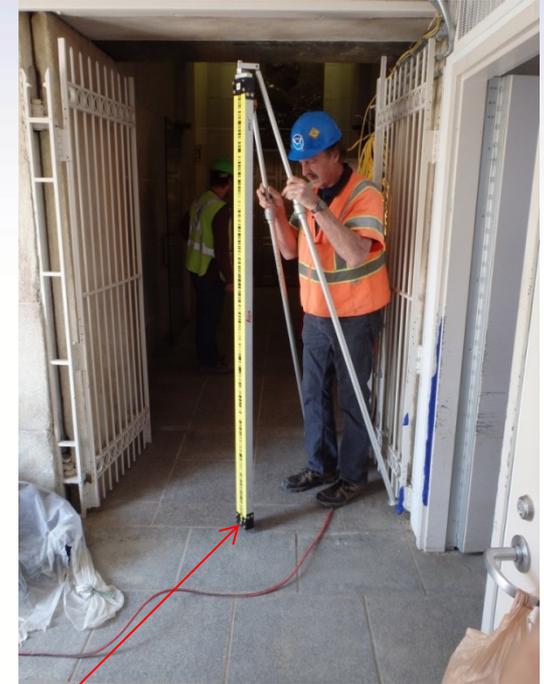


W M 2014 Leveling Loop 4 (4/22/2014)

- ZERO MILESTONE
- MERIDIAN STONE



Leveling



“W M FLOOR 3”

CTBUH

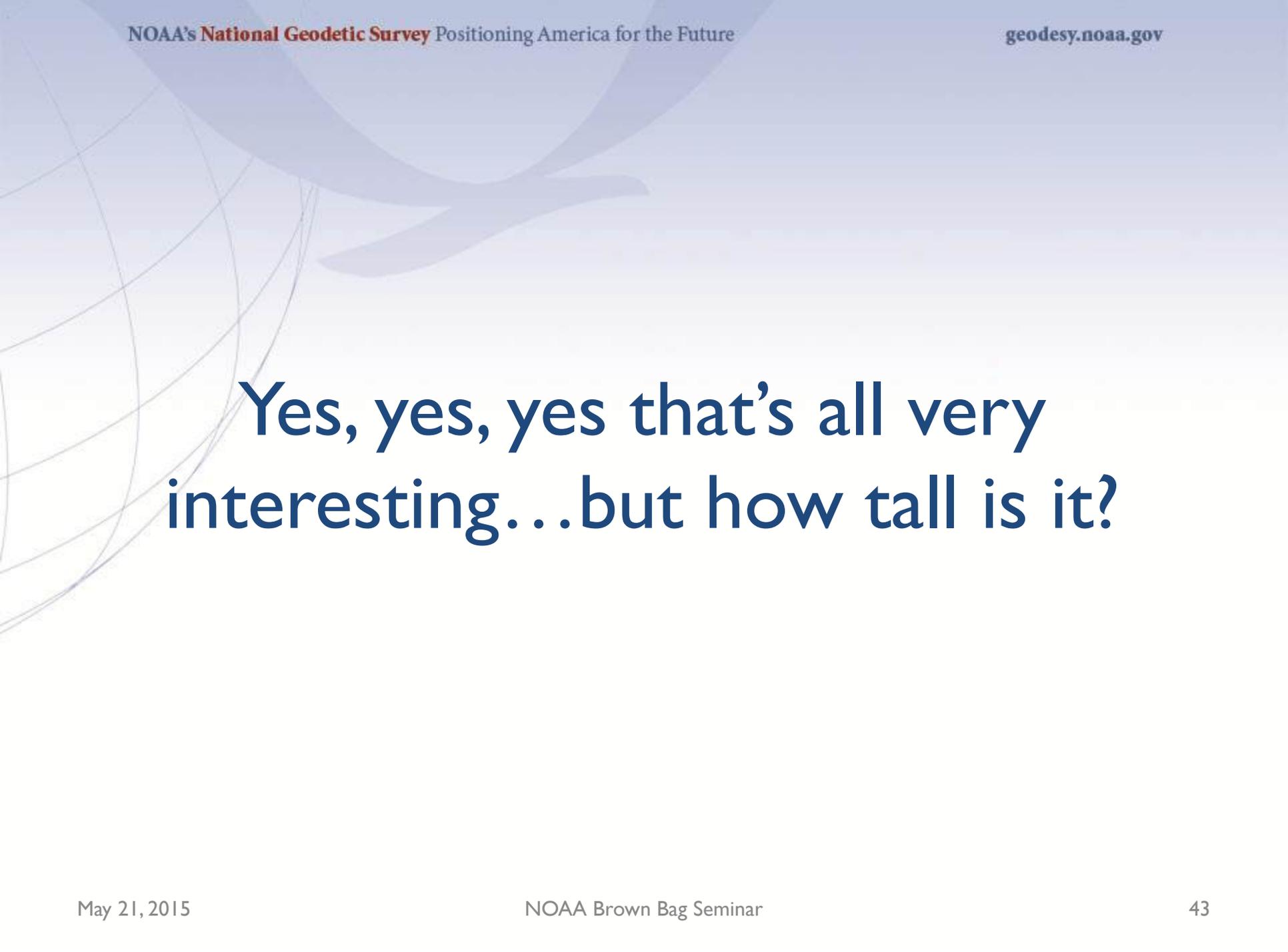
- Council on Tall Buildings and Urban Habitat
- International arbiters of building heights
- Measure to the “*threshold of the lowest significant open-air pedestrian entrance*”
- CTBUH says: “use W M FLOOR 3”

Putting it all together

- Published coordinates:
 - Ground points with latitude, longitude (NAD 83) and orthometric height (NAVD 88)
- Leveling:
 - Confirm/Compute **NAVD 88** heights and “*architectural* heights” (relative to W M FLOOR 3) on all ground points.
- Traverse (angles and distances):
 - Transfer both types of heights to the peak and compute latitude and longitude at the peak
- GPS:
 - Far too noisy too use as primary methodology. Kept in reserve.

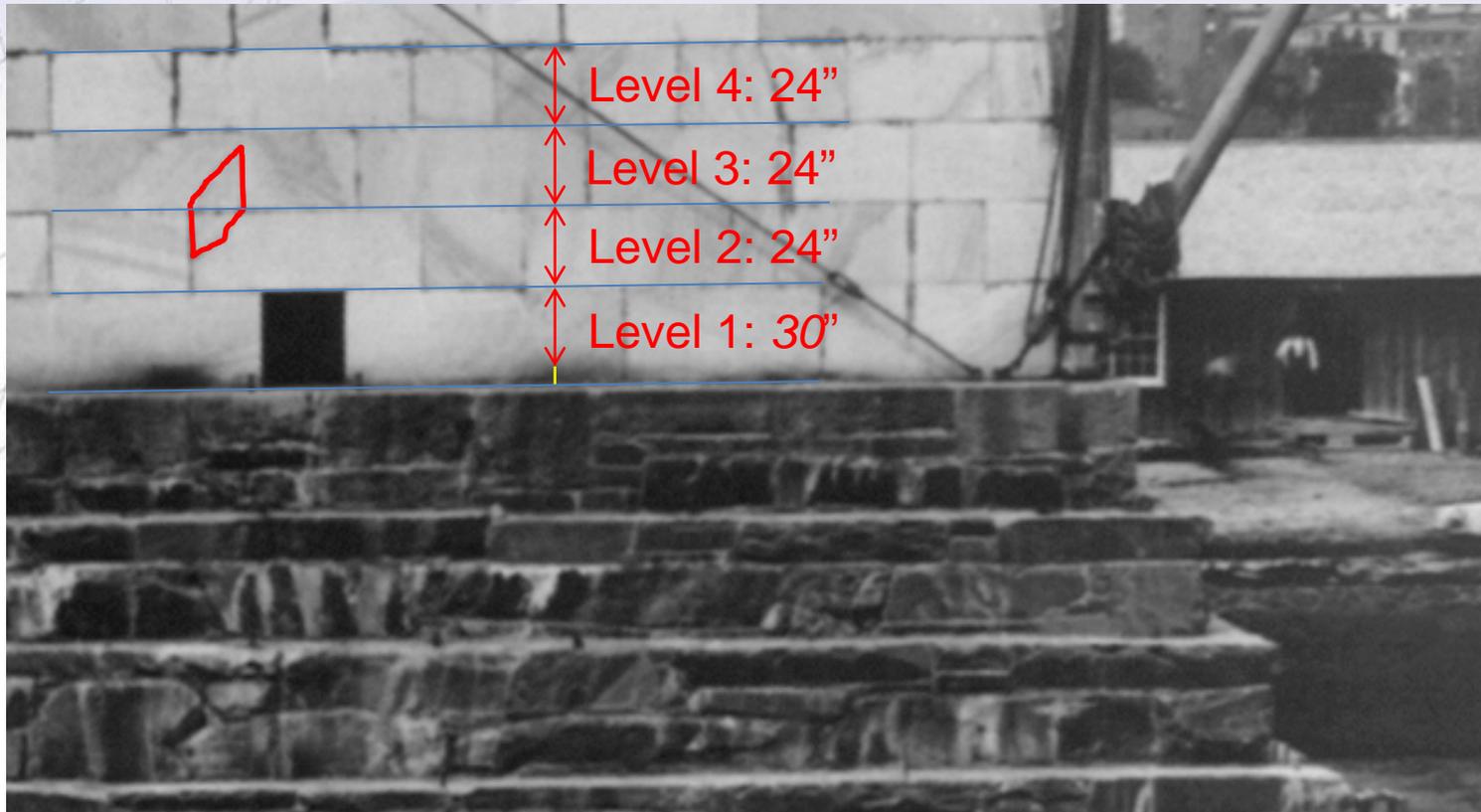
NSRS Computed Values

Coordinate Type	Value	Standard Deviation	Datum
Latitude	N 38° 53' 22.08257"	2.0 mm	NAD 83(2011)
Longitude	W 77° 02' 06.86428"	1.0 mm	NAD 83(2011)
Ellipsoid Height	149.172 m	1.0 mm	NAD 83(2011)
Orthometric Height	181.261 m	1.0 mm	NAVD 88



**Yes, yes, yes that's all very
interesting...but how tall is it?**

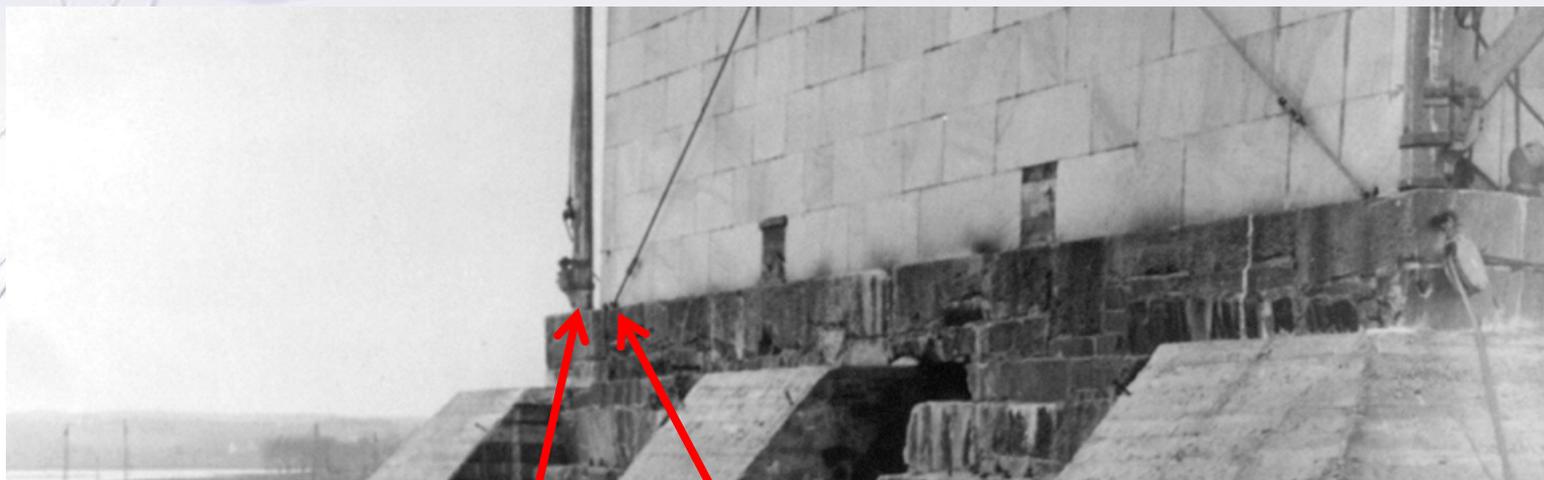
Historical Detective Work



Historical Detective Work



The SW corner - 1879



Hole for post

Eyebolt

The SW corner - 2014



Eyebolt

Round Hole
(3 1/4" diam,
gravel
filled)

"W M CASEY SW"

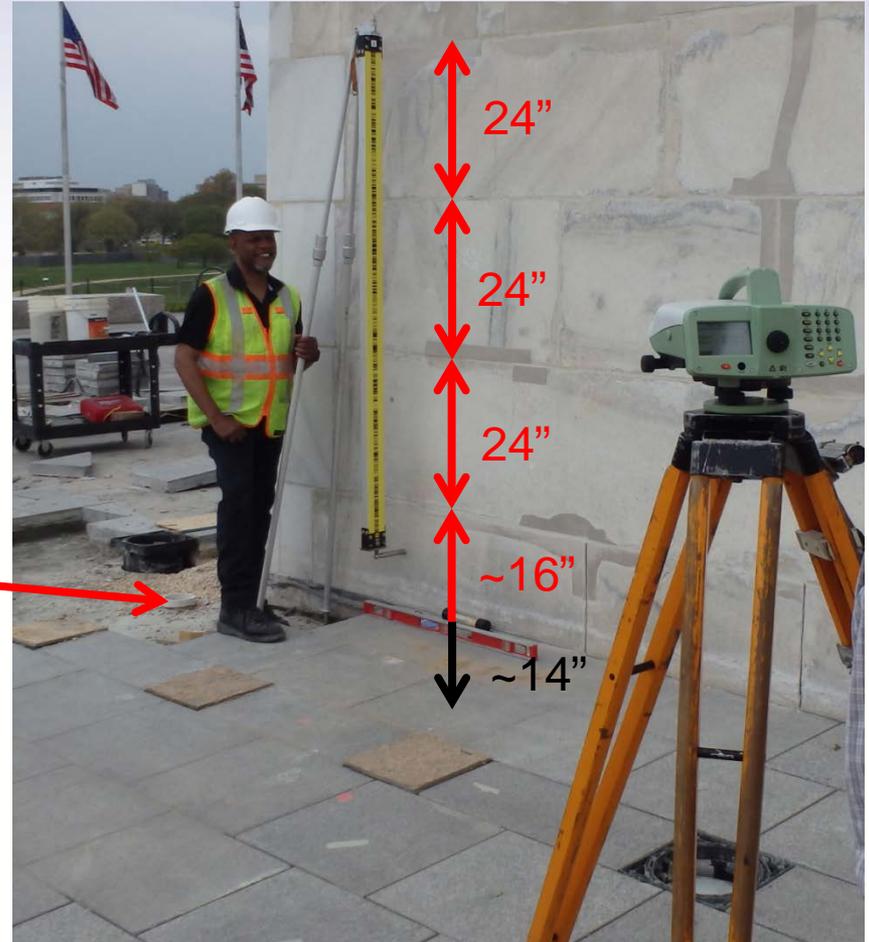
W M CASEY SW



- One of four such marks found in 1999
 - Named by NGS:
 - W M CASEY NW
 - W M CASEY SW
 - W M CASEY SE
 - W M CASEY NE

PAVERS vs Foundation

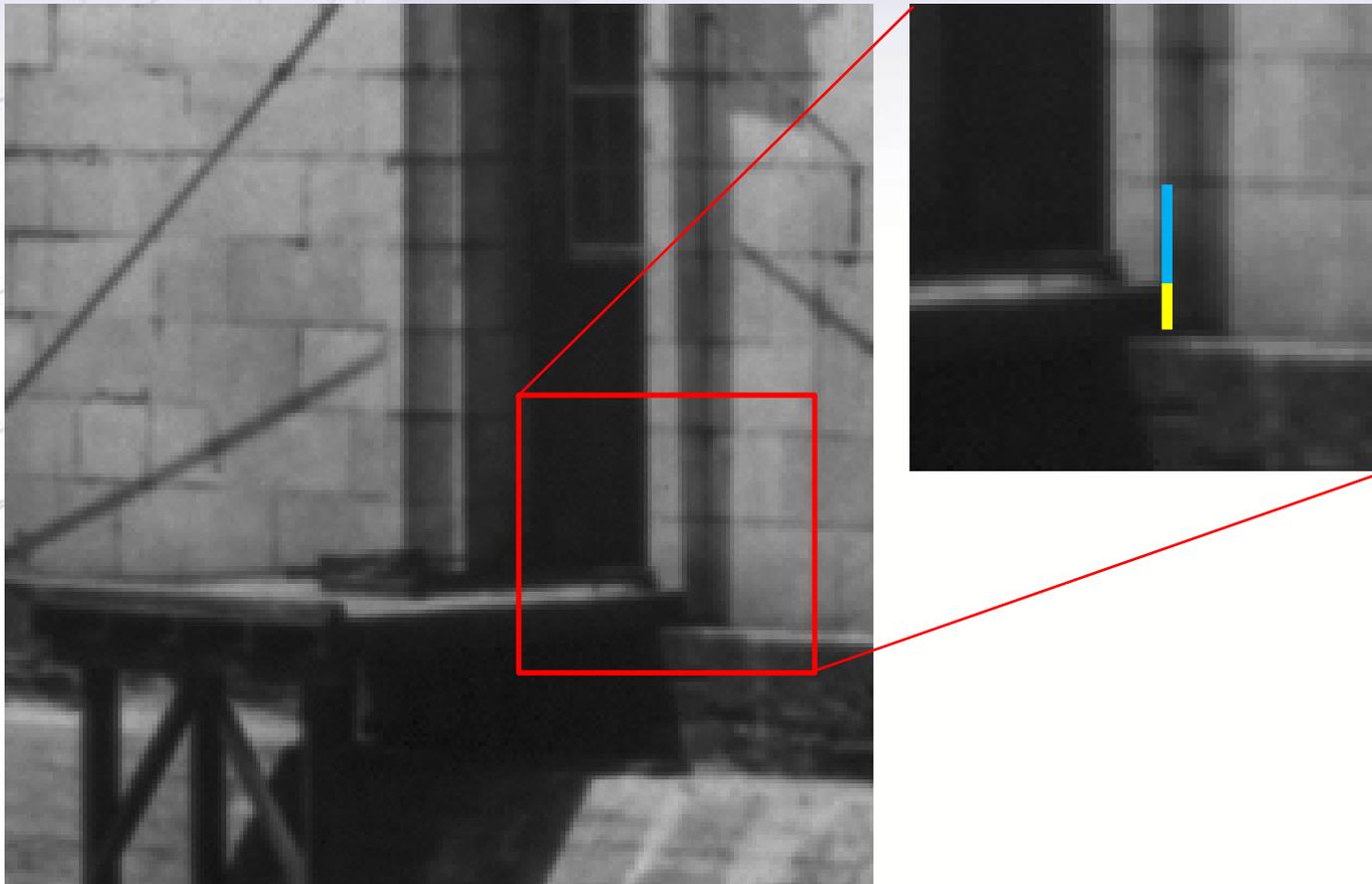
CASEY SW
(at bottom of PVC tube)



The CASEY Marks

- The National Archives contain all of the materials written by Casey
 - Haven't *yet* seen a reference to *where* Casey chose to measure 555' 5 1/8 inches from
 - Some evidence points to these four marks re-discovered in 1999
 - Leveling proves all four are within 4 mm of each other in height
 - Averaging them for references

Foundation vs Threshold



Level 1: 30"
Blue: 21"
Yellow: 9"

Final Architectural Heights

By Casey's (presumed) method:

- 1885: 555' 5 1/8 inches (to a pointed peak)
- 1999: 555' 3 5/8 inches* (to a rounded peak)
- 2014: 555' 4 1/64 inches* (to a rounded peak)

By CTBUH standards in 2014:

554' 7 11/32 inches (to a rounded peak)
(a difference from the 1885 value of over 9.75")

* Presumes Casey's method was to use the average level of the four "Casey marks" as a starting point.

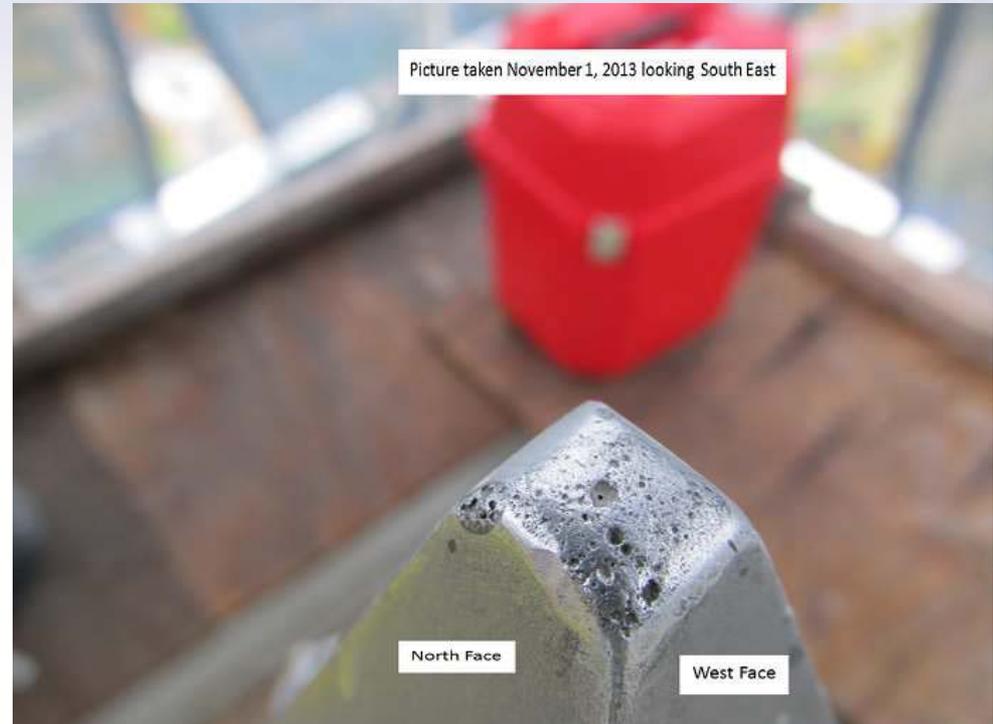
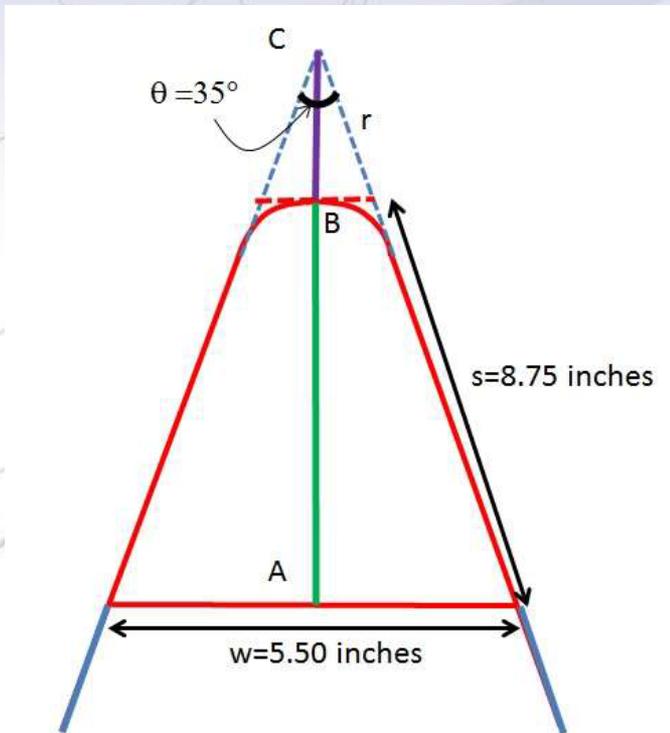
Relationship to past values

- Why isn't the building 555' 5 1/8 inches?
- How was the above value computed?

Why the disagreement?

- If the 4 CASEY marks are where Lt Col Casey measured his height, why did we get 555' 4 1/64 inches, when he got 555' 5 1/8 inches?
- Two reasons
 - Rounding of the peak
 - Measurement error

Rounding of the peak

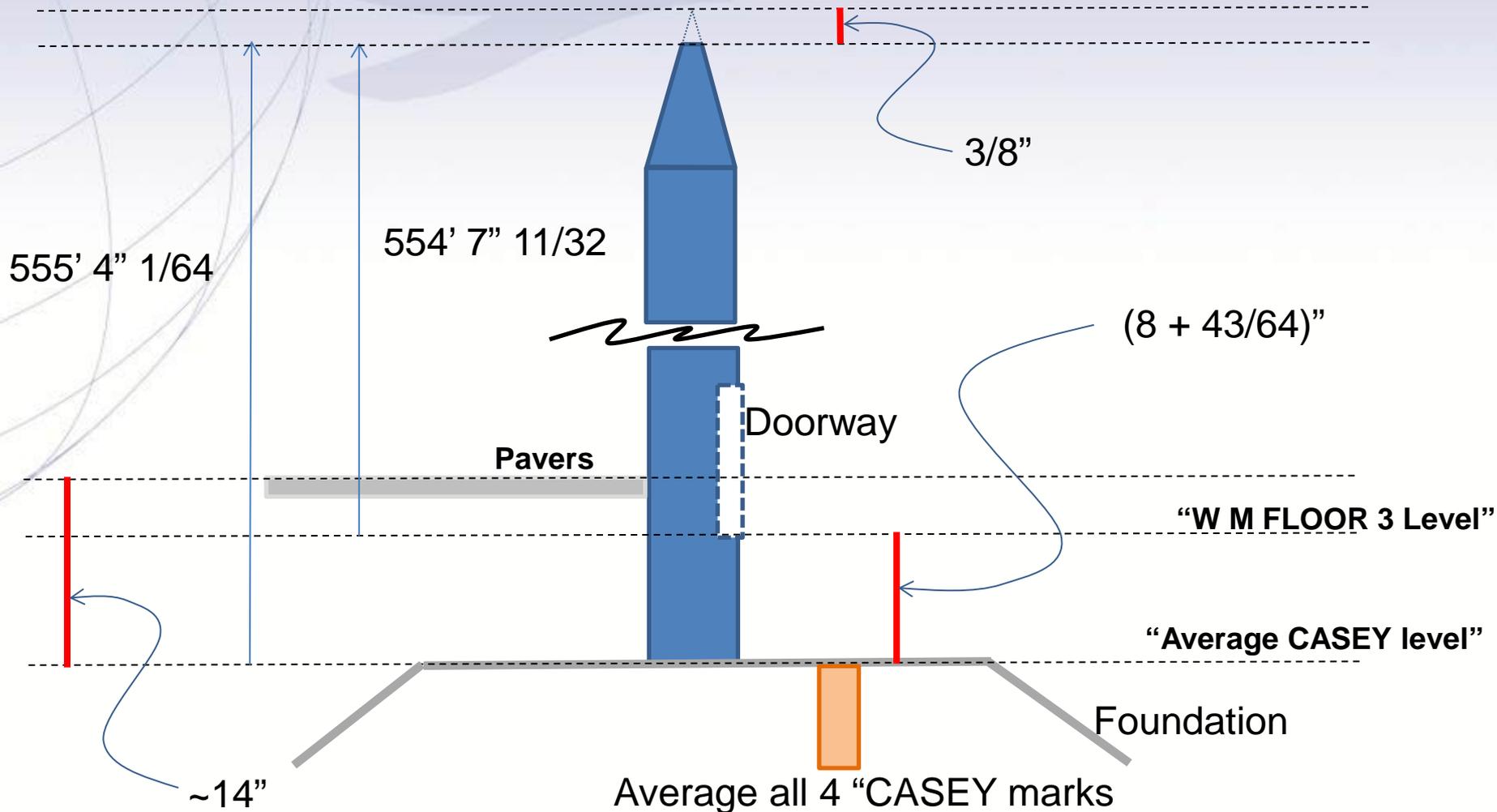


Approximately $\frac{3}{8}$ inch of the $1 \frac{1}{8}$ inch disagreement comes from height loss due to rounding of the peak

Magnitudes of contributions

Reason	Inches
1) A different starting point	8 43/64
2) Rounding of the aluminum apex	3/8
3) Measurement Error in 1884 and 2014	47/64
Combined	9 25/32

How things stack up: 2014 values

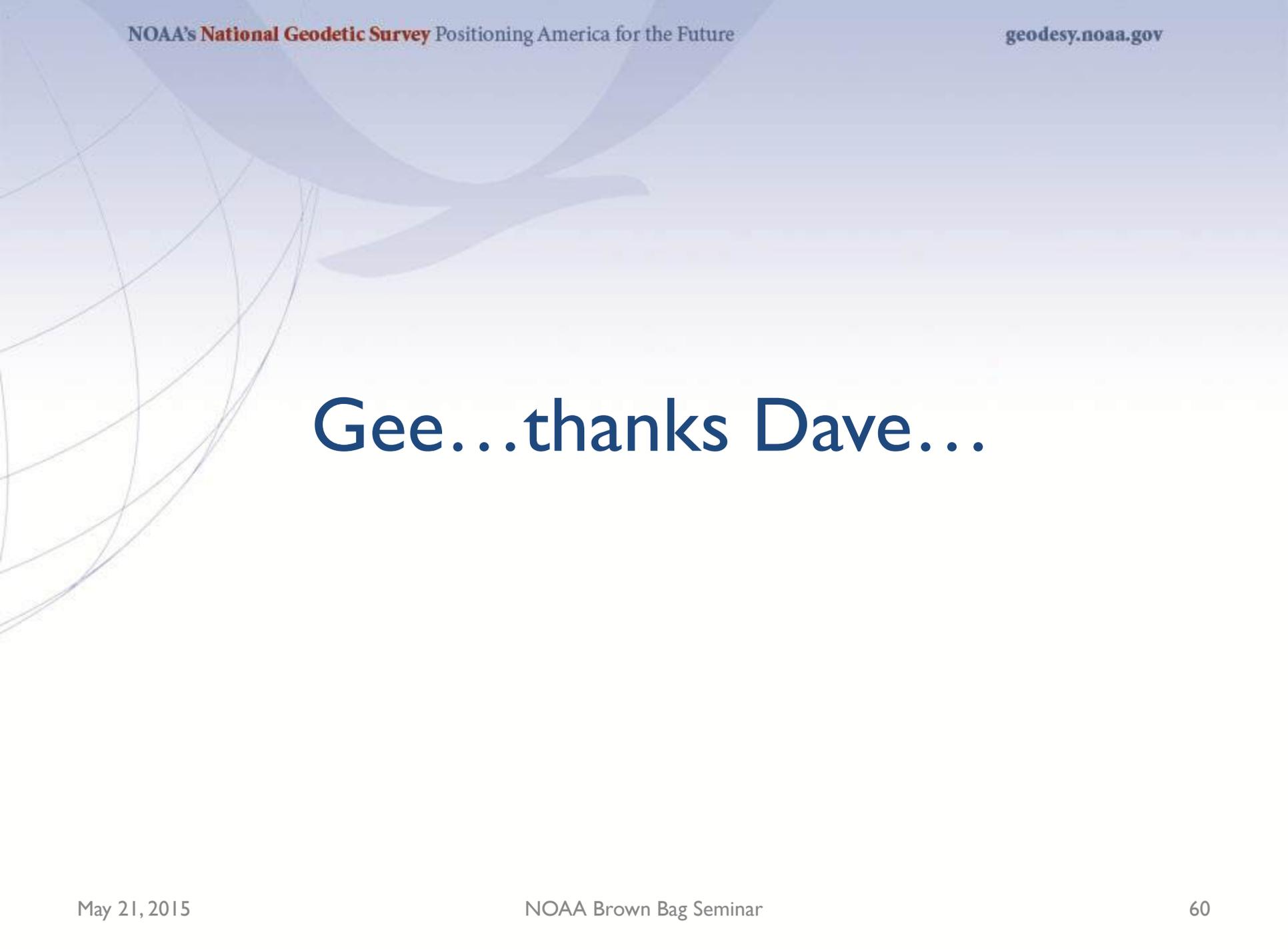


Summary

- NGS determined the latitude, longitude, ellipsoid height and orthometric height of the peak of the WMM to 1-2 mm
 - Baseline for future monitoring surveys
- NGS computed the architectural height of the WMM to modern international standards to +/- 1.0 mm
 - Disagrees with the historic 1885 height by almost 10 inches
- Of that 10 inches, all by $\frac{3}{4}$ inch are immediately explainable
 - The $\frac{3}{4}$ inch remainder is likely measurement error from 1885 or errors in our assumption about how the 1885 height was determined

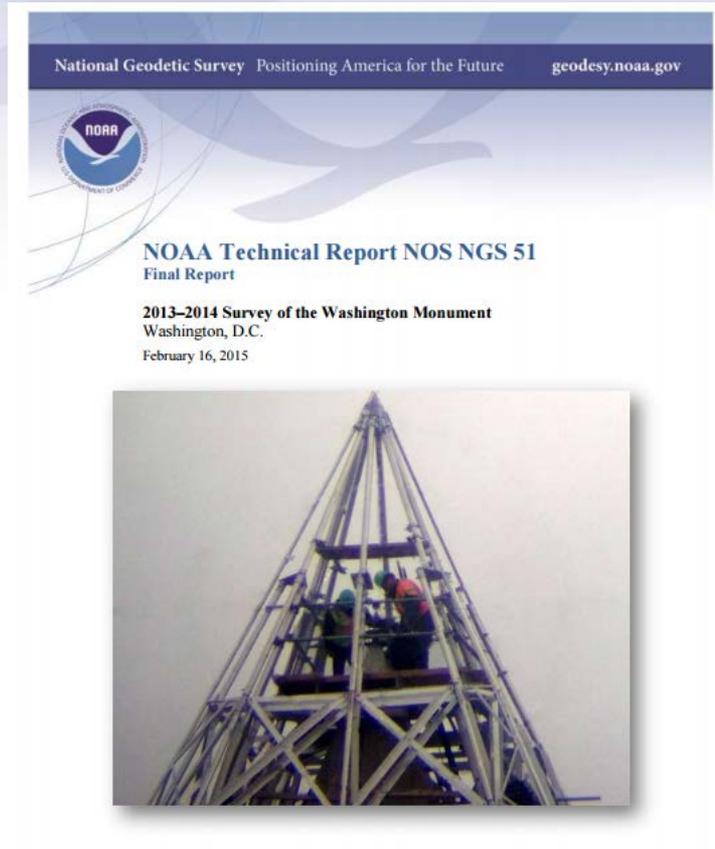
All that hard work...





Gee...thanks Dave...

Questions?



<http://www.ngs.noaa.gov/surveys/ngs/wm2013/>



Thank you!

Extra Slides

Doorway changes

- 1885 – By Casey's order:
 - West entryway sealed off
 - East entryway reduced to 8' high
 - East entryway to have 2 marble doors

Aluminum Apex

	Original Engravings	What is Visible, What is Not, and What is New
North Face	<p>JOINT COMMISSION AT SETTING OF CAPSTONE.</p> <p>CHESTER A. ARTHUR. W. W. CORCORAN, <i>Chairman.</i> M. E. BELL. EDWARD CLARK. JOHN NEWTON. <i>Act of August 2, 1876.</i></p>	<p>JOINT COMMISSION AT SETTING OF CAPSTONE.</p> <p>CHESTER A. ARTHUR. W. W. CORCORAN, <i>Chairman.</i> M. E. BELL. EDWARD CLARK. JOHN NEWTON. <i>Act of August 2, 1876.</i></p>
West Face	<p>CORNER STONE LAID ON BED OF FOUNDATION JULY 4, 1848.</p> <p>FIRST STONE AT HEIGHT OF 152 FEET LAID AUGUST 7, 1880.</p> <p>CAPSTONE SET DECEMBER 6, 1884.</p>	<p>CORNER STONE LAID ON BED OF FOUNDATION JULY 4, 1848.</p> <p>FIRST STONE AT HEIGHT OF 152 FEET LAID AUGUST 7, 1880.</p> <p>CAPSTONE SET DECEMBER 6, 1884.</p>
South Face	<p>CHIEF ENGINEER AND ARCHITECT, THOS. LINCOLN CASEY, COLONEL, CORPS OF ENGINEERS.</p> <p><i>Assistants;</i> GEORGE W. DAVIS, CAPTAIN, 14TH INFANTRY. BERNARD R. GREEN, CIVIL ENGINEER.</p> <p><i>Master Mechanic.</i> P. H. MCLAUGHLIN.</p>	<p>CHIEF ENGINEER AND ARCHITECT, THOS. LINCOLN CASEY, COLONEL, CORPS OF ENGINEERS.</p> <p><i>Assistants;</i> GEORGE W. DAVIS, CAPTAIN, 14TH INFANTRY. BERNARD R. GREEN, CIVIL ENGINEER.</p> <p><i>Master Mechanic.</i> P. H. MCLAUGHLIN.</p>
East Face	<p>LAUS DEO.</p>	<p>Repaired, 1934, National Park Service Department of the Interior</p> <p>LAUS DEO.</p>