PLANS, SPECIFICATIONS AND COST
OF PROPOSED WESTERN BRANCH OF
THE SOUTHWEST LAND TUNNEL

BY

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Armour Institute of Technology

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PLANS, SPECIFICATIONS, and COST of PROPOSED WESTERN BRANCH of the SOUTHWEST LAND TUNNEL.

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The Proposed Western Branch of the Southwest Land Tunnel.

This thesis contains the general design of a proposed western branch of the Southwest Land Tunnel.

The City of Chicago obtains its water supply from Lake Michigan by means of intake cribs situated from two to four miles off shore. At the present time the large area south of Thirty ninth street is supplied by only one pumping station, which receives its water from the Sixty eighth street crib. Mr. John Ericson, city engineer of Chicago, in his report of May 1905, says:— "Assuming this station to supply all that district lying south of Thirty ninth street, we have an area of 96.6 square miles depending entirely on this one station; while the northern portion of the city, comprising 94 square miles (less than one-half of the total area), is equipped with eight pumping stations with a present available capacity of 446,000,000 gallons per day.

"Since the completion of the Central Park avenue pumping station, it may be claimed that the southern portion of the city derives some benefit from the 24-inch main in California avenue supplied by this station.

Deducting for this the district lying between Thirty ninth street and Forty seventh street, amounting to 7.6 square miles, we still have an area of 89 square miles entirely dependent on the Sixty eighth street pumping station.
"The population of the City (school census, 1900) was 2,007,695, of which 348,467 is south of Forty seventh street, the balance of the 1,659,228 being north of Forty seventh street. If this latter number be equally distributed over the entire north territory, the population would amount to 16,300 inhabitants per square mile. On this basis a supply of 150 gallons per capita per day would call for 2,445,000 gallons per square mile, an amount the Sixty eighth street pumping station could not deliver to the south side. As a matter of fact, however, the population is not equally distributed; but, for the purpose of intelligently estimating the ultimate needs of the southern portion of the city, it would be well to consider each square mile of territory capable of sustaining 16,300 inhabitants."

It is therefore seen that a more extended system should be constructed to supply the south western portion of the city and relieve the Sixty eighth street pumping station. Accordingly in the year 1906 work was started on this new system which is known as the "Southwest Land and Lake Tunnel". To supply this system a new crib is being built to stand within a few hundred feet of the present Sixty eighth street crib which is two miles from shore.

From the crib a 14-foot tunnel runs to Seventy third street and Bond avenue and continues to Yates avenue where the main tunnel is to be 12 feet in diameter. A branch is to lead off at this point south on Yates avenue,
while the main tunnel continues west in Seventy third street to State street. From this point are two branches, one running south on State street, while the other is to continue west on Seventy third street to Western avenue.

It is this last section from Seventy third street and State street to Western avenue and Seventy fifth street, known as section 4 of the Southwest Land Tunnel, with which this thesis is concerned. No appropriation has yet been made for this branch, but a spur 709 feet long has been run west from Seventy third street and State street, and a gate shaft has been constructed on this spur, so that at any time the proposed branch can be constructed and connected with the main tunnel.

The branch will supply a pumping station at Seventy fifth street and Western avenue. Quoting from Mr. Ericson's report: "In order to provide for a probable territorial expansion on the west, which has not yet been taken into consideration, the pumping station should be located as near as practical to the western boundary without making the tunnel unnecessarily long."

From Seventy fifth street and Western avenue water will be distributed in the territory between Ashland avenue on the east and Forty eighth avenue on the west and between Forty seventh street on the north and Eighty seventh street on the south, though the Stock Yards may also be supplied if it is deemed advantageous.

The capacity of the tunnel will be such that it can supply 100,000,000 gallons of water per 24 hours. Mr.
Ericson in his report says: "Of course, provision need not be made at once for all of the future increase, but the tunnel and the pumping station should certainly be of sufficient capacity and size to ultimately take care of the whole district, with whatever assistance can be obtained from the Sixty eighth street station."

The pumping station will at first be designed for 50,000,000 gallons per 24 hours but with additional room so that it can be enlarged for the ultimate 100,000,000 gallons.

The entire "Southwest Land and Lake Tunnel" is in rock and is concrete lined. A gate shaft will be located at Loomis avenue and Seventy third street and two temporary working shafts will also be located one at Lowe avenue and Seventy third street and the other at Leavitt street and Seventy third street. From the permanent shaft on the pumping station site the tunnel will be run north in Western avenue for a distance of 700 ft., and then concrete lined.

This will be met by the tunnel running from the Leavitt street shaft, which will turn a right angle at Seventy third street and Western avenue. From the Leavitt street, Loomis avenue, and Lowe avenue shafts the tunnel will be run in both directions, east and west, with enough grade to provide for drainage purposes, so that the water will drain to the shafts and be pumped from there to the surface.
The diameter of the shafts through the material overlying the rock is to be six inches greater than the diameter through the rock, so that the lining above the rock will have a shoulder of rock to support it.

A different size of cross section of tunnel has been used than that used by the City of Chicago. We have used what is designated as an eight-foot tunnel, whereas the city uses a nine-foot tunnel. With the ultimate capacity of 100,000,000 gallons per 24 hours, the velocity of flow for the size adopted in our design will be only about three feet per second.

The horse-shoe shape has been used because it is easier to blast than the circular section, because the bench can be taken out better in the horse-shoe shape. This shape is also better than the circular, because for the same height of tunnel there is more area in the former shape and even if there were pressure from the rock (which there is not) the sides d a and b g (see figure on page 6) could be made vertical. Quoting from Cain's "theory of Steel-Concrete Arches" page 119, for tunnels through earth, "When a tunnel is constructed through firm earth, the active horizontal earth pressures are small and even nil in some cases, so that the portion from d to a and b to g (see figure on page 6), may be made vertical".---- "The inverted arch at the bottom a c b is intended to prevent the forcing in of the sides."
CALCULATIONS.

Dimensions of tunnel section given on plate 3.

Area above springing line = \( \frac{1}{2} \times \pi \times (8.25)^2 \) = 26.728 square feet.

Perimeter of invert, \( p = \frac{1}{2} \pi d + d \arcsin \left( \frac{2d' - d}{d} \right) \) where \( d \) = diameter and \( d' \) = mid ordinate, \( p \) = perimeter.

Perimeter of invert = \( \pi x 16 - \left( \frac{1}{2} \pi x 16 + 16 \arcsin \frac{0.8125 - 1.1}{0.8125} \right) \).

\( p = 50.266 - \left[ 25.133 + 16 \times \frac{63.95}{57.3} \right] \)
\( p = 50.266 - 42.989 = 7.277 \) feet.

Perimeter of two sides, \( p = \pi 16 - \left[ \frac{1}{2} \pi x 16 + 16 \arcsin \frac{0.8125 - 1.1}{0.8125} \right] \).

\( p = 50.266 - \left[ 25.133 + 16 \times \frac{57.60}{57.3} \right] \)
\( p = 50.266 - 44.013 = 6.253 \) feet.

Area of segment of a circle \( a = \frac{1}{4} d p + (d' - \frac{1}{2} d) \sqrt{d'(d - d')} \)

Area invert segment \( a b c = \frac{1}{4} x 16 x 7.277 + (0.8125 - \frac{16}{2}) \sqrt{0.8125 (16 - 0.8125)} \)
\( a b c = 29.108 - 7.1875 \sqrt{12.34} \)
\( a b c = 3.858 \) square feet.
Area two side segments \(a + b + f + g\) f = \(1/4 \times 16 \times 6.253 + (0.6041 - \frac{16}{2}) \sqrt{0.6041 (16 - 0.6041)}\)
\[a = 25.012 - 7.3959 \div 9.299\]
\[a = 2.452 \text{ square feet.}\]

Area rectangle \(a + b\) \(f + e = 3.0625 \times 7.0417 = 21.565 \text{ square feet.}\)

Total cross section of tunnel, \(A\)
\[A = 26728 + 3.858 + 2.452 + 21.565 = 54.603 \text{ square feet.}\]

Total perimeter = \(12.959 + 7.277 + 6.253 = 26.489 \text{ feet.}\)

Hydraulic radius \(r = \frac{A}{p} = \frac{54.603}{26.489} = 2.06 \text{ feet.}\)

Ultimate capacity of pumping station 100,000,000 gallons per 24 hours.
\[\frac{100,000,000}{24 \times 60 \times 60} = 1157.4 \text{ gallons per second.}\]
\[\frac{1157.4}{7.481} = 154.7 \text{ cubic feet per second.}\]

\[v = c \sqrt{rs} \text{ Chezy's formula where } v = \text{velocity of water in feet per second, } c \text{ is a coefficient, } r \text{ = the hydraulic radius and } s \text{ is the slope.}\]

\[q = a v = a c \sqrt{r} \frac{h}{l} \text{ where } q = \text{cubic feet of water per second, } a = \text{area of cross section in square feet, } h = s, \text{ where } h \text{ is drop in feet for a distance of } l \text{ feet.}\]

Kutter's formula for the coefficient \(c\) is, in this particular case, a trifle high for what has been found in actual measurements for a conduit similar in size and shape to the one under consideration.

In Merriman's, "Treatise on Hydraulics", page 293, is given the result of tests of the Sudbury conduit by Pteley and Stearns; they found the coefficient \(c\) to equal about 136 for that part of the conduit lined with neat cement.
We shall accept this value of $c$ in our case instead of
the higher value given by Kutter's formula.

$$154.7 = 54.603 \times 136 \sqrt{2.06 \frac{h}{8.5 \times 5280}}$$

$h = 9.4$ feet drop.

When the pumping station is working at its full
capacity of 100,000,000 gallons per 24 hours, the lift will
be less than 10 feet.

Thickness of concrete lining.

Theoretically, no lining will be needed as the
rock stands up itself but it is necessary to obtain a smooth
inside surface to reduce the friction of the water and also
to exclude any water which may slip in through the rock.

Cain, in his "Theory of Steel - Concrete Arches"
page 115, states in regard to tunnel arches: "The
indetermination as to the real acting forces is much more
pronounced for tunnels, so that experience has to be
resorted to. Rankine gives the following formula, founded
on practice, for the minimum thickness, $t$ of tunnel arches,

$$t = \sqrt{C} \frac{r}{r}, \quad r = \frac{a^2}{b}$$

$t$ is in feet, $a =$ rise of arch and $b =$ the half span, both
in feet.

For ground that is firm and safe, $C$ is assumed to
equal .12

$$t = \sqrt{.12} \left(\frac{4.125}{4.125}\right)^2 = .703 \text{ feet}$$

$.703 \text{ feet} = 8.44 \text{ inches}$.

The thickness of the lining in our design is 8
inches with a minimum of 4 inches. It is thus seen that our design would be about strong enough if for an earth tunnel instead of a rock one and will easily hold up any loose rock which may be liable to fall. No reinforcement will be used in any part of the lining.
LEVELS AND BORINGS.

A line of precise levels has been run on Seventy third street from State street (the elevation of a point being known) to Western avenue and Seventy fifth street. A profile drawing is shown on Plate 2.

Eight borings have been made by the City of Chicago along the proposed route of the tunnel to determine the elevation of the rock.

Through the courtesy of Mr. Geo. F. Samuels, Engineer in charge of the Southwest Land Tunnel, data have been obtained on these borings and also valuable assistance on the specifications.

The map of the tunnel route has been obtained from the Map Department of Chicago.
One type of head frame.
PROPOSAL

for

Western Branch of the Southwest Land Tunnel.

City of Chicago.

Special Notice.

Contractors are particularly requested to carefully read the specifications, and they must examine for themselves the location of the proposed work, in order that no misunderstanding may exist in regard to the character of the excavation to be made, or the general nature of the work to be done. The measurements stated herein are approximate only, and bidders are notified that the engineer reserves the right to increase or diminish any of said measurements, and that no allowance will be made in case of their increase for any sum above the price bid, nor, in case of decrease, for any real or supposed damage or loss of profit occasioned by such diminution; but the time specified in the tender for the full completion of the work will be proportionately increased or diminished. Bidders must state a price per lineal foot for the tunnel and for the permanent shafts, which price will include all work specified on bidding sheet, all the labor, as well as the furnishing of all material, and it will also include all "grubbing and clearing" and "bailing and draining" and, in general, all expense incurred by and in consequence of a faithful compliance with each and every one of the requirements of the annexed specification, and for thoroughly and faithfully completing the whole of said work in the manner therein
View in a "9 foot" tunnel
specified.

A bond approved by the Commissioner of Public Works will be required for the faithful performance of the contract in a sum equal to the amount of the contract price.

Any bidder whose proposal shall be accepted by the Commissioner of Public Works shall appear in the office of the Commissioner within ten days from the date of notice of such acceptance and execute the contract and furnish the bond for the performance of the work as provided.

No bid will be accepted from or contract awarded to, any person who is in arrears to the City of Chicago upon debt or contract or who is a defaulter, as surety or otherwise, upon any obligation to said City. The engineer reserves the right to determine the time and place for commencing and prosecuting the work referred to herein; and bidders are informed that under no circumstances will any deviation from the specifications be allowed without the written permission of the engineer, whose interpretation thereof will be final and conclusive.

Companies or firms tendering bids for the following described work must state in the proposals the individual names and places of residence of persons comprising such company or firm, as well as the names of all persons interested with them therein. The Commissioner of Public Works expressly reserves the right to reject any or all bids which he may deem prejudicial to the public interest.
Drilling in a tunnel heading.
SPECIFICATIONS

for

Proposed Western Branch of the Southwest Land Tunnel.

City of Chicago

Proposition.

1. An 8-foot tunnel in rock to be lined with cement concrete.

Shafts.

2. Permanent Shafts: One at south east corner of Western avenue and Seventy fifth street, and one at Loomis and Seventy third streets. Each of these shafts shall be constructed as follows:

3. That part of the shaft through the rock shall be excavated to such a diameter that the thickness of the concrete lining shall be not less than eight (8) inches at any point.

4. That portion of the shaft through the material overlying the rock shall have a concrete lining not less than eight (8) inches in thickness at any point.

5. The clear inside diameter shall be ten (10) feet through the rock and ten feet six inches (10 1/2) through overlying material.

6. Steel Shell: The contractor shall submit a detailed drawing of the steel shell to be used in the permanent shafts, showing the thickness of the steel, method of riveting, and all details, and the same shall meet the approval of the engineer before such work shall
7. These shafts shall be extended below the bottom of the tunnel a distance of five (5) feet, forming a sump, the bottom and sides of such sumps to be lined with concrete, having a uniform thickness of eight (8) inches.

8. The sump of the permanent shaft at Loomis street shall be constructed as shown in the plans, the sump as at first constructed being filled with concrete below and around the tunnel so as to allow the tunnel to pass through the shaft and leave a sump at one side three (3) feet in diameter for pumping purposes.

9. Iron Ladders: There shall be built into the concrete lining of the shafts iron ladders from top to bottom, of the form and dimensions as shown on the plans. The entire expense shall be merged in the total cost of the shaft as determined from the price bid per lineal foot.

10. The iron work of these ladders as well as all other iron work built into any part of the shafts or tunnel, no matter where located, shall be coated with water-proof paint of good quality except such parts thereof as are bedded in the concrete.

11. Doming: Upon the completion of the entire work and after the permanent shafts are no longer required for construction purposes, they shall be domed over as per detail plans submitted, at a point about five (5) feet below the surface of the street, using two (2) twelve (12) inch I beams and two (2) twelve (12) inch channels with concrete
arches to be placed between the beams. The thickness of the arch shall be twelve (12) inches and tie rods of the diameter and number as shown on the plan shall be used in tying the sides of the shafts and the beams together.

12. Manhole covers shall be furnished and placed by the contractor.

13. The whole top of the street dome at the Loomis street shaft shall be covered with six (6) inches of concrete. The shaft between the street level and the dome shall then be filled with earth well tamped and the street paving and sidewalk restored to the condition obtaining when work was begun and in accordance with the City ordinances governing street and sidewalk paving.

14. Temporary Shafts: One on Seventy third street at or near Leavitt street and one on Seventy third street at or near Lowe avenue.

15. These two shafts shall be used as working shafts in connection with the construction of the tunnel and shall be finally domed over and filled in as hereinafter specified, when no longer needed for carrying on work in the tunnel.

16. These shafts shall be ten (10) feet inside diameter.

17. When these shafts are no longer required, the sump shall be filled with concrete mixed as hereinafter specified. The unfinished parts of the tunnel lining shall be completed and neatly connected with the finished parts so as to make the tunnel continuous through these shafts.
The entire space in the shaft above the lining of the tunnel shall be filled for a height of ten (10) feet with concrete well rammed in.

18. The shafts, shall be filled in with the earth or clay excavated from them, above the concrete filling.

19. The filling shall be made in horizontal layers about nine (9) inches thick and shall be thoroughly rammed with continuous wetting.

20. The portion of the timbering or lining of the shafts above a point five (5) feet below the ground surface shall be removed and the filling continued to the surface of the street. The streets and sidewalks shall then be restored to the same condition as they were before work was begun, and shall be approved by the engineer.

21. The cost of all material and labor required to construct these working shafts including filling of same, shall be merged in cost per lineal foot of tunnel, and no extra compensation of any kind will be allowed.

22. It is hereby understood and agreed that in case the engineer in charge shall consider it desirable or necessary as the work progresses, to increase or diminish the depth of all shafts from what is specified and shown in the plans, such increase or decrease shall not exceed eight (8) feet, the contractor to be paid for the actual number of lineal feet of shaft as completed and that the price bid per lineal foot in the case of the permanent shafts. For the two (2) working shafts no extra allowance will be made on account of the above variation in depth.
Tunnel.

23. Alignment: The alignment for the tunnel will be as shown on the plan which shows the location of the tunnel, subject to such modifications as may be directed by the engineer.

24. Grade: For drainage purposes the grade of the tunnel will be established so as to provide for a rise in each drift leading from each shaft, of one (1) foot in one hundred and fifty (150) feet to one (1) foot in seven hundred and fifty (750) feet.

25. Size of Tunnel: The cross section of the finished tunnel shall be as shown in the plans.

26. Lining: The tunnel shall be lined with concrete of a thickness of at least four (4) inches but preferably eight (8) inches, as shown in detail in the plans. The cross section of the tunnel and thickness of lining shall obtain for the entire length of the section to be constructed under this contract.

27. The contractor will not be allowed extra compensation for any additional thickness in the lining when it is required by reason of any extra excavation made by the contractor or by any accident, slipping, sliding, or falls.
Materials.

28. Portland Cement: By the term concrete as used in these specifications shall be understood a Portland Cement concrete.

29. The Portland cement shall be of the best quality of domestic manufacture and shall stand the following tests:

30. Specific Gravity: The specific gravity of the cement shall be not less than 3.10.

31. Fineness: It shall leave a residue of not more than 8½ by weight on the No. 100 sieve, and not more than 25½ on the No. 200 sieve.

32. Time of Setting: It shall develop initial set in not less than thirty minutes, but must develop hard set in not less than one hour, nor more than ten hours.

33. Tensile Strength: Briquettes one inch square in cross section shall develop not less than the following tensile strengths and shall show no retrogression in strength within the periods specified:

Neat Cement.

<table>
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<th>Age</th>
<th>Strength.</th>
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<td>24 hours (in moist air)</td>
<td>175 lbs.</td>
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<tr>
<td>7 days (1 day in moist air, 6 days in water)</td>
<td>500 lbs.</td>
</tr>
<tr>
<td>28 days (1 day in moist air, 27 days in water)</td>
<td>600 lbs.</td>
</tr>
</tbody>
</table>

One part cement, three parts standard sand.

| 7 days (1 day in moist air, 6 days in water) | 170 lbs. |
| 28 days (1 day in moist air, 27 days in water) | 240 lbs. |
34. Soundness: Two pats of neat cement of normal consistency about three inches in diameter, one-half inch thick at the center and tapering to thin edges, and a ball of the same material about 1 1/4 inches in diameter, shall be kept in moist air for a period of 24 hours.

(a) A pat is then kept in air at normal temperature (68° Fahrenheit), and observed at intervals for 28 days.

(b) A pat is kept in water maintained as near 68° Fahrenheit as practicable, and observed at intervals for 28 days.

(c) The ball is placed in water at normal temperature, which is gradually (in about half an hour) raised to boiling and maintained there for three hours.

The pats, to pass the requirements satisfactorily, shall remain firm and hard and show no signs of distortion, blotching, checking, cracking, or disintegration. The ball when removed from the water shall show no signs of checking, cracking, or disintegration.

35. Chemical Requirements: The cement shall not contain more than 1.75% of anhydrous sulphuric acid (SO₃), nor more than 4% of magnesia (MgO).

36. Inspection: All cements shall be inspected, and those rejected shall be immediately removed by the contractor. A period of at least twelve days shall be allowed for the inspection and necessary tests. Cement failing to meet the seven-day requirements may be held awaiting the results of the twenty-eight day tests before rejection.
37. **Storage:** The contractor shall provide a suitable weather-tight building for storage facilities so that at least ten days' supply is always on hand to enable the city to make the necessary tests before the cement is used, and no cement will, under any circumstances, be allowed to be used until such tests have been made. The cement shall be dry and free from lumps.

38. **Packages:** Cement shall be packed in strong cloth or canvas sacks, or in sound barrels lined with paper, which shall be plainly marked with the brand and the name of the manufacturer.

39. **Weight:** A barrel of cement shall contain four bags and shall weigh not less than 376 pounds net. A bag shall contain not less than 94 pounds net of cement. The weights of the separate packages shall be uniform.

40. **Sand:** Sand for the concrete work shall be clean torpedo sand, free from loam or dirt and shall be acceptable to the engineer. All sand with over thirty-five per cent voids will be rejected.

41. **Stone for Concrete:** The stone shall be sound limestone "crusher run", except it shall pass a one and one half inch screen and be caught on a dust screen. It shall be entirely free from dust, sand, dirt, or any foreign substance and shall be acceptable to the engineer.

42. **Concrete:** The concrete shall be made in the following proportions: One (1) part of Portland cement, three (3) parts of torpedo sand, and six (6) parts of broken stone.

43. The cement and sand shall be measured and
thoroughly mixed in its dry state until the whole mass shows an even shade.

44. To the above mixture shall be added sufficient clean water to mix to a plastic mass, fluid enough to subside rapidly when attempted to heap into a cone shape. To this mixture shall be added the crushed stone and the whole mass shall be turned over not less than three (3) times, or until every fragment is thoroughly coated with the mortar.

45. In case the contractor uses machinery for mixing concrete, the machine shall be a batch mixer subject to the approval of the engineer, and if at any time the results of such machine mixing are not satisfactory to the engineer, the machine shall at once be removed and satisfactory machinery provided.

46. The forms and lagging shall be plastered with 1/4 of an inch of mortar made as for the concrete, but with no admixture of stone, and the concrete shall be quickly and carefully deposited in place without throwing, and shall be spread in layers of six (6) inches in thickness, and each layer shall be thoroughly rammed until the water rises to the surface.

47. No concrete shall be laid in water.

48. As soon as the lagging and forms shall have been removed, any and all exposed surfaces of concrete in the shafts or tunnel shall be scraped clean of any inequalities due to lagging or other cause and pointed when necessary.
It shall then be finished with a wash of thin grout of cement and powdered stone applied with trowels.

Special Requirements.

49. Explosives: All blasting shall be done in a careful manner and the amount of explosives used in any one charge shall be so limited as to avoid any damage to public or private property. The contractor will be held responsible for any damage done to public or private property by reason of his operations, and shall make good at his own expense any damage to public or private property.

50. The contractor shall at all times conform to the ordinances of the City of Chicago regulating the storage of explosives and other materials.

51. Whenever any explosive is used, it shall be in an amount and of a strength and applied in such a manner as not to shatter the rock beyond the specified limits of the thickness of lining specified, and so as not to distort the overlying strata.

52. Whenever the tunnel is on a straight line or tangent, the surface shall be perfectly straight and the entire perimeter at all points must be true and the surface perfectly smooth.
53. Where any curve occurs on the alignment of the tunnel, the tangents shall be connected by a circular curve having a radius of sixty (60) feet (degree of curve 95° 30'). The radial section of the tunnel on said curve shall be the same and shall be built in the same manner as on tangents.

54. Borings: Borings have been made on the line of the tunnel for the purpose of determining the approximate elevation of the rock line, which borings are shown on the profile (see plate 2).

55. The city does not know or pretend to know, nor does it undertake to state the nature of the materials through which the tunnel and shafts are to be built. The contractor shall assume all risks arising from or out of the nature and formation of the materials through which the tunnel and shafts are to be built. No claims for extras will be considered that grow out of the presence of other materials than solid rock that are encountered in the construction of the tunnel or shafts.

56. Centering: The centering and lagging both in shafts and tunnel shall be of sufficient rigidity to admit of the concrete lining being thoroughly rammed in place without yielding. The centering must remain in position until the concreting is complete and until, in the opinion of the engineer, the cement has taken a sufficient set.

57. The contractor shall furnish at his own expense all forms and lagging necessary to place the concrete
lining of shafts and tunnel, and the cost of such forms and lagging is to be merged in the price bid per lineal foot of shaft or tunnel. All surfaces of forms coming in contact with concrete shall be dressed smooth. Lagging shall be made from lumber not more than six inches wide and shall be surfaced one side and sized both edges and closely fitted.

58. Cages: A cage shall be used at each shaft for the hoisting of men and materials during the construction of the tunnel, and full precautions shall be taken to insure perfect safety. Safety catches of approved design, efficiency, and strength shall be used in connection with the cages, so as to hold them in case of accident.

59. At no time while excavation is in progress in the various drifts in the rock shall the concrete lining be brought closer to the face of the drift than 500 feet, except upon the written permission of the engineer, and the contractor will be held responsible for the integrity of the lining at all times, and shall make such necessary repairs and renewals to said lining in case the concrete lining is injured while blasting is in progress or in case such repairs or renewals are made necessary by other causes.

60. At meeting points of headings any offsets due to errors in levels or alignment shall be gradually overcome as the engineer may direct.

61. All rubbish, refuse, and muck of every kind and
description shall be removed daily as the work progresses, and under no circumstances will any muck or other materials be allowed to be used in filling any voids or spaces, either in the invert or arch that may be necessary to be filled outside of the specified thickness of the concrete lining.

62. Supports and Timbering: The contractor shall furnish all necessary timbering and will be held responsible for the proper support of the sides and roof of the tunnel and the sides of the shafts, as the work progresses, with timber or other supports. All timber work is to be removed from the shafts and tunnel as the lining advances. If at any time, however, it shall be considered necessary, for the safe and proper execution of the work, to leave any planks or timbers permanently in place, such planks or timbers may be left in place with the consent of the engineer, but such consent must be in writing.

63. In the event that any planks or timbers are allowed by the engineer to be left permanently in place, the contractor shall not be allowed any extra compensation for the value or cost of the material or labor involved in such work; the cost of same shall be merged in the price bid per lineal foot of shaft or tunnel constructed.

64. Ventilation and Lighting: The contractor will be required to keep the shafts and tunnel free from smoke and noxious gases at all times in order to enable the workman, as well as the engineer and his assistants, properly and
safely to perform their duties. The contractor shall use electricity for lighting the tunnel.

65. Change in Elevations or Distances: The shafts shall be constructed to a depth as shown on the plans (subject to such increase or decrease in depth as hereinbefore specified), and the tunnel built for the distance and on the lines and grades shown on the plans. Should the engineer consider it necessary to alter the alignment or grades in the course of the work as it progresses, or should the total length of the tunnel be more or less than that indicated on the plans, such changes or deviations shall not affect the force of these specifications, and the contractors shall have no claims for extras on this account.

66. Disposal of Material: All material excavated, whether from the shafts or the tunnel, shall be the property of the contractor and shall be removed by him as fast as it is brought to the surface, and disposed of at his own cost and expense. Under no condition will the contractor be permitted to deposit any excavated material or any other material on the public highways, or in the river, lake, or harbors, except by the written permission of the engineer.
General Requirements.

67. Engineering and Inspection: The contractor is required to afford the engineer or his assistants or any other help that said engineer may designate, all proper assistance and facilities in order to establish and determine the lines and grades upon which the shafts and tunnel are being constructed, and for the further purpose of enabling said representatives to take cross sections, measurements, etc.; also to allow proper inspection of the methods employed in constructing the work, and of the quality of any material delivered or used in the tunnel.

68. Streets and Public Grounds to be kept Free of Rubbish: The contractor shall keep the streets and all public grounds of the city free from all rubbish and debris at all times during the progress of the work.

69. City Ordinances: In all the operations connected with the work herein specified that are performed within the limits of the City of Chicago, all city ordinances controlling or limiting in any way the actions of those engaged on the works or affecting the materials applied to them must be strictly complied with.

70. Office and Shelter: The contractor shall provide and maintain, where required, at least four hundred and fifty (450) square feet of floor space, divided into two rooms, in a suitably heated building with doors, tables, lockers, locks, telephone, etc., near the work for the use of the engineer and his assistants.
71. Final Acceptance: Any material or work which does not satisfy the requirements of these specifications may be rejected by the engineer at any time before the final acceptance of the work, and the contractor shall make good any deficiencies at his own cost.

72. Responsibility for Damages and Accidents: The contractor will be required to guard the public effectually from liability to accident in consequence of his operations during the whole progress of the work, both by day and by night, and will be held responsible for any damages that the city may have to pay in consequence of neglect on the part of the contractor or his employes to protect the public against such accidents.

73. The contractor will also be held for all damages that the City of Chicago may have to pay to private individuals in consequence of the acts or doings or neglect of said contractor or any of his employes in connection with the work called for by these specifications.

74. Damages to City Property: The contractor will also be held responsible for any damage or injury that may be done to any property, public or private, or to any water pipes or sewers, and in case of any injury or damage caused through or by his operations, such damages to any public or private property must be made good by the contractor at his own cost and expense.

75. Examination of Work: The engineer shall be permitted to remove such portions of the work as he may
at any time think necessary to enable him to determine the character and quality of the materials or work, and the contractor shall restore such work, at his own expense in case it shall have been done improperly, and at the expense of the City of Chicago if found to have been done in a proper manner.

76. Bond Required: The contractor shall execute and deliver a bond in a sum equal to the amount of the contract price, with good and sufficient sureties to be approved by the Commissioner of Public Works, to insure the performance of the work in the time and manner required in the contract, and also to save, indemnify, and keep harmless the City of Chicago against all liabilities, judgments, costs, and expenses which may in any wise accrue against said city in consequence of the granting of the contract or the doing of the work thereunder, or which may in any wise result from the carelessness or neglect of the contractor or his agents, employes, or workmen, and any such judgment, without notice of the pendency of such suit, shall be conclusive against the contractor and his sureties on such bond, not only as to the amount of such damages, but also as to their liability; and conditioned also for the payment of all claims or demands whatsoever which may accrue to each and every person who shall be employed by such contractor or any assignee in or about the performance of the contract.

77. Failure to furnish security: If the bidder to
whom the contract is awarded shall fail to appear at the office of the Department of Public Works, either in person or by his agent, within ten days after being addressed through the post office of the City of Chicago, and enter into contract for constructing said tunnel, or shall not within twenty days, after being so addressed, furnish the required security, he shall forfeit his claim to the work, and the check deposited by him with his bid shall be forfeited to the city.

78. Sub-Letting Work: No contractor will be allowed to sublet the whole or any part of his work, or make an assignment of the moneys to be paid him. Under no circumstances will permission be given to sublet the work, either in whole or in part.

79. Bidders in Arrears or Default: No bid will be accepted from, or contract awarded to, any person, firm, or corporation that is in arrears or in default to the City of Chicago upon any debt or contract, or that is a defaulter, as surety or otherwise, upon any obligation to said city.

80. Right of Engineer to Decide Questions: The right is hereby reserved by the engineer to decide finally all questions arising as to the proper performance of the work; and in case of improper construction or of non-compliance with the contract in any manner, the engineer may suspend such work at any time, or may order the partial or entire reconstruction of said work, if improperly done,
or declare the contract forfeited and have the same relet. He may also adjust the difference of damages or price, if any, which the contractor, failing properly to construct such work, in case of default, should pay the City of Chicago according to the just and reasonable interpretation of said contract. In all such matters the decision of the engineer shall be final between the parties thereto.

81. Forfeiture of Contract: In case of the forfeiture of the contract or in case of its abandonment by the contractor for any cause whatsoever, the engineer may, if he deem best, take possession, on behalf of the City of Chicago, of all tools, machinery, apparatus, appliances, and plant of whatsoever kind used in connection with the work and may make use of the same in the completion of the work. The value of such plant shall be determined by three appraisers, one appointed by the Commissioner of Public Works, a second by the contractor, and the third chosen by the two appraisers already named. In case of the refusal or neglect of the contractor to name an appraiser, such appraiser shall be named by the Judge of the Probate Court of Cook County. The appraisement shall be in writing, and the value fixed by any two of such appraisers shall be final and conclusive between the parties. When the value is so determined, if there be anything due the City of Chicago from the contractor by way of damages or otherwise, the amount so found by the said appraisers shall be applied to discharge such indebt-
edness or shall be held by the city until the amount of damages due the city shall be ascertained. If nothing is due the city from the said contractor and there is no claim for damages against him, the amount so found to be due shall be paid to the contractor.

82. Workmen and Overseers: The contractor further agrees to employ only competent and skilled workmen and overseers to do the work called for by these specifications, and whenever the engineer shall inform the contractor in writing that any person is, in his opinion, incompetent, unfaithful, or disorderly, such person shall be discharged by the contractor from the work and shall not again be employed thereon.

83. The contractor shall so conduct his work as not to impede or interfere unnecessarily with the traffic on public highways, or interfere with the work of other contractors.

84. Orders. To Whom Given: Whenever it is necessary to give directions and the contractor is not present on any part of the work, orders shall be received and obeyed by the foreman or overseer having charge of the particular work in relation to which orders are given.

85. Claims for extra Work: No claims whatsoever will be allowed for extra work or material unless some changes in or additions to the work herein specified or shown on the accepted plans or drawings requiring additional outlay by the contractor, shall first have been ordered by the
City Council of the City of Chicago.

86. Payment for Extra Work: If any extra work or extra material is ordered by the City Council, the price to be paid therefor shall be fixed by the order of the City Council. If the City Council shall fail to fix the price to be paid for any extra work or extra material it orders, then the price to be paid therefor shall be fixed by the engineer. If the contractor is not satisfied with the rate of prices so fixed, he shall within ten days of the date of fixing said prices make a request, in writing, of the engineer for the appointment of three appraisers or arbitrators in the manner provided in paragraph 81, and these three shall finally determine the rate of prices to be paid for such extra work in the same manner as provided in paragraph 81, for determining the value of plant; and the rate of prices fixed by any two of these appraisers shall be final and conclusive between the parties. The additional work, however, shall not be delayed while the rate of prices is being fixed, but shall proceed at once on being ordered by the City Council.

87. The contractor shall deliver to the engineer on or before the tenth day of each month, a written statement of amount of claims, if any, for extra work done and extra materials furnished during the previous month, or for extra expense incurred from any cause whatsoever; otherwise claims for extras during that month shall be forfeited and waived.
88. Fees for Patented Inventions, etc.: All fees for any patented invention, article, or arrangement that may be used upon, or in any manner connected with, any work in any work in these specifications or proposal, shall also be included in the contract price, and the contractor shall defend any suit which may be brought against the City of Chicago for use or infringement of patents.

89. Failure of Contractor to Pay Employees: Whenever the engineer shall have reason to believe that the contractor has failed to pay any workman or employe for work performed on or about the work contracted for, he shall order and direct that no vouchers or estimates be issued and no payments be made upon such contract, until the engineer shall be satisfied that such workmen and employees have been fully paid, and no final payment will be made until the contractor shall have satisfied the engineer that all workmen and employees have been fully paid.

90. Whenever the engineer shall notify the contractor, by notice personally served or by leaving a copy thereof at the contractor's last known place of abode, that no vouchers or estimates will be issued or payments made on the contract until the workmen and employees have been paid, and the contractor shall neglect or refuse, for the space of ten days after such notice shall have been served, to pay such workmen and employees, the city may apply any money due or that may become due under the
contract to the payment of such workmen and employes, without other or further notice to said contractor; but failure of the city to retain and apply any of such moneys, or of the engineer to order or direct that no vouchers or estimates shall issue or payments be made, shall not in any way affect the liabilities of the contractor, or of his sureties, to the city or to any such workmen or employes upon any bond given in connection with such contract.

91. Nature and Intent of Specifications: The nature and intent of these specifications and drawings are to provide for the work herein enumerated to be fully complete in every detail for the purpose designed, and the contractor hereby agrees to furnish everything necessary for such construction, notwithstanding any omissions in the drawings or specifications.

92. The Commissioner of Public Works may require any or all bidders to present evidence of his or their competency and ability to perform this work in a satisfactory manner and within the time specified. If any bidder called upon to produce such evidence fails to do so within five days, the Commissioner of Public Works shall have the right to reject his bid.

93. When the bids are opened, tabulated, and canvassed, the Commissioner of Public Works will award the contract to the lowest responsible bidder.

94. The city reserves the right to reject all bids.
95. The Work as a Whole: The work as a whole includes the furnishing of all tools, labor, material, and necessary appliances to construct the shafts and tunnel; all excavations and removal of material as specified hereinbefore; the cleaning out of and off from the premises and the removal of all refuse; the making of all repairs to the lining, and the completion in a thorough and workmanlike manner of all the work of every kind and description, included in the foregoing specifications and shown on the drawings.

96. Method of Payment: If the rate of progress is satisfactory to the engineer, monthly estimates will be made of the value of the work done and on or about the sixth day of each month, a voucher for ninety per cent of the value of the work done during the previous month will be issued, the remaining ten per cent to be reserved until the completion and final acceptance of the work by the engineer.

97. Proposals: The proposals of the parties bidding for the work shall be made out in accordance with the attached form of proposal.

98. Comparison of Bids: Bids will be compared on the basis of the approximate number of lineal feet of shafts and tunnel to be constructed.

Time of Completion: The work described in these specifications shall be commenced within fifteen days after the signing of the contract and completed not later than
a year and a half after the date of the contract.

100: Irregular Bids: Bids that are not on the attached form, or that are made conditionally, or that are not accompanied by the required check or deposit, will be rejected without consideration.

101. Payment: Payment for the work herein specified will be made from the Water Fund in accordance with the authority of the Common Council of the City of Chicago, as provided for in an ordinance, entitled "An ordinance making appropriations for corporate, school, and public library purposes for the fiscal year from January 1st, 1908, to December 31st, 1908."
PROPOSAL.

To the Commissioner of Public Works.

Sir:—The undersigned, having carefully examined the plans, read the annexed specification, and gone over and personally examined the ground in which it is proposed to construct the tunnel and other work named below, hereby propose to furnish all the materials, and to do all the work required to construct and finish, ready for use, the tunnel and other work specified, in strict accordance with all the requirements of the annexed specification, and in compliance with the foregoing notice, at the price or rates per lineal foot set opposite the items of said tunnel or other work in the column for such prices as set forth below; viz.,—

Permanent Western avenue Shaft

(45 lineal feet in earth) ($_________) per lineal foot
(53 lineal feet in rock) ($_________) per lineal foot

Permanent Loomis avenue Shaft

(46.5 lineal feet in earth) ($_________) per lineal foot
(67 lineal feet in rock) ($_________) per lineal foot

16702 lineal feet of eight (8) foot tunnel in rock, including two (2) working shafts, with necessary concrete and earth filling. ($_________) per lineal foot of tunnel.

Prices shall be written in ink and must be stated
in both writing and figures.

The above prices include doing all other work and furnishing all other materials required by the contract, specifications, and plans.

All the work included in this proposal is guaranteed by the contractor for the period of one year from the date of the acceptance of the work, and any necessary repairs within that time shall be made by him as part of his contract.

Five per cent of the contract price shall be held for the above specified time for the purpose described and set forth in the specification.

This proposal is made under the express condition, and the undersigned expressly agrees, that in case the same is accepted by the City of Chicago and the undersigned should fail or neglect to enter into such contract with said city for the performance of the within specified work as shall be required and approved by the Commissioner of Public Works and within ten days of the acceptance of the proposal, the certified check for an amount equal to ten (10) percent of the price bid deposited herewith shall be thereby forfeited to the City of Chicago.

Name ____________________________________________
Address __________________________________________

Name ____________________________________________
Address __________________________________________

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METHOD OF PROCEDURE.

Work will be begun at the four shafts simultaneously. The Lowe avenue, the Loomis avenue and the Leavitt street shafts are so located that one side of the street can be kept open for traffic. The shaft at the pumping station site is away from any highway.

The depth to the bottom of the five-foot sump of the four shafts varies from 98 to 119 feet below datum, the grade gradually rising as the tunnel runs westward. This is because the rock, as shown by the borings, comes up closer to datum as we go west on Seventy third street, and the ground also rises considerably. The grade has been adjusted so that the center line of the tunnel is about the same depth in rock and also about the same depth below the street surface.

To obtain this condition, it was necessary to run a steeper grade westward from each shaft than was run eastward. From each shaft the heading which will be driven east will be on a grade of one foot rise in 750 feet and the heading which will be run west from each shaft will be on a grade of one foot rise in 150 feet.

Cross sections will be taken as the work progresses, both in the shafts and in the tunnel. The lining of concrete will be not less than four inches thick at any point but preferably will be eight inches in thickness. The cross sections will be measured at
intervals of about five feet as this is about the progress at each complete blast of the heading.

When the concreting commences,(which should not be begun until all the excavation has been made for the tunnel and each section has met with the section driven from the next shaft) the thickness of the lining will be measured at every form length and no matter what thickness may be needed at any point it will be filled solid with concrete.

In case bad rock is found in excavating so that it is necessary to line the tunnel as fast as it is excavated, the concrete lining will be injured in places. The lining can be repaired when the smoothing coat of powdered stone and cement is applied.

In sinking the shafts the lining will be carried down with the excavation simultaneously till rock is reached. After the rest of the shaft is sunk, the lining above the rock will be replaced by the permanent concrete lining. The part of the shaft through rock will not be lined until the tunnel has been lined.
ESTIMATE.

This estimate does not include the cost of engineering. The authorities for computing the cost of materials and labor per foot of finished tunnel are several. Gillette's "Rock Excavation" has been consulted and data have also been obtained from Mr. Frank Berry of the Southwest Land Tunnel.

The cost of the contractor's plant was obtained from the various manufacturers of the equipment that would be used, and the interest and depreciation of the plant was divided by the number of feet of tunnel constructed from each shaft to obtain the cost per lineal foot. The remainder of the costs was furnished by the writers, who have had experience on this class of work.

Estimate of contractor's plant at each shaft.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-60 H.P. boilers</td>
<td></td>
<td>$730</td>
</tr>
<tr>
<td>1- hoisting engine (2500 lbs.)</td>
<td></td>
<td>330</td>
</tr>
<tr>
<td>1- air compressor for 4 drills</td>
<td></td>
<td>1346</td>
</tr>
<tr>
<td>1- air receiver</td>
<td></td>
<td>110</td>
</tr>
<tr>
<td>5-3 1/4 in. rock drills</td>
<td></td>
<td>181.20</td>
</tr>
<tr>
<td>4-4 1/2 in. double screw columns</td>
<td></td>
<td>43.20</td>
</tr>
<tr>
<td>8- complete sets steel to 8 feet</td>
<td></td>
<td>12.54</td>
</tr>
<tr>
<td>4-50 feet lengths 1 inch hose with</td>
<td></td>
<td>28.80</td>
</tr>
<tr>
<td>couplings</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>1-set blacksmith's tools</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>1-generator 6 K.W.</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>1-suction fan</td>
<td></td>
<td>136</td>
</tr>
<tr>
<td>1-steam engine for generator</td>
<td></td>
<td>136</td>
</tr>
</tbody>
</table>
1- steam engine for fan at $101. 101.
1-pump and brass fittings " 105. 105.
1- derrick " 150. 150.
1- concrete batch mixer " 300. 300.
1- blasting machine " 25. 25.
1- hoisting cage " 100. 100.
1-3 foot bucket " 15. 15.
300 feet of 3/4 inch steel cable at per 100 - 10. 30.
6-1 cubic yard dump cars " 60. 360.
6- turnouts and switches " 22.50 135.
Miscellaneous; tools; lumber;
buildings; piping; & etc. Total 1700.

We will assume that each plant operates for the
construction of 5280 feet of tunnel.

The cost of plant per lineal foot of tunnel

\[
\frac{7905.32}{5280} = \$1.50
\]

Cost per foot of track at .35
Cost per foot of cable leading wire at .02

1.87

Interest and depreciation on plant assumed to be
30 per cent per annum. The work will take 1 1/2 years for
completion.

\[
\$1.87 \times .20 \times 1.5 = \$0.56 \text{ per foot of tunnel.}
\]

Interest on money for two years invested in land
at each shaft. $2500 x .12 = $300.

\[
\frac{300}{5280} = \$0.06 \text{ interest per foot of tunnel.}
\]

Interest and depreciation of plant per foot of tunnel .62
Cost per lineal foot of excavating and timbering shaft in earth.

Labor per 1.5 feet of shaft equal to one shift.

<table>
<thead>
<tr>
<th>Role</th>
<th>Rate</th>
<th>per day</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- foreman</td>
<td>$5.00</td>
<td></td>
<td>$5.00</td>
</tr>
<tr>
<td>6- laborers</td>
<td>2.50</td>
<td></td>
<td>15.00</td>
</tr>
<tr>
<td>1- engineer</td>
<td>0.625</td>
<td>per hour</td>
<td>5.00</td>
</tr>
<tr>
<td>1- fireman</td>
<td>2.50</td>
<td></td>
<td>2.50</td>
</tr>
<tr>
<td>1- carpenter</td>
<td>0.50</td>
<td>per hour</td>
<td>4.00</td>
</tr>
<tr>
<td>1- blacksmith</td>
<td>3.50</td>
<td>per day</td>
<td>3.50</td>
</tr>
<tr>
<td>1- machinist</td>
<td>3.50</td>
<td></td>
<td>3.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>38.50</strong></td>
</tr>
</tbody>
</table>

Labor for excavating 1 foot of shaft $25.67

Labor for concreting 1 lineal foot of shaft.

<table>
<thead>
<tr>
<th>Role</th>
<th>Rate</th>
<th>per day</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- foreman</td>
<td>$5.00</td>
<td></td>
<td>$5.00</td>
</tr>
<tr>
<td>1- engineer</td>
<td>0.625</td>
<td>per hour</td>
<td>5.00</td>
</tr>
<tr>
<td>1- fireman</td>
<td>2.50</td>
<td></td>
<td>2.50</td>
</tr>
<tr>
<td>3- topmen</td>
<td>3.00</td>
<td></td>
<td>9.00</td>
</tr>
<tr>
<td>3- bottom men</td>
<td>3.00</td>
<td></td>
<td>9.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>30.50</strong></td>
</tr>
</tbody>
</table>

Labor for concreting 1 lineal foot of shaft $5.08

Materials for lining 1 foot of shaft.

\[\frac{23.3}{27} \text{ cubic yards concrete for 1 lineal foot.}\]

<table>
<thead>
<tr>
<th>Material</th>
<th>Rate</th>
<th>per bbl.</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>.88 bbl. cement</td>
<td>at $1.40</td>
<td>1.23</td>
<td></td>
</tr>
</tbody>
</table>

Torpedo sand, including purchase price and hauling to shaft.

<table>
<thead>
<tr>
<th>Material</th>
<th>Rate</th>
<th>per cubic yard</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>.41 cubic yard sand</td>
<td>at 1.50</td>
<td>.62</td>
<td></td>
</tr>
</tbody>
</table>

The crushed stone costs nothing as the rock excavated is used and the shaft through earth is not lined until the shaft has been sunk through the rock.
Materials used for construction 1 lineal foot of shaft.

Iron ladder in shaft, at $ .50 per foot $ .50

Coal used during excavation.

5 tons per 3 feet of excavation.

1.67 tons per foot at 2.50 per ton 4.17

Coal used during concreting is merged in that used during tunneling as the shaft can be concreted at the same time the tunnel is being excavated.

Lubricating oil used during excavation.

1 gallon per 6 feet of concreting.

1/6 gallon per foot at .50 per gal. .08

37.35

10 per cent of the cost of the work is withheld until the completion of the work.

$37.35 x .10 x .06 x 1.5 = $ .34 interest

37.69

Profit 15 per cent

5.66

43.35

5 per cent of the contract price is held for one year after completion of the work.

$43.35 x .05 x .06 = $ .13

Total cost per lineal foot of shaft through earth 43.48
Cost per lineal foot of excavating shaft in rock.

The interest and depreciation on the plant will not figured for the shafts, but will be added in on the total cost of the tunnel.

**Labor per 1.5 feet of shaft equal to 1 shift.**

<table>
<thead>
<tr>
<th>Labor</th>
<th>Rate</th>
<th>Per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- foreman</td>
<td>at $5.</td>
<td>$5.</td>
</tr>
<tr>
<td>1- engineer</td>
<td>.625 per hour</td>
<td>5.</td>
</tr>
<tr>
<td>1- fireman</td>
<td>2.50 per day</td>
<td>2.50</td>
</tr>
<tr>
<td>1- oiler</td>
<td>2.50 per day</td>
<td>2.50</td>
</tr>
<tr>
<td>1- topman</td>
<td>2.50 per day</td>
<td>2.50</td>
</tr>
<tr>
<td>2- drill runners</td>
<td>4.10 per day</td>
<td>8.20</td>
</tr>
<tr>
<td>2- drillers' helpers</td>
<td>3.50 per day</td>
<td>7.00</td>
</tr>
<tr>
<td>1- blacksmith</td>
<td>3.50 per day</td>
<td>3.50</td>
</tr>
</tbody>
</table>

Total: **36.20**

**Labor per lineal foot of shaft**

Cost of materials per foot for excavating shaft.

25 lbs. dynamite at $13.00 per 100 lbs. **3.25**

25/3 electrical fuses 6 foot wire at $3.54 per 100 **.30**

10 feet connecting wire destroyed **.02**

**Labor for concreting 6 lineal feet of shaft.**

<table>
<thead>
<tr>
<th>Labor</th>
<th>Rate</th>
<th>Per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- foreman</td>
<td>at $5.</td>
<td>$5.</td>
</tr>
<tr>
<td>1- engineer</td>
<td>.625 per hour</td>
<td>5.</td>
</tr>
<tr>
<td>1- fireman</td>
<td>2.50 per day</td>
<td>2.50</td>
</tr>
<tr>
<td>3- topmen</td>
<td>3.00 per day</td>
<td>9.00</td>
</tr>
<tr>
<td>1- bottom men</td>
<td>3. per day</td>
<td>9.00</td>
</tr>
</tbody>
</table>

Total: **30.50**

**Labor per lineal foot of concreting** **5.08**
Iron ladder in shaft, per foot $ .50
Coal used during excavation.
8 tons per 3 feet.
2.67 tons per foot at $2.50 per ton 6.67
Lubricating oil used during excavation and concreting.
1.5 gallons per 3 feet of excavation.
1/2 gallon per foot at $.50 per gallon .25
Coal used during concreting is merged in that used during tunneling.

Materials for lining 1 foot of shaft the same as in earth.

Cement 1.23
Sand .62

42.25

The crushed stone costs nothing.

10 per cent of the cost of the work is withheld until the completion of the work.

$42.25 x .10 x .06 x 1.5 $ .38 interest .38

42.63

Profit 15 per cent 6.39

49.02

5 per cent of the contract price is held for 1 year .15

Total cost per foot of shaft through rock 49.17

- 47 -
Cost per lineal foot of excavating tunnel.

Labor per 10 feet of tunnel for two gangs.

<table>
<thead>
<tr>
<th>Position</th>
<th>Rate</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- foreman</td>
<td>at $5.</td>
<td>per day</td>
<td>$5.</td>
</tr>
<tr>
<td>1- engineer</td>
<td>&quot; .625</td>
<td>per hour</td>
<td>5.</td>
</tr>
<tr>
<td>1- fireman</td>
<td>&quot; 2.50</td>
<td>per day</td>
<td>2.50</td>
</tr>
<tr>
<td>1- oiler</td>
<td>&quot; 2.50</td>
<td>per day</td>
<td>2.50</td>
</tr>
<tr>
<td>3- top men</td>
<td>&quot; 2.50</td>
<td>per day</td>
<td>7.50</td>
</tr>
<tr>
<td>4- drill runners</td>
<td>&quot; 4.10</td>
<td>per day</td>
<td>16.40</td>
</tr>
<tr>
<td>4- drillers' helpers</td>
<td>3.50</td>
<td>per day</td>
<td>14.</td>
</tr>
<tr>
<td>10- muckers</td>
<td>&quot; 3.</td>
<td>per day</td>
<td>30.</td>
</tr>
<tr>
<td>1- blacksmith</td>
<td>&quot; 3.50</td>
<td>per day</td>
<td>3.50</td>
</tr>
<tr>
<td>1- cage man</td>
<td>&quot; 2.50</td>
<td>per day</td>
<td>2.50</td>
</tr>
<tr>
<td>1/2- electrician</td>
<td>&quot; 3.</td>
<td>per day</td>
<td>1.50</td>
</tr>
<tr>
<td>1- pumpman</td>
<td>&quot; 3.</td>
<td>per day</td>
<td>3.</td>
</tr>
<tr>
<td>1- powderman</td>
<td>&quot; 3.</td>
<td>per day</td>
<td>3.</td>
</tr>
<tr>
<td>1- skinner and mule</td>
<td>3.</td>
<td>per day</td>
<td>3.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>99.40</td>
</tr>
</tbody>
</table>

Labor for 1 foot of tunnel

Materials for blasting 1 lineal foot of tunnel.

<table>
<thead>
<tr>
<th>Item</th>
<th>Rate</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 lbs. dynamite</td>
<td>at $13.</td>
<td>per 100 lbs.</td>
<td>2.34</td>
</tr>
<tr>
<td>22/5 electrical fuzes 8 foot wire</td>
<td>at $4.08 per 100</td>
<td></td>
<td>.18</td>
</tr>
<tr>
<td>6 feet of connecting wire destroyed</td>
<td></td>
<td></td>
<td>.01</td>
</tr>
</tbody>
</table>

Labor for concreting 16 lineal feet of tunnel.

<table>
<thead>
<tr>
<th>Position</th>
<th>Rate</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- foreman</td>
<td>at $5.</td>
<td>per day</td>
<td>$5.</td>
</tr>
<tr>
<td>1- carpenter</td>
<td>&quot; .50</td>
<td>per hour</td>
<td>4.</td>
</tr>
<tr>
<td>1- engineer</td>
<td>&quot; .625</td>
<td>per hour</td>
<td>5.</td>
</tr>
<tr>
<td>1- fireman</td>
<td>&quot; 2.50</td>
<td>per day</td>
<td>2.50</td>
</tr>
</tbody>
</table>
3- topmen       at $3.  per day    $9.
3- bottom men   "  3.  per day    9.
1/2 electrician "  3.  per day    1.50
1- skinner and mule "  3.  per day  3.

Labor per lineal foot of concreting  $2.44

Materials for lining 1 lineal foot of tunnel.
We will assume the average thickness of the lining to be 10 inches.

22.6 cubic yards of concrete for 1 lineal foot.
27/.85 bbl. cement       at $1.40  per bbl.  1.19
.39 cubic yard sand at 1.50 per cubic yard      .59

Coal used in boilers during excavation equals
10 tons per 20 feet of excavation.
1/2 ton per foot         at $2.50 per ton  1.25

Lubricating oil used during excavation.
1.5/20 = $.08 per foot               .08

Coal used during concreting.
8 tons per 32 lineal feet.
8/.25 ton  at $2.50 per ton    .63

Two temporary shafts are to be built, the price of these being merged in the price per foot of tunnel.
Assume the shafts to be 105 feet deep.
Two shafts equals 210 feet.
Assume the price of excavation the same through earth and rock. $45 per lineal foot.
The stone can be sold as it comes from the tunnel and is worth about $.40 a yard.

2.86 cubic yards are excavated per lineal foot of tunnel and this expands about 10 per cent when broken up by the blasting.

2.86 x 1.10 = 3.14 cubic yards per lineal foot.

3.14 cubic yards at .40 per cubic yards = $1.25

Ten per cent of the cost of the work is withheld until the completion of the work.

$17.97 x .10 x .06 x 1 = $.11 interest

As conditions are not ideal and large quantities of water may be met with or bad rock be encountered we will figure on a profit of 30 per cent.

Five per cent of the contract price is held for one year after the completion of the work.

$23.50 x .05 x .06 = $.07 interest

Adding in the interest and depreciation of the plant per foot of tunnel

Total cost of tunnel per foot = $24.19
BIBLIOGRAPHY.

The writers have consulted the following authorities:

Burr, "Tunneling under the Hudson River".
Cain, "Theory of Steel-Concrete Arches".
Drinker, "Tunneling, Explosives, and Rock Drills".
Engineering News (Nov. 14, 1907).
Engineering Record.
Gillette, "Rock Excavation".
Ihlseng, "Manual of Mining".
Merriman, "Treatise on Hydraulics".
Prelini, "Tunneling".
Stauffer, "Modern Tunnel Practice".
DRILL HOLES in TUNNEL HEADING

C = CUT - 8'-HOLE. 8 Sticks of dynamite each hole.
H = HELPER - 6'-HOLE. 7 Sticks of dynamite each hole.
R = RIM - 6'-HOLE. 6 Sticks of dynamite each hole.
B = BENCH - 4'-HOLE. 4 Sticks of dynamite each hole.

PLATE 4

SUBMITTED WITH THESIS
Scale: ½ = 1'
CHICAGO, 1905
Ernest [Last Name]
Steel Forms for Tunnel
Forms spaced 5' apart

- Line within which no rock projection will be permitted
- 1-PI-6½ x 2-6'
  Key of arch
- Lagging-2½ x 26'
- 5' bolts

PLATE 5
Drawn for use with thesis
Scale: 1" = 5' on stone.