PROJECT REPORT
LEVELING OF THE WASHINGTON MONUMENT
AND THE
WASHINGTON MALL

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On Tuesday, August 23, 2011 the mid-Atlantic area was shaken by a magnitude 5.8 earthquake centered near Mineral, Virginia. Events of this magnitude are highly unusual for the region around the nation's capital. Fortunately the effects of quake were generally mild and caused only modest amounts of structural damage to buildings and other structures. One structure that did incur some significant damage was the Washington Monument. In part due to its height of slightly more than 555 feet, the upper portion of the Monument suffered several significant cracks that have forced the closure of the structure until such time as repairs can be made by the National Park Service (NPS). Since that time NPS has been actively engaged in a number of efforts to determine the extent of damage caused by the quake to not only the Washington Monument but also the numerous other monuments and memorials in the area of the Washington Mall. One area of concern was what, if any, settlement or subsidence occurred in the area of the Washington Monument and others structures to the west including the Jefferson and Lincoln Memorials. Few visitors to the sites today appreciate that all of the structures from the Washington Monument west to the Potomac River are constructed on fill of sand, gravel and blue clay. A 1950 report by the U.S. Geological Survey shows the 25 foot deep foundation of the Monument is approximately 65 feet above bedrock. This type of fill can be especially vulnerable to the effects of soil liquefaction as have been noted in numerous other earthquakes.

As it just so happened, at the time of the event, the National Geodetic Survey (NGS) had been engaged in developing an agreement with NPS to perform periodic geodetic leveling observations in the vicinity of the Mall area. NGS and its predecessor agency the U.S. Coast & Geodetic Survey (USC&GS) had conducted 17 different leveling campaigns in and around the area since 1884. Many of the surveys were performed as small projects including only certain parts of the area commonly referenced as "The Mall." This area is most often recognized by the public as that portion of the city which

extends from just east of the Capitol building to the Potomac River and sandwiched between Constitution Avenue on the north and Independence Avenue on the south. Many of city's biggest attractions are located in this area including buildings of the Smithsonian Institution and the National Gallery of Art on the east side and numerous memorials on the west such as those honoring Washington, Jefferson and Lincoln as well as World Wars I and II, Korean War and Viet Nam conflict. This hugely popular area is administered by NPS National Mall and Memorial Parks (NMMP).

Since the various leveling campaigns did not cover large enough areas to give a consistent picture of any height changes that might be occurring in the area, the agreement being development between NGS and NPS would call for periodic reobservations of the Mall area, typically every 3-5 years that would provide sufficient measurements to bench marks outside of the Mall and in the same epoch so as to provide an accurate assessment of vertical motions that may be occurring. It is already known that the Washington Monument, weighing in at almost 91,000 tons, has been settling since it was completed in 1884. The previously mentioned USGS report indicates that the Monument had settle 0.05 ft (1.5 cm) from 1900 to 1930 for an average of approximately .0016 ft per year (.0005 m). This compares very closely with the values derived from the different leveling campaigns performed by C&GS/NGS (Table 1).

Dates	Hgt Diff meters	Hgt Diff inches	Annual Settlement Rate (meters)
1884-1901	-0.010	-0.4	(1)
1901-1907	-0.006	-0.2	-0.0010
1907-1912	-0.011	-0.4	-0.0023
1912-1926	-0.013	-0.5	(2)
1926-1974	-0.016	-0.6	-0.0003
1974-1984	-0.002	-0.1	(3)
1984-2012	-0.004	0.0	-0.0001
Total	-0.062	-2.3	

Table 1
Settlement at the Washington Monument

1) 1984 Report from Mueser-Rutledge-Johnson & Desimone
2) Computed using 5 yr avg from 1907-1912 + 4 yr avg from 1926-1974
3) Computed using 5 yr avg from 1926-1974 + 5 yr avg from 1984-2012

The concern that NPS now had was to determine if there may have been any additional settlement caused by the "event." To provide that information, NGS was asked to perform a new leveling program as quickly as possible at the beginning of 2012. Working closely with NMMP staff NGS drafted a plan for First-Order Class II leveling that would start at existing bench marks to the north and west of the Capitol, run west along the Mall to the Washington Monument, circle the area of the Tidal Basin to include the Jefferson Memorial follow the Potomac River north to the new Martin Luther King

(MLK) and Lincoln Memorials, then east across the area of the Reflecting Pool back to the area of the Washington Monument and then continue north across Constitution Avenue across the Ellipse to tie into a deep rod bench mark at the southwest entrance of the White House. Additionally it was decided that a spur line should be observed from the vicinity of the Jefferson Memorial south to the single long-term tide gauge in the District of Columbia maintained by the National Ocean Service, Center for Operational Oceanographic Products and Services as part of the National Water Level Observation Network. Leveling field observations were completed on April 10, 2012. Ultimately this network included 57 existing and 5 new marks for a total of 62 bench marks covering approximately 10.9 miles (17.50 km) double run leveling (Figure 1).

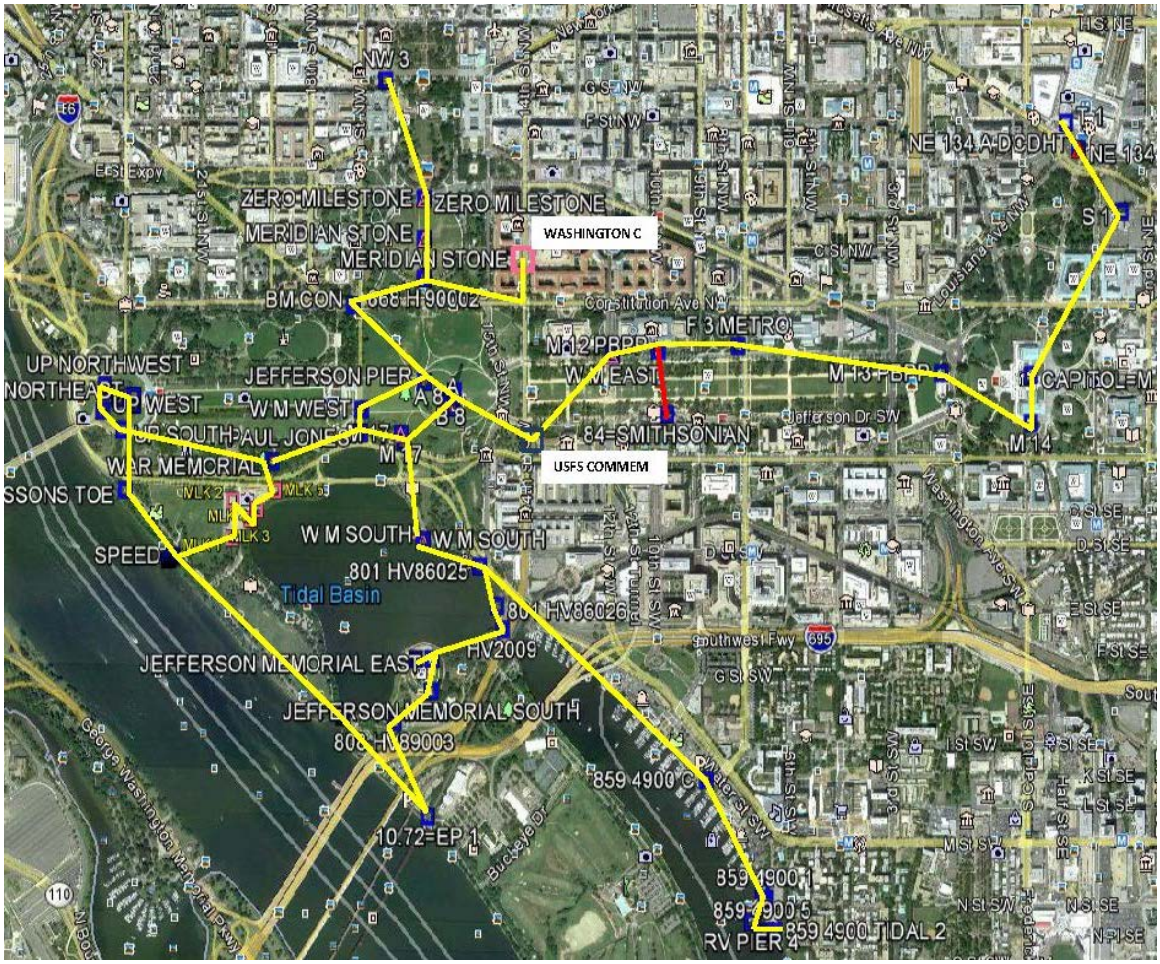

Figure 1
General plan of 2012 leveling route

One of the most immediate considerations faced by the NPS and the NGS level team was timing. Not wanting to run levels in the winter meant that early spring was the best opportunity. As these operations were to be conducted out of the NGS headquarters office in Silver Spring, MD the logistics of travel were not an big concern. However putting the team together so as to have the least impact to ongoing programs they were working on and to perform the leveling during a time when the tourist traffic had not reached full swing were major issues. The weather in early spring was very cooperative

and the team, consisting of an observer, two rodmen and a pacer began observations on March 7, 2012. All observations were conducted with a Trimble DiNi 12* geodetic level (Figure 2) with 3-meter calibrated rods (Figure 3). After some discussion with NMMP staff the decision was made to begin the actual observations at the Washington Monument to complete the loop consisting of the Tidal Basin, Jefferson, MLK and Lincoln memorials as soon as possible as these are the areas most visited by tourists and the Cheery Blossoms were coming out a bit early so completing this portion ahead of the anticipated crowds was deemed most logical. While the team was working on this part of the project significant efforts were being made by NMMP staff to get their colleagues at NPS Presidents Park, which covers the Ellipse and the White House to allow the level crew access to the Ellipse and the two significant bench marks there the Meridian Stone and the Zero Milestone, as well as access to a deep rod bench mark (RS) located near the southwest entrance to the White House grounds. All of the NPS staff involved were extremely supportive which eventually ensured that the level team could connect to these extremely important marks.

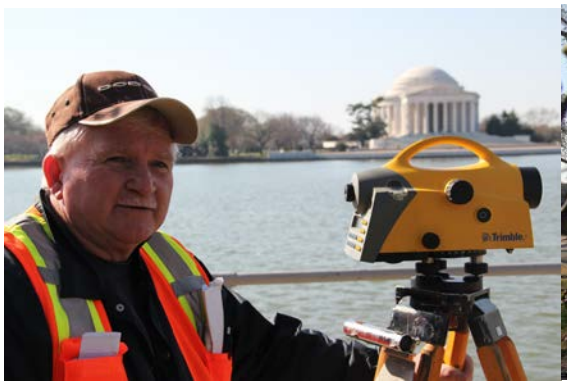

Figure 2
Observer D. Crockett with Trimble DiNi 12

Figure 3
Rod man C. Dean with single piece 3-meter rod

(* Reference to a commercial product does not constitute an endorsement of the product or manufacturer by the National Geodetic Survey.)

The first geodetic leveling to the Washington Monument was conducted by USC&GS in 1884 as part of the initial trans-continental leveling program begun in 1877, that formed the foundation of a consistent national vertical reference frame that we enjoy today as the North American Vertical Datum of 1988 (NAVD 88). At that time a single connection was made to a bench mark at the Washington Monument that was shortly covered by construction and not seen again until 1999. This was followed in 1901 by another level program that established 4 bench marks at or near the Washington Monument that were subsequently releveled in 1907 and 1912. When C&GS revisited the Monument in 1921 the marks from 1901 had all been destroyed so they were required to establish a new mark. This mark, designated C 1 (HV1842) was a standard C&GS bench mark disk embedded in the sill at the entrance to the Monument on the east side – a very conspicuous location. This mark was releveled as part of 5 separate C&GS/NGS (the agency was renamed in 1970) projects during 1926, 1942, 1972 and 1974 providing a high degree of integrity to estimates of settlement at the Monument. During 53 years from when the mark was set to the final leveling the 5 surveys indicated a total settlement

of 1.6 cm (.05 ft) for an annual rate of .3 mm/year. The next survey conducted by NGS was in 1984 and by that time bench mark C 1 had been removed as a result of some remodeling of the entrance way. In an effort to ensure that there would be good quality bench marks available for future surveys NGS decided to install special marks of a style similar to those used in previous surveys of the White House. The marks made of stainless steel consist of a cylindrical plug 9 cm long, 2.5 cm in diameter with a treaded cap that can only be removed with a special tool (Figure 4). To use the mark the cap is removed and a stainless steel pin 23 cm long and specially machined to fit into the opening is inserted into the plug. The rod is placed on the pin during observations and once completed the pin is removed and the cap replaced to make sure the plug doesn't fill with debris. Two such marks designated A8 (HV8076) (Figure 5) and B8 (HV8077) (Figure 6) were placed in the Monument on the north and south facing walls. During 2009 similar style marks were set in both the Jefferson and Lincoln memorials. The location of all of these marks is such that they can accurately reflect any height changes to the monuments as well as being inconspicuous so as to have minimal impact on the appearance of the face of the monuments.

Figure 4
Stainless steel bench mark and tool

Figure 5
Station A 8, HV8076

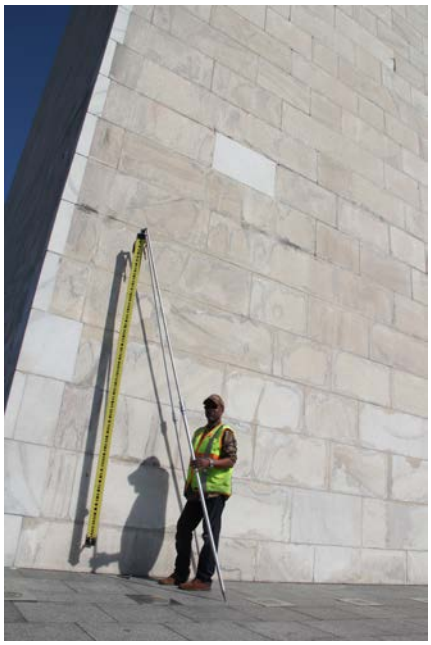

Figure 6
Rodman E. Duvall on B 8

Since 1984 these marks have been releveled 7 times during 1992 (twice), 1998, 1999, 2000, 2009 and 2012. Over that time both marks appear to have settled 4.3 mm or approximately .2 mm per year (Table 2 and Table 3).

From Station	To Station	Difference Hgt Diff (m)	NGS Year	From 1984	Archive #
A (HV1841)	A 8 (HV8076)	1.5151	1984		L-24834
A (HV1841)	A 8 (HV8076)	1.5127	1992	-0.0025	L-25362
A (HV1841)	A 8 (HV8076)	1.5135	1992	-0.0016	L-25364
A (HV1841)	A 8 (HV8076)	1.5126	1998	-0.0026	L-25942
A (HV1841)	A 8 (HV8076)	1.5117	1999	-0.0035	L-25942
A (HV1841)	A 8 (HV8076)	1.5115	2000	-0.0036	L-25942
A (HV1841)	A 8 (HV8076)	1.5107	2009	-0.0044	L-27230
A (HV1841)	A 8 (HV8076)	1.5107	2012	-0.0044	L-27915

Table 2
Leveled Height Differences from A to A 8

From Station	To Station	Difference Hgt Diff (m)	NGS Year	From 1984	Archive #
A (HV1841)	B 8 (HV8077)	1.5732	1984		L-24834
A (HV1841)	B 8 (HV8077)	1.5715	1992	-0.0018	L-25362
A (HV1841)	B 8 (HV8077)	1.5717	1992	-0.0015	L-25364
A (HV1841)	B 8 (HV8077)	1.5705	1998	-0.0028	L-25942
A (HV1841)	B 8 (HV8077)	1.5699	1999	-0.0033	L-25942
A (HV1841)	B 8 (HV8077)	1.5696	2000	-0.0037	L-25942

A (HV1841)	B 8 (HV8077)	1.5692	2009	-0.0040	L-27230
A (HV1841)	B 8 (HV8077)	1.5690	2012	-0.0042	L-27915

Table 3
Leveled Height Differences from A to B 8

Based on the multiple leveling campaigns conducted by USC&GS/NGS since 1901, the Washington Monument appears to have settled 6.2 cm (0.20 ft.) or an average rate of .5 mm per year. The small difference between the two settlement rates stated above can easily be reconciled by the fact that there were periods of approximately 21 years since 1901 during which no leveling was performed and that prior to 1984 there were several different bench marks that were used in the various leveling efforts. That fact that there were considerable advances in leveling instrument technologies over that time frame are likely of only modest consequence since the leveling standards used by USC&GS/NGS have remained virtually unchanged for almost 80 years and the distance over which the leveling has been conducted from the Washington Monuments primary bench mark designated A (HV1841) is less than 100 meters. All of the leveling conducted by USC&GS/NGS is considered to be at least First-Order Class II and have an estimated accuracy between adjacent marks of not more than .7 mm as described in the Federal Geodetic Control Committee "*Standards and Specification for Geodetic Control Networks*" of 1984. As the distance from the primary bench mark and the Washington Monument is so short this standard has been used as the threshold for describing the accuracy of the height differences.

Bench Mark A, sometimes called the "Mini-Monument" was originally set by the Office of Public Buildings and Grounds (PBG), later called the Office of Public Buildings and Public Parks (PBPP) and later absorbed into the U.S. Army Corps of Engineers. The bench mark, set during the reconstruction of the foundation of the Monument sometime before 1889, consists of a concrete obelisk twelve and a half feet long and three feet wide at its base tapering to one and a half feet at the top and resting on a concrete platform that is twelve feet square. The top of the obelisk is flat to support a level rod and is recessed a little over a foot below ground level and protected by a cast iron utility access cover (Figures 7, 8 and 9). The mark is rarely seen by the public and even the occasional news story or You-Tube video only partly describe this marks significance -- http://www.youtube.com/watch?v=ioZIwoFT_LA

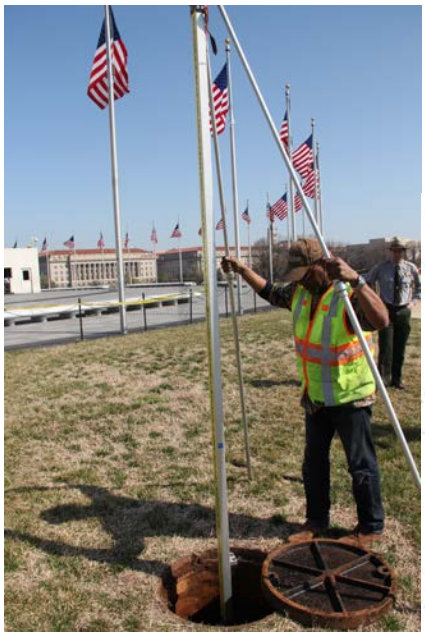

Figure 7
General location of "Mini Monument"

Figure 8
"Mini Monument" detail

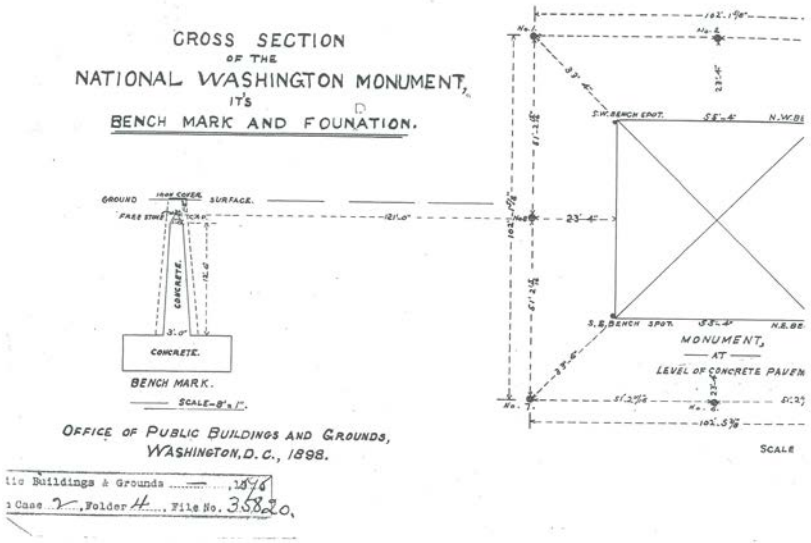

Figure 9
Mini Monument Specifications

Bench mark A was first used by USC&GS in a leveling program in April, 1901 when USC&GS was requested by the OPG Superintendent to validate the height difference between this mark and several others located at the corners of the Washington Monument that had previously been determined by OPG in 1899. The work conducted by USC&GS showed no difference at that time. Additional local leveling from monument A to bench marks at the Washington Monument was conducted by USC&GS in 1907 and 1912. During that time the leveling indicted settlement of the Washington Monument of

approximately 1.8 cm. Station A was subsequently tied into the growing national vertical network being developed by USC&GS in 1914. The station was reobserved as part of six different regional leveling projects during 1926, 1942, 1972, 1974, 1992 and 2012. Those campaigns also included the Capitol Bench Mark (HV2017) which is one of the oldest geodetic bench marks in the District of Columbia having been set in 1884. A comparison of heights differences from the Capitol Bench Mark to A over that time indicates station A appears to have uplifted approximately 1 cm sometime during 1926 to 1942. Additional observations from 1942 to 2012 seem to indicate that station A has continued to uplift but only in the range of 3-4 mm (Table 4). As the leveling distance from the Capitol to the Washington Monument is approximately 3 km this difference is in excess of the expected leveling error. This analysis does not suggest any reason for the difference.

From Station	To Station	Difference Hgt Diff (m)	Year	From 1914	NGS Archive #
CAP BM (HV2017)	A (HV1841)	-16.3890	1914		68956
CAP BM (HV2017)	A (HV1841)	-16.3870	1926	0.0020	L-11240
CAP BM (HV2017)	A (HV1841)	-16.3790	1942	0.0100	L-10084
CAP BM (HV2017)	A (HV1841)	-16.3747	1972	0.0143	L-22646
CAP BM (HV2017)	A (HV1841)	-16.3758	1974	0.0132	L-23294
CAP BM (HV2017)	A (HV1841)	-16.3746	1992	0.0144	L-25354
CAP BM (HV2017)	A (HV1841)	-16.3729	2012	0.0161	L-27915

Table 4
Leveled Height Differences from Capitol Bench Mark to A

Discussion with NPS have indicated that it is likely that repair efforts for the Washington Monument will require scaffolding similar to that which was used during the 1999-2000 restoration. At that time NGS will work with NPS to mount a dual-frequency GPS receiver on the Pyramidion as was previously performed during 1999-2000. No specific details have been worked out at this time but NGS will encourage NPS to allow the receiver to collect data continuously for at least 3-5 days. During that time additional GPS observations will be conducted at other strategically selected passive control stations in the Mall area. Comparing repeat observations with those from the 1999-2000 campaign and referenced to the network of Continuously Operating Reference Stations (CORS) can begin to provide more reliable information on the nature of regional subsidence in and around the District of Columbia which is estimated to be approximately 1.4 mm per year as described in the 1973 report by S. Holdhal and N. Morrison "*Regional Investigation of Vertical Crustal Movements in the U.S. Using Precise Relevelings and Mareograph Data*." No dates have been set for these observations at this time.

While the project also made connections to other historical monuments in the Mall area as previously mentioned, the lack of significant repeat reobservations precludes any determination of settlement at this time. The only other leveling to the Jefferson and Lincoln Memorials was performed in 2009 and the leveling from this project matched the

values at those sites within the tolerance of First-Order Class II. The final analysis of the 2012 leveling data was unable to detect any vertical motion at the Washington Monument related to the August 23, 2012 earthquake.

It is impossible to complete a project of this nature without a team of dedicated professionals working collaboratively. Special recognition goes to those listed below:

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