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FOUNDATIONS FOR MEMORIALS AND MONUMENTS ON THE NATIONAL MALL

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ABSTRACT

As the western end of the National Mall in Washington, DC was made by filling in portions of the Potomac River, memorials and monuments have required deep foundations. The site history including stream channels, canals, and materials used in filling various areas has had a large impact on the development of the Mall. Variations in geologic conditions along the Mall have affected the types of foundations used. One of the earliest structures, the Washington Monument, was sited to account for problem soils. Its foundation was underpinned during construction to compensate for low-strength soils. Shallow-founded portions of the Lincoln Memorial, the Reflecting Pool, and the Jefferson Memorial have experienced settlements requiring repair. Foundations for the Korean, Vietnam, and World War II Memorials were designed as deep systems due to the presence of compressible deposits at their respective sites and in the case of the World War II Memorial the presence of a flood zone. The US Capitol is founded at a higher elevation on spread footings bearing on compact Pleistocene terrace deposits.

This paper will the present the types of foundations used for memorials and monuments, the performance of the systems, and the resulting remedial actions where required.

INTRODUCTION

This paper will present an overview of the geology of the Washington, DC area and a description of the foundations of many well-known structures on the National Mall.

GEOLOGY

The Washington, DC area is located within the Coastal Plain and Piedmont Physiographic Provinces. The boundary between these two provinces, known as the Fall Line, runs southwesterly from the District of Columbia-Montgomery County boundary near Silver Spring across the Potomac River north of Roosevelt Island. Downtown Washington, DC is located within the Coastal Plain. The Coastal Plain typically contains Pleistocene terrace deposits and recent river alluvium at the lower levels, rising into exposed Cretaceous sediments on higher ground. The Piedmont Province extends from the Hudson River near Nyack, NY to a point just north of Montgomery, Alabama. It is predominantly a rolling upland developed on intensely folded and faulted metamorphic and igneous rocks. Local relief is on the order of 50 ft, with occasional greater relief near deeply cut stream valleys. Dissection is often greatest near the Fall Line. The metamorphic rocks in the Washington area include the Wissahickon Formation, the Sykesville Formation, and the Laurel Formation. The igneous rocks are more recent intrusions into the older metamorphic rocks. A thin mantle of soil covers much of the Piedmont.

Rock

Top of rock within downtown Washington, DC ranges from about Elev. +100 ft along the lower reaches of the Rock Creek to about Elev. -450 ft at the Anacostia waterfront. (Darton 1951) Elevations are referenced to Mean Sea Level. A portion of Darton's map is presented on Figure 1.

Cretaceous Deposits

The Cretaceous coastal plain sediments consist of a succession of wedge-shaped layers which were deposited in relatively shallow seas on the sloping bedrock surface by streams flowing eastward out of the continental interior. The interfaces between successive Cretaceous formations dip towards the southeast and the wedges thicken in the same direction. The Cretaceous sediments are lenticular on a large flowing eastward out of the continental interior. The interfaces between successive Cretaceous formations dip

flowing eastward out of the continental interior. The interfaces between successive Cretaceous formations dip towards the southeast and the wedges thicken in the same direction. The Cretaceous sediments are lenticular on a large scale as a result of changing conditions of deposition but are much more regular in stratification than the younger overlying soils. The lowermost Cretaceous strata are grouped in the Potomac formation and consist primarily of the Patuxent arkosic sands and Patapsco clays. Erosion has removed a great thickness of the Potomac formation in downtown Washington. The Potomac formation is not present at the western portion of the Mall, but appears between 12th and 7th Streets and is approximately 250 ft thick at the Capitol. (Mueser, Rutledge, Wentworth & Johnson, 1970)

Pleistocene Terrace Deposits

The uppermost natural sediments in the downtown Washington area comprise a succession of river terrace deposits of Pleistocene times which overlie the Cretaceous formation. A time gap of many million years is represented at the discontinuity between the two major groups of materials. These Pleistocene terraces consist of a mixture of silty and sandy clays with sands, interlayered and lensed in a complex pattern. While continental ice did not reach south to the Washington area, Pleistocene terraces were formed by debris carried in streams charged by glacial meltwater flowing from the north and northwest. The complicated alteration of soils in the terrace is a result of successive changes of sea level and rate of flow of runoff during periods of glaciation and interglacial stages. At the time of ice advance the level of the sea fell with respect to the land, stream gradients increased and sediment load decreased, resulting in a period of erosion or downcutting. During recession of the glacier inflow increased, sea level rose and comparatively coarse-grained materials were deposited. As the warming trend continued, the area was inundated and the finest grained sediments were laid down. A series of these flattop terraces at several characteristic elevations have been identified in the Washington area. These include the 25-foot terrace, the 50-foot terrace, with surface elevations between 40 and 60 ft above sea level, and the 90-foot terrace with surface elevations between 70 and 100 ft above sea level. Each terrace exhibits a characteristic change in gradation in a vertical profile from coarse-grained and gravelly soils at its base to sands, silts, and clays at shallower depths, corresponding to the change from low sea level at the start of ice retreat to high sea level at the warmest time of the interglacial period. Capitol Hill is at a promontory of the 50-foot terrace. The remainder of the Mall lies within the 25-foot terrace and recent deposits as illustrated in Figure 2. (Mueser, Rutledge Wentworth & Johnston, 1970)

Fill

A layer of urban fill is present throughout the city. Deep fills are present at the west end of the Mall west of the Washington Monument and include dredge spoils. Fill is 20 to 25 ft thick at the west side of the Monument, and increases to 30 to 40 ft at the Lincoln Memorial. Elsewhere the fill is relatively thin, except in isolated areas.

A PARTIAL HISTORY OF THE NATIONAL MALL

Many of the early structures requiring deep foundations in Washington were constructed on the Mall. The Mall runs between Independence and Constitution Avenues, from the US Capitol to the Potomac River. A history of the Mall is instructive in understanding subsurface conditions in this part of Washington, DC. The Civil War spurred tremendous growth in Washington so many of the structures cited here were constructed in the years following that era.

L’Enfant’s Plan

Pierre L’Enfant was a French-born urban designer selected by George Washington to develop the basic plan for Washington, DC. In 1791 L’Enfant proposed a plan in which he envisioned the Mall as the central axis of the Monumental Core. The Mall was to be the foremost avenue of the city, the so-called "Grand Avenue." It was to run west from the Capitol to a point directly south of the President's House where its terminus would be crowned by an equestrian statue of George Washington. According to L'Enfant's plan, the Mall was to be "four hundred feet in breadth, and about a mile in length, bordered by gardens, ending in a slope from the houses on each side."

During the course of the 19th century, L'Enfant's formal design for the Mall was largely forgotten. During the Civil War, the Mall grounds were used for military purposes, such as bivouacking and parading troops, slaughtering cattle and producing arms. In 1872, a 14-acre tract at 6th and B Streets was given to the Baltimore and Potomac Railroad for the construction of a depot. The railroad was also granted permission to lay tracks north to south across part of the Mall. (National Park Service, 2001a)

Canals

The canals of Washington were intended to be a major transportation artery in the scheme to build the federal city into an important port and trade center. An important part of George Washington’s and Pierre L’Enfant’s thinking was a canal through the middle of Washington, to link the Potomac and Anacostia Rivers. One of the main purposes of this canal

was to provide a means of transporting goods to the center of the city, eliminating the need to haul them from the river. L'Enfant also expected the canal to be a beautiful waterway which would contribute to the aesthetic value of the city. L'Enfant's canal would run east from the Potomac at the mouth of the Tiber Creek nearly to the Capitol, then proceed southeast, splitting into two branches south of the Capitol. One branch would empty into the Anacostia just west of the Navy Yard, and the other branch would trend to the southwest, incorporating James Creek, which entered the Anacostia in a small bay just east of the arsenal (Greenleaf's Point). The canal routes are shown on McClelland's map presented in part as Figure 3.

The Washington City Canal was built essentially as planned except that the lower portion of the James Creek branch was not included. Construction began in the mid-1790s, but it was almost entirely constructed between 1802 and 1815, with much of the work done between 1810 and 1815. The Tiber Creek was converted into a portion of the canal from its outlet at 17th and Constitution eastward to the Capitol. Prior to its channelization, the Tiber Creek occupied a broad basin along what is now Constitution Avenue, but extending nearly to D Street NW between 13th and 14th Streets NW and a similar distance south of Constitution Avenue in the same area. It was also called the Goose Creek in this area. When it was converted to the canal, its channel was filled in where it diverged from the canal's alignment, forcing all of its flow into the canal. A portion of the canal to the west of the Capitol is shown in Figure 4.

The total length of the Washington City Canal was 15,330 feet, and the original depth was about 4 feet. The Canal was used intermittently from 1816 to about 1850. It was subject to filling by sand and silt from both ends, from the Potomac and Anacostia Rivers. After about 1850 it was virtually useless, victim to sedimentation, inadequate maintenance, and the railroad. It was reputed for collecting sewage and presenting objectionable odors at low tide, as well as posing a potential health hazard. In 1871 the Board of Public Works began filling in the canal from the Rock Creek Basin to the Anacostia River. This was essentially completed by 1881 except for the last two blocks between L and N Streets South. The Constitution Avenue section was partly made into a covered sewer by building a new wall parallel to one of the canal walls, arching over the intervening space to form a conduit, and filling in the unneeded channel outside the sewer. Some of this old sewer was used in the 1970s to carry storm water and air-conditioning cooling water from Federal buildings to the Tidal Basin. The lower part of the James Creek was made into a canal in 1876, and was filled in again gradually between 1916 and 1931. Canal Street SW charts the course of the canal south of Maryland Avenue. A portion of Canal Street has since been renamed Washington Avenue. (Williams, 1972)

Fill Placement at the Mall

In 1882 the US Congress appropriated funds to commence a major "Land Reclamation Project." Dredging of the Potomac River as well as the mouth of the Tiber Creek led to the creation of East and West Potomac Parks. Figure 5 shows the western portion of the Mall in 1866, prior to the placement of fill. The reclamation work, conducted by the US Army Corps of Engineers, nearly doubled the length of the Mall and created more than 700 acres of new land within the city's "Federal Central Enclave." (Land Reclamation Project, 2000)

This had the effect of lengthening the Mall to approximately 2 miles and extending it westward to its present boundaries by about 1900, creating an area of poor soil conditions. According to a map prepared by the District of Columbia Office of the Engineer Commissioner in 1896 shown on Figure 6, the Potomac River's boundaries had been established at their present locations, the Tidal Basin adjacent to the Jefferson Memorial had been created, and the Mall had generally taken on its present shape. The piers in the present day Washington Channel along Maine Avenue reflect the original eastern shoreline of the Potomac River from the 1850s.

The McMillan Plan

In 1900 The Senate Committee of the District of Columbia was directed to prepare a comprehensive plan for the development of the entire park system in the District of Columbia. The resulting plan, known as The McMillan plan, was published in 1901. It relied heavily on L'Enfant's plan of 1792 for the Mall. One major goal was to beautify the Mall including the newly reclaimed Potomac Flats. The Committee was tasked with eliminating such undesirable elements as the railroad station, railroad tracks at grade, grazing animals, sheds, and other occupants and restoring the uninterrupted green space envisioned by L'Enfant.

The areas west of 17th Street and east of 14th Street were developed in general accordance with the McMillan Plan. At the base of the Washington Monument the McMillan plan called for a cut of up to 27 ft to create a formal sunken garden on the west and a fill of up to 25 ft to create a terrace on the east. Congress authorized $5 million for this work in 1928. However, studies performed under the Independent Offices Act of 1931 suggested that this earthwork could endanger the stability of the Monument. Based on those studies, a decision was made to consider other plans, both formal and informal, for the Monument Grounds. (Improvement of the Washington Monument Grounds, 1931)

STRUCTURES ON THE MALL

Washington Monument

The site originally chosen for the Washington Monument was at the intersection of the east-west axis of the Mall with a north-south line centered on the White House. Due to the poor soil conditions at the intersection, the location was shifted approximately 370 ft east and 123 ft south to a point where better ground conditions were present. Construction began in 1848 with private funds raised by subscription. The Monument foundations were established at approximately Elev. 15 ft atop sand and clay soils of Pleistocene Terrace deposits of Strata T1(A) and T2. When funds ran out in 1856 work was stopped, with the Monument at a height of 152 ft. Congress was repeatedly approached for funding, but the Civil War intervened. Ultimately funding was forthcoming from Congress in the late 1870s to resume construction. At that time, concerns were raised about the ability of the spread foundations bearing on these soils to carry the load of a masonry structure in excess of 500 ft in height. Thomas Lincoln Casey, an experienced lieutenant colonel from the US Army Corps of Engineers, designed a scheme to underpin the foundations, increasing the contact area of the foundation from 6400 sq ft to 16,000 sq ft. Buttresses were added to provide load transfer to the underpinning. Excavations for the underpinning extended to approximately Elev. +3 ft, the groundwater level at that time. The new foundations bear on Pleistocene Terrace Stratum T3, a very compact silty sand, with gravel, and have performed satisfactorily. Total settlements since completion of underpinning are about 7 in. More than 60 percent of this settlement occurred as the Monument was built from 152 ft to 555 ft in height. A perspective through the foundations and soils is shown on Figure 7. Construction of the buttresses as part of the underpinning is shown on Figures 8 and 9.

World War II Memorial

The World War II Memorial was constructed between 2002 and 2004. Soils at the site consist of recent fill, dredged fill, tidal marsh deposits, Cretaceous deposits, and saprolite. (US Army Corps of Engineers, 1997) The Cretaceous deposits and saprolite are relatively thin. The Memorial is designed to bear on rock at a depth of about 30 ft below grade. The Memorial is surrounded by a structural slurry wall keyed into rock, which provides a groundwater cutoff and support for the perimeter. The interior of the Memorial is supported on H piles driven to rock.

These methods of support were chosen due to the poor soils at the site and the need to minimize impact of construction on the memorial elm trees surrounding the site, both in terms of limiting the zone of disturbance and minimizing drawdown of groundwater and potentially drying out the tree roots. The slurry wall also addressed concerns about the effects of drawdown on the Reflecting Pool with its timber piles and slab on grade. A photograph of a reinforcing cage being lowered into the WWII Memorial slurry wall is presented on Figure 10.

Reflecting Pool

The Reflecting Pool was constructed in 1920 and 1921. Borings made in 1920 indicated top of rock ranging from Elev. –17 to –40 ft. Overlying soils are probably similar to those at the World War II Memorial, except that Cretaceous deposits are presumed absent. According to drawings from 1921, piles driven to support the coping of the Pool extended to rock at approximately Elev. -30 to -40 ft, with a limited number of piles encountering rock as high as Elev. -25 ft on the northeast corner. Piles are composite, consisting of a concrete upper section placed within a steel shell and a timber lower portion. The bottom of the Pool is a slab on grade.

Rainbow Pool

The Rainbow Pool was constructed in 1920 and 1921. It was supported on composite piles similar to the Reflecting Pool, with tips on rock between approximately Elev. -17 and -28 ft. It was removed to permit construction of the World War II Memorial, and was reconstructed within the Memorial.

Lincoln Memorial

The Lincoln Memorial was constructed between 1914 and 1922. Test borings were made in 1913 to determine top of rock and to determine that rock was at least 2 ft thick. Subsurface conditions were “sand over mud (clay) and gravel over coarse sand over mud (clay) over rock.” Rock was determined to consist of blue gneiss reported in the original boring logs as having “a very hard makeup consisting of considerable quartz.” Penetrating the rock was achieved by alternately driving the drill with a sledge hammer and lifting and dropping the drill. In this way two feet of rock could be drilled in two to eight hours. (Boring logs for the Lincoln Memorial, 1913)

Rock is at approximately Elev. -30 to -45 ft, and site grade is approximately Elev. 29 ft. Ground surface at the time of construction was approximately Elev. 16 ft. The height of the Memorial above grade is approximately 100 ft.

Foundations for the main building consist of two portions. The portion below the original ground level of the park, known as the subfoundation, comprises 122 concrete piers formed within steel cylinders driven to rock. The cylinders vary in length from 49 to 65 ft and in diameter from 3’-6” to

4’-2”. They were sunk by being heavily weighted and water-jetted to a depth of absolute resistance. They were excavated by hand, the excavation extended 2 ft into bedrock and the cylinders filled with concrete, with a steel reinforcing cage set in each cylinder. Above the subfoundation is the upper foundation, consisting of concrete columns approximately 45 ft high constructed atop these piers, with the column tops joined by arches cast integrally. The terrace wall and approaches were to be founded similarly in the original design, but changes were made as a result of the test borings and the wall was constructed on a shallow foundation. Due to continuing settlement of these structures, a decision was made in 1920 to underpin them to rock. The freestanding columns were shored with timbers and underpinning pits sunk to depths of 12 to 14 ft. Caissons were started by drifting from the pits to the locations of the footings for the columns and terrace wall. Caissons were excavated with picks and shovels down into rock, and dewatered by air pumps. Concrete was placed in the caissons up to within 6 in of the bottom of the footings. The 6-in spaces were subsequently dry packed. The access pits were backfilled and reinforced concrete struts constructed from the foundation wall of the main building to the freestanding columns to the terrace wall. The work was performed on every second set of columns and footings, and the intervening sets similarly underpinned when the first sets were completed. The approaches were underpinned using needle beams and girders supported on concrete piers to rock. All of the steelwork was subsequently encased in concrete. (Conklin, 1927)

In addition to the visible portions of the Memorial, a series of below-grade chambers are present extending east under the circle to the west end of the Reflecting Pool. The National Park Service formerly conducted tours of these chambers but discontinued them because the floors were slippery due to persistent dampness in the passageways. A photograph showing the Memorial under construction is shown in Figure 11. A transverse section is shown on Figure 12, and shows the portion below grade extending toward the Reflecting Pool.

Thomas Jefferson Memorial

Ground was broken for the Thomas Jefferson Memorial in 1938 and it was completed in 1939. It is supported on piers to bedrock which extend a maximum depth of approximately 140 ft. The top of the dome is approximately 130 ft above the roadway. Piers were selected for support of the Memorial due to poor soil conditions.

Vietnam Veterans Memorial

The Vietnam Veterans Memorial is supported on concrete piles driven approximately 35 feet to rock. Ground was broken in March 1982 and the memorial was dedicated in November 1982. As at the Jefferson, piles were selected due to poor soil conditions.

Korean War Veterans Memorial

The Korean War Veterans Memorial is supported on H-piles driven 40 to 50 feet to rock. Piles were selected for the Memorial due to poor ground conditions at the west end of the Mall. Ground was broken in November 1993 and the Memorial was dedicated in July 1995.

Franklin Delano Roosevelt Memorial

Ground was broken in September 1991 and the Memorial was dedicated in May 1997. The Memorial is supported on 900 steel piles driven approximately 80 ft to rock. Again, piles were selected due to poor ground conditions at the west end of the Mall. (National Park Service, 2001b)

SUMMARY

The selection of foundation type in Washington, DC is driven by subsurface conditions, building design, cost and schedule. In general, the major memorials and monuments on the western half of the Mall require deep foundations to rock, due to the poor quality of the soils in this area, most of which are dredge spoil placed in the late 1800s. Museum demands below grade call for deep foundations, often combined with slurry walls, to provide high quality space without intruding on sight lines. Off the Mall, deep foundations are generally dictated by the need to develop underground space for parking or building function while supporting the neighboring structures and streets.

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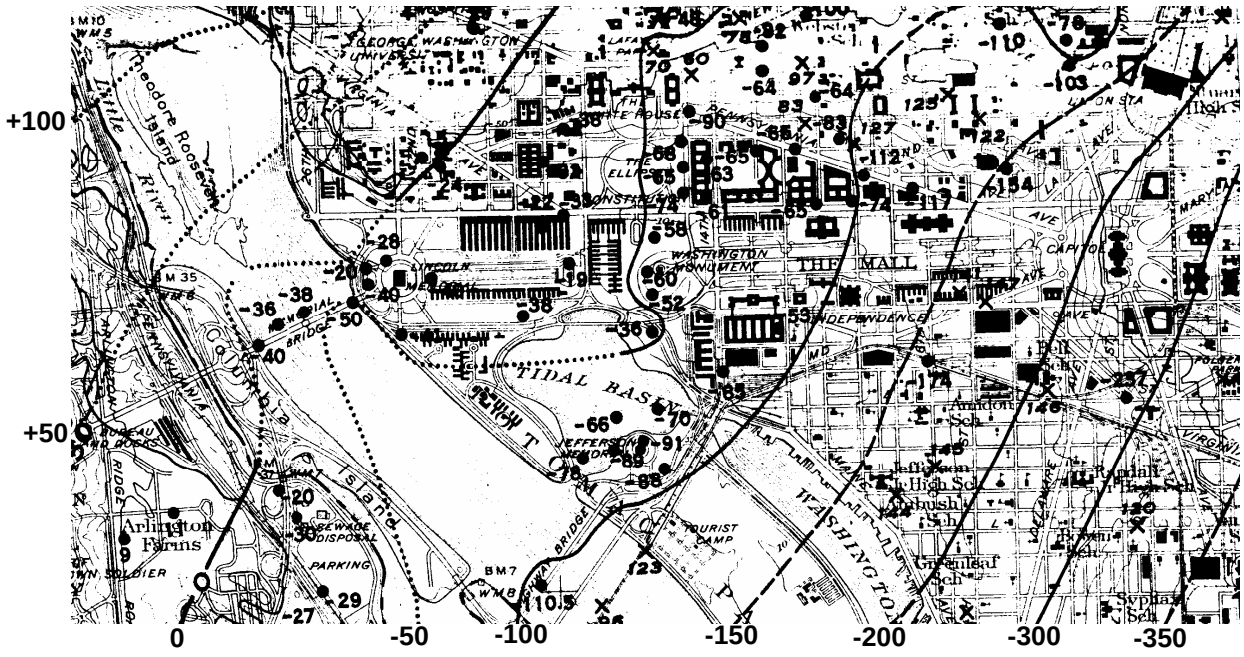

Fig.1. – Portion of Darton's map.

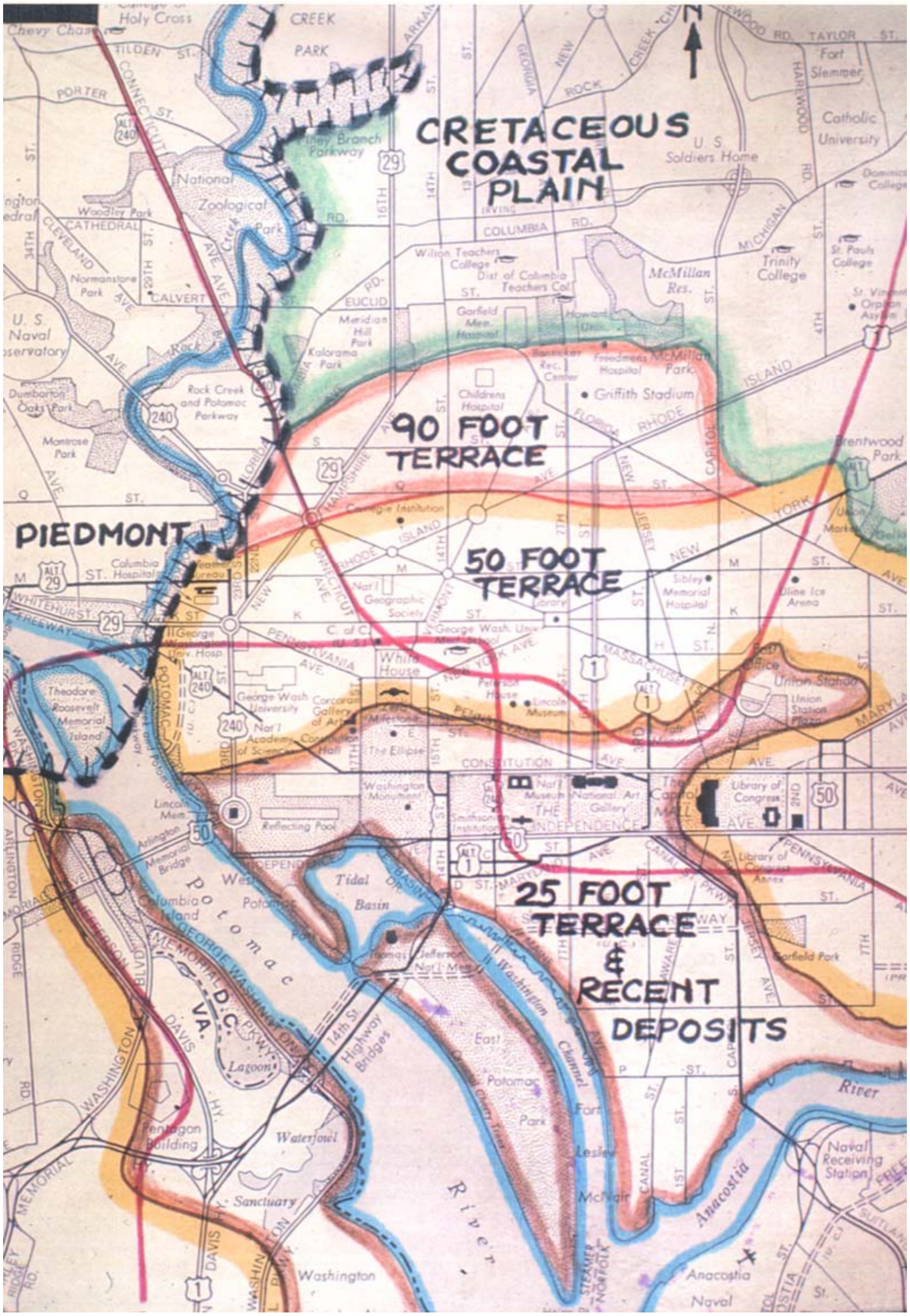

Fig. 2. – Limits of Pleistocene terraces. (Courtesy of James P. Gould.)

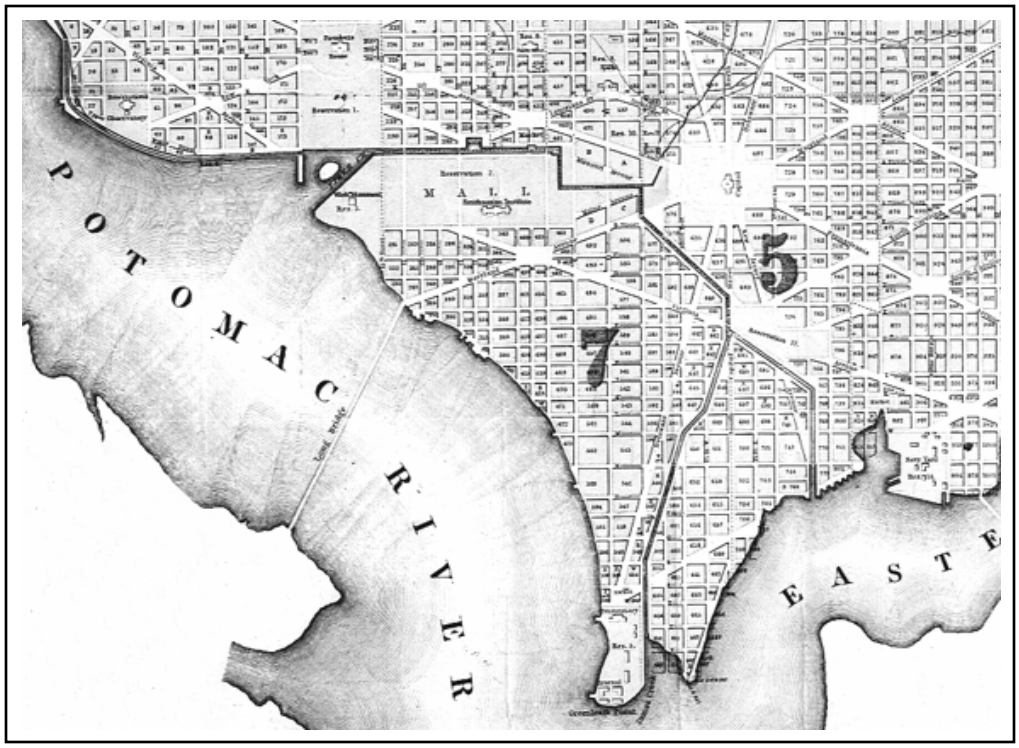

Fig. 3. – Portion of McClelland's Map (1850)

Fig. 4. Washington City Canal & U.S. Capitol about 1858. (Photo from Library of Congress Collection)

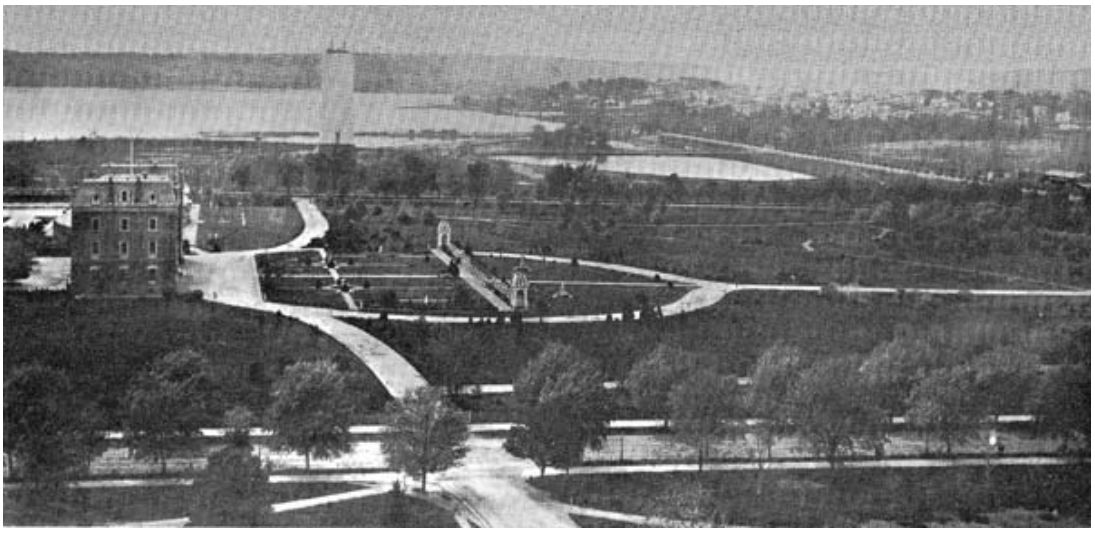

Fig. 5. Looking West along the Mall; Agriculture Department at left, with partially completed Washington Monument and Potomac River in background, 1866. (Photo from Library of Congress Collection.

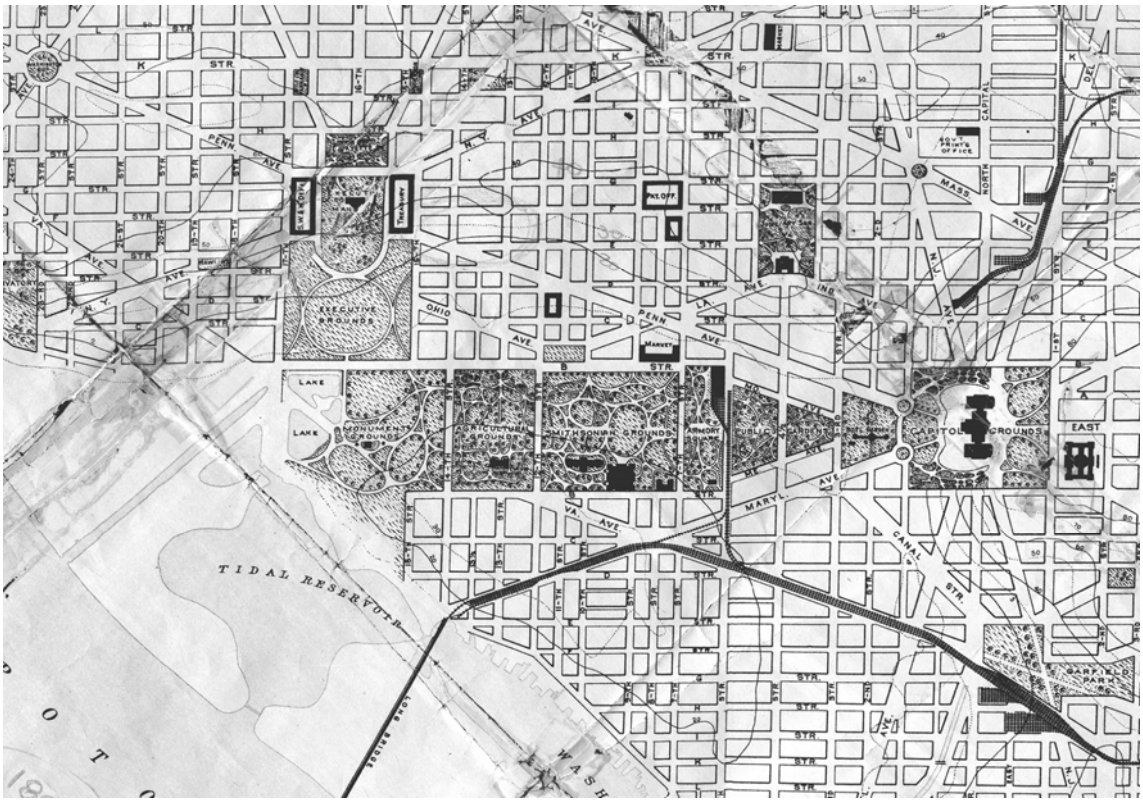

Fig. 6. Portion of DC Engineer's Map of 1896

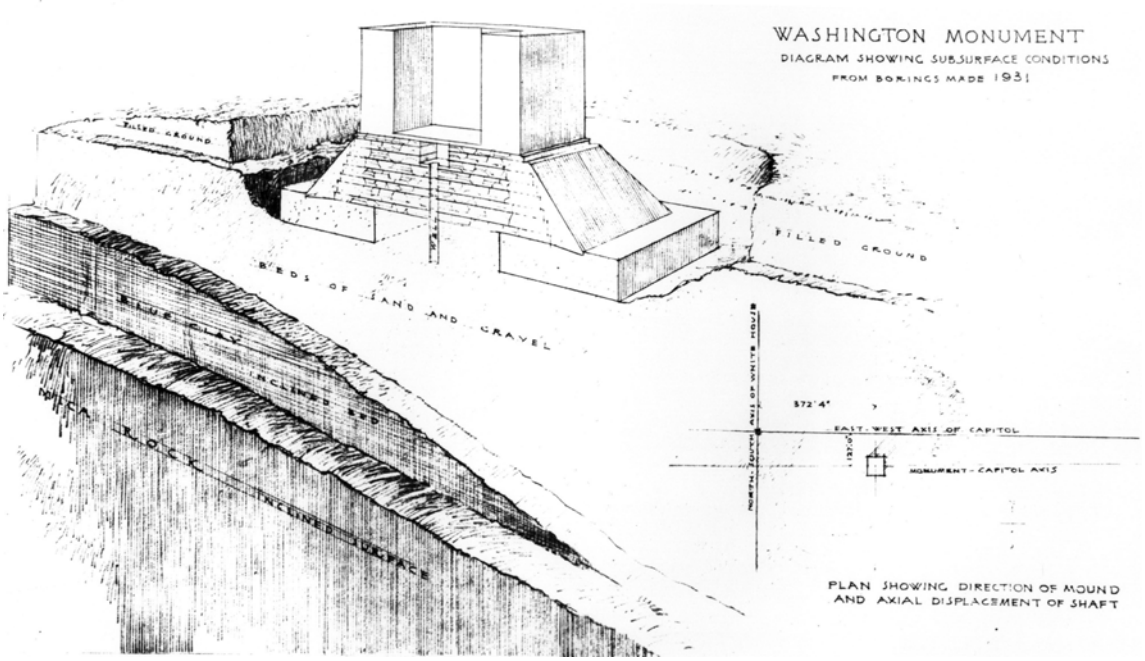

Fig. 7. Perspective view at the base of the Washington Monument (1931)

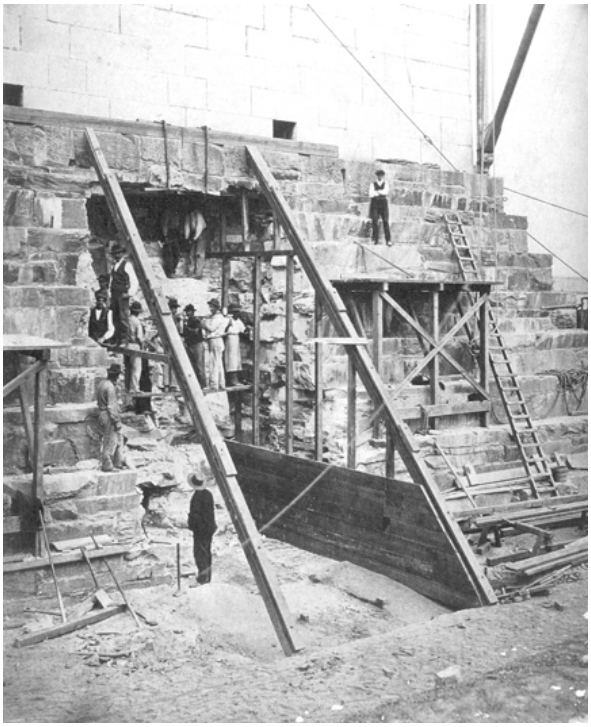

Fig. 8. Constructing buttresses at Washington Monument (1879)

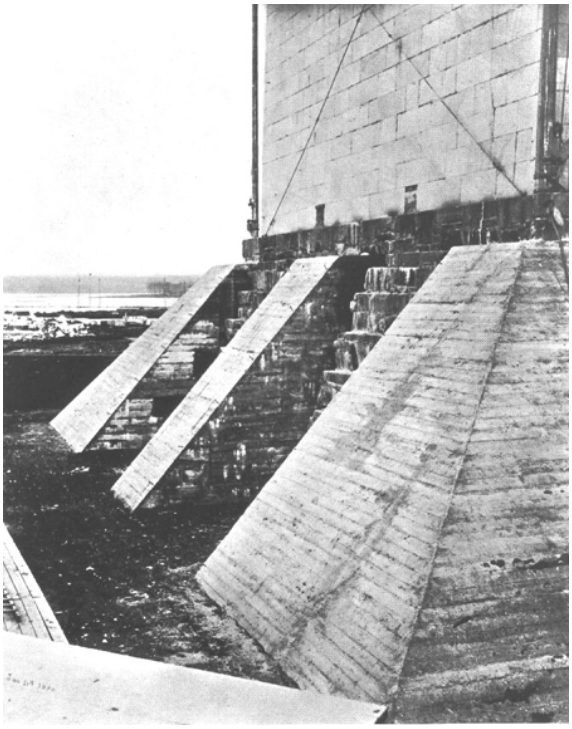

Fig. 9. Completed buttresses at Washington Monument (1879)

Fig. 10. Reinforcing cage being placed for WWII Memorial Slurry Wall (2002)

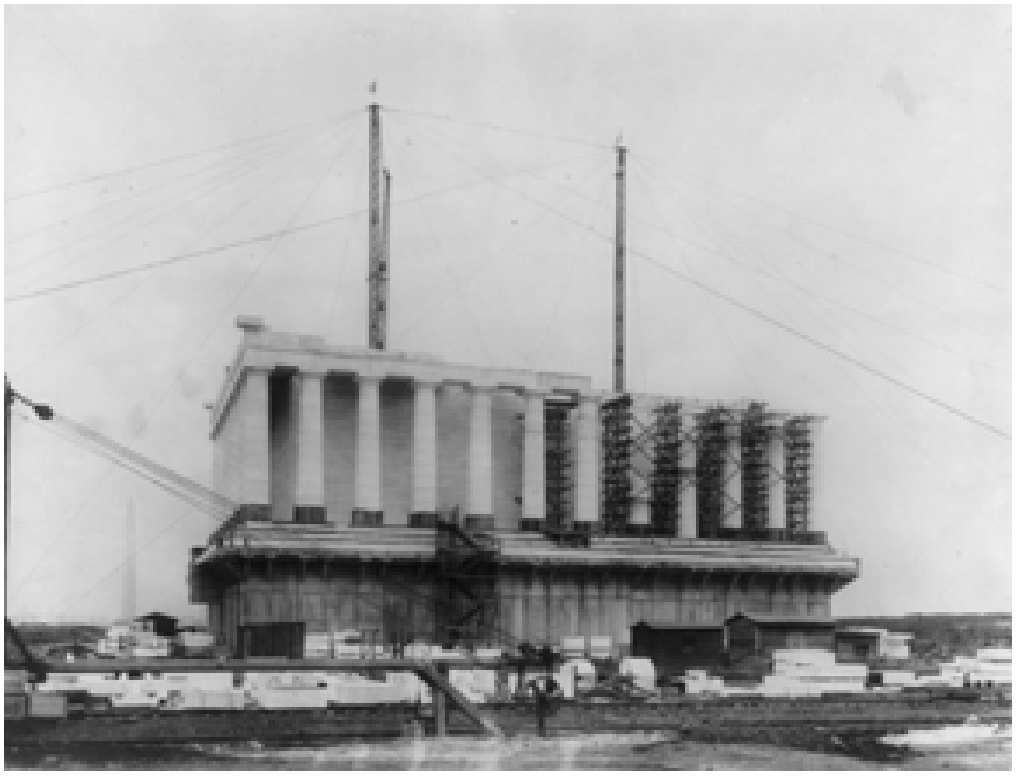

Figure 11 – Lincoln Memorial under construction (1916)

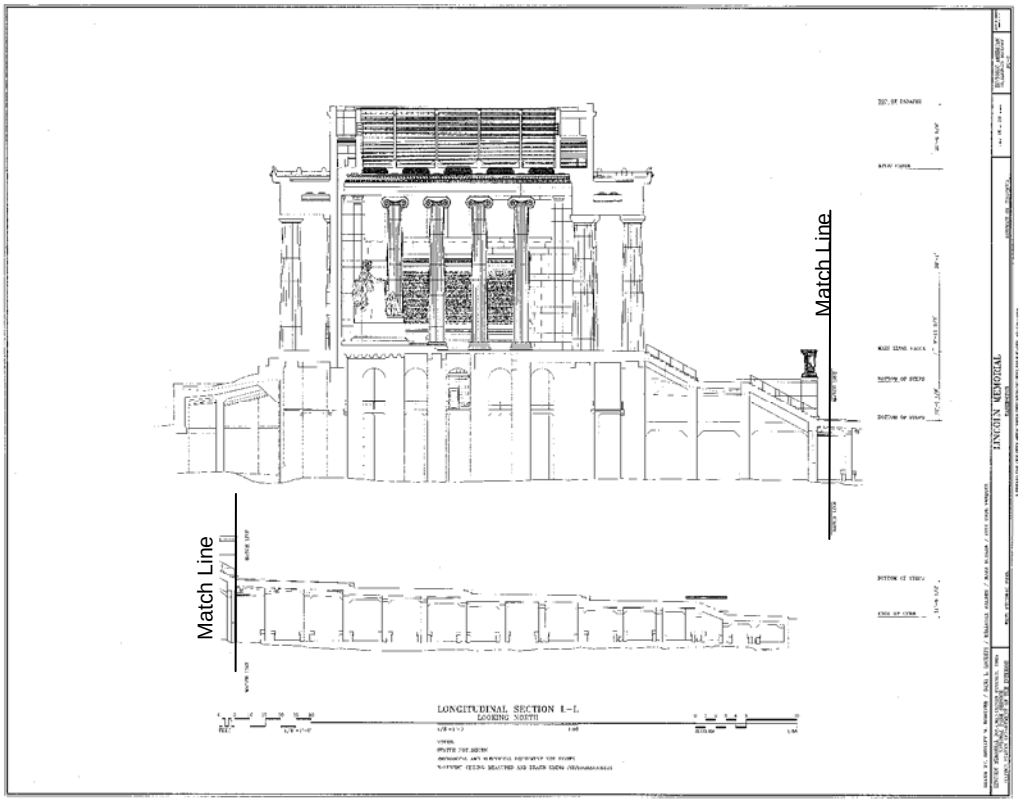

Figure 12 – Historic American Buildings Survey drawing of Lincoln Memorial (1993)