Title: **Myth-busting: The Incredible “Shrinking” Washington Monument**

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Dru Smith
Dr. Dru Smith first entered NGS in 1995 after receiving his PhD. in geodetic science from Ohio State University. From 1995 until 2000 he performed gravity and geoid research, resulting in the GEOID96, CARIB97, MEXICO97 and GEOID99 geoid models. In 2001 he spent a year working for the Executive Secretariat of the Interagency GPS Executive Board, helping shape government GPS policy. In 2001 he returned to NGS and focused his research on using the CORS network to model the ionosphere. He is a member of the Institute of Navigation, the American Geophysical Union, the International Association of Geodesy and has previously served on the Board of Directors for the American Association for Geodetic Surveying.

In February 2015, the Washington Monument "shrunk" almost 10 inches (248 millimeters), when the United States National Oceanographic and Atmospheric Administration (NOAA)'s National Geodetic Survey (NGS) used CTBUH height criteria to determine the true architectural height of the famous cenotaph. As part of a dialogue with CTBUH, NGS used precise instrumentation to determine that the height of the structure was 554 feet, 7 11/32 inches tall (169.046 meters) instead of 555 feet, 5 1/8 inches (169.294 meters) as previously recorded. When the data was released around the President's Day holiday, the report was widely circulated in the media. CTBUH Journal Editor Daniel Safarik interviewed Dru Smith, chief geodesist of the NGS, to investigate a little further into the specifics of the project.

First things first. Most of our members use math extensively and sophisticated software to design, construct, and operate tall buildings. But many probably don't know exactly what a geodesist does. Can you shed a little light?

Geodesists are scientists who work in the field of geodesy, which focuses on the determination of the size and shape of the earth, its gravity field, and the positions of points on the earth. As part of that work, we also incorporate geodynamics and geophysics, such as the wobble of the rotation pole or the drift of tectonic plates. At its core though, geodesy is a measurement science, and geodetic surveys such as the measurement of angles, distances, gravitational attraction, etc., have been the core of geodesy for centuries.

The Washington Monument recently underwent an extensive renovation. Why did the NGS undertake a remeasurement of the structure during this time?

The NGS has had a collaborative relationship with the National Park Service (NPS), the stewards of the Washington Monument (WM) and the National Mall area, for nearly a century. The most visible part of that collaboration has been geodetic leveling surveys to points around the base of the WM, which can detect differential height changes at the submillimeter level. The purpose has been to monitor whether any subsidence has occurred around the National Mall area.

However, two special surveys were done, one in 1934 and one in 1999, where NGS actually occupied the peak of the monument with survey instruments. This was possible because in both of those years, scaffolding surrounded the monument for renovations. In 1934, the survey was a triangulation survey (angles measured between distantly-sighted objects, such as church spires and flagpoles), which helped determine the latitude and longitude, of the peak. This was useful, as the Washington Monument peak is a reasonable point for surveyors to sight from the ground, but it had never before been directly occupied to determine its latitude and longitude. The 1999 survey was primarily a demonstration of the capability of GPS (the Global Positioning System) to accurately determine elevation (see Figure 1).

Having an accurate determination of the actual peak of the WM in latitude, longitude and elevation helps the NPS in its mission of maintaining the monument, since these determinations can be used to help detect tilts or sinking. As such, when NGS learned that the WM would again be encased in scaffolding (to repair damage from a 2011 earthquake) we sought, and obtained, NPS permission to occupy the peak again (see Figure 2). However, this time, our goal was to position the peak to millimeters, something that had not been done in the past. The reason was that we hoped to establish a baseline for future surveys, should they occur, to monitor any motion of the peak.

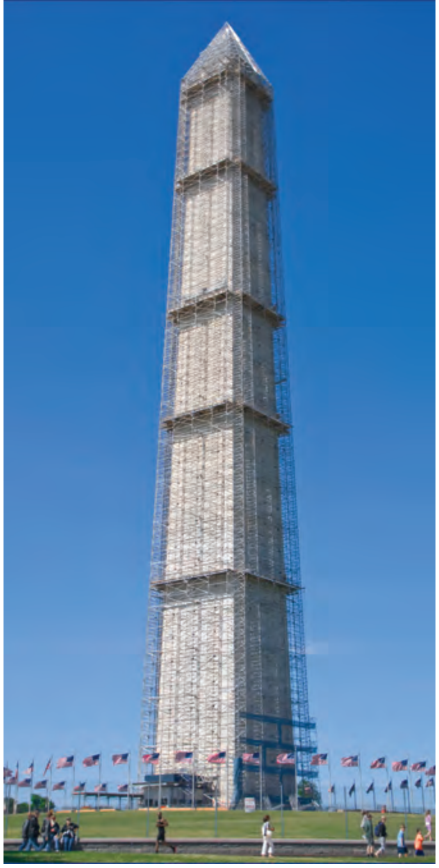

Figure 1. Washington Monument enclosed in scaffolding. © Ron Cogswell. Source: Wikimedia Commons

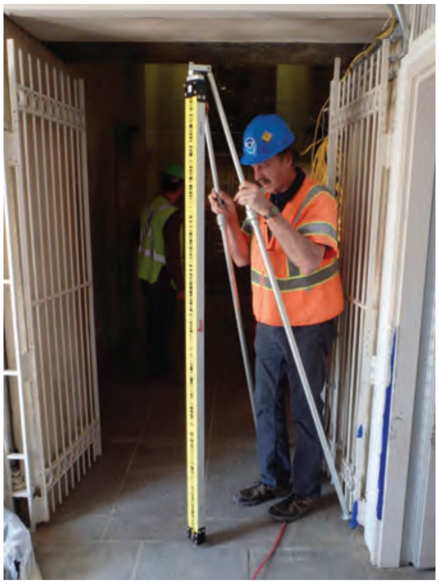

Figure 2. Height is measured from the level of the lowest, significant, open-air, pedestrian entrance to the architectural top of the structure (CTBUH criteria).

NGS did not set out to determine the architectural height of the monument itself, but as such a measurement had usefulness (in determining if any actual compression of the building occurs over the years), not to mention general public interest, it was deemed worthwhile to expend the additional effort to properly collect what was needed to add this measurement to the overall survey.

What kinds of equipment and methodology did you use for the latest measurement (I'm hoping the answer has the words "rappelling" and "lasers" in it)?

NGS was not involved in rappelling, but the NPS has some wonderful pictures of the initial damage assessment phase, where rappelling from the peak was done! Lasers played a small role – our collimators, devices that narrow and align particle beams, use lasers – but most of the electromagnetic work of our instruments is via microwaves.

There were three basic phases of the survey, each with its own equipment and purpose: Geodetic leveling, traverse, and GPS.

Geodetic leveling is a line-of-sight survey used to determine height differences from one point to another. The main equipment is a geodetic level and a pair of level rods. The process uses short, balanced sight lengths, back to one rod, then forward to another. This pattern continues, eventually connecting two points of interest. Using this method, two types of heights were determined at all points in and around the monument: North American Vetical Datum (NAVD) 88 "orthometric" heights (which are the official elevations used in all Federal geospatial products) and "architectural heights" (determined by adopting the CTBUH recommendation for where "zero architectural height'" should be) (see Figure 3).

Traverse uses a Total Station and Reflectors. A Total Station looks like a traditional survey instrument with a scope, but unlike historic instruments which could only measure horizontal angles and vertical angles, a Total Station can also electronically measure slope distances to a reflector as well (see Figure 4). The traverse survey measured angles and distances between about 10 different points around the monument. Using this data, we were able to transfer both orthometric and architectural heights to the peak, as well as determine its latitude and longitude.

How did GPS play a role?

GPS was used in this survey, but with some difficulty (which we had also experienced in 1999). A GPS survey consists of a "geodetic-quality" GPS receiver (much more expensive and accurate than the one in your smartphone) to position points to a few centimeters. In our

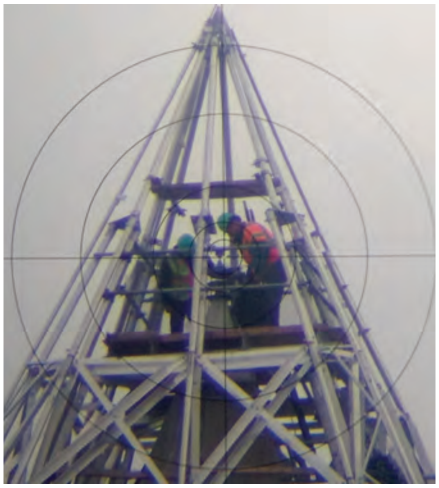

Figure 3. The view of the top of the Monument as viewed through the Total Station surveying tool.

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> “We asked ourselves ‘how exactly do you measure the height of a building?’ and realized we did not have an obvious answer. As such, our team did some research online. The CTBUH came to the forefront quickly as the exact body we were looking for – arbiters of tall buildings with an explicit standard to which we could adhere.”

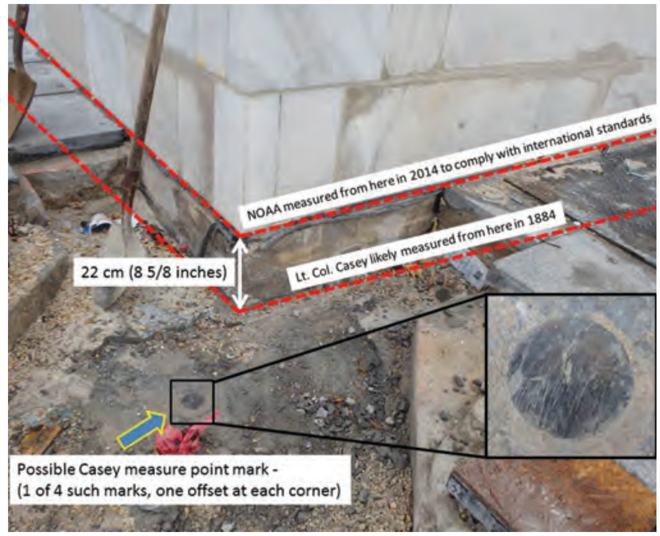

Figure 4. Illustration of the measuring points used by Lt. Col. Thomas Casey in 1884 and the 2014 measuring point used by NOAA to meet CTBUH standards.

case, the scaffolding surrounding the peak caused some disruption to the signals coming in from GPS satellites, so the solution was not as accurate as if we had an “open sky view.” To further assist with GPS at the peak, we also had GPS receivers surrounding the WM at other points that were part of the survey. Ultimately, however, the accuracy of GPS could not compete with what was being determined from the leveling and traverse surveys, and the GPS solutions were used as “reality checks” on our final numbers, but were not part of the overall final computations.

What was the process of deciding to use the CTBUH criteria, the confirmation of criteria with the Council, and their application in the actual measuring process?

It was through the diligence of our planning team that we worked with CTBUH. As I mentioned earlier, geodesists are measurement scientists at their very core. And measuring the height of something means asking “what exactly am I measuring”? We asked ourselves “how exactly do you measure the height of a building?” and realized we did not have an obvious answer. As such, our team did some research online. The CTBUH came to the forefront quickly as the exact body we were looking for – arbiters of tall buildings with an explicit standard to which we could adhere.

We had a pretty good idea of what CTBUH would consider the “level of the lowest significant open-air pedestrian entrance” at the WM (the standard to which architectural heights are to be determined), but to be meticulous, we identified four candidate locations in the WM that could ostensibly have fulfilled that criteria. We took pictures and videos and sent a full explanation of why we thought each point could be considered a candidate. The CTBUH reviewed the information we sent, and chose the point which we had named “W M FLOOR 3”. That was, in fact, our first guess, but it was reassuring that CTBUH concurred with this choice.

With that decision approved by CTBUH, all points in the survey could have a height determined that was relative to W M FLOOR 3, including the height of the peak itself.

How many times has the Monument been measured before, and how did criteria change for determining the starting point of measurement?

Of those groups that could arguably be considered to have provided an “authoritative” architectural height of the monument, I am aware of only three such measurements. The first is from a hand-written report by Lt. Col. Thomas Casey, Chief Engineer in charge of the WM construction from 1878 until its completion in 1884. Around 1885, one of his reports states that the monument is 555 feet 5 1/8 inches. Unfortunately there is no mention in that report of how such a height was determined, and especially no mention of where he considered “zero architectural height” to be.

The second determination was by NGS in 1999, using GPS. Unfortunately, while a number of preliminary architectural heights were publicized, there was never a final official architectural height publicly announced. However, during 1999, four round metallic (likely brass) rods, driven into the foundation, set a few feet off of each corner of the monument, were found. There is some circumstantial evidence that one or all four of these rods served as the “zero” for the 1885 height determination. Some geodetic forensics done in 2014 (using the 1999 data) indicated that an architectural height that used these four marks (on average) as a “zero” would be only about 1 ½ inches (38 millimeters) off of the 555 feet 5 1/8 inches (see Figure 5). We have no evidence in our archives that NGS actually used the CTBUH criteria in 1999, however.

The third and final determination of architectural height was done in our 2013–2014 survey, whereby we used both methods: the CTBUH standard (measuring to “W M FLOOR 3”) and what we have come to call “the Casey method” (averaging the four corner marks to give us a zero). The difference between these two zero levels is almost 9 inches (229 millimeters), which is the primary, but not only, reason why the height we determined by CTBUH standards in 2014 mismatches the 1885 height by over 9 inches.

What are some of the changes that have happened on the ground and at the tip over that time?

The grounds surrounding the WM have changed significantly over the years, from the draining of a nearby lake to the re-routing of roads, to the buildup of grassy walkways and the laying down of a paved plaza around the entire structure. But little of the structure itself has changed. And, as none of our measurements actually reference anything like "ground level", these changes to the grounds themselves are essentially immaterial to the actual surveys that have happened over the years.

The peak, being aluminum and designed to be struck by lightning, had already "melted" some by the time it was inspected in 1934. When we returned in 2013, we measured very carefully and determined that about 3/8 of an inch (10 millimeters) had been worn off the pointed peak (by lightning, weathering or other causes).

How have the methods of measurement, as well as the criteria used, changed over time?

Interestingly, geodetic leveling and traverse surveys (without the electronic distance measurements of today) existed in the 1880s in very similar fashion as they do today. Some accuracy gains have occurred in both instrumentation and methodology, but the concepts are the same. GPS is obviously new, but using it in this environment was simply not the best choice for accuracy in this particular survey.

We have hypothesized that Casey measured the WM height to points he'd set in the foundation, flush to the top of the foundation. This criterion is the primary reason there is over nine inches of difference between the 1885 height and the 2014 height. In fact, in old photographs where both the doorway and the foundation level are visible, it is clear that there is approximately nine inches of difference between the two, so there is no real mystery involved – it's all a matter of where one starts to measure.

What has happened to the markers now that the renovation and surveying is complete?

In 1999, when NGS rediscovered these markers, we arranged with the NPS that, upon replacement of the pavers (as renovation was being completed), that PVC tubes, capped at the top, would surround and protect and provide access to the four Casey marks for future surveys. This system remains in place, and in the 2013–2014 renovation the same agreement was arranged with NPS. Visitors to the WM who look just a few feet off of any of the four corners will find a metallic lid set flush with the pavers. That lid opens up to a tube that goes down a foot (305 millimeters) or so to allow access to one of the Casey marks.

Any angry letters? Conspiracy theories?

Nothing quite so dramatic, though it was a little discouraging to see so many news organizations make misstatements or overly dramatize the new height. The false implication was that the WM had somehow "shrunk" 10 inches. We continue to field questions and continue to clarify the actual findings. But ultimately the real, successful (but less publicly interesting) goal was that we positioned the peak of the WM to one to two millimeters and also determined its architectural height to one millimeter. Any future surveys of similar accuracy will be able to compare to the 2013–2014 survey and any changes at the millimeter level should be detectable. Not that we expect any, but you can't know unless you measure! ■

Unless otherwise noted, all photography credits in this paper are to National Oceanographic and Atmospheric Administration (NOAA).