THE ARLINGTON
MEMORIAL BRIDGE

Thesis for the Degree of C. E.

JAMES B. RASBACH

1929

THESIS

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CROSSING THE POTOMAC RIVER AT WASHINGTON

IN THE DISTRICT OF COLUMBIA

BY

JAMES B. RASBACH,Bs.C.E.

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CONTENTS

CHAPTER ONE.

Purpose of the Bridge and Provisions for Its Construction.

I. Conception of the Idea and Its Aim.

Bounding the District of Columbia on the West flows the Potomac River, long noted for its placid beauty and navigable utility, but more particularly because it formed the barrier between the "Old Dominion", the Commonwealth of Virginia, representing the South, and the seat of Government of the Union during those trying days of the Civil War. Long prior to that time, however, the desirability for the construction of a memorial bridge spanning the river had been conceived, the thot in all probability having first originated in the great mind of one of our most distinguished Presidents, Andrew Jackson. Daniel Webster in an address presented July 4, 1851 said, as follows:

> "Before us is the broad and beautiful river, separating two of the original thirteen states, which a late President, a man of determined purpose and inflexible will, but patriotic heart, desired to span with arches of ever-enduring granite, symbolical of the firmly established union of the North and the South. That President was Andrew Jackson."

Ten years after the words of that famous orator were spoken the Potomac River became the dividing line between the two warring sections of our country. It becomes entirely fitting then, that those two sections, now again reunited into a more firmly established Union should construct a span which shall bind them more closely both literally and symbolically to the memory of the sons of each who gave their lives in support of their respective ideals. And how much more fitting will it be if such a structure be completed during the life of the last of the survivors of that great conflict.

II. Preliminary Legislation.

For over eighty years the desirability of such a structure had not been lost sight of, but it was not until 1901 that the movement received any serious consideration from Congress, at which time the Senate Park Commission suggested a bridge at the sight of the Lincoln Memorial, a notable change, since all former proposals had considered a bridge to be built farther upstream. No action was taken in support of that suggestion until the passing of the Public Buildings Act of March 4, 1913, providing, as follows:

> Sec.23. That a Commission is hereby created, to consist of the President of the United States, the President of the Senate, the Speaker of the House of

Representatives, and the Chairmen of the Committees on Public Buildings and Grounds of the Senate and House of Representatives, for the purpose of investigating and reporting to Congress a suitable design for a Memorial Bridge across the Potomac River from the city of Washington to a point at or near the Arlington estate in the State of Virginia, and the commission is hereby authorized to expend the sum of $25,000.00 in providing such designs and for making such surveys and estimates of cost as they may deem advisable, and report as early as may be to Congress.

It was not until nine years later that the funds were made available thru an appropriation in the executive and independent offices appropriation act, approved June 12, 1922, as follows:

"To enable the commission created by section 23 of the public buildings act approved March 4, 1913, to investigate and report to Congress a suitable design for a Memorial Bridge across the Potomac River from the city of Washington to a point at or near the Arlington estate in the State of Virginia, together with such surveys and estimates of cost as they may deem advisable, to be expended under the direction of the commission and to remain available until expended, $25,000.00"

III. Preliminary Investigation.

The Commission, as constituted by the act of Congress, comprised of men prominent in the affairs of the Nation; men having the desire to obtain such a memorial as might surpass in every way all former attempts at grandeur in such a structure. It was necessary, however, for the Commission to seek advice of expert engineers who must be qualified to solve the multitudinous problems arising, so that the structure might be sound from an engineering standpoint as well as perfect from the architectural viewpoint. The Commission, therefore, appointed the Director of the Office of Public Buildings and Public Parks of the National Capital to be Executive and Disbursing Officer. That post is filled by appointment by the President from the commissioned personnel of the Corps of Engineers of the United States Army. Lieutenant Colonel C. O. Sherrill, thus, became the Executive and Disbursing Officer. Colonel Sherrill resigned from the Army in 1926, and his post was taken by Lieut. Col. U. S. Grant, 3rd, Corps of Engineers, and that officer has since rendered invaluable aid to the Commission. The services of an eminent and capable bridge engineer being required, Mr. John L. Nagle was chosen, and Mr. Nagle has since remained in the capacity of Designing Engineer. To him, more than to any other, should go the credit for the solution of the multifarious problems arising from the design. The work shall remain a glorious example of his great skill and accuracy, as an engineer.

The Commission decided to employ the services of famed architects to supply information needed to make the structure archtecturally perfect, and to collaborate with and advise the Designing Engineer. The Commission of Fine Arts was asked to furnish names of suitable artists, and, from the list suggested, the renowned firm of McKim, Mead and White was chosen, a contract being subsequently entered into for their services.

Preliminary investigations were then commenced, and, since various other Federal Committees as well as the Engineer's Corps of the U. S. Army had previously recommended the construction of such a bridge, together with the published plans and data, the work of the Commission was much simplified. Earlier plans had contemplated a bridge farther upstream than the accepted site, but the proposals for the developement of the Mall, following the building of the Lincoln Memorial, convinced the Commission that the most feasible location would be on a line from the Lincoln Memorial to the Lee Mansion in the Arlington Cemetery. The Mall, which has the form of a long narrow parkway, has as its principal axis a line thru the center of the Capitol of the United States and the Washington Monument, which line is almost due East and West. In accordance with the Federal Building Program which is now in progress, the massive and glorious buildings housing all of the activities of the Federal Government will be located along the outside of the Mall. The stately and massive Lincoln Memorial is built on the shore of the Potomac River in the line of the axis of the Mall at a distance of 4249.162 feet from the Washington Monument. and 8748.774 feet from the center of the Capitol of the United States. The Arlington Memorial Bridge, as proposed, would diverge to the South from the axis of the Mall by an angle of about 24 degrees, which, however, would be balanced by a roadway entering thru Potomac Park into Rock Creek and Potomac Parkway.

The project forms the greatest memorial of modern times, carrying out the treatment of the Nation's Capital in accordance with the plans of Washington and L'Enfant; and how much more fitting it becomes when it carries L'Enfant's Mall to his final resting place at the portico of the Lee Mansion. The cortège of the Nation's fallen heroes will pass from the Capitol, by the Lincoln Memorial, and thence over the glorious Potomac to their final resting place in the Arlington National Cemetery.

The bridge will furnish a magnificient entrance into the city of Washington for the Lee Highway, coming across the entire country from Los Angeles, California. And finally, and perhaps its greatest value lies in the fact that it will complete the binding together of the North and the South into one great and indivisible Union, knowing no sectional lines.

The accepted bridge would consist of nine spans, four masonry spans on either side of the river joined by a bascule draw span. Its total length would be 2,138 feet, with a total width of 90 feet, there being two 15 foot sidewalks flanking a 60 foot roadway. The spans would be of low, graceful curves, thus avoiding the possibility of dwarfing the dignified and stately Lincoln Memorial. However, tho the arches would be low, fully ninety five per cent of the comparatively light river traffic would easily pass under the masonry arches, thus preventing frequent openings of the draw. The Potomac River is not navigable past Georgetown which is in sight from the bridge.

All of the masonry spans were to be faced with solid blocks of the finest white granite, and the facies and pier heads carved with appropriate figures. Pylons at each end of the bridge were to be decorated with fine statuary, the general architecture having been defined as simple and severe.

A plaza in front of the Lincoln Memorial joined to a monumental flight of steps leading down to the water, where landings for boats, both large and small, were to be provided. At the Virginia end of the bridge the plaza opens for roads passing along Columbia Island, the Lee Highway crossing to the main land over a separate bridge at the north end of the island, and the Mount Vernon Boulevard passing in a similar manner from the south end of the island. When the Arlington Memorial Bridge was first designed, the Mount Vernon Boulevard had not been authorized, but it has since been joined thereto. The main axis of the bridge was to be carried over a twin bridge crossing the boundary channel from the island to the Virginia shore and thence to Arlington.

Thru cooperation, between the designing engineer and the Office of Public Buildings and Parks, the needed surveys were performed. The United States Engineers aided by the taking of preliminary soundings and core borings along the proposed center line of the bridge.

The commission reported to congress on April 22, 1924, submitting their complete recommendation together with detailed estimates therefor, and a suggested schedule of appropriations to carry out the project. The text above will convey the general proposals of the commission and will therefore not be elaborated upon, the general description of the project following being in strict accordance with the decision of the commission. However, there is included below a complete estimate of the cost and the schedule of appropriations as it appeared in the report, since it is believed that a more comprehensive idea of the immensity of the proposal can be obtained thru its consideration.

Extract of Pages 44-51 Report of Arlington Memorial Bridge Commission dated April 22, 1924 i.e. estimate of cost; summary for entire period:

Estimates of Cost-- Summaries for entire period

	All granite construction as proposed by the architects.	Substituting concrete for granite where feasible	
		Omitting formal treatment of Columbia Island and Memorial Entrance	As proposed by the Executive Officer.
	Proposal I	Proposal II	Proposal III
Memorial Bridge proper	$9,250,000	$7,250,000	$7,250,000
Bridge plaza and water gate	2,300,000	1,000,000	1,000,000
Columbia Island	6,480,000	1,200,000	2,880,000
Parkway and Memorial Entrance to Cemetery	2,390,000	480,000	1,390,000
Extension of B Street Eastward to Capitol and widening to 120'	2,070,000	2,070,000	2,070,000
Widening Twenty-third Street from Washington Circle to B St.	160,000	160,000	160,000
Grand total for project	22,650,000	12,160,000	14,750,000

Proposal I: Constitutes the ideal solution; it contemplates the completion of the entire project as indicated on the drawings, using white granite for all steps, walls, walks, soffits of arches, and all other visible faces excepting the pavement of the roadways.

Proposal II: Represents the most economical solution consistent with reasonable demands of appropriateness; it contemplates the completion of the project as indicated on the drawings, omitting the formal treatment of Columbia Island, the Lee Highway Bridge across the boundary channel, and the Memorial Entrance to the Cemetery (but retaing the avenue across Columbia Island as indicated), substituting concrete for granite in all sidewalks, steps, and soffits of all arches excepting a return of suitable width in granite along the faces of the arches, using granite elsewhere as in Proposal I.

Proposal III: Is a mean between the two foregoing proposals and is a satisfactory solution having due regard to economy; it contemplates the completion of the entire project as indicated, substituting concrete for granite as in Proposal II.

(Note by author: the report of the Commission recommended the acceptance by Congress of Proposal III.)

Ten-year program of expenditures and construction

End of--	Expended during year	Work to be completed during year
First year	$500,000	Engineering forces organized; equipment, plant, instruments, and furniture purchased; working drawings prepared, grading and dredging finished, consultants retained, and contracts let for actual construction work on bridge.
Second year	2,500,000	Work on river piers half completed.
Third year	2,500,000	Work on piers completed and construction of arches and superstructure begun.
Fourth year	2,500,000	Arches and superstructure finished; draw span installed; plaza and water gate at Lincoln Memorial, avenue across Columbia Island, twin bridge over boundary channel, parkway to Cemetery half finished.
Fifth year	2,000,000	Ornamentation of main bridge and twin bridge over boundary channel and all work started in fourth year finished, thus providing access across bridge into Cemetery over completed avenue.
Sixth year	1,000,000	In the last five years the formal treatment on Columbia Island will go forward with the filling of the Island by the dredging in Virginia Channel and by dumping from trucks. The memorial entrence to the Cemetery and all landscape work will be finished at the end of this period, including the improvement of B Street and Twenty-third Street.
Seventh year	1,000,000	
Eighth year	1,000,000	
Ninth year	1,000,000	
Tenth year	1,000,000	

The above program is based on Proposal III, involving a total expenditure of $14,750,000.

If Proposal I is adopted, the yearly expenditure after the second year as indicated above will be increased about 67 per cent, the expenditures for the first two years remaining unchanged.

If Proposal II is adopted, the expenditures for the first five years will remain as above, those for the last five years will be reduced to about 50 per cent, making $500,000 per year for the period.

Detailed Estimates.

Memorial Bridge.

Engineering;	
Piers, 100,000 cubic yards concrete, at $28	$2,800,000
Arches and deck, 24,000 cubic yards reinforced concrete, at $30	720,000
Structural steel, 1,800 tons, at $150	270,000
Draw span, complete with lifting mechanism but not ornamented	450,000
Protection for draw span	50,000
Grading for approaches, 100,000 cubic yards earth, at $0.75	75,000
Dredging, 800,000 cubic yards, at $0.12	96,000
Engineering and contingencies	439,000
Total	$4,900,000
Ornamentation and embellishment:	
Ornamentation of draw span	250,000
Granite facing for piers, spandrel walls, and balustrades, 120,000 cubic feet, at $10	1,200,000
Statues along balustrades, 40, at $9,800	392,000
Entrance pylons--	
Groups, 4, at $28,000	112,000
Bas-reliefs, 16, at $9,000	144,000
Eagles, 4, at $3,000	12,000
Ornamental lamp posts, 40, at $460	18,400
Models	4,150
Architecture and contingencies	217,450
Total	$2,350,000
Total for Memorial bridge as recommended herein	$7,250,000

Bridge Plaza and Water Gate.

Engineering:	
Dredging, 150,000 cubic yards, at $0,12	$18,000
Sea wall, 2,000 linear feet, at $75	150,000
Piling, 32,000 linear feet, at $1	32,000
Asphalt paving, 30,000 cubic yards, at $4.50	135,000
Curbing, 8,000 linear feet, at $2.25	18,000
Sidewalks, concrete, 10,000 square yards, at $2,40	24,000
Concrete for steps, back walls, etc., 5,000 cubic yards at $30	150,000
Engineering and contingencies	43,000
Total	$570,000

Ornamentation and embellishment:

Granite facing, copings, walls, etc., 30,000 cubic feet, at $10	$300,000
Sculpture-	
Groups, 2, at $28,000	56,000
Lions, 8, at $3,000	24,000
Eagles, 2, at $3,000	6,000
Ornamental iron lamp standards, 20, at $460	9,200
Models	1,800
Architecture and contingencies	33,000
Total----------	$430,000

Total for Bridge Plaza and Water Gate as recommended herein---------------------------$1,000,000

Formal Treatment of Columbia Island.

Engineering:

Sea wall, 2,000 linear feet, at $75	$150,000
Piling, 30,000 linear feet, at $1	30,000
Asphalt paving, 75,000 square yards, at $4.50	337,500
Curbing, 12,000 linear feet, at $2.25	27,000
Sidewalks-	
Concrete, 20,000 square yards, at $2.40	48,000
Gravel, 10,000 square yards, at $1.25	12,500
Twin bridge over boundary channel, 10,000 cubic yards reinforced concrete, at $30, without ornamentation	300,000
Lee Highway Bridge, 6,500 cubic yards, at $30	195,000
Steps, boat landings, etc., concrete, 8,000 cubic yards, at $30	240,000
Sodding, trees, shrubbery, etc	100,000
Engineering and contingencies	140,000
Total----------	$1,580,000

Ornamentation and embellishment:

Granite facing for twin bridge, 30,000 cubic feet, at $10	300.000
Granite facing for Lee Highway Bridge, 15,000 cubic feet, at $10	150,000
Granite facing, copings, walls, pavilions, etc., 37,000 cubic feet, at $10	370,000
Sculpture-	
Seated figures, 6, at $10,000	60,000
Groups, 2, at $28,000	56,000
Figures at top of columns, 2, at $20,000	40,000
Statues, 8, at $9,800	78,400
Ornamental iron lamp standards, 40, at $460	18,400
Bas-relief at base of column (14 feet by 48 feet 6 inches)	100,000

Ornamentation and embellishment continued

Models	$6,000
Architecture and contingencies	121,200
Total	$1,300,000

Total for treatment of Columbia Island as recommended herein----------------------------$2,880,000

Parkway and Memorial Entrance to Cemetery.

Engineering:

Asphalt paving, 32,000 square yards, at $4.50	$144,000
Sidewalks, 8,000 square yards, a t $2,40	19,200
Curbing, 10,000 linear feet, at $2.25	22,500
Crossing Pennsylvania Railway--	
Reinforced concrete, 3,000 cubic yards, at $30	90,000
Back filling, 25,000 cubic yards, at $0.50	12,500
Concrete back walls, steps, etc., 5,000 cubic yards, at $30	150,000
Sodding, trees, shrubbery, etc.,	10,000
Driveways through Cemetery, three-fourths mile, at $60,000	45,000
Engineering and contingencies	46,800
Total	$540,000

Ornamentation and embellishment:

Granite facing, copings, walls, etc., 60,000 cubic feet, at $10	$600,000
Sculpture	
Statues in niches, 8, at $8,000	64,000
Busts on colums, 34, at $500	17,000
Equestrian in court	30,000
Ornamental iron lamp-posts, 40, at $460	18,400
Ornamental iron fence, 400 linear feet, at $115	46,000
Models	2,600
Architecture and contingencies	72,000
Total	$850,000

Total for parkway and memorial entrance to Cemetery as recommended herein 1,390,000

Straightening and Widening B Street

Property and improvements to be acquired	$1,300,000
Asphalt paving, 96,000 square yards, at $4.50	432,000
Curbing, 28,220 linear feet, at $2.25	63,495
Sidewalks, 50,000 square yards, at $2.40	120,000

Straightening and Widening B Street--Continued

Engineering and Contingencies	$154,000
Total	$2,070,000

Widening of Twenty-third Street

Asphalt paving, 23,000 square yards, at $4.50	$103,500
Resetting curbs, 8,000 linear feet, at $1.50	12,000
Sidewalks, 13,500 square yards, at $2.40	32,400
Engineering and Contingencies	12,100
Total	$160,000

The extract from the report as shown above includes only those items contained in Proposal III, whereas the report submitted to Congress contained, in addition, the extra costs applicable to Proposal I as well as the possible reductions obtainable from the adoption of Proposal II.

IV. Authorization for Construction.

The findings of the Commission and its report were approved by the 68th Congress in Public Act 463, which was signed by the President February 24, 1925. The Act accepted the recommendation of the Commission authorizing the construction of the project in accordance with the suggestion contained in Proposal III, and provided for the appropriation of the sum of $14,750,000 over the period of ten years.

Thus became possible the greatest memorial project ever attempted by any nation, the cost of which was to exceed by far that of any similar structure in the world, involving the expenditure of nearly $15,000,000, and providing as it does a magnificent correlary for the massive $50,000,000 Federal Building program adjacent to the bridge approaches.

CHAPTER TWO.

Description of the Bridge.

I. Organization of Forces.

The actual work of completing the final design of the bridge devolved upon the Designing Engineer, Mr. John L. Nagle, with the invaluable aid of the Executive and Disbursing Officer, Lieut. Col. U. S. Grant, 3rd, Director of the Office of Public Building and Public Parks of the National Capitol. The Assistant Director of that office, Major J. C. Mehaffey, Corps of Engineers, U. S. A., and the Chief of the Engineering Division, was given immediate charge of the design.

A complete staff of Engineers, Draftsmen and Computors was immediately employed, great care being exercised to obtain a high class of personnel, which was made possible by allowing the Commission to engage experts from civil life without being governed by the Civil Service Regulations. Thus no salary limits became necessary, and it was not required of an applicant to have been enrolled on the Civil Service Register.

The staff was immediately engaged in performing the vast amount of detail work which was necessary before any contracts might be let. Presumably there was never before such a bridge designed, nor one for which the minutest details were so carefully worked out, involving such complete investigations and exhausting calculations.

The Commission was most fortunate in having available the services and advice of many experts in the various departments of the Government , many of whom were equipped to render invaluable assistance. The Federal Fine Arts Commission, whose approval of design was necessary, contributed much advice, and the United States Engineers Office cooperated to the fullest extent. In addition various groups of citizens as well as individuals aided to the best of their ability, and so, when the project in its entirety is completed, the whole community, peculiarly symbolical of the Nation as it is, may look upon the structure with just pride in its achievement.

The Commission contracted with Mr. W. J. Douglas of New York City, one of the world's foremost bridge engineers, to act as consultant, and his services have since been available when required. It was the original intention of Congress that the consulting architects and engineers be obtained by competative bids for their services, but permission was granted to secure them by choice and that policy was carried out.

II. Final Design of the Bridge

1. Architectural Type.

The axis of the bridge will pass thru the center of mass of the Lincoln Memorial and the Lee Mansion in the Arlington National Cemetery. It will be composed of nine spans, the one in the center being a bascule draw. The face of the shore abutment on the District of Columbia side is located at a distance of 760 feet from the center of the Lincoln Memorial, from which point all stationings are referred, while the corresponding face of the abutment on Columbia Island has a stationing of 2,618 feet. Between these points are the spans of varying lengths, symmetrical about the center of the draw span, numbers one and nine measuring 182 feet from the face of the abutment to the center line of the piers; numbers two and eight being 205.17 feet between the centers of the piers; numbers three and seven being 211.33 feet between the centers of the piers; spans four and six being 228 feet from the centers of the piers to the centers of the draw span abutments. The draw span will have a length of 225 feet between the centers of the abutments.

The roadway at the center of the draw span will be at an elevation of 43 feet above mean low water. From that point it will slope downward in each direction along the line of an inverted parabolic curve, its elevation becoming 31 feet at the pylons forming the entrances to the bridge. The curve of the arches is in the form of a segment of a circle, which shape was considered to be the most graceful and to allow the most pleasing proportions. The arches, having a large span in comparison to their center height, are low and flat, thereby increasing the beauty of their lines, and at the same time furnishing an attractive structure which will in no way dwarf the stately Lincoln Memorial to which it leads.

The eight spans flanking the bascule draw will be constructed of reinforced concrete faced with white granite. The draw span, which will be of the bascule leaf type, will be constructed of metal so treated that it exactly corresponds to the adjacent masonry spans. All operating machinery, lookout stations, tenders, etc., will be contained within the abutments, so that there may be no jarring note to the beauty of the bridge.

The bridge will have a width of 60 feet between curbs, providing for six lanes of moving traffic. There will be no street car tracks. On either side of the roadway there will be 15 foot sidewalk flanked by a carved stone balustrade, bringing the total width of the bridge to 94 feet from face to face of the granite spandrel walls.

The pier facies will each have carved figures of the American Eagle, and other such decorations, and there will be carved figures above each pier. Two pylons mark the entrance to the bridge at each end, and these will have a height of 40.feet. They will be adorned in different ways by sculptural groups, representing the indivisibility of the Nation, and the joining together again of the North and the South. The bridge will be 2,138 feet long between these pylons.

An underpass will be built thru each shore abutment, thereby providing for traffic to pass at right angles to the structure without interfering with the main bridge traffic. The distance between the faces of these underpass abutments is 2,056.66 feet.

Columbia Island, which forms the terminus at the Virginia end, is taken into the main project since it is desired to formally develop that area so that it may increase the grandeur of the project. The Island was originally a marshy place in the Potomac River which was covered by the high tide. The United States Engineers Office constructed the Island from material dredged out of the channel of the river, such that its present area is approximately 130 acres. The shore lines have been changed so that they lie at right angles to the axis of the bridge. The Island being long and narrow with its major axis parallel to the Virginia shore, from which it is separated by a narrow channel known as the Boundary Channel, provides an ideal site for a formal park developement. A plaza will be constructed here upon which will be placed two stately columns, each having a height of 166 feet, one being symbolical of the North and the other of the South, each surmounted by statues of Victory. These shafts will form a magnificent frame for the Lincoln Memorial as it is viewed from the Virginia shore.

The plaza will also furnish a terminus for roads coming from the North and the South, these being respectively the Lee Highway and the recently authorized Mount Vernon Boulevard, while the main axis of the bridge will be produced thru the plaza by two roads having a "tapis vert" between. This latter, bounded by hedges and rows of elms, rises by a gentle slope to the foot of the steep hill in front of the Lee Mansion, which point forms the ideal spot for the chief memorial entrance to the Arlington National Cemetery.

At the Washington end of the bridge a corresponding plaza will be constructed. The axis of the bridge bears south about 24 degrees from the axis of the Mall; therefore for symmetry a similar roadway will be constructed at a corresponding angle to the north. The latter will lead into the Rock Creek and Potomac Parkway, which when it is completed, will provide an unbroken park drive extending from the tip of Hain's Point in East Potomac Park, thence thru West Potomac Park, over the bridge plaza, and continuing thru the Rock Creek and Potomac Parkway, National Zoological Park, and Rock Creek Park to the Maryland boundary. Thus a motorist can, by either using the bridge plaza or the underpass thru the shore abutment, enjoy a park drive of approximately ten miles in length without any interference from the main city traffic. The underpass was provided to prevent any congestion between the bridge traffic and that on the park drives.

At the entrance to the Cemetery will be constructed an additional plaza, the rear of which will be in the form of a semi-circular retaining wall 30 feet high, which will be decorated with niches, pilasters, and tablets emblematic of the Sacred Shrine to which the traveler approaches. From the terrace surmounting this retaining wall there will be framed, thru the lofty columns on Columbia Island, the Memorial Bridge over the placid Potomac, the Lincoln Memorial 5,808 feet distant, that lofty spire which is the Washington Monument, and in the far distance, 14,556 feet away, the glistening white dome of the Nation's Capitol.

The roadways leading from the Cemetery plaza will connect with the existing roads, there being contemplated few changes in the Cemetery proper, except the construction of a roadway leading more directly to the Amphitheatre and the Tomb of the Unknown Soldier.

An important part of the bridge project is in the widening of North B Street from the Capitol Grounds to the river, thus providing a direct and adequate approach to the bridge, bordered as it will eventually be by the massive and handsome government buildings, and the world famed parks. This grand boulevard will also greatly relieve the present congested traffic on Pennsylvania Avenue, which it nearly parallels.

The final project to be consummated by the Commission will be the widening and developement of 23rd Street from Washington Circle southward to B Street, at a point directly north of the Lincoln Memorial. Thus will be provided an outlet for all bridge traffic directly in the northwest section of the city, as well as an increased outlet during times of increased traffic in West Potomac Park

2. Engineering Features.

All foundations for the bridge and its subsidiary structures are carried down to hard bed-rock, the piers and abutments of the bridge proper being constructed of solid masses of concrete faced with granite from a point 3 feet below mean low water, taken as the datum plane, to the springing line at a height of 10 feet above the same datum. The six piers are of three different sizes, in groups of two to each size, in accordance with their positions about the draw span, tho all of them have parallel faces for a distance of 48 feet on each side of the bridge axis, the differences in length being in the cut-waters. The upstream cut-waters are constructed of circular segments swung from off-center radii, such that the intersections of their arcs present a dull point to the current, a tangent to these segments splaying out to the full width of the pier. The downstream cut-waters are in the form of circular segments having similar tangents splaying to the full width of the pier. Piers 1 and 6 have overall lengths of 128 feet $1\frac{3}{4}$ inches, and widths of 38 feet; piers 2 and 5 are 129 feet $1\frac{3}{4}$ inches long and 39 feet in width; and piers 3 and 4 are 131 feet $1\frac{3}{4}$ inches in length and 41 feet in width. The widths given are at the rock beds, and continue upwards to the granite line at which point there is a set-back, and above which there is one other, such that the pier widths above the water line are in each case 6 feet less than the values given.

The draw span abutments have a length of 136 feet $3\frac{1}{2}$ inches thru the cut-waters, with a width of 60 feet at the rock bed 13 feet of which is in the form of a footing to balance the thrust of the fixed arches, which footings, having a vertical height of 7 feet, then gradually taper back, so that the abutments have a width of 47 feet at a point 15 feet below mean low water, from which they continue with that width to the granite line. The main width of the draw span abutments above the water line is 41 feet.

The shore abutments are of rectangular shape having no cut-waters. They are 96 feet in length and have a width and similar cross section, less the cut-water ends, as the draw span abutments at the bed rock-surface, their footings being on the shore side to balance the thrust of the end arches.

It has been previously stated that the bridge is being constructed of long flat arches having in general a circular shape. The dimensions of these arches was the subject of much discussion and involved computations, since there were many unusual problems met with in the course of their design. Elaborate formulae were derived to fit both the intrados and the extrados, so that accurate coordinates could be computed for any point about a vertical plane thru the crown of the arch, which was taken as the origin of coordinates. The clearance at the crown, measured from the springing line, is 22.725 feet for arches 1 and 9; 24.725 feet for arches 2 and 8; 26.356 feet for arches 3 and 7; and 27.378 feet for arches 4 and 6. Since the springing line is at an elevation of 10 feet above mean low water, and since the maximum tide is only about 3 feet, it is readily seen that for arches 4 and 6, those being nearest the draw span, there will be about 34 feet clearance to the water at high tide. Furthermore the clear elevation of those arches at a point 27 feet from the crown is over 32 feet above high tide, and at 45 feet from the crown there is an elevation of the soffit sufficient to give a clearance of 29 feet to the highest normal water. It is thus seen that there is ample clearance for much of the normal traffic on the river without the necessity of opening the draw. Georgetown, forming the western part of the city of Washington, is the head of the navigable portion of the river, and since the channel has not a great depth few large boats pass the site of the bridge. Perhaps 2% of the comparitively light traffic may require the opening of the draw.

The figures above, which incidentally, give an excellent criterion of the flatness of the arches, are not appliable to the river at flood stage, which has shown as high as 13½ feet above mean low water, altho the normal floods do not usually exceed 5 feet.

The main part of the arch barrel is constructed of reinforced concrete, the sides being faced with huge blocks of granite, in the form of voussoir stones. In general the arch barrels have a thickness of 6 feet at the skewback, at which point they join to the piers or abutments, gradually tapering to a uniform thickness of 2.25 feet at the crown point. Their thickness at a point 5 feet in from the skewback varies from 4.57 to 4.59 feet, from which point the extrados splays to the greater thickness at the skewback. Each arch barrel is provided with five key blocks, one at each skewback, one at each quarter point, (half way up the arch), and one at the crown.

Cross walls are spaced 8 feet in the clear and have a thickness of 2 feet, their reinforcing bars running down into the main arch barrel. Passages are provided thru the cross walls so that it will be possible to walk under the deck from the shore abutments to the draw span abutments. Conduits, pipe passages drainage etc., are provided thru openings let into the cross walls.

The deck, consisting of the roadway and sidewalk slabs of reinforced concrete, is supported by the cross walls. Over the piers and abutments the deck is supported by heavy end beams of concrete resting on longitudinal beams which are in turn supported by columns and diagonals, all being of the same material, and being very heavily reinforced.

The roadway has a general thichness of 11 inches with a crown of 7½ inches, while the sidewalk has a thickness of 6 inches and slopes ¼ inch per foot toward the curb.

The granite voussoir stones form the soffit of the arches at their bottoms, which are cut to the true intrados curves. Their top surfaces form steps, there being eight such steps for the shortest arch and eleven for the long arch next to the draw span, the intermediate arches having a proportional number. The voussoir stones are keyed and anchored to the cross walls and arch ring. The spaces formed between the steps in the tops of the voussoir stones and the pier stones will be filled by courses of granite ashlar stones, there being seven and ten courses, respectively, for the shortest and longest arches as named above. This granite ashlar masonry thus forms the facing of the spandrel walls, to which they are securely anchored. The courses of stones run in straight lines from the steps in the voussoirs, thru the ashlar masonry, and match the courses in the pier stones. Tho these courses are on straight grades they are not exactly horizontal, from a consideration of which some idea of the vast amount of labor involved in the computation of the dimensions of the stones may be obtained. Furthermore, the top course of stones, over the voussoirs, ashlars, and pier stones, have their top surfaces cut to the true parabolic curve of the bridge, thus greatly complicating the work of computing their dimensions and preparing them in the quarry. Above the top ashlar course comes the coping course, which will be surmounted by the balustrade course also of carved masonry. The voussoir stones are cut to have a thickness of 2 feet and 2 inches on their top surfaces. The ashlar stones which rest upon them vary in thickness from ten inches to one foot, the concrete coming in the rear of the ashlar stones bringing the total thickness of the spandrel walls to the dimension of the tops of the voussoir stones.

The bascule draw span was not designed in the office of the Commission, which submitted bids to firms specializing in such designs. These bids were returned by several companies who entered into the contest, and who subsequently offered their designs, Many excellent plans were submitted but the Strauss Engineering Corporation won the award, and a contract was made with them for the amount of $31,000.00. This sum was in payment for the complete design and for inspection service during the erection. The span will be in the form of two jackknives which will swing on trunnions from each of the draw span abutments. The spans will be counterbalanced, and will be actuated by electric motors housed over the abutments and under the decks in such a manner that no machinery will be visible. The spans will be of steel construction faced with rustproof plates and surmounted by aluminum balustrades, all of the exterior surfaces being so treated as to exactly resemble the adjacent masonry spans.

3. Materials of Construction.

One purpose of the bridge being to present an attractively decorated structure from an architectural standpoint, it was decided that in order to obtain the best possible appearance, and the quality of white granite desired, the Government would select and purchase all stone, and that the construction contractors would only be required to properly place the stones on the structure. The Commission,therefore,advertized for bids, and,after carefully testing and studying the various samples submitted, let contracts for the granite as follows:

A. Granite for piers and abutments in the amount of $303,140.84 to the Stone Mountain Granite Corporation of Georgia.

B. Granite for the superstructure in the amount of $1,350,000.00 to the North Carolina Granite Corporation, with quarries at Mt. Airy.

C. Granite for the boundary channel bridge in the total amount of $282,900.00 was let to three separate companies, since the contracting companies had been asked to bid on three separate classes, and it became necessary to accept the lowest bid for satisfactory stone.

The quality and type of the cement and steel used in the structure will not be discussed at this time except to say that the specifications very completely covered the subject, and were in agreement with the most rigid practices.

Storage facilities in ample quantity were available for the various contracting companies, who were allotted all necessary space on the Washington end of the bridge. The majority of the materials have been brot to the site in barges, and since gravel and sand formed by far the greatest amount of material needed, those substances being dredged from the bed of the river in the near vicinity, it was not necessary to store them upon the shore, the material being taken directly from the barges as required. The Government constructed an elaborate granite storage yard upon the Virginia shore with adequate trackage facilities connected to the P. B. & W. R. R., over which all of the stones have been freighted. From the storage yard the stones are loaded upon barges and taken to the bridge as needed. All stones being cut to exact dimensions, and not being interchangeable, it became necessary that they be plainly and accurately marked and numbered, and that the storage system be so designed and managed as to avoid costly mistakes and confusion.

CHAPTER THREE.

I. Piers and Abutments.

It was decided to let contracts for the construction of the bridge in three separate contracts rather than to give the enire work out in one contract. There was to be a contract for the piers and abutments, one for the superstructure, and one for the bascule draw span.

Accordingly, in November of 1925 bids were advertised for the construction of the piers and abutments to be built in accordance with very rigid specifications. Eleven companies submitted bids, the figures running from $1,299,000 to $3,022, 000, a very wide range, with the average amount in the vicinity of $2,000,000. It is interesting to note that the Designing Engineer had estimated that the bids should run only a little less than the average of the bids actually received. However, the H. P. Converse Company of Boston, by far the lowest bidder, was given the contract. The specified time of completion of the work was to be from 550 to 730 days, weight having been given the various bidders in accordance with the dates of completion which they had offered in their bids, $400.00 being allowed for each day. Thus that amount per day was used in canvassing of the various bids, and that sum was to be allowed the contractor for every day less than his specified time limit which he required to complete the work, limited only to the minimum of 550 days. An equal amount per day, however, was to be forfited by the contractor for every day over his specified time limit which he required.

As a matter of fact the Converse Company did not complete their work before the date specified in their contract, but time extensions were allowed, because of additional work later contracted for, and because of delays which were beyond his power to prevent, and so he was not held to lose by his failure to complete the work on time. The company received, for the original contract and the extra work, the total sum of $1,396,875.43.

The work covered by this, the first contract, called for the construction of six piers and four abutments as described above, extending from bed-rock, at an average elevation of a little over 40 feet below mean low water, to the elevation of the springing line at 10 feet above the same datum. The contract also called for the setting of granite facing from an elevation of -3 feet to the top, together with the setting of the skew-back stones. All stones were to be completely anchored to the concrete backing them up, and were to be set to extremely accurate limits.

The estimated quantities furnished in the advertisements had called for 31,867 cubic yards of Class B concrete (1;2:4 mixture); 54,822 cubic yards of Class C concrete (1:3:5 mix);

460,224 pounds of reinforcing steel; and the setting of 58,457 cubic feet of granite. These estimates were essentually accurate, except that in all probability more of the Class C concrete was required because of the uneveness of the rock surface, but the added quantity was negligible. Payment schedules were allowed in accordance with the degree of completion of the work, certain sums being allowed when a specified amount of work had been completed.

The method of exposing the surface of the bed-rock was optional with the contractor, but the entire surface had to be exposed over the whole area of the pier and in the dry. Furthermore, all loose material and rock of less than ½ cubic yard in size were to be removed. It was specified that, should the rock surface be smooth, holes be bored and dowels be inserted for the purpose of holding the mass of the piers in true position.

Obviously, the open caisson method formed the simplest means of accomplishing the desired results, and the contractor used that method, driving 5/8 th inch sheet steel piling to the rock surface, the piling being held in place and completely braced by 12 by 12 inch timbers on the inside. The water and mud were then excavated and spilled into the river, except at the shore abutments, where it was deposited on the shore.

II. Superstructure

The contract for the arches of the bridge, composed of the erection of the entire superstructure within the limits of the entrance pylons, less the bascule draw span, was advertised for bids on October 10, 1927. The advertisement was in the form of a pamphlet which contained 31 pages of general and detailed specifications, and was accompanied by a set of contract drawings containing 35 sheets of very detailed plans, all prepaired in the office of the Commission. The time for the completion of the contract was limited to 730 days, and the work contemplated was the "construction of the arch barrels and superstructures of the eight masonry spans, the superstructures of the six intermediate piers and the two shore abutments, and the foundations, superstructures, and underpass arches of the approaches to the shore abutments." It is thus seen that this contract provided for the completion of the bridge proper, less the draw span, except for the erection and carving of certain of the ornamental features at the bridge entrances, and for the special carving on the faces of the piers. It should be noted that this contract called for the construction of the underpass abutments, which had not been included in the previous contract, since it had been decided to construct an underpass on each shore providing for traffic following the river, subsequent to the awarding of the first contract.

The contract for the construction of the superstructure, which, tho it had the designation of Contract 16 was the second construction contract , was awarded to the Hunkin-Conkey Company of Cleveland, Ohio, the low bidder, the sum named being $1,576,000.00. Extras have since been allowed to the amount of $75,376.00, and it is believed that before the work is completed an additional $10,000.00 will be allowed, bringing the total to $1,661,000.00.

Carefully prepared estimates of quantities showed that 41,690 cubic yards of concrete and 5,919,900 pounds of reinforcing steel would be required, and that 224,300 cubic feet of granite, furnished without cost to the contractor, must be set. It is obviously impossible in a work of this length to completely describe all of the details, either of the proposed work or the manner of its accomplishment, so that it becomes necessary to merely outline herein the more important considerations of this contract.

The specifications stated that the "arch barrels shall be constructed in four longitudinal sections, each approximately one-fourth the width of the barrel, face to face of granite with a longitudinal key-block between adjacent sections; the precise width of each longitudinal section being such that the total weight of each, having regard to the weight of the granite voussoirs of the two outside sections, shall be the same". Because of the four various span lengths, the contractor was required to furnish four steel arch centers, each properly designed to carry the full load, and to be so adjustable that when loaded the centers would be deflected to the true position of the soffits. Provision had been previously provided for their support and anchorage on a shelf below the water line on each pier and abutment. The program of pouring each longitudinal section was provided in the specifications, each section being divided into four blocks, the two adjacent to the piers to be poured first and simultaniously, followed by the two central blocks, similarly poured, all being separated by tranverse key-blocks, at the crown, each skewback, and at the quarter points. The order of pouring of the various longitudinal sections was also specified. In the actual construction, the steel arch centers , composed of braced parallel steel ribs, hinged at the crown, were floated into position in half sections, fastened at the crown, and jacked into place after which they were fastened and tied.

The lagging was to be blocked from the steel centers, and was to be smooth finished and entirely free from any knots or other markings, and to be formed to the true intradosal curves of the arches. Three-ply laminated sheets of a size approximately 4 feet by 8 feet were used, the quality of such a grade that it resembled that used in the manufacture of the best furniture.

In the outside sections the granite voussoirs were to be set first, and in accordance with rigid specifications, the blocks to be moved as often as necessary to place them in their true positions. Great care was taken in the placing of the concrete on the soffits, no gravel being used in the $3\frac{1}{2}$ inches nearest thereto, granite chips in rich cement being required. The soffits were required to be rusticated and tooled to simulate the six-cut brush-hammering of the soffit of the granite voussoirs for a distance of ten feet measured from the face of the bridge.

The method of construction of the spandrel walls, cross walls, sidewalk and roadway slabs, together with the expansion joints and such required features as the drainage system, etc., were fully covered by rigid specifications in accordance with the accepted close standards, and while necessarily most important in the actual bridge are not of sufficient importance to be accorded further space in this work.

The superstructure contractor was required to move all granite from the granite storage yard upon the Virginia shore, all Lewis and dog holes necessary for lifting and handling the stones, as well as all holes for clamps, anchors, bolts, etc., having been previously cut at the quarries. All of the stones were in reach of a 45 ton crane travelling on a standard gauge sidetrack, and the maximum weight of a single stone was specified not to exceed 15 tons. The contractor was required to do no ornamental carving, that service either haveing been previously done or to become the subject of subsequent contracts.

The stones were required to be set to line, level, and position, having joints of uniform thickness, all stones to be thoroughly washed and cleaned and wet before setting, and each to lay in a full flush bed of rich, fresh mortar, to be composed of non-staining waterproof Portland cement, and sand, all to be of an approved color. The proportions specified were to be one part cement and two parts sand, and all face joints were to be raked out to a depth of $1\frac{1}{2}$ inches and pointed with a mortar of equal proportions of cement and sand. Vertical joints were to be rammed full with thin flat blades.

All stones were required to be firmly anchored to all back-up concrete ~~concrete~~, which was to be poured after the setting of each two courses of stone. (This was later amended to require the backing-up after each course of stone was in position, and the leaving of one full day between each operation.)

The joints of the coping and balustrade courses, and ornamental courses above the sidewalk line were to be raked out and filled with a plastic material, composed of whiting mixed with drying and non-drying oils having the property of oxidizing and hardening at the exposed surface, but of remaining plastic beneath the surface.

The stones had been previously cut to very accurate limits, and the contractor was therefore required to set the stone to a tolerance of 3 thousandths of a foot. After the setting of the voussoir stones the courses of the pier stones were set so as to agree with any slight discrepancies in the former. After both the voussoir stones and the pier stones had been set, very accurate levels were run to determine the differences from the contract elevations. Great care had been previously taken to prevent any of the stones falling below their true elevations, since it was obviously impossible to enlarge a stone tho it could be trimmed down so that its top came at the true level. The results of the levelling over the stones determined the amount to be trimmed, if any, before the setting of the ashlar stones. However, the work had been so carefully done, and the stones had been reset if found incorrect in their original positions, that the amount of trimming was surprisingly small.

III. Draw Span.

As previously stated, the Strauss Engineering Corporation won the award of the design of the draw span. They prepared elaborate plans and specifications, which may be more fully appreciated when it is said that in the advertisement for bids, which was dated June 15, 1928, there were 46 pages of general and detailed specifications, and in addition, a bound set of 55 pages of contract drawings. The contract, which was given the number 22, called for completion of the work before the expiration of 560 days after the awarding of the contract. The Phoenix Bridge Company of Chicago was the low bidder, and received the award for the sum of $912,611.00. At the time that this is written the company named has not begun the work of erection, tho they have much of the needed material at the site, and will shortly begin to set it in place.

There can be contained herein only a breif summary of the contemplated work, since of itself, the draw span if fully described, and analyzed, would require a thesis of as great a length as perhaps all of the rest of the main bridge.

The span will consist of two bascule leaves, operated about trunnions, and balanced by counterweights. The trunnions will be 216 feet center to center, and the leaves when opened will allow 140 feet in the clear. Each leaf comprises two main bascule trusses, which will be 66 feet, center to center, connected by floor beam trusses carrying the floor stringers. There will also be fascia trusses, each 11 feet 9½ inches outside of the bascule trusses, the measurement given being center to center.

The fascia will be composed of formed sheets of 3/16 inch rustproof plates fastened to structural steel girts by spot welding, there being on each side of each leaf, 34 panels equally spaced, and in the form of the voussoir stones of the masonry arches. Surmounting these will be formed plates of the same material, above which will be placed Torus moulding and the balustrade with caps, both of the latter being of aluminum, each balustrade being cast in one piece. All discs, buttons, key-blocks, base moulding, cap and hand rail will also made of cast aluminum, all of which will have a thickness of 3/8 inch.

There will be two navigation lamps both on the upstream and downstream sides, one being on each side of the ornamental casting forming the centerline of the span.

The contract calls for the construction of a reinforced concrete road slab, flanked on either side by a reinforced sidewalk slab, which shall match those features on the adjacent masonry spans. The roadway will later receive an asphalt surfacing. Granite curbs are to be set, as is also all granite work, on the fascae of the abutments, the abutment cut-water caps, and the abutment tops including the granite deck seats and the operator's and guard's cabins. As has been elsewhere stated, these cabins are housed in the abutments, and actually form a part of the ornamentation of the bridge, the occupants thus having their quarters housed in such a manner that there will be no detraction from the beauty of the bridge.

In part the specifications say: "that the bascule leaves shall be erected in closed positions, and it is intended that the east half shall be completely erected and opened before erection of the forward arm of the west half extends beyond the panel point No. 9." The panel point named is comparitively near the abutment, and so it is seen that provisions have been made for keeping the chanhel open for navigation while erection is going on, the actual opening being, however, only about 80 feet.

A partial extract of the estimated quantities entering into the construction of the bascule draw span show:

Structural steel	
Carbon steel ----------------------	2,560,000 lbs.
Silicon " ----------------------	1,256,000 "
Rust-resistant steel Fascia plates ----	59,000 "
Cast aluminum balustrades, mouldings, key-blocks, etc. ------------	39,200 "
Roadway deck	
Concrete --------------------------	360 cu. yds.
Reinforcing steel ----------------	104,300 lbs.
Sidewalk deck	
Concrete --------------------------	92 cu. yds.
Reinforcing steel ----------------	3,900 lbs.
Counterweights	
Concrete at 271 lbs per cu. ft.	
East leaf ----------------------	638 cu. yds.
Adjustment blocks --------------	102 " "
Concrete at 262 lbs per cu. ft.	
West leaf ----------------------	638 " "
Reinforcing steel ----------------	87,300 lbs.

The rust-proof ornamental steel fascia plates are to receive one shop coat of red lead paint, as is also all structural steel, while the cast aluminum ornamental work is to be given one shop coat of aluminum primer, both on the inside and outside surfaces.

After erection all of the ornamental work shall receive one coat of Detroit Graphite Company's, No. 426 gray, or equal, followed by a second coat of Detroit Graphite

Companies Degraco, or equivalent, having a color which, in the opinion of the contracting officer, satisfactorily matches the color of the granite work. Since the underside of the leaves will not receive any ornamental covering, not being readily seen except when passing under the draw, or when the latter is in the raised position, the structural steel contained in each leaf will receive a first coat similar to that described above, followed by a second field coat of Detroit Graphite Companies' No. 38, light, or equal.

However, there seems to be a popular beleif that the undersides of the leaves will eventually be covered by aluminum plates, to prevent the possibility of any unsightly feature of the bridge being visible from any viewpoint.

There will be alternating electric current, 60-cycle, 3-phase, 4,000 volts, delivered to the draw span for the operation of a motor-generator set used in providing operating current for all draw span motors. All operating machinery will be furnished, and erected by the contractor. The motor-generator will transform the alternating to direct current for the use of all operating motors, and will be in the form of a 4-unit set, consisting of one 300 horsepower induction motor, two 100-kilowatt 500-volt direct current generators, and one 25-kilowatt exciter.

Provision is made for a possible failure of the electric current, the contract calling for the furnishing and erecting of a gasoline engine generator set, capable of operating all machinery in an emergency. The engine must develop 240-brake horsepower, and will be a 3-unit set, consisting of the engine, one 100-kilowatt direct current generator, and one 25-kilowatt exciter.

IV. Auxiliary Connections.

Whereas the auxiliary connections of the bridge are of extreme importance, in the completion of the project from a memorial as well as an utility standpoint, it remains that those connections come as a subsequent developement, secondary to the main bridge structure. Naturally they are of sufficient importance to receive complete descriptions in a treatise purporting to fully cover the entire project. However, it is believed that the general description already furnished should suffice in such a work as this, being, as it is, a thesis dealing principally with the main structure. Furthermore, the actual work of construction has not yet been begun on any of the auxiliary connections, with the single exception of the boundary channel bridge, tho the dredging incidental to the construction of the water gate at the Washington entrance to the bridge will, in all probability, be started during the coming summer.

The boundary channel bridge, having a span of 100 feet, crossing from Columbia Island to the Virginia shore on a prolongation of the main bridge axis, is now in a preliminary stage of construction. In general, it will be exactly similar in appearance to the main bridge, from which it is separated by 852.67 feet, the distance from the westernmost underpass abutment of the longer bridge, to the centerline of the shorter structure, which centerline is at a distance of 3570 feet from the center of the Lincoln Memorial. A 50 foot underpass is provided thru each abutment. The granite for the boundary channel bridge was purchased at a cost of $282,900.00. The contract for the construction of the foundations and superstructure, including the placing of the granite, was awarded to the N. P. Severn Company, of Chicago, for the sum of $338,000.00. The specifications contained in the advertisement for bids were very similar to those for the larger bridge, there being 36 pages of printed general and detailed specifications.

It is interesting to note that the rock bed is nearer the surface at the site of the boundary channel bridge, and the contractor has successfully used built-up wood piling, consisting of 3 pieces of 3 by 12 inch timbers, 20 feet long, so formed together that the center piece makes a tongue and groove, allowing for a tight joint in the seams. At the present writing the contractor has not yet reached bed-rock, tho he is in a strata of rotten-rock immediately surmounting the hard bed.

CHAPTER FOUR.

Surveying and Inspection Service.

I. Horizontal Control.

After the commission was first appointed, preliminary surveys were prepared, these being later revised and enlarged so that a comparatively accurate topographic map was completed. For the preliminary study that map was sufficient, but the extreme limits of accuracy decided upon made an elaborate system of precise stations necessary, whose distances and directions from the origin of stationings, the center of mass of the Lincoln Memorial, must be known to the smallest possible limits. All of the survey work has been ably done under the direction of Mr. George E. Clark, Chief of the Survey and Drafting Section of the Office of Public Buildings and Public Parks, to whom the author has acted ~~as acted~~ as First Assistant Chief for the last three years.

The problem was further complicated by the fact that the saw-tooth glass roof construction of the Lincoln Memorial prevented the exact center of the building being occupied as an instrument station, altho a signal was erected so as to rest directly over the true center, and an instrument station was established on the upper parapet of the structure, which station was on the exact line thru the center of the Lincoln Memorial, and the center of the Lee Mansion, the accepted axis of the bridge. It was possible to accurately measure the distance to the parapet station, and all subsequent stationings were referred to it.

There were available a rather large number of triangulation stations, which had been established by the United States Coast and Geodetic Survey, but unfortunately these stations had been established at different times, and for varying purposes, and had never been adjusted into a common net. Some few of them had been closely connected to the prime stations of the Survey, but the majority were of third order triangulation.

It was decided to utilize certain of the more precise stations for the establishment of geographic positions, and geodetic azimuths, and to connect these to a separate system of triangulation for the bridge, which system should consist of a large quadrilateral of approxitately rectangular shape, having a measured base on either side of the river. Consequently, two stations were chosen on each shore, all four of which were visible, each from the other. One of those on the Washington shore was placed in the granite sub-base of the Ericsson Memorial, about 875 feet south of the bridge axis. The other stations were marked by U. S. P. B. & P. P. standard brass triangulation markers. Sub-surface markers were set at these points, at a depth of about five feet, and directly above them, in solid concrete structures, not connected directly to the sub-surface markers, were placed similar surface markers.

The two bases were then measured by the most precise chaining methods, thru the use of invar tapes, the tapes being supported upon chaining stakes placed in accordance with the method used in the standardization of the tapes, which service had been supplied by the United States Bureau of Standards. Accurate levels were obtained over the chaining stakes, and the measured results were reduced to the horizontal. Temperatures were obtained from centegrade thermometers attached to each end of the tape. The measures were repeated several times, the results obtained after computing showing the East Base, on the Washington side, to have a length of 2579.2737 feet, and a probable error of 1 in 1,101,000, while the West base was found to have a length of 2405.6064 feet, and a probable error of 1 in 2,327,715. The results of the measurements were most satisfactory, particularly those of the base on the Virginia shore, while the East base showed a precision far above the accepted standards.

The turning of the horizontal angles was next accomplished, and it became necessary to take many sets from each station, in order to have the angles of a sufficiently precise nature to be comparable to the precision of the distance measurements. Several sets of direction angles were turned from the quadrilateral corners, but a number of sets of repetition angles were found to give more satisfactory results. For this purpose an excellent transit, having verniers reading to 10 seconds of arc, was found to give remarkable results. All angles were turned from each station, and in addition, all of the accepted triangulation stations previously mentioned were cut in. The horizontal angles were turned in the following manner:

1. With the telescope direct, and the plates set at zero, both vernier readings being recorded, the angle from the left to the right station was read, and both verniers again recorded.
2. With the plates clamped at the first reading the left station was again sighted by using the lower motion, and the angle to the right station again turned as above. This was continued until the angle had been turned six times, the results being accumulated in the plates, which were then read and recorded. Naturally 1/6th of the plate reading was the mean of the 6 turnings.
3. The telescope was then reversed, and without disturbing the plate setting, the exterior, or horizon angle from the right to the left station was turned six times as described above. This comprised one-half of a set. The method, which is somewhat similar to the method usually employed for repetion angles, except for the order of pointings, and the manner of computation of the results, tended to remove instrument errors as well as furnishing six turnings of each angle.

If the plates had returned to zero after the turning of the exterior angle six times, as they should, the the original value was checked. If however there was a remainder left in the plates, of say, 30", the reading being, 359°-59'-30", one-sixth of the difference was added to the mean of the first six turnings, and a mean of the two results taken.

If however, the plates had gone past zero, and had a reading of say, 00°-00'-30", one-sixth of the difference was subtracted from the mean of the first six turnings, and the mean taken as above.

4. The plates were then again set to zero, and the process was repeated, turning this time, however, the exterior angle first.

When the work had been finished there had been taken 12 turnings of each angle. The summation of the final results should add to 360°-00'-00", but should they not, a proportionate horizon correction was applied to each. The 24 turnings comprised one set, and to be accepted, the horizon closure must have been less than 03", and in addition, not more than 05" was allowed between the direct and reverse turnings of any angle.

Several sets of all of the angles from each station were observed, and the means taken. The results were remarkably close, entirely within the desired precision.

After all required field data had been obtained a "Least Square Adjustment" of the quadrilateral was computed by the Doolittle method. The small residuals obtained were an added criterion, tending to prove the accuracy of the field work.

Stations exterior to the main quadrilateral were placed upon the bridge axis on the Washington shore, and these were accurately connected to the quadrilateral. Thru them excellent means of determining stations were available, since they were closely connected to the origin of stationing. However the bridge axis cutting, as it did, thru the quadrilateral near its middle, and at right angles, approximately, to the base lines, the stations on the ~~on the~~ Virginia shore were useless as measuring stations. It therefore seemed advisable to expand the main figure, thru the inclusion of two more stations at the intersection of the bridge axis with the base lines. These were then established, and while the final results were satisfactory, from the standpoint of line, since they were proven to be directly on the bridge axis, they were found to be slightly off from the original base lines, tho the discrepancy was but a fraction of an inch in each case. All necessary data for these additional stations was then determined, the turning of angles to them from all of the original stations being required, as well as all angles from the new stations to all others in the system. The results of the original quadrilateral were not disturbed however, the figure presenting a double quadrilateral contained within the original figure, thereby greatly complicating the computing of the adjustment, which however, the author hereof accomplished in such a manner as to allow of all necessary control of a rather high order of precision. The least square adjustment, which was made by the Direction Method, required 11 condition equations in order not to disturb the original figure. These condition equations comprised 6 angle equations, 3 length equations, and 2 side equations. The results showed a probable error of an observed direction to be plus or minus 4.90", which, altho it may appear high upon first inspection, was however rather satisfactory, since no local corrections nor weight adjustments had been previously applied to the observed angles. In the description of the method of turning the angles as described above, the angles were computed for horizon closure, and so corrected merely as a criterion of their worth, the actual read values being used for the adjustment, causing the apparant probable error to be larger than tho the local adjustments had been previously applied. All of those corrections therefore appeared in the conditional equations, and furthermore, the fact that the angles required to meet the conditions of the double quadrilateral, were required conditionally to agree with the angles which had been previously adjusted in the original figure. Those circumstances therefore made the V's appear to be relatively higher than they would otherwise have been, and consequently the Probable Error appears relatively high. It is the belief of some eminent authorities, with which the author concurs, that the general practise of applying the so called "Least Square" adjustments to the individual angles, while it undoubtedly offers lower apparent probable errors, actually does not reduce the true probable error, and is actually more apt to increase the error of any observed direction. That, of course, does not apply to weight adjustments, which however, were not applied in this case, since the angles were all turned under similar conditions, and were furthermore, because of position, of equal worth.

From the known triangulation stations, whose geographic positions were known, the data for computing the geodetic positions of the stations of the bridge system was obtained, the resulting positions furnishing geodetic cccordinates used in locating the stations on the maps. Accurate geodetic azimuths were computed between all stations. The azimuth of the bridge axis, from Station East, on the axis of the bridge at the Washington shore, was found to be 65°-05'-55.34", the azimuth being measured from the south.

The most valuable result of the system of triangulation was the establishment of the exact position and stationing, referred to the origin, of that station on the bridge axis on the Virginia shore, which was called West, since it thereby furnished a means of locating work from from that end of the bridge, and within exacting limits, a feat otherwise impossible since there was no way of making a direct measurement across the river.

The corners were also used for the purpose of locating range points, and for the centering of the cofferdams, as well as for the checking of the forms after the cofferdams were unwatered. These stations proved to be of great value until the piers had been built up to such a point that the bridge centerline could be accurately and permantly located upon them.

II. Vertical Control.

The District of Columbia is included in the general adjustment of the precise level net of the United States, as established by the United States Coast and Geodetic Survey, there being several bench marks of that net in the District. The key bench, however, is the so called "Capitol Bench Mark", located on the Capitol building, and it was from this that the levels establishing the elevations of the bench marks used in the construction of the bridge were run. The Office of Public Building and Public Parks ran a closed loop from the Capitol bench, thru a series of benches which they located in the vicinity of the Lincoln Memorial. The levels were run with a standard U. S. C. & G. S. Precise Level, and the loop was subjected to a rigid least square adjustment, the resulting elevations of the bench marks being referred to the datum of the United States Engineers Office, being mean low water in the Potomac River. The elevations obtained were specified for use in all work in connection with the bridge.

All of the preliminary work was referred directly to those bench marks, but as the work progressed, and as the bridge began to take shape, secondary benches were established at the site, thereby avoiding the necessity of running level lines of any great length. After the piers and abutments had been constructed up to an elevation of plus 10 feet, being the limit of Contract No. 1, plugs were set into the cement on the bridge axis, and at the ends of each pier and abutment. These plugs were very carefully located for line, the axis being repeatedly thrown down from the parapet station before the centerline was established, and the off-set plugs were set at equal and exact distances from those in the center, and at right angles to the axis of the bridge. Careful measurements were made, and accurate stationings determined, such that all subsequent work could be located from these plugs. Precise level lines were then run over all plugs, and,after many check runs,the elevations determined. Thus were provided stations which served both as accurate line and position stations, and as precise bench marks as well. Subsequently, as the work progressed the plugs were used to carry elevations and lines to points higher up, and after the decks had been poured over the various arches, and piers and abutments, additional plugs were placed in a manner similar to that already described. Obviously, because of the temperature deflection of the arches, which, measured from the reference temperature of 55 degrees, Fahrenheit, has a varience, plus or minus, of about three-eighths of an inch, the upper bench mark plugs could not be located on the arches. They were,therefore, set into the deck, over the piers and abutments, and tho the granite and concrete forming the latter naturally expands and contracts with the varyong temperatures, the divergences are negligible.

Precise level lines of the same accuracy, and connected into the same loops, were run over the Virginia shore, furnishing bench marks for the work located there.

III. Surveying Methods.

Much of the surveying work has been covered in the description of the control surveys, but there is a vast amount of routine work connected with the construction of such a bridge, and there will, therefore, be included herein a brief outline of the methods employed.

The various contractors have been required to lay out all work, and to be entirely responsible in having each part come at its true position and grade, and they have been required to move any part or piece as often as necessary in order to place it in its proper relation to the rest of the structure.

The government has , however, maintained a survey party at the site, whose purpose it has been to check all work layed out by the contractors, as well as to do any surveying work incidental to any part of the project not yet fully determined. This party, which is furnished by the Office of Public Buildings and Public Parks, has been composed of from four to eight men, or more, varying with the season, and with the amount of work being carried on. The chiefs of party have been graduate Civil Engineers, and have been picked for their ability, those chosen usually having had the rank of Assistant Engineer in the Civil Service, or its equivalent, if employed on the Arlington Memorial Bridge roll, which is not subject to the Civil Service Regulations. The personnel have, for the most part, been student engineers of George Washington University, pursuing their studies during the evening hours, or those who have had some technical education elsewhere, or its equivalent in experience. Thus a rather high type of survey party has been assigned to the checking work, all members of which have been carefully selected for ability, and thoroughly trained and coached in the requirements of their work.

The instruments and equipment furnished have been of an excellent grade. While it is not intended to advertise, nor to condemn, the product of any company, it is only just to say that Berger transits and levels have given excellent results, and a Gurley level has proven most satisfactory. For almost all of the work short sights have been obtainable, and New York level rods, without targets, have given good results, but for the most accurate work of an ordinary nature, targets have been used. Of course, when precise levels have been run, precise rods of the yard type have been used. All level rods have been sent to the Bureau of Standards for comparison with the standards of the United States, before being used in the field, and the necessary corrections applied to the results obtained from their use. All tapes and chains used at the bridge have been of the finest quality procurable, and they have also been previously sent to the Bureau of Standards for calibration, the values being supplied for each ten foot mark, and when used the corrections made proportionate between the two nearest calibrated marks. Furthermore , after they have been in use for some time, and it becomes possible that their lengths have changed, they are again sent to the Bureau. Invar chains of 50 meters and of 100 feet in length have been used for the most accurate work, while steel chains of 300 feet, 200 feet, and 100 feet have been used for all ordinary work. A good quality of box tape, in lengths of 50 feet and 100 feet have been commonly used by the surveyors, these also having been previously calibrated at the Bureau of Standards. The tests at the Bureau have always been for the tape when supported thruout its entire length, and also when swung as a catenary, the corrections then being given from the zero end to each of the 10 foot marks, when swung as a catenary. This greatly facilitated the computing of the results. Temperatures have been recorded on accurate thermometeres, but great difficulty has been had in insuring that the thermometer recorded the actual temperature of the tape. On certain occasions, when measuring from pier to pier, the loop of the tape would hang near the water, while the ends would rest upon the concrete well above the water line, and in consequence, great difficulty was had in getting the true temperature of the tape. Standard tension apparatus has been used for all accurate measures, and chaining levels have been run so as to be comparable to the accuracy of the distance measurements.

As has been previously stated all work is held to very close limits. It might be generally said that all important features, such as the granite and its joints, are so accurately set that no discrepancies are discernible to the naked eye. As an illustration of this , it is only necessary to say that the top of the coping course, which,at the time of this writing, is being set on the Washington end of the bridge, will at one point be 3/8 th of an inch above its true elevation on the parabolic curve of the bridge axis, but that this point of extreme divergence is proportionately compensated to the true grade at points nearly 200 feet distant each way. The average discrepancy in the elevation of the balustrade will, in all probability, be less than 1/16 th inch. It must be understood that these are accumulated errors, being only a few thousandths of a foot in perhaps each of the courses beneath the coping course. The stone lines, and the mortar joints are so nearly perfect that it requires very careful study to find the few points where the stones vary even slightly from their true positions. All mortar joints are $\frac{1}{4}$ inch in size, and so carefully are the stones cut and set, that the eye can hardly find a variance from course to course, and then only by carefully following the stone lines, while suspended upon scaffolds over the side of the bridge, in such a position as will not be provided an observer after the completion of the bridge.

The chief of the survey party keeps in very close contact with the work in progress, and the contemplations of the various contractors. Obviously, when any work is laid out the contractor is desirous of completing that particular unit, and it consequently becomes necessary for the government surveyors to promptly complete their work of checking. Adequate bench marks and line points are provided, and these are utilized by the checkers, who go about their work in a very systematic and orderly manner.

A rather large amount of computation work has been required of the survey party assigned to the bridge, by far the greatest part being the computations of the elevations of the joints of the ashlar masonry, and of the coping course above it. On each arch, after the voussoir stones and pier stones were in place, accurate levels were run over their tops, and the discrepancies from the true elevations determined. The cuts were then specified, and it became necessary to compute the elevation of each joint, to the nearest thousandths of a foot, involving a great deal of work because of the inequalities of the stone dimensions, and the sloped grades of their tops. All vertical joints are staggered, the joints of every other course being vertically above the joints of the alternate courses below them. The top ashlar course, and the coping course above it, are on the parabolic curve, and the computation of the corrected elevations of the joints of these courses required a vast amount of work.

Considerable work was done for the purpose of determining the effect of temperature upon the deflection of the arches. Naturally, some accurate data had to be procured before the setting of the voussoir stones of any arch could be properly accomplished, and in order to insure that the various arches, set at different temperatures, would be relatively the same. After the first arch had been set, using the theoretical amounts of deflection, and allowing consequently for the expansion or contraction due to the temperature, accurate levels were run at frequent intervals, the temperatures being recorded at the time of each run. Curves were then plotted, and computations performed, from which was found that the previously computed theoretical values very closely checked the amounts actually observed, both for the arch ring, and after the deck had been poured, and that no appreciable errors would arise from the use of the theoretical equations. An excellent opportunity for very exhaustive tests on the subject of the temperature deflection of arches was presented, that subject never previously having been fully or completely determined, and there being no accurate or reliable data available, based on actual observations in the field. The United States Bureau of Standards was therefore engaged in the making of those tests, and to that end there was installed much equipment, and many valuable and extremely accurate instruments and recording devices. The work is not yet completed, and no data has been published, but will be made the subject of a complete report and discussion at some subsequent date. The author hereof had hoped to include in this work a complete discussion of the method employed, together with a discussion of the results obtained, but because of the above circumstances is forced to omit that work.

IV. Inspection Service.

In addition to the survey party assigned to the bridge, the government has a corps of inspectors on the site, whose purpose it is to carefully observe all work. These are headed by a Resident Engineer, Mr. H. N. Crichton, who has as his assistants, competent engineers, and in addition, experienced granite, concrete, and steel inspectors, each of whom is charged with observing all construction in his respective line, which goes into the make-up of the structure. The quality of the various component parts of all concrete, and of the varying types of all mortars used, is very closely watched. Slump tests are made from samples of each pour, and cylinders are made from each batch of strength concrete, which are subjected to compressive tests, the forms for all important work remaining in place until the tests show the desired strength. The compression tests are made at the Bureau of Standards.

The government secured the services of a granite expert, before the awarding of any contracts for the purchase of stone, and his advice was utilized in the making of selections from the various samples submitted. In addition, there has been maintained a complete staff of granite inspectors and checkers, at the quarries, whose duty it has been to carefully watch all stones, for both quality, and the cutting to exact dimensions.

CHAPTER FIVE.

Engineering Features of Construction.

There have been included in the text above, a great many of the multifarious problems of interest from an engineering standpoint, which have been observed during the course of construction. They were included with those portions of the description to which they applied, since it was thot that they would thus more nearly clarify, in the mind of the reader, a conception of the immensity of the work. Mention should be made, however, of some of the more unusual features observed during the course of construction, up to the present time.

As this is written, the Washington end of the bridge is rapidly nearing completion, from the standpoint of the superstructure contract, there remaining but a single course of ashlar stones to be laid at the ends of the majority of the arches. The coping course, part of which is in place, will follow, after which will come the balustrade and rail courses. The cut-water cap stones will not be placed until all danger of damage to them, from falling objects, is removed, thru the completion of the work above. The Virginia end of the bridge will require the rest of this year for completion. The arch rings and all voussoir stones are in place, while the cross walls on one arch have been poured, the deck on that arch now in the process of being poured. The contractor has, naturally, benefited from his experience in constructing the Washington end, and the work will go forward more smoothly on the other half.

The contractor for the draw span construction, who will shortly begin his work, will require from 8 to 10 months to complete the erection. The work on the boundary channel bridge will, in all probability, be completed during this year. When the word completion is used, it should be understood to refer to the finishing of the present contracts, and the making of a structurally complete bridge. There will remain, however, the special ornamentation, carving, and completion of the entrance pylons before the main structure is complete. The work, closely connected to the bridge, which is not yet begun, includes the construction of the water gate, plazas, entrance pylons, etc., not to mention the construction of the roadways. Within a year the bridge would be usable, if the roadways across Columbia Island, and on the Virginia shore were completed, but those features will retard the actual utilization of the structure, until, perhaps, the autumn of 1930.

There will be required five more years for the completion of the entire project, during which time the formal treatment of Columbia Island, memorial entrance to the Cemetery, improvement of B Street, and Twenty-third Street, and all landscape work will be finished.

It may be seen, however, that the main part of the program, the bridge proper, will be practically completed during this year, or early in the following year, at which time there will have passed, four years, since the first work of construction began.

The excavation for Abutment 1, which was the first work attempted, gave more trouble than all of the rest of work in the first contract. The shore, at its rear, was "made ground", being composed of a fill of earth, brick, cinders, broken concrete, etc. When the caisson was excavated, the spilled earth was piled on the shore side, and because of its great weight, on the filled ground, the bank pushed out carrying the caisson with it. Whereas, there had been an 18 inch clearance allowed, from the neat cement line to the sheet steel piling, the latter, after being moved out, was found to be nearly 2 feet inside the concrete line at one point. The contractor was not forced to construct a new caisson, but was required to place an equal amount of concrete to that lost at the moved point, at some other section of the abutment, so as to maintain the same net volume. The concrete was poured against the piling on the shore side, no forms being laid, and the steel was not removed. The rock surface at the southeast end of this abutment was found to be nearly 60 feet below the water line, and the piling being too short, required splicing, which gave some difficulty in keeping the water out. Floods overtopped the piling three times, causing some delay and expense. Grains of wheat were forced into the joints in the sheet steel piling, which, when they expanded, rendered the caisson nearly water tight. Some difficulty was had with Pier 5, the piling not having been driven to rock, resulting in mud washing in. This was stopped by placing weak concrete, which was later cut out, and replaced with the proper mixture, to the correct form lines.

The rock surface was found to slope gradually from the Virginia end, downward toward the Washington end, which was as had been indicated by the core borings. The surface of the rock was everywhere most satisfactory, being sufficiently rough to insuse the proper holding of the piers and abutments, without the use of dowels.

The first contractor had some difficulty in the placing of back-up concrete, behind the face stones of one of the piers, near its top. He had attempted to make one fill behind two courses of stone, which was equal to about 10 feet in height, the concrete, when placed,moving the stones out. It was then necessary to cut out a large amount of concrete, remove the stones, and reset them.

The remarkable accuracy of the computations of the deflections of the steel arch centers, after placing of the full load upon them, has been discussed. They were so constructed, however, that little was left to chance, and provisions had been made on the sides of the piers for their support. Not so, however, with the centers for the underpass abutments. These centers were constructed of timber bents, with the lagging wedged into place. The bents rested upon the ground, and it was difficult to determine the proper position of the bed, such that, when loaded, it would be deflected to the true position. When the centers were removed, it was found that both the upstream and downstream voussoirs were nearly ½ inch too high at the Washington end, while the Virginia underpass was more nearly to true grade. The high stones were then trimmed, so that their tops came at the true elevation.

Weather conditions have been generally favorable for all contractors. Floods in the river have caused some delay, tho there have been no unusually high waters. Ice has formed no serious drawback, the river not having frozen over to such an extent that the tug boats could not readily break the thin ice crust which had formed. High winds have caused more damage, particularly to the superstructure contractor, who has lost forms on several occasions, and whose concrete plant was once blown over, and destroyed, during a wind storm.

The setting of granite has not been allowed during the winter months, between the dates of November 15 th, and March 15 th, because of the inability of preventing the freezing of the mortar. The pouring of concrete has been allowed thruout the winter, however, tho the contractor was required to thoroughly heat all materials, and protect all concrete, when in place, from the possibility of freezing.

The quality of the work having been of a high degree, the contractors have, of necessity, been forced to employ many skilled artisans, to whom they have paid a relatively high wage. There have been no labor troubles, and at no time have the contractors had any difficulty in procuring help, either skilled or unskilled.

There have been a surprisingly low number of serious accidents, and these have been, for the most part, due to the carelessness of the workmen. One death was caused, by the failure of the steel boom of a large derrick, engaged in the pulling of sheet steel piling, the boom bending under the strain and, swinging around, striking three men, two of whom were not so seriously injured.

CONCLUSION.

There remains little to be said. It is believed that the thesis as presented above, very fully and accurately covers the subject, as titled, both as to description of the project in its entirety, and of the manner of its accomplishment, to date. It is believed, that its perusal should give the reader a comprehensive idea of the immensity of the work, and the glory, and grandeur, which will be, once it is completed, that greatest memorial structure ever conceived and accomplished by man, The Arlington Memorial Bridge.

BIBLIOGRAPHY.

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2. The sets of complete drawings and specifications for the various contracts, which have been issued to date;

3. The conversations which the author has had with the various officials interested in the structure, all of whom have been named herein;

4. And, finally, to the position of Associate Engineer, and Assistant Chief of the Surveying Section of the Office of Public Buildings and Public Parks, which the author has held, giving him an unusual opportunity to observe the work during its progress.

James B. Rasbach.
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