VOL. XIV. 1900. PART I.

TRANSACTIONS
OF THE
Canadian Society of Civil Engineers

JANUARY TO JUNE, 1900.

. . . CONTENTS . . .

Portrait, HENRY T. BOVEY, PRESIDENT, 1900, Frontispiece.

ILLUSTRATIONS.

PROCEEDINGS.

Montreal:
Printed for the Society by JOHN LOVELL & SON
1900.

Henry T. Bovey

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OF

The Canadian Society of Civil Engineers.

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The Society will not hold itself responsible for any statements or opinions which may be advanced in the following pages.

"*The papers shall be the property of the Society, and no publication of any papers or discussion shall be made except by the Society or with permission of the Council.*"—*By-Law No.* 47.

NOTE:—Owing to delay in the receipt of the Manuscript of Professor Owen's lectures on "Transmission of Electrical Power," the publication of Volume XIII, Part II, is held over.

CONTENTS.

ILLUSTRATIONS.

PROCEEDINGS.

INSTRUCTIONS FOR PREPARING PAPERS, ETC.

In writing papers, or discussions on papers, the use of the first person should be avoided.

They should be legibly written on foolscap paper, on one side only, with a margin on the left side.

Illustrations, when necessary, should be drawn on the dull side of tracing linen to as small a scale as is consistent with distinctness. They should not be more than 10 inches in height, and *in no case* should any one figure exceed this height. Black ink only should be used, and all lines, lettering, etc., must be clear and distinct.

When necessary to illustrate a paper for reading, diagrams must be furnished. These must be bold, distinct and clearly visible in detail for a distance of thirty feet.

Papers which have been read before other Societies, or have been published, cannot be read at meetings of this Society.

All communications must be forwarded to the Secretary of the Society, from whom any further information may be obtained.

The attention of Members is called to By-laws 46 and 47.

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O 1901.

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Thursday, 18th January.

ROBERT A. ROSS, Member of Council, in the Chair.

Prof. R. B. Owens delivered the third of a series of lectures on the "Transmission of Electrical Power."—(Vol. XIII., Part II.)

Thursday, 15th February.

DR. H. T. BOVEY, President, in the Chair.

The following donations to the Library were reported :—

Volumes of "Scientific American," from Mr. Geo. S. Brush, M.Can.Soc.C.E.

"A Text Book of Mineralogy," from Mr. J. Spenard, A.M.Can. Soc.C.E.

Paper No. 148.

CONSTRUCTION OF THE ONTARIO AND BERRI STREET SUBWAYS, BROCK STREET TUNNEL, AND NOTRE DAME STREET VIADUCT.

By STUART HOWARD, M. Can. Soc. C. E.

The writer, in describing in a general way the construction of the several works in this Paper, wishes to state that the structures differ very little from works built for the same purpose, but hopes that the drawings and contemplated and final completed costs may be of some use to his brother Engineers. The writer, who was fortunate enough to have charge of the designing and superintendence of the above mentioned works, wishes to thank Mr. P. W. St. George, M. Can. Soc. C. E., under whose supervision they were carried out, for his courtesy in allowing him to write this paper.

Concrete was used very extensively in all the foundations below ground, the masonry being all rock-faced Ashlar in regular courses, the backing being made up of large stones and concrete, well-bonded to the face stones ; the cement was the best to be had in the market, and was mixed in the proportion of 1 of cement to 2 of coarse sand, for the Ashlar work and backing, and for the bridge seats and coping 1 to 1.

ONTARIO STREET SUBWAY.

This subway was constructed to permit of a roadway being built under the C. P. R. tracks at Hochelaga, which at this point numbered ten in all. The masonry retaining walls extend upon the south side, from the east side of the street in front of the Stock Yards hotel to the west side of Moreau street, and on the north side, from Moreau street to a point about 22 feet west of the west end of the subway proper, the walls being for a considerable distance on solid rock. The descending grade at each end is 1 in 20. The bridge carrying the tracks being 165 feet in length, by 40 feet in width, with a clear headway of 2 feet, it was impossible to give any more height, as the lower portion of the subway could not have been properly drained. The total length of the retaining walls is as follows: upon the south side, 649 feet, and on the north, 378 feet, and are built according to the sections shown on plate 18, and stepped down so as to conform to the natural surface of the upper ground. The clear span between the perpendicular retaining walls is 40 feet; the copings being at the upper ends about 2 feet above the street surface and 16 feet at the subway, and surmounted by an iron fence composed of cast-iron posts placed every 10 feet, with 3 lines of 1 1-2 inch gas pipe, the fence being 3 feet 3 inches in height; this fence is returned across the bridge on the limit of the Railway Right-of-way, the posts being bolted to the trough plates, and to a plate holding in the concrete, in which the ties are bedded. The subway bridge is 156 feet long and 40 feet in width, with a central wall extending the entire length, on which are bolted 14 latticed channel columns, carrying plate girders of a depth of 2 feet, the ends of these girders resting upon the bridge seats of the abutment walls. At right angles to these plate-girders are bolted iron trough plates, the ties being bedded in concrete in these troughs, and brought to the proper railway grade. The concrete for this work was composed of 1 of Portland cement, 1 of clean river sand and 4 parts of broken stone.

The excavation under the tracks was taken out without interrupting the railway traffic, piles having been driven close to the side of the rails in such a position as not to interfere with the masonry work ; they were then cut off and capped, and stringers slipped in under the ties, the whole making a pile trestlework. The retaining wall at the west end was returned up the east side of the street in front of the Stock Yards hotel, a distance of 50 feet, the street being graded to give easy access to Ontario street. The subway from end to end has been paved in scoria blocks, 5 foot sidewalks laid, new drain put in, as also water and gas pipes, and gullies.

The estimated cost was $85,000, and the actual cost as per details:

Earth excavation..	11,970 cub.-yds. at	29½ cents	=	$ 3,531.15
Rock excavation..	52 "	80½ "	=	41.86
Rock faced Ashlar	3,061 "	$8.57½	=	26,248.07
Cut stone Masonry..	200 "	$10.25½	=	2,051.00
Stone behind walls	663 "	$3.00	=	1,989.00
Temporary trestle..			=	3,500.00
Timber in same—price allowed for old..			=	1,215.00
Paving..			=	11,905.91
Fencing			=	1,200.00
Concrete..			=	5,000.00
Iron superstructure and columns..			=	16,400.00
Superintendence and sewers..			=	10,476.00
				$83,557.99

The cost of the subway proper under the tracks, including excavation, masonry, temporary bridge, bridge and floor system, amounted to $38,000.00; the cubic contents measured to the outside of the masonry walls were 169,000 cubic feet, equalling 22½ cents per cubic foot; $243.00 per lineal foot of subway, or $4.50 per square foot of area.

The contractors for the ironwork were the Dominion Bridge Co., and for all the other items Messrs. Laurier, Rheaume & Desormeau.

BROCK STREET TUNNEL.

This tunnel was constructed, to open up a roadway from Craig street to the wharf, and is situated at Beaudry street, about eight-tenths of a mile east of the Post Office, and a third of a mile east of the Berri street subway, and has already proved its great use, the carters being able to take double the load they were formerly able to, the approach from the wharf being so heavy and the descending grade so steep by the ramps to Notre Dame street and down again to Craig street. The total length of the tunnel and approaches is 905 feet, measured from the south side of Craig street to the southerly limit of the Canadian Pacific Railway's cribwork on the wharf; the tunnel itself from portal to portal has a length of 666½ feet with a grade of 1 in 43.

The approach at the Craig street end is 200 ft. long and 40 ft. wide, with a 10 foot sidewalk on the west side, leaving a clear roadway of 30 feet. Upon the east side of this approach is a masonry retaining to Notre Dame, of a width of 35 feet. This roadway has a grade of wall, which sustains an upper roadway leading from Craig street 1 in 14½, the height at the north portal being 21 feet above the tunnel floor. The coping of this wall is stepped to suit the grade of the upper street, with an iron pipe fence similar in construction to that at the Ontario street subway.

The portals of the tunnel are of masonry, and extend a length of 8 feet, the arch stones being toothed so that the courses of brickwork are built into them exactly. The arch is a semi-circle with a radius of 15 feet, and springs from the floor of the tunnel, thereby giving a clear headway at the key stone of 15 feet. The brickwork at the haunches immediately above the masonry springing course is 4 feet 3 inches wide, and is stepped up until at the key it is 1 foot 5 inches in depth.

The intrados of the arch is of fire brick, 9 inches in thickness, the backing being of hard red bricks, the whole being laid in cement mortar, 1 of cement to 2 of sand; this brickwork has been most carefully laid, and thoroughly bonded, and all the courses kept perfectly straight throughout. On the top of the brickwork, and extending nearly to the haunches, is a thickness of 9 inches of concrete, composed of 1 of cement, 2 of sand and 4 of stone, and over this concrete No. 20 galvanized corrugated iron; the stone filling to the underside of the tunnel roof planking being carefully laid in by hand and well consolidated. This stone filling acts as a drain, any water from above descending to the 6 inch open jointed pipe which is laid upon a bed of concrete, and on the same grade as the tunnel.

The north end of the tunnel for a distance of 103 feet was built in open cutting, as the depth over the crown would not admit of tunnelling, and the excavation did not interfere with any traffic. After the brickwork, concrete and iron were completed, the excavated material was filled over, and again brought to the original surface. This work, as also the north east retaining wall, was completed December 15th, 1893.

The south approach consists of a bridge to carry the tracks of the Canadian Pacific Railway; the abutments are 36 feet apart with a mean length of 39 feet, and, in order not to interrupt the traffic of the railway, the tracks had to be carried by a temporary trestlework. As at the Ontario street subway, piles were driven from above and close to the track; they were then cut off below the surface, and timber caps put on; stringers were then slipped under the ties, forming a regular timber trestlework; the excavation was then proceeded with, and cross bracing put in wherever necessary. The piles were driven in such a position as not to interfere with the building of the abutments. This mode of procedure was most satisfactory, the entire work being done very expeditiously. The tracks are carried upon eight plate girders, 2 feet 6 inches deep, put in in pairs and braced sideways by latticed girders; the flooring is composed of 10 inches x 10 inches creosoted timbers laid close together, the joints being thoroughly caulked with oakum; this structure cost $4,900.00. On the outside of the south portal hollow quoins were left in the recesses of the abutments, into which solid lock gates 12 inches thick and 14½ feet in height are fitted, the gates closing against a 12 inch timber, let into the mitre wall, and well bolted; this timber is put in after the close of navigation, a 6 inch plank taking its place during the summer season. This gate was to prevent the entrance of the water during any rise in the river, but the water finds its way from behind the abutments, and up into the tunnel by its pressure, and is of little use except to prevent ice entering the tunnel and injuring the walls. The difference of level between the wharf and Craig street is 21 feet, the highest freshet known being 13½ feet above the floor of the tunnel, at the south end.

The drifting of the tunnel was accomplished without any accident whatever, and the timbers were placed as shown on the section. A heading was first drifted from the south end about 10 x 11 feet, and timbered; the excavation for the tunnel itself was then carefully done, the timbering being put in as soon as each section was excavated, until the whole area required was complete. The upper roof longitudinals as also the roof boarding were left in. When the masonry haunches were completed, the centering for the brickwork proper was put in, and the upright timbers cut out one by one as the work progressed, the roof timbers being supported from the brickwork. After the concrete over the arch was done, the corrugated iron was put in position and the space above filled in with large sized broken stone.

The tunnel was built from both ends, and when the walls met, no difference was found either in alignment or level. The key of the arch is of stone. When the walls met in working from each end, a shaft was sunk from the street above, and the brickwork completed, an inscription stone containing the city archives, coins of the realm, photographs, and plans in a copper box being placed in the side wall. In the tunnel there were used approximately 350,000 fire bricks, 1,300,000 hard red bricks, 1,450 cubic yards of masonry, 1,110 cubic yards of concrete, 50,000 pounds of corrugated iron, 3,600 cubic yards of stone filling, and 15,000 cubic yards of excavation. The north approach has been paved with scoria blocks, the tunnel and south approach with porphyry blocks. The roadway is 25 feet in width with a 5 foot elevated sidewalk on the west side only, protected by an iron pipe railing.

"Engineers' Estimate of Cost."

Excavation for walls and open built tunnel	c ys.	6,750	at 50c. _	$3,375 00
Filling over tunnel (open cut)	"	2,200	" 25c.	550 00
Masonry in retaining walls...............	"	900	" $9.00	8,100 00
do in north and south portals.......	"	390	" $12.00	4,680 00
Cut stone copings, walls and portals.......	"	80	" 14.00	1,120 00
Excavation for Can. Pac. Ry. bridge......	"	1,650	" 1.00	1,650 00
Pulling down and rebuilding old ramp wall................................	"	145	" 5.00	725 00
Stone behind walls......................	"	250	" 2.50	625 00
Temporary C.P.R. bridge......				1,500 00
Open built tunnel	L. ft.	96	x $126.00 =	$12,096 00

Tunnel drifted (per lin. foot).

Excavation.........	c.ys.	27	at $ 1.50 =	$40 50
Key stone...........	"	.055	" 12.00	0 66
Masonry foundation.	"	1.54	" 10.00	15 40
Fire bricks	in.	600	" 40.00	24 00
Red do	"	2,000	" 24.00	48 00
Concrete	cys.	2	" 9.00	18 00
Corrugated iron....	lbs.	85	" 10 00	8 50
Stone behind wall..	cys.	1.7	" 3.00	5 10
Tile pipe, 6".......	1 ft.	2	" 0.35	0 70
Centres and headings	"	1	" 9.00	9 00
Filling over arch...	cys:	4.25	" 1.00	4 25
Extras......				0 89

$176 00 x 557 feet = 98,032 00

$132,453 00

The contractors' final estimate for this work amounted to $131,696 67.

The other items in the Engineers' Approximate Cost, not included in the contract for the tunnel proper, were as follows:—

Railings on Copings and in Tunnel,	**942 lineal ft.**	**at $1.75 =**	**$ 1,648.00**
Iron Bridge to carry C. P. R. tracks..		=	5,000.00
Flood gates at South Portal..		=	400.00
Porphyry Paving in Tunnel.. ..	**1,964 sq. yds.**	**at $4.50 =**	**8,838.00**
Sidewalk in Tunnel..	300 "	" 3.50 =	1,050.00
Curb in Tunnel..	667 lin. feet	at 70c. =	467.00
Curb at North End	200 "	" $1.00 =	200.00
Scoria Block Paving..	1,092 sq. yds.	at 3.50 =	3,822.00
Drains and Macadamizing..		=	4,200.00
Engineering and Contingencies..		=	17,000.00
			$42,625.00

This work was completed for the sum of $42,304.00, the Engineer's estimate for the total work being $175,078.00; whereas the total cost when completed was $174,000.00. This amount really covered many little items which were unforeseen.

The contractors for the tunnel portion of the work were Messrs. Lafontaine & Lemoine, and the iron bridge was put in by the Dominion Bridge Co.

BERRI STREET SUBWAY.

This subway was commenced at the end of May, 1893, and before the winter set in the whole work, with the exception of the paving, was completed. This subway was designed to give an easy approach from Craig to Commissioners' street, Berri Lane, or Barrack street being widened, and a new street opened up between St. Louis and Notre Dame streets. The subway proper extends from Champ de Mars street to the Canadian Pacific Railway freight shed, a total distance of 430 feet. The approach from Champ de Mars street has a descending grade of 1 in 39 to the arch under Notre Dame street a distance of 180 feet, the roadway under the arch and the eastern approach from Commissioners' street being practically level for a distance of 250 feet.

Between Champ de Mars and Notre Dame streets there is an upper roadway upon the south side of the subway, with a width of 20 feet, and upon the same side, extending from Notre Dame to Commissioners' street, a similar upper road of a width of 30 feet. Heavy retaining walls are built to sustain these roadways, the copings being stepped to suit the grades of the streets, and surmounted by an iron pipe fence similar to the other structures already described. The arch was originally designed with a clear span of 45 feet, as permission could not be obtained from the Hospice St. Charles to build the north westerly retaining wall upon their property, but, at a later period after nearly all the arch stones had been cut, and the centres made, permission by the Hospital authorities was granted and the span widened to 52 feet. Any engineer now viewing this arch would naturally say, what an extraordinary structure, an arch at one end with the abutment carried forward to carry an iron viaduct. Why was it not all carried out in iron? When the Berri Street Subway was designed, no plans had been made, nor was the idea broached of any extension of the Canadian Pacific Railway into the present Place Viger Station, but when the work was well under construction, the scheme matured in time to prevent the building of the north westerly retaining wall.

The arch centering was made very strong, the lagging only being carried down to the top of the third course above the springing; many centres are made so weak that the weight of the arch stones causes the haunches to settle, and the crown to spring up. Care was also taken to build the arch evenly from both sides, so as to distribute the weights carefully; all the stones being used were also loaded upon the centering, keeping it in place.

The change in the span of the arch necessitated a great deal of extra work; new centres had to be made, and about 8 feet in height of the northerly abutment torn down, and moved forward 7 feet. By referring to the drawing of the arch, you will see that it is formed by radii from seven centers, which were arranged so that the curve might conform as nearly as possible to a true ellipse. In order to utilize as many as possible of the old arch stones, only a few had to be thrown out, the same radii being kept, and a new central one of a larger radius or 46 feet 6 inches inserted, raising the key stone, only 6 inches. The arch stones were cut very truly to the radii, and the whole structure built most carefully, and when the centres were removed no settlement whatever could be measured. The section of the arch shows clearly the top crown line, which was formed of masonry whenever depth would allow, and concrete in the shallow portions, the whole being covered with a 3 inch thickness of asphalt, allowing any water to drop into the back stone filling, and out through the weepholes. The retaining walls were built according to the section shown, with a face batter of 1 in 12, the coping being laid on a perfectly straight line, and with an iron pipe fence on top. The old retaining wall on Barrack street which the writer had the pleasure of building some years formerly was demolished, the stone as far as possible being used in the new work, and the south end of the Dalhousie Square depot was underpinned, and reconstructed to correspond with the other faces of the building. An iron staircase was built, opposite St. Paul street, for pedestrians to descend to the lower level or subway. The writer has given sections of two elliptical arches, one with a rise of 1-3rd of the span, the other rise being 1-4th of the span, together with a table showing, by letters, the spans, radii and dimensions, which he hopes will be of some practical use.

Engineers' Estimate for Subway with 45 Foot span Arch.

Excavation..	cub. yds.	25,000	at	45c.	=	$11,250.00
Filling over arch..	"	900	"	30c.	=	270.00
Masonry in old wall torn down and rebuilt..	"	800	"	$6.00	=	4,800.00
Masonry in arch abutments.. ..	"	650	"	9.00	=	5,950.00
Masonry in arch stones and copings		267	"	14.00	=	3,738.00
Masonry in retaining walls...	cub. yds.	3,410	"	9.00	=	30,690.00
Asphalt on arch..	sq. yds.	400	"	2.50	=	1,000.00
Stone behind walls..	cub. yds.	650	"	2.50	=	1,625.00
Cutting down wall at depot...	"	360	"	4.00	=	1,440.00
Paving in scoria..	sq. yds.	3,637	"	3.50	=	12,730.00
Engineering and contingencies..						10,500.00
						$83,993.00

Deduct north-west wall, 922 cubic yards at $9.00.. ..	8,298.00
	$75,695.00
Add additional cost of altering to 52′ span..	2,000.00
	$77,695.00

The 45 foot span according to these figures would amount to $280 per foot in depth of arch, and for a 52 foot span $310 per foot in depth of arch. The cost of the arch proper according to contractors' figures amounted to $281 per foot in depth. The total cost of the contractors' work, including paving, amounted to $67,000, and the engineering and contingencies the sum of $10,255, making a total of $77,255. The contractors for the arch, paving and walls were Messrs. Madore and Frechette.

NOTRE DAME STREET VIADUCT.

This viaduct has been built on the lines of Notre Dame street, between the Berri street subway arch and the East side of Lacroix street, for the accommodation of the Canadian Pacific Railway, their tracks leading to the new Viger Square Hotel Depot, passing beneath the structure. The northerly abutment of the Berri street arch had to be widened, not altogether for its additional strength, but in order to suit the spans of the bridge itself.

In addition to the two abutments, the northerly one of which was carried down Lacroix street on a curve, there are 21 pedestals with copings 3½ feet x 12 feet, and 22 with copings 3½ feet square. The pedestals as far as the north end of the old Dalhousie Square passenger depot are at right angles to the axis of the bridge, the remainder as far as the north abutment being placed at an angle of 54° 41′ 30″, so as to suit the curves of the tracks approaching the depot at Viger square the north abutment being parallel to them. The total length of the bridge proper between the abutment bridge seats being on the west side, 437′ 3″; on the centre line, 452′ 10″ and on the east side, 468′ 5″. The width of the bridge between the outside plates is 52′ 3″, the five lines of columns being placed 11 feet centre to centre. The columns are composed of 2 channel irons, and one eye beam, resting upon rocker bases, having also rockers at the top, to allow for the contraction and expansion of the steel. Upon these columns which are thoroughly braced transversely are placed the longitudinal plate girders. The spans of these girders are, 4 clear spans of 38′ 3″, 2 of [illegible], and one of 59′ 6″, and one 54′ 1¼″, besides the tower spans. The columns on the long pedestals are placed 7′ 9½″ centre to centre, which constitute the towers, the depth of the girders being 4′ 3″ deep for the short 38′ 3″ spans, and 5′ 3″ for the longer ones.

On the top these girders and at right angles to them are placed the iron floor beams, composed of 10¼″ eye-beams, extending the whole width of the bridge, and at 4 feet centres; upon these eye-beams, which are bolted to the girders, are placed the 3-16 inch buckled plates, the buckled portions being 4 ft. sq., and made in long lengths; these plates are riveted to the eye-beams and strengthened longitudinally by T bars. The roadway is composed of concrete and wooden block paving, with a stone curb, and firimite sidewalk of a width of 8′ 1½″ upon each side, leaving a clear roadway between the curbs of 36 feet, a double electric car system of tracks being placed in the centre, the trolley poles which are of iron being bolted to the outside plates and bracketted to the columns. The buckled plates before the concrete was laid were painted with hot asphalt, which has had the desired effect of making the bridge almost perfectly water tight. The fence posts were of cast-iron 3 inches in diameter, with bosses; they were placed every 8 feet, and bolted to the outside plates;there are 4 lines of 1½ inch gas-pipes passing through them, the top bar being 3′ 4″ above the sidewalk level at the outside of the bridge. The triangular portion of the bridge down Lacroix street has a length of curved abutment of 140 feet. And on the south side one column and 2-60′ girder spans of a depth of 6 feet, girders extend from these outside girders to the bridge seat of the abutment, of a depth of 3 feet, and at distances of 13′ 3″ parallel to the main bridge. At right angles to them are placed 12 inch eye-beams, at 4 feet centres; and on these the buckled plates and scoria block paving with concrete. During the construction of the bridge a temporary roadway was made upon trestlework, west of the structure, so that the traffic was not much interfered with, the cars being carried this way, and only stopped when the connections were made at the north end. The old wall along the east side of Notre Dame street, which the writer also constructed for the Canadian Pacific Railway, had to be torn down, a great quantity of the stone being used in the bridge abutments and pedestals.

It would be well to note here that this wall was built during the winter months, the thermometer being from 15° to 20° below zero for days together, the sand and cement were warmed, as also the water, and the stones subjected to a steam jet to thoroughly clear-off any snow or ice, and yet we had great difficulty in pulling this wall apart, showing conclusively that masonry can, without any fear, be built during winter time, care being taken.

Engineers' Estimate of Cost.

Excavation..	cub. yds.	28,000	$ 0.65	$18,200.00
Tearing down old walls..	"	1,300	1.50	1,950.00
Temporary bridge and grading road..				3,000.00
Masonry in abutments..	cub. yds.	1,400	9.00	12,600.00
Paving and sidewalks..	sq. yds.	2,720	3.50	9,520.00
Masonry in pedestals..	cub. yds.	414	10.00	4,140.00
Cutstone on pedestals and bridge abutments..	"	180	14.00	2,520.00
Removal, etc., of water-pipes....				2,500.00
Stone-filling behind walls.. ..	cub. yds.	100	4.00	400.00
Superintendence and contingencies				15,000.00
				$69,830.00

Iron Superstructure.

In colums.. .. ..110,000 lbs.
In girders.. .. ..460,000 "
Buckled plates & T beams 250,000 "
Floor beams.. .. ..165,000 "
In cross bracing, etc.. .. 97,000 " 1,082,000 lbs. at 3½ cts., $35,665 which equals a total cost of $105,495.00. The amounts paid were to the contractors, Madore & Frechette, $43,270.00: to the Dominion Bridge Co., $35,505.00; for blocks for roadway alteration of water pipes, superintendence and small contingencies, $24,191,000, or a total of $102,966.00; the amount of iron in the Bridge Co.'s tender was 1,090,000 pounds.

The Lacroix street portion was estimated at $25,000.00; and the amounts paid were to the contractors, Madore & Frechette, $16521.00; to the Dominion Bridge Co., $6,568.00, and for superintendence, $1,600.00, a sum total of $24,689.00.

Taking out the items in the bridge proper, namely, pedestals, steelwork and flooring, the structure being to back of bridge seats, a mean of 460 feet in length, a width of 52 feet, and an average depth of 30 feet, the cubic contents would be 717,600 cubic feet, at a cost of $40,425.00; or 5.63 cents per cubic foot, $88.00 per lineal foot of bridge, or $1.70 per square foot of area. The columns are 22 feet long, and any extra depth can be allowed up to 30 foot columns by adding $1.25 per cubic foot to the above cost.

NOTE.—The plates in connection with this paper (following) have been incorrectly engraved as belonging to Vol. XIII.

Thursday, 15th March.

Dr. H. T. Bovey, President, in the Chair.

Mr. L. Skaife gave notice of his intention to bring forward the following motion: "That the rooms of the Society be kept open on all public holidays."

A short paper on "The Canadian Pacific Railway Transfer Slip," by Mr. H. J. Wadsworth Finch, Stud.Can.Soc.C.E., was read.

Thursday, 29th March.

Dr. H. T. Bovey, President, in the Chair.

Prof. R. B. Owens delivered the fourth, and last of a course of lectures on the "Transmission of Electrical Power."—(Vol. XIII., Part II.)

Thursday, 12th April.

Dr. H. T. Bovey, President, in the Chair.

The following donation to the Library was announced:—

"Architectural Engineering," from Mr. Paul Weatherbe, A.M.Can. Soc.C.E.

Mr. L. Skaife, seconded by Mr. T. W. Lesage, moved: "That the rooms of the Society be kept open on all public holidays."

Moved in amendment by Mr. G. Janin, "That the matter be referred to the Library Committee, with the addition, that the Society thinks that it is not necessary to keep the rooms open on holidays."

After some discussion, Mr. Skaife withdrew his motion, and the matter was allowed to drop.

Messrs. J. S. Vindin, L. Skaife and R. T. Gough, having been appointed scrutineers of the ballot for the election of members, declared the following elected:—

MEMBERS.

C. H. DAVIS, W. A. JOHNSON,
J. G. SULLIVAN.

ASSOCIATE MEMBERS.

E. A. FORWARD, B. H. FRASER,
H. B. WALKEM.

Transferred from the class of Associate Member to the class of Member:

R. S. LEA.

Transferred from the class of Student to the class of Associate Member:

R. E. HUNTER.

STUDENTS.

H. M. DAVY, A. J. R. MACDOUGAL,
A. L. KILLALY, R. T. MACKEEN.
A. C. MACDOUGALL, J. P. WALKER,
F. A. WISE.

Paper No. 149.

PURIFICATION OF SEWAGE BY MEANS OF THE SOIL

(Sewage Farm).

By GEO. JANIN, A.M.CAN.SOC.C.E.

PROTECTION OF WATER SUPPLIES BY THE SUPPRESSION OF THE RIVERS' POLLUTION.

In mentioning the danger of polluting by the sewage of the cities the streams which generally supply drinkable water to these same cities or their surroundings, we must give credit to Great Britain for having first submitted to her scientists the study of this great question, which brought on, in 1878, the vote, by the British Parliament, of the "Rivers' Pollution Prevention Act," obliging the municipalities to practically eliminate the noxious principles of sewage water before emptying it in the streams.

England's example was followed in the whole of Europe, especially in Paris, where the "Roads and Bridges Engineers Corps," to which I had the honour to belong, has made the most marvelous progress in the establishment of purification fields at Gennevilliers and Achères.

Unfortunately, in this country, we do not follow this example, and, boasting of the ampleness and copiousness of our rivers, our municipalities seem to court epidemics, in spite of the advices of their Boards of Health, and empty their impure sewage in the streams at the bottom of which generally lie deposits or banks of sawdust from the numerous mills lining the shores.

This neglect of the interests of health arises principally from the considerable expenditure anticipated by engineers in estimates based on special methods of treatment for sewage water. If, then, the most practical and cheapest system of sewage farms continued without any serious enquiry to be declared unsatisfactory and unavailable in our climate, there would be a danger of sewage pollution of streams becoming permanent in this country, to the great detriment of the purity of our water supplies generally.

In order to assist in counteracting this state of things, the author of this paper will endeavour to destroy any prejudice which may still exist against sewage farms amongst the members of the profession.

PURIFICATION BY THE SOIL AND AGRICULTURAL UTILIZATION OF SEWAGE.

Soil purification of sewage is the method now in favour in England, Germany and France. In the last named country, I had the honour of co-operating in the installation of this system with the learned engineer Durand Claye and his colleague, M. Masson, inspector of the drainage of the City of Paris. This process consists, as you know, in the filtration of sewage water through a permeable soil affording a sufficient thickness and all facilities for the outflow of the purified waters, either by a sufficient porosity of the subjacent stratum or by artificial drainage.

That the soil is the most perfect purifier of waters charged with organic matter is proved, first, by the organic purity of spring water, second, by careful experiments with impure waters, which are subjected to analysis before and after percolation through the soil.

THEORY OF THE PURIFICATION OF SEWAGE POURED ON THE SOIL.

The following information is taken principally from the remarkable report of Mr. Schloesing, reporter of the Health Committee of Paris (France).

When impure water, that of sewers for instance, is spread on light land, the insoluble matter remains on the surface. Some of the more minute portions, however, go a short way down, but soon stop; so that below a depth which varies with the nature of the ground, but which seems never to exceed two or three inches, there are no more solid particles to be found. This is the first effect produced; it is simply a mechanical filtration.

The water, now free from insoluble matter, goes down further, and an extremely thin coating of liquid gathers round each particle of earth. Thus divided, the water offers an enormous surface to the air confined in the ground; and the second effect of irrigation then takes place, *i.e.*, the combustion, by the oxygen in the air, of the organic matter dissolved in the sewage water. This is not a violent and visible phenomenon like fire; it is a slow combustion without any external sign, and which reduces all organic impurities into carbonic acid, water and nitric acid. This combustion is even more perfect than the other, for it burns up the nitrogen, which fire cannot do.

As to the insoluble matter retained on the surface, it also undergoes slow combustion, especially when ploughing has divided it and incorporated it with the soil. All that remains is a fine sand which will constitute a part of the minerals in the ground.

But how is it then that the oxygen of the air can under these conditions completely consume the organic matter of sewage and nitrify the nitrogen ?

According to the researches of Messrs. Schloesing and Muntz, in in 1877-1878, this remarkable property is owing to the action of living organisms, existing in vegetable soil as well as in sewage water, and able, like the microderma aceti and others, the functions of which Pasteur has so well described, to transport the oxygen of the air on organic matter.

These are the experiments of Mr. Schloesing: If you pour regularly and in small doses sewage water on any kind of sand, mixed with a little humus and placed in a vertical glass tube, you will immediately get in the lower part perfectly pure water containing all the nitrogen of the sewage water in the form of nitric acid or nitrate, according to the nature of the sand.

If for this mixture of sand and humus or arable soil you substitute quartz sand calcined up to red heat, the purification does not take place in the first days, but only after a few weeks, and then, however, as completely as in the first case. The water collected in the lower part of the glass tube is perfectly pure; it contains all the nitrogen of the sewage water under the form of nitric acid.

Further, if, in the second case, and whilst complete purification is taking place, you send through the glass tube a current of chloroform (experiments of Mr. Muntz), the purifying power ceases completely and resumes only after the sand has undergone a protracted washing.

From these experiments we may draw the following conclusions:—

1. That purification by means of sand, free from organic matter, does not take place in the first days of the watering, because the germs of the nitrifying organisms are then non-existent.

2. That these germs can be brought in by sewage water and develop in sufficient quantities within a few weeks, and

3. That in vegetable soil, on the contrary, the purification begins immediately because the organisms are in full possession of the ground.

The researches of Mr. Muntz indirectly confirm this explanation, for, as chloroform has the property of paralysing all organisms acting as ferments, the purifying power ceases as long as the action of chloroform lasts.

Let us now see, with regard to practical work, what conclusions we can draw from these scientific notions, to be applied to the choice of land intended for the purification of sewage water. As the action of air is indispensable and the water should get through the soil easily, the latter should as much as possible be light, permeable and be of sufficient thickness above the sheet of liquid and the impermeable stratum. The filtered water should also be able to flow away easily either because the surface of the impermeable stratum offers an easy grade, or else artificially by means of drains. It is absolutely necessary to get rid of the filtered water. It is easy to understand that, if it could accumulate in the same place, the thickness of purifying soil might be diminished and become too slight to secure complete purification.

More or less arable ground, therefore, containing a greater or a smaller proportion of humus, is suitable for purifying sewage water, whilst assimilating its fertilizing elements. But the poorest land, pure sand even, secures after a short time a purification just as complete, as the sewage water itself furnishes the germs of the same nitrifying organisms as those enclosed in the humus of arable land.

In many documents relative to sewage water, plants are erroneously classed with the soil as purifying agents; the bare soil without any vegetation suffices for complete purification.

Plants live on mineral compounds: carbonic acid, water, ammonia, nitric acid, phosphates, etc., and do not absorb organic substances, or only very small proportions of them.

However, they help purification, but in another way, mechanically as it were. They facilitate and determine in a notable degree the evaporation of the water poured on the ground, and thus contribute to getting rid of the liquids (experiments of Marié-Davy in the municipal garden of Gennevilliers). Besides, they consume a large portion of the ammonia or nitric acid produced, thus removing it from the purified water.

Therefore, as far as purification strictly speaking is concerned, cultivation is only of secondary importance; but from the agricultural standpoint this importance is very great, since we can thus make use of all the fertilizing elements contained in sewage water. This is the experiment of Mr. Marié-Davy: Four old stone-work tanks, 33 feet by 26, which had formerly been used for attempts at chemical purification, were filled to a height of 6 1-2 feet, with the average soil of the Gennevilliers' plain. Drainage pipes were placed at the bottom, which like the sides were covered with an impermeable coating. This impure water poured into each tank and the purified water issuing from the drainage pipes were both exactly measured. Different plants such as lucerne, maize, beet roots, corn, etc., were cultivated on the surface of the tanks and weighed with great care at harvest times.

Out of 12,700 cubic yards of liquid introduced per acre in half a year, less than 848 reached a depth of six feet. Generally speaking, Mr. Marié-Davy found that only one-fifteenth of the water poured on the surface reached the lower liquid level.

Vegetation acts therefore as a powerful vertical drainer; the soil transforms the impure water received, oxydizes it and produces an excellent liquid manure.

Plants in their turn absorb for their own benefit the useful elements of this manure, and give back to the atmosphere by means of evaporation the greater portion of the liquid which has served as a means of conveyance.

The soil is itself highly enriched by the organic matter which it takes from the sewage, and thus an economical value is given to the method of soil purification. Many analyses of vegetables grown on such soil have been made, and in no case has any diseased or unsafe food product resulted from the use of these fields as market gardens.

Thus, the filtration through the soil and the agricultural utilization complete one another. Not only purification, but also restoration, accomplish themselves, and the system bears out the axiom of the learned English hygienist, Edwin Chadwick: circulation always; stagnation, never!

In order to demonstrate the harmlessness of this system, it is advisable to quote the opinions and the experiments of a great many scientists, and first to mention the statement made by Dr. Frankland of the Royal Society who declares that: "Sewage, even though infected with cholera and typhoid fever, has never, when employed in irrigation, communicated disease either to parties living on the land so irrigated or to the consumers of the products thereof."

Here are now some extracts from a remarkable report made to the French Senate in December, 1888, by Mr. Cornil* in a debate concerning the purification of sewage water in Paris:—

"There has been much attention directed lately as to what becomes of micro-organisms when they pass through permeable soil. With my assistants, MM. Chantemesse and Widal, I have made—and Mr. Grancher on his side has also made—experiments to know what becomes of micro-organisms of a determined kind, easily recognized by its characteristics, poured on the surface of one of these large tubes filled with Gennevilliers soil.

"We have thus placed on the surface of our tubes microbes of typhoid fever, and we have sought if these micro-organisms of typhoid fever passed through the soil and were found in the water collected at the lower part of the tubes. Well, none pass through, even if the experiment is repeated for several weeks. Mr. Grancher repeated it for several consecutive months, and was unable to find even one.

"The soil at a given depth is therefore absolutely impermeable to microbes. This fact has also been confirmed by a series of experiments of another kind.

"When, by means of perforating apparatus, you obtain a sample of earth collected at a depth of one meter and examine it with reference to micro-organisms, none are found. You cannot find any of those which have been sown on the surface of the soil. Therefore, the microbes do not pass into the water of the drains which discharge the liquid poured as sewage water on the surface.

"After having filtered through a meter or a meter and a half of earth, this impure water appears perfectly clean, clear, containing scarcely any micro-organisms, and notably none of those sown on the surface. Thus, if you sow micro-organisms on the surface of

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* Senator and Professor of Microbiology at the Faculty of Medicine of Paris.

soil and collect what issues from the test-tubes, *i.e.*, the drainage pipes, no trace is found of the micro-organisms sown; they have remained on the way, at 30, 40, 50 centimeters below the surface of the ground.

"They are not destroyed, but they are buried so to speak, and the soil is their cemetery.

"In any case, these experiments in tubes are absolutely conclusive with regard to the clarification of the water.

"These same experiments were made this year again in tanks at Gennevilliers, which had been used for chemical purification. These tanks are closed, in their lower portion, by an impermeable concrete; they are therefore absolutely watertight and filled with Gennevilliers soil.

"They have a surface of five acres, and a depth similar to that of the soil of the place, *i.e.*, two meters or two meters and a half.

"Sewage water was poured on this soil in considerable quantities for a certain number of days, or even for several months; then the water which had passed to the lower end was successively collected and found to be absolutely pure.

"It was examined in a chemical and bacteriological point of view.

"Chemically it contains very little dissolved matter.

"The quantity of micro-organisms contained in this water varies between 40 and a maximum of 600 per cubic centimeter, whilst that found in sewage water is 80,000 to 200,000 per cubic centimeter.

"This water issuing from the Gennevilliers soil does not contain any more micro-organisms than that of the Vanne or the Dhuys*. This results from all the experiments, all the analyses, and specially those made by M. Miquel. There are no more micro-organisms in this water than in the pure spring water furnished to the inhabitants of Paris."

After having heard the favourable opinion of so many learned men, after having passed through so many successful experiments made in the numerous purification fields of England, France and Germany, how is it that this system needs still to be defended against certain prejudices ?

For it must be admitted that despite its superiority it has adversaries. Some are in good faith, but have been misled by imperfect experiments, to which reference will be made later. Others are mere grumblers blindly following their preferences for other systems or directly interested in the working of rival schemes.

Notwithstanding the evident superiority of the soil purification system, it is proper, considering the prejudices still existing, to illustrate, even briefly, the rules regulating the establishment and working of the purification fields—the violation of which rules has caused the few failures of the system.

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* Rivers supplying water to the City of Paris.

The purification of sewage by the soil can be accomplished in two different ways:

1st. The simple pouring or the flooding of prairies and heavy crops.

2nd. The methodical watering in succession of lands used for intensive gardening.

The largest number of failures recorded can be ascribed to the first method often used in England. For, inspired by a pennywise economy, in order to devote to the pouring the smallest possible surface, this method causing flows of high graded sewage water, cannot easily agree with the rules of the methodical filtering of impure water through the soil. The result frequently is an imperfect purification, and, in any case, a swampy aspect of the flooded fields as well as disagreeable emanations for the neighbourhood.

On the contrary, the following rules of the second method are always easy to observe; and their fulfilment is, in nearly all cases, crowned with success.

OPERATION OF THE PURIFICATION THROUGH THE SOIL, WITH THE RULES ORIGINATING FROM SUCH OPERATION.

The operation process of purification through the soil admits of two motions, one of the water, the other of the air.

The motion of the water consists of:—

1st. The apportionment of impure waters on the surface of the ground, the filtering through the purifying soil, followed by the combustion of organic matters.

2nd. The outflowing of purified waters.

The motion of the air consists of an exchange between the soil and the atmosphere continuously renewing the oxygenic supply of the soil in proportion as such supply is spent by the combustion of organic matters contained in the water.

Man has an entire control of the motion of water and must regulate its pouring and outflowing according to the purifying power of the soil.

There is evidently a close connection between those two motions and the purifying power of the soil; to wit: the aeration and the movement of the water are really the purveyors whilst the soil is the instrument of the purification.

To sum up, the rules which govern a good and complete purification are as follows:—

First rule. To select ground porous enough to allow water to easily permeate and to give free access to a sufficient quantity of air for the working out of combustion. This degree of porousness or purifying power is determined by direct experiments, the best known being that of Dr. Frankland, which is as follows:—

In a vertical tube 2 meters in length and of $0^{m}25$ to $0^{m}30$ diameter, the lower end of which rests on gravel contained in a tank, samples of the different beds of the soil to be tested and placed in the same order in which they exist in the natural ground.

You pour daily on the soil a known and constant volume of sewage w[illegible] during several weeks. You then pass to a higher daily dose of sewage which you again keep up for several weeks, and so on, increasing the dose constantly until the analysis of the filtered liquids shows that the maximum dose has been reached, beyond which purification is no longer complete.

From this experiment it is easy to conclude what a square meter of the soil tested, and, consequently, what a hectare of it will purify at most per day or per year. We can only deduce from it the time required for purification, *i.e.*, the length of time during which the impure water should remain in the soil before being discharged. It is in days the quotient of the number of litres of water which the soil can hold* by the number of litres of impure water this same soil can purify per day.

By this method Frankland has shown that a cubic meter of pure sand or chalk can purify per day up to 33 litres of London sewage (litre—61.017 cubic inches), and that soil of mixed sand and clay or marl possesses still greater purifying power.

Evidently, in working out these data, we must remember that in practical work on a large scale we cannot realize exactly the conditions it is easy to observe in a small experiment, and that it is therefore desirable to reduce somewhat the maximum doses determined in the laboratory.

Second rule. To regulate the time of pouring and the quantity of sewage water poured each time, so that the water may take to run through the filtering soil *all* the time necessary for its purification.

Third rule. To underdrain, if necessary, in order to give to the purified water a regular issue.

In a word, the object is to obtain, as nearly as possible, a continuous and regular distribution since purification, a phenomenon of slow combustion and aeration—a mechanical fact—are both regular and continuous.

These are, as briefly enunciated as possible, the laws of operation of the purification by arable soil.

It follows from this exposé, as said before, that high dosed pouring alone has caused partial failure; not because it is bad in itself, but because the rules of purification by the soil imply certain

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* A number which can easily be experimentally determined by weighing the tube full of dry earth before introducing the water and weighing it again after saturating contents and allowing discharge of liquid surplus.

absolute conditions such as selection of the ground, apportionment of sewage waters, underdraining, which are sometimes neglected on account of difficulties of ascertainment and of the great expenses they entail.

On the contrary, in all cases where irrigation has been moderately practised and where vegetation has helped purification, by returning to the atmosphere a portion of the purified water, success has been attained. To recall only a few of these successful experiments, I shall quote the purification field of Gennevilliers (Paris), where the annual dose of irrigation amounts to from one to four million gallons per acre; of Reims (France), where the dose is about the same; of Dantzig (Northern Prussia), where the average annual dose is three million gallons; and of Aldershot Camp (England), where the dose is also of about three million gallons per acre. A recent report (1899), made by Her Majesty's order to the Imperial Parliament, by Professor Fred. W. Andrews, M.D., F.R.C.P., D.P.H., etc., on the working of this sewage farm, the products of which are principally used for dairy purposes, affirms the absolute innocuousness of the system both with regard to odor and to the quality of the milk and butter produced by the animals fed on the yield of the farm. Professor Andrews says, amongst other things:—

" In concluding these remarks upon the farm, I will say that it " appeared to me to be an excellently managed one (by Col. Alf. "Jones, V.C., Assoc. M. Inst. C. E.), and as free from objection-" able features as any sewage farm could be. I could detect no " nuisance at the time of my visit . . . .

" I am unable to find any conditions on the farm liable to render " the milk produced thereon more dangerous for human consumption " than that from any other well-managed sewage farm, and I have " already stated that no evil results have yet been proved to occur " from sewage fed dairy produce as a whole."

These purification fields not only fill the hygienic programme of complete purification, harmlessness, absence of perceptible emanation for the neighbourhood, but also fill the economical programme as in Gennevilliers, where the value of land has increased fourfold since it is irrigated; in Reims where a company has rented the purification field for a period of thirty-six years, and after paying a heavy annual rental to the city, still realizes large benefits, and in Dantzig, where the purification field is rented at large profits.

The testimony in favour of the system with regard to its already lengthy applications in Europe and the more recent ones in the United States could be multiplied, but it will be preferable not to go beyond the instances already mentioned and to discuss the last and principal objection of the adversaries of the system, *i.e.*, that the severity of Canadian winters would interrupt the work of purification.

Like at Dantzig, where the thermometer registers as many degrees of cold as here, and where the system has been operating uninterruptedly for twenty-five years, it has been working successfully for three years in spite of the Canadian winters at only a few miles from Montreal. The sewage water of St. Laurent College has been successfully undergoing purification since January, 1896. The following extract from the annual report for 1897 of the Board of Health of the Province of Quebec confirms this, and also gives a description of the first sewage farm established in the province. Plan is annexed. The extract is as follows:—

" SEWAGE FARM OF ST. LAURENT COLLEGE.

" As we foretold in our last annual report, we can this year speak
" by experience of sewage farms in our climate.

" Effectively the St. Laurent College, near Montreal, which discharged
" its sewage water in a small creek passing through the
" village, entrusted in the autumn of 1897 the establishment of a
" farm for distribution and purification of its sewage to Mr. G.
" Janin, a civil engineer of Montreal, who had formerly taken part
" in the sanitation works of Paris.

" The works of this farm, which we followed with attention, were
" finished sufficiently early in the winter, and of January, 1898, to
" enable us to state that, as we had supposed, the methodical distribution
" of the sewage had gone on with ease in temperature
" of more than 20 degrees Fahrenheit below zero. As there is no
" reason for supposing that what took place in the severe winter
" of last year will not equally take place in subsequent winters,
" we can conclude that it is now proved that sewage farms are
" perfectly compatible with the climate of the Province of Quebec.

" The sewage farm at St. Laurent College occupies a surface of
" an acre and a half, and receives at present the sewage water of a
" population of about five hundred persons, or an average flow
" of 4,500 gallons of sewage water per 24 hours. This sewage,
" which formerly was discharged directly into the village ditch,
" now passes through a 10-inch eathenware pipe into a 9,000
" gallon tank placed beside the building containing the motive
" power used for the different requirements of the College.

" This tank is absolutely watertight, and can, in case of need,
" contain all the sewage water produced in 48 hours. A centrifugal
" pump placed in a well beside the tank, and worked by the
" ordinary college motive power, raises in about 40 minutes the
" daily amount of sewage, and forces it through an iron duct three
" inches in diameter, into a distribution canal running along the
" south side of the farm. In order that, after the pumping has
" stopped working, nothing of a nature to obstruct may remain
" in the elevating pipe, it is emptied into the tank as soon as the
" pumping is over.

"From the distribution canal the sewage is directed at will by "means of gates into any one of the twelve longitudinal and five "lateral trenches which divide the farm into fifty-five parallelo-"grams of fifty feet in length, and twenty feet in width each, on "which vegetables, fertilized and watered by the sewage, are cul-"tivated. In the middle of each of these parallelograms there has "been placed porous earthenware pipes of three inches diameter, "about four feet below the surface of the ground. This drain "collects the sewage water after it has undergone purification in "the soil*, and conveys it to a ditch running along the northern "side of the farm. This ditch ends in the village creek, into which "the unpurified sewage of the college formerly flowed.

"Around the farm, large ditches have been opened or regraded "in order to let the water of the neighbouring ground discharge "freely and to prevent it from invading the farm or overloading "the underground sheet of water below said farm.

"To hinder the inconvenience resulting from the proximity of "the underground sheet of water, which in this low ground is only "a few feet below the surface, the level of the ground has been "raised by a filling of arable land, from sixteen to eighteen inches "in height.

"Not only has the sewage farm worked uninterruptedly in winter, "as we have said previously, but during the summer the produce "has been very satisfactory although no great efforts were made "for cultivation.

"Finally, then, we must note the success of this first application "in our climate of a system which works to the advantage of health "in the other countries of the old and new continents, and direct "to it the attention of our municipalities."

The members of the profession will find the system tried both more completely and on a larger scale in the sewage farm of St. Denis ward of this City. The works which have been entrusted to the writer by the City Corporation (under the direction of Mr. P. W. St. George, city surveyor, and Mr. S. Howard, engineer in charge), have just been concluded. This farm, which covers a surface of about twenty acres, is established approximately on the model of that which has been worked successfully for some time at Brockton, Mass., and as shown in annexed plan, is divided into regular beds, separated by small earth embankments so as to divide the irrigation according to requirements of cultivation and amount of sewage to be distributed.

The sewage water flows by gravitation into a well which communicates with two tanks placed beside each other. These tanks can be used in turns; a movable grate in each of them stops the passage of insoluble matter. From the tank the sewage water

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* By the oxidation of the organic matter.

passes into two parallel earthenware pipes, eighteen inches in diameter, which distribute it by means of earthenware gates on any of the beds when it may be required. At the end of the pipes there exists an overflow arrangement which can spread any surplus water on a large surface of ground, to be devoted for the present to rough cultivation.

The soil has been regularly levelled and subdrained by means of farm tiles covered with a foot of coke. These farm tiles are at about five feet below the surface, and end in an open ditch made of brick which in its turn pours its contents into another ditch when they finally flow into the Back River.

The soil of the farm is approximately constituted as follows:—

1. One foot loam.
2. One foot loam and gravel.
3. Two and one-half feet light clay mixed with sand and gravel.
4. One and one-half feet quicksand.

The impermeable bottom is hard pan. This farm will receive at present the sewage and a portion of the surface water of a district containing actually a population of about 2,000.

To begin working it the only thing now required is the completion of the main sewer which is to convey the sewage to it, and which will be finished at latest next spring.

The writer believes he has now covered all the important points of the subject. He has gone through the theory of purification by the soil, and has given an insight into some of its practical applications in the old world, the United States and Canada. He believes, therefore, he is fully justified in concluding with the following statement:

A municipality called upon to pronounce on the choice of a system for external sanitation can only proceed on the path followed by all the cities which have had to solve this grave problem by adopting the same sanitation methods. They have been tested and their use confirmed by long experience, and have given the most complete satisfaction, either in reference to health or for the proper agricultural utilization of the quantities of refuse produced in cities.

But it may be objected that the realization of the exterior sanitation of cities will cause heavy expenditure.

That is true, and yet municipalities should understand that, if they have to pay for bringing in pure water, they must equally, and the obligation is no less strict, pay a second time to remove this same water encumbered with the refuse of the town, and finally pay again to purify it by regular and intermittent irrigation on a soil both suitable and cultivated, so that, whilst harmless to the neighbourhood, it may be of use to cultivation.

What municipalities will spend on internal and external sanitation they will recover in the lengthening of human life and the diminution of the budget of hospitals.

DISCUSSION.

Mr. Stuart Howard.

The vexed question of sewage disposal has within the last few years become very serious, the contamination of the rivers and streams, from many of which cities, towns and vilalges derive their drinking water, has been prevented by law, and the question then arises, what to do with the sewage. Many of the older places in England, France, Germany, and even on this continent, have adopted some system of sewage farm, or sewage destruction, either intermittent filtration, flooding, chemical or septic tanks. Especially is it so in the State of Massachussets, every outlying district of Boston adopting one or other of the systems, the whole country for miles round being by the State converted into a system of receiving reservoirs for the supply of water to the city itself and neighbouring towns and villages, so that the emptying of drains into the water courses has been prohibited. Brockton has a model sewage farm, situated close to the main thoroughfare, along which stand the residences. No disagreeable odour is apparent, and the crops grown are most prodigious. The sewage farm lately constructed for the disposal of the sewage from St. Denis Ward of the City of Montreal, has already ten acres prepared, and can be increased in size as the place grows.

This farm was built by Mr. Janin as contractor, and it was mainly through his efforts and advice to the Road Committee that the scheme was adopted, and there is no doubt it will be a success, and the means, the writer trusts, of other places following suit

The question has been asked regarding the water in times of freshlets and heavy storms. The writer may say that St. Denis Ward has been laid out with a separate system, only a sufficient amount of water to flush the sewage being allowed to enter the main drains.

It has also been asked as to the acreage of farm required. This question has been thoroughly discussed in England, and decided that one acre is sufficient for the sewage of from 500 to 600 inhabitants.

Mr. Janin's paper would be made doubly interesting if he would give the approximate cost of preparing an acre of farm, and also the cost of all the different systems, so that anyone dealing with the matter of sewage disposal, would be able to arrive at the most economical, as well as the most advantageous. Many of the questions relating to the action of microbes, etc., will, the writer believes, be thoroughly answered in Mr. Lea's paper, which is the next to be read before the Society.

Thursday, 26th April.

Dr. H. T. Bovey, President, in the Chair.

The following report was received from the scrutineers of the ballot for the election of Members on April 12th:—

"We, the undersigned scrutineers, beg to revise our count of the 12th instant, by adding the name of H. T. Morrison as Associate Member.

J. S. VINDIN.
R. T. GOUGH."

It was moved by Mr. E. A. Rhys-Roberts, seconded by Mr. H. Irwin, and carried: "That the revised report of the scrutineers of the ballot for the election of members be accepted."

It was moved by Mr. W. McLea Walbank, seconded by Mr. W. McNab: "That the Society should express to the Corporation of the city its opinion that the office of Building Inspector should be filled by a competent engineer or architect."

A committee, consisting of Messrs. W. McLea Walbank, W. McNab and C. H. McLeod, was appointed to draft and forward a resolution in connection with the foregoing.

Messrs. E. A. Rhys-Roberts and G. Legrand, having been appointed scrutineers of the ballot for the election of Honorary Member, declared Lord Strathcona and Mount Royal duly elected as Honorary Member.

Paper No. 150.

SEWAGE DISPOSAL.

By R. S. Lea, Ma.E., M.Can.Soc.C.E.

It is a remarkable fact that, while Damascus, Nineveh, Babylon, and many other ancient cities of the old world, were provided with abundant artificial water supplies and extensive systems of sewerage, it is only within the last half-century that the drainage system of London, the greatest of modern cities, has been brought to such a condition of efficiency as to permit of its general use in the removal of household waste.

During the long, dark period of the Middle Ages, which succeeded the dismemberment of the Roman Empire, sanitary provisions were almost entirely neglected, the narrow streets and alleys of the crowded cities were made the receptacles for the waste products of the teeming populations, and bodily filth even came to be regarded as a mark of holiness of mind. The penalties for these ignorant violations of natural laws followed in the form of terrible plagues and epidemics, while the unfortunate misconception of the nature of the offence suggested no more effective remedy than the wearing of sackcloth and ashes.

In London, during the seventeenth and eighteenth centuries, rough drains were constructed for the removal of surface water; but for the household waste or sewage proper the gutters, occasionally supplemented by pits or cesspools, remained the only method of disposal. In later years, as the methods of construction improved, the storm-water drains were sometimes used for sewage as well; while earth closets and various pail systems for direct removal began to be substituted for the vaults and cesspools.

Meanwhile an artificial water supply had been introduced, and in 1847 the drainage system had been improved and extended to such a degree that it was made compulsory to discharge into it all sewage of every description. This was a return to the water carriage system of the ancients, in which the liquid wastes serve as a vehicle for the removal of the solid, with manifest advantages from an economical as well as a sanitary point of view. Yet, through a desire to utilize the manurial qualities of the excremental matter, many places continued for several years to employ some form of Direct Removal, without the admixture of water, for this portion of the sewage. But the objectionable features unavoidably connected with such methods, together with the increase in the number of public water supplies, soon tended towards the general adoption of the cleanly and efficient water carriage system, which, in America at least, may now be said to be almost universal. The assumption that such is the case will therefore be made in the further discussion of the subject matter of this paper.

Having provided the drains for its collection and transportation to some distant point, the first and most natural method of disposing of sewage in this highly diluted form was to turn it into the nearest body of water; and this was usually done without much regard to its volume. This system, while generally proving quite satisfactory to the community employing it, very soon began to develop into a nuisance for many of its neighbours, and as the construction of drainage systems became more general, it was soon evident that there was a limit to the quantity of sewage which could be disposed of in this way. Not only did many of the rivers soon become unfit for sources of water supply, but some of the smaller ones were practically becoming converted into large open sewers, disgusting in appearance as well as dangerous to health.

The small streams, dense population, and extensive industries of England, rendered her particularly liable to suffer from this condition of things. A Royal Commission, appointed to inquire into the question of stream pollution, made its first report as early as 1870, and in 1876 the Rivers Pollution Bill was passed, making it compulsory to purify sewage by some kind of artificial treatment before discharging into a watercourse. The passage of such an Act naturally led to the appearance of a great number of so-called "processes," patented and otherwise, for the treatment of sewage. It also had the effect of stimulating the investigation by scientific men, into the nature and constitution of the particular substances which gave to sewage its offensive and dangerous character.

This was a period of remarkable progress in the science of biology and organic chemistry. The processes of fermentation and the decomposition of organic matter were shown to be, under some conditions at least, dependent upon the action of living organisms, and not purely chemical, as was previously thought to be the case. Further investigation has proved this to be true, under all conditions and circumstances. The ideas and theories brought forward were soon put to practical test in the construction of a number of working plants, and as the studies and investigations have proceeded the results from these works have been of the greatest assistance in pointing out the direction in which the researches should be pursued.

In France and Germany the subject has been developed along the same lines, but in America the necessity for such action was at first by no means so evident, by reason of the relatively sparse population and the immense size of the rivers and lakes. Nevertheless, in some of the New England States, the conditions began to be approximately similar to those common in Europe, and the problem of preventing stream pollution had already occupied the attention of the legislatures of some of these States, notably Massachusetts, previous to 1887, when the latter State undertook the well-known series of experiments which have since been carried on under the directions of its Board of Health. As a general thing, however, the matter was given little consideration. Occasionally, when a water supply became seriously threatened, the subject was given a certain amount of discussion, but the tendency was, in most cases, to look upon the matter as an indication of the necessity for a new water supply rather than for special treatment of sewage, and to regard the pollution of rivers in this way as rather in the natural order of things.

Within the past few years, however, the increase and spread of sanitary knowledge has brought about a change in these ideas, and since 1890 several effective systems of artificial disposal have been built, and are in operation in different parts of the country. Lately, a period of protracted drought has compelled several cities to resort to the use of polluted river water, in order to reinforce their ordinary supplies, and it has become evident that the normal growth will soon compel many of them to turn to the large rivers for their permanent supply. In view of this certain outcome, and of the fact that the rate of river pollution will be much in excess of the growth of population, the wisdom of permitting the continuance of such pollution is at least questionable. In Connecticut and New Jersey legislative action during the last few months has placed the control of the streams in this respect in the hands of bodies appointed for that special purpose.

Evidence of a similar change of public sentiment in other States marks the present time as the beginning of a general movement in this direction. Besides, the experience of the last twenty-five years, in conjunction with the results of numerous observations and experiments, have shown conclusively that many of the systems hitherto proposed are unscientific in principle, as well as incapable of effecting the required degree of purification in an economical manner. So that we have now arrived at a stage where the matter is simplified by the clearing of the field of a number of elaborate contrivances, expensive as well as inefficient.

The evidence all points to the conclusion, that the nearer the process can be kept to that of Nature the more satisfactory will be the results. In fact, in the light of present knowledge, it is probably not too much to say that there is really but one feasible and effective method for the treatment of sewage; or rather that those processes which have been shown to be capable of producing the results required in an economical manner, are based upon the same general principles.

ORGANIC MATTER.

Of the different substances composing sewage, only those of organic origin give rise to the necessity for its purification. Hence, by considering the true nature of organic matter, and the changes it undergoes, an idea may be obtained of the operations actually taking place in any of the various purification processes, as well as the essential features of each method, and the conditions necessary for its proper working. With this object in view the accompanying diagram (A) annexed, has been prepared, as a graphical representation of the main facts relating to the origin and constitution of organic matter, and of the subsequent transformation and changes which sooner or later it must pass through.

Organic matter includes all those combinations of the chemical elements whose formation depends upon the processes of life, and which are therefore derived from the substance of either plants or animals. The various forms which it may assume are set out, in the order in which they occur, around the arc of the circle in the diagram,—the direction in which the changes proceed being shown by the arrows. The vertical line at the top of the diagram divides these processes into a period of life and growth, and one of death and decay. At the bottom of the diagram, below the line marked "complete oxidation," is represented the inorganic material of the earth's crust, which consists almost entirely of inert mineral substances, whose chemical affinities are completely satisfied, and which are therefore without any kind of available energy. The meaning of this will be evident from the following illustration:—

When a weight is raised or a spring compressed, an expenditure of energy is necessary, because work must be done,—in the one case against the force of gravitation, and in the other against the molecular forces which resist change of shape in elastic bodies. The compressed spring and the lifted weight are now said to possess potential energy, because if the one is allowed to assume its original form, or the other to descend to the earth, the energy which has been expended upon them will, in some form or other, be set free again. And it must be further observed that there always exists the tendency towards the liberation of energy stored in this way, whenever the opportunity is offered, which renders the arrangement one of *instability*.

Exactly the same condition of things exists when the chemical affinities (attractive forces) of some of the atoms of a compound for oxygen, say, are unsatisfied. So long as this combination is prevented from taking place, so long may the compound be said to be in a condition of instability, and to possess potential energy, which will become available whenever the oxidation is allowed to take place. This energy is of the same nature and is measured by the same units as that given out by the descending weight or the expanding spring.

Now, the maintenance of life and growth, the power of motion and capacity for doing work, possessed by animals, requires the supply of a corresponding quantity of energy. This we know they obtain from their food, which is ultimately derived from the substance of plants. Plants draw the nourishment necessary for their life and growth from the earth and air, in the shape of materials capable of no further oxidation, and hence entirely devoid of energy. Nevertheless, paradoxical as it may appear, out of such simple, inert materials, the green plants can build up substances, complex in structure, and possessing the rich store of potential energy which fits them for animal food. They are enabled to do this by virtue of a mysterious substance called chlorophyll, which gives them their green colour, and which has the wonderful power of absorbing from sunlight the energy necessary for the purpose.

On the left of the diagram, just above the line of "complete oxidation," is a representation of Plant Life. The space enclosing the words "chlorophyll + sunlight" corresponds to the leaves and other parts of the plant, where this process of food manufacture is carried on. From the earth by way of the roots comes water (H_2O) nitrates (KNO_3 etc) and other salts in solution; from the air, by absorption through the leaves, carbonic acid gas or carbon dioxide (CO_2), and in the case of some plants pure nitrogen. These stable but inert compounds are here broken apart, a portion of the oxygen removed and returned to the air, and the remaining elements built up into *less stable* but *more complex* substances, such as starch, cellulose, sugars, fats, etc. (see diagram). Thus the energy abstracted from the light waves which is expended in this process of deoxidation, is stored up in these substances, which thereby become capable of furnishing food for animals. Animals, by means of their organs of digestion and assimilation, construct from these materials and incorporate in their tissues, compounds still more complex, but of greater instability (see diagram). By oxidation in the lungs or other breathing apparatus, they obtain from them the amount of energy necessary to maintain bodily heat and motion, in just the same way as energy is supplied to a heat engine by the combustion of fuel. The animal body not being a perfect machine, does not utilize all the energy in its food, but rejects a large proportion of it in the form of excretions, which share the general fate of all dead organic matter represented on the right side of the diagram.

In the manner outlined above, and in a fashion more or less direct is continually being produced "Living Organic Matter," represented on the diagram to the left of the vertical line. And in due course it will join the "Dead Organic Matter" (shown on the other side of the line) either in the form of excretions of living plants and animals, or their bodies after death; and were it not for the processes of disintegration and decay which are everywhere in operation, these constant additions would soon accumulate to such an extent as to check and ultimately stop all life by overwhelming it with its own waste, and by exhausting the materials necessary for its existence. It is this second or *destructive* phase, shown on the right half of the diagram, which is of most interest in this connection, because, as we shall see, it represents the changes which take place in the process of purifying sewage.

SEWAGE.

We are now in a position to return to the consideration of what sewage actually is.

As it flows in the mains of a modern drainage system it is composed of the discharges from water closets, the liquid waste of kitchens and laundries, the drainings of butcher shops, slaughter houses, markets, stables and manufactories; and, where surface water is admitted, the refuse from streets, backyards, etc. These substances are mixed with a varying quantity of water, which is usually at least as great as the ordinary water supply; so that in spite of the great variety of waste materials which it contains, it is, when fresh, a comparatively innocent looking liquid, cloudy or milky in appearance, but without any particularly disagreeable odour. It is, in fact, dirty water, which contains, partly in solution, and partly in suspension, a certain quantity of organic matter derived immediately from many different sources, but ultimately formed in the manner already described.

The problem of sewage disposal is then the problem of so treating this organic matter, as to destroy it, or render it incapable of offence.

In the diagram "freshly dead organic matter" is shown just to the right of the vertical centre line. As we have seen, it consists almost entirely of the four elements, carbon, hydrogen, oxygen and nitrogen, combined in a great variety of ways. As we have also seen, it is this complicated arrangement of the atoms, and the relatively small proportion of oxygen, which constitutes the difference, from a chemical point of view, between organic matter and the simple inorganic substances from which it was built up.

The following table (1) by Dibdin shows the actual character of six typical organic substances:—

TABLE I.

SUBSTANCE.	PERCENTAGE OF			
	NITROGEN.	HYDROGEN.	OXYGEN.	CARBON.
Gelatine..........	18.3	6.6	25.1	50.1
Chondrine.	14.4	7.1	29.4	49.1
Albumen..........	16.0	7.1	22.0	53.0
Cellulose (woody fibre)	....	6.2	49.4	44.4
Starch...........	....	6.2	49.4	44.4
Fat, stearic acid...	....	12.7	11.3	76.0

Compounds, like the first three, containing nitrogen, are characteristic of organic matter of animal rather than of plant origin, and are capable of more offensive decomposition. They all contain oxygen, but in relatively small proportions, as will be seen by referring to the chemical formulae of the inorganic substances from which they are derived. The additional amount, which is required to completely oxidize the carbon, hydrogen and nitrogen, is given in table II. which follows (also by Dibdin).

TABLE II.

Pounds of oxygen required to oxidize every 100 lbs. of substance:—

Substance.	OXYGEN REQUIRED.				Oxygen already present	Difference or additional Oxygen, required for complete oxidation of substance.
	By the Nitrogen	By the Hydrogen	By the Carbon	Total Required		
Gelatine....	52.3	52.8	133.3	238.4	25.1	213.3
Chondrine.	41.1	56.8	131.0	228.9	29.4	199.5
Albumen....	45.7	56.8	141.4	243.9	22.0	221.9
Cellulose....	....	49.6	118.4	168.0	49.4	118.6
Starch...........	....	49.6	118.4	168.0	49.4	118.6
Fat, stearic acid..	....	101.6	202.5	304.1	11.3	292.8

The small proportion of mineral matters present in these substances is of no importance in this connection, and may be disregarded.

This table shows that the proportion of oxygen in fat, for instance, is so small that nearly three times its own weight of oxygen is required for its complete oxidation. Considering the fact that five cubic feet of ordinary air contains about one cubic foot of oxygen, the above table will give some idea of the quantity of air necessary in some of the purification processes to be presently described.

The complex molecular structure of these organic compounds produced in the processes of deoxidation, has been obtained at the expense of stability, and this implies the existence of a continual tendency towards a re-oxidation of the elements whenever the combinations in which they may be held are broken up. How to produce this in the most direct and economical manner is the object to be aimed at in any system of sewage purification.

If the temperature of an organic substance is raised to what is termed its *kindling point*; in other words, if it is set on fire, the oxygen of the atmosphere will combine with it, and in this manner its oxidation will be accomplished,—the liberated energy manifesting itself in the form of heat. If certain chemicals are brought in contact with it, such as the permanganates, oxygen is set free in the nascent condition, and will combine with it, and so bring about its complete oxidation. Such violent methods are, however, impossible or difficult to accomplish on any considerable scale, as well as uneconomical. Though, in a sense, accomplishing the same object, they are obviously entirely different in method from the mild and equable processes which nature has provided for the removal of the vast quantities of animal and vegetable wastes which are produced from year to year.

BACTERIA.

These natural forces, which can bring about the oxidation of organic matter even more effectively than those of heat or chemical energy, exist in the bodies of the smallest and humblest of living organisms. These are the bacteria, or microbes, or germs, as they are variously called, which exist in the surface waters, in the air, in the upper layers of the soil; in fact, wherever they are needed. They are of the very simplest structure, consisting of but a single cell, and are of almost inconceivable minuteness. A faint idea of this may be obtained from the fact that a sphere 1-25 of an inch in diameter could contain 500 millions of the larger ones, and it would take more than a thousand of them, placed in a row, to reach across the diameter. Yet, they have been studied and classified into hundreds of different species, whose habits of life, characteristic products, form, etc., are now well known. While individually insignificant, it is only necessary to consider the enormous quantity of waste material which they are constantly disposing of in order to see how important are the results of their aggregate action.

In shape they are spherical (the *cocci*), rod-shaped (the *bacilli*), spiral-shaped (the *spirilla*). That they may exist in a flourishing and active condition, certain attendant circumstances are necessary, such as presence or absence of air or light, a certain degree of warmth, moisture, etc. As we shall see, they constitute to a great extent the "forces of nature," which the engineer engaged in the problem of sewage disposal must "direct to the use and convenience of man." Other facts relating to them which are of importance in this connection, are as follows:—They are possessed of enormous vital activity, and in the presence of dead organic matter and other favorable conditions, are capable of multiplying with almost incredible rapidity, so that their action is to a certain extent, automatically adjusted to the amount of work they have to perform. It was at first doubtful whether they should be classified as plants or animals; but it is now definitely decided that they belong to the class of colourless plants. They reproduce by fission,—a simple process by which a single bacterium divides itself in the middle, thus producing two. An exceedingly small proportion of them, which includes the pathogenic or disease-producing germs, are *parasitic*,—that is, they exist upon or in the body of a living host. But the great majority are *saprophytic*, which means that they live upon dead and decaying organic matter. A few species are able to exist either as saprophytes or parasites, and are called *facultative*.

Another classification depends upon their ability to live in the presence or absence of free oxygen, e. g.:—

1. *Aerobic*, requiring the presence of oxygen.
2. *Anaerobic*, unable to exist in the presence of this gas.

Facultative anaerobes, which occur in sewage in large numbers, can live either with or without oxygen.

By their methods of obtaining their food, or by the products of their life and action, the saprophytic bacteria—aerobic and anaerobic—are enabled to break up the complex molecules of organic compounds into simple ones, and ultimately bring about their complete oxidation. The process is a gradual one, and is accomplished in successive steps by different groups of bacteria, many of which can act upon the organic matter only when it has been transformed by passing through certain preparatory processes, which have been effected by other groups. It is by reason of this consequent division of the work, together with the fact that the chemical products of one species are often inimical to the life of another, or even to its own when greatly accumulated, that it is possible to modify and largely intensify their action by a certain degree of artificial regulation and control.

DECOMPOSITION.

The process may be followed with the aid of the diagram, but it must be remembered that it is a very intricate one; and that, therefore, it is possible to show only the most important of the changes which take place, and the order in which they occur.

If the waste material (freshly dead organic matter) is exposed to the atmosphere under such circumstances as will permit all parts of it to have free access to the air, it is immediately attacked by numerous members of the aerobic group of bacteria, which, if other conditions are favorable, thrive and multiply with great rapidity. Besides obtaining the means of supporting their own existence, they cause, by their action in doing so, a breaking up of the chemical combinations of the organic substances, whereby the oxygen of the atmosphere is enabled to combine with the carbon of the compound, producing carbonic acid gas. The oxidation of carbon leaves the nitrogen and hydrogen to unite in the form of ammonia, or of various ammoniacal salts.

This process, the intermediate steps of which are very complicated, and imperfectly understood, is indicated in the diagram by the outer path connecting "freshly dead organic matter" with "ammonia, etc." If the supply of oxygen is not interrupted, a further oxidation of this "ammonia" will take place, the hydrogen to water, and the nitrogen to nitrites and nitrates. This is brought about by means of other species of aerobic bacteria belonging to what is called the nitrifying group. Some of these (the nitrous organisms) can thus change ammonia (NH_3), into nitrous acid (HNO_2), while others (the nitric organisms) complete the oxidation to nitric acid (HNO_3). These acids combine with any bases present, such as soda, potash, lime, etc., to form nitrites and nitrates. This oxidation of the nitrogen of ammonia is known as "nitrification," and is thus the work of certain specific organisms. It has been studied very carefully in connection with the experiments on intermittent filtration of sewage, made by the Mass. Board of Health, the results of which are very fully set forth in its report. Its action, shown by the production of nitrates, appears to proceed to a certain extent coincidentally with the oxidation of the carbon, and is very susceptible to temperature conditions, the supply of oxygen, overworking of the filters, and other circumstances. The nitrates, which, with the water and carbonic acid, represent the final products of this whole process of decomposition, are purely mineral substances, completely oxidized and entirely without energy. These operations, therefore, represent the complete destruction of organic matter, by its successive conversion into substances of less and less complexity of structure, but of greater and greater stability, until it is finally resolved into the water, carbon, dioxide, and nitrates out of which it was originally built up, and in which form it is again available for use in the structures of other plants and animals.

These operations, which are truly as old as the hills, have always been familiar to us, though until very recently entirely misunderstood. The changes taking place were thought to be purely chemical, and brought about by mere exposure to the air, or, as in the case of the rapid disappearance of manures in cultivated lands, by the action of the growing plants, and of the soil itself. This view is now known to be entirely incorrect, and it has been repeatedly shown that, however abundant the air supply, no decomposition can take place without the presence of bacteria. On the other hand, as we shall presently see, certain of these micro-organisms are able to set up a process of decomposition in organic matter, and even produce a certain amount of oxidation, under circumstances where air is carefully excluded.

PUTREFACTION.

It is decomposition under such conditions as these which we shall next consider. The breaking up of the organic compounds is now brought about by various species of the anaerobic bacteria, which find in the exclusion of air and light just the conditions necessary for their development. Their action does not proceed with the same outward simplicity as that of the aerobes, but is accompanied with the production of offensive odours, noxious gases, and other disagreeable manifestations characteristic of what is termed putrefaction.

It is this kind of decomposition that goes on in organic deposits at the bottom of stagnant pools, in cesspools and the like,—and wherever nitrogenous organic matter is prevented from having access to air. Even where the decomposition is to outward appearance entirely aerobic, the preliminary disintegration which enables the air to get free access, must often be of this nature.

The chemical changes are entirely different from those taking place in aerobic decomposition. Certain species of the anaerobes have the power in the presence of organic matter of de-nitrifying nitrites and nitrates,—that is, deoxidizing them. When the circumstances are favorable to such action the nitrogen is set free as nitrogen gas, while the oxygen attacks the organic matter, bringing about the formation of carbon dioxide and other gases. The chemical changes are at first, however, especially in the case of sewage, of the nature of what the chemists term *hydrolysis*, or the breaking up of organic compounds by the action of water. This action often results in the liquefaction of refractory and otherwise insoluble substances, like fibrin or cellulose, which process is accompanied by the formation of many gaseous compounds of carbon, hydrogen and nitrogen. These, and many other chemical changes, which take place according to the attendant circumstances, are described in detail by Dr. Samuel Rideal in the Journal of the Society of arts.* Referring to the anaerobic decomposition of the organic matter in sewage, he says:—"Very similar changes, mainly hydrolytic, are accomplished by the large class of organic substances called 'enzymes,' which, though not living, are products of animal and vegetable life. . . . Their importance to us is shown by the fact that a large number of them are the products of the bacteria or other fungi, and are powerful agents in their resolving action. By their means a bacillus is not only able to act in its immediate neighbourhood, but also at a considerable distance, through the soluble ferments it forms and disengages."

As indicating the complex nature of the process his chemical classification of the "fermentations which occur in the first or hydrolytic part," is quoted as follows:—

"1. The solution and decomposition of albuminous bodies.

"2. The fermentation of urea.

"3. The fermentation of amido-compounds formed from the albuminous bodies.

"4. The formation of organic acids and the fermentation of their salts.

"5. Cellulose or methane (CH_4) fermentation.

"6. The hydrolysis of carbohydrates (sugars, fats, etc.).

"7. The formation of small quantities of sulphur compounds, like H_2S, mercaptan, etc. This from the odour of the products often attracts the most attention."

This process is indicated in the diagram by the first part of the inner path connecting "freshly dead organic matter" with "ammonia, etc." It takes place very rapidly, as compared with purely aerobic processes, and results in a very considerable reduction in the amount of organic matter, in the formation of volatile gases, etc. Though the changes which have taken place are in the right direction, the process of decomposition is as yet very incomplete. Many of the resulting products are highly offensive in character, but the solid portions have been largely liquefied, and otherwise altered so as to bring them into a condition which renders them readily oxidizable.

If, now, in the natural course of events, or by artificial means, air is brought in contact with them, the volatile gases will be dissipated, and gradually the aerobic bacteria will take up the work and carry it on, as shown by the diagram, to the points where nitrification

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*Vol. XLVI, p. 81, Dec., 1897, and Vol. XLVII, p. 683, Jan., 1899 (Cantor Lecture) begins; which, with the final oxidation of the nitrogenous and carbonaceous residues of the previous processes, proceeds in much the same way as that already described in connection with aerobic decomposition.

The two processes outlined above, though beginning under opposite conditions, and proceeding in an entirely different manner, achieve in the end the same result, viz., the destruction of organic matter by its conversion into stable, gaseous and mineral substances. They are nature's methods, and have been in operation over the surface of the earth since the first appearance of life upon it.

Under conditions of abundant aeration they are without any disagreeable or other noticeable features. Where the air has no access, putrefaction takes place, and when complete and efficient drainage systems were first constructed, it was this tendency of the sewage to putrefy when discharged broadcast into relatively small streams which created the demand for its purification. Ignorance of the true nature of the processes involved led to many attempts to accomplish this by purely artificial means, but experience has shown, that these efforts to supplant nature on such a large scale have always resulted in practical failure.

Since that time the investigations of the biologists have shown the reasons why they have failed, and at the same time have led to the discovery and employment of methods which are proving successful, because, by providing the most favorable conditions and removing or holding in check those which operate adversely, they assist nature in every way; the result being that purification takes place at many times the rate possible when not thus controlled. To this extent only are such methods artificial.

CHEMICAL ANALYSIS.

Before proceeding with a description of these methods, we must refer to the subject of the chemical analysis of sewage; because it is by means of it that it is possible to follow the progress of purification, to compare the working of different processes, to determine their efficiency by testing the effluents, and to discover, when these are not satisfactory, at what stage or in what way the process is going wrong.

The principal determinations in a chemical analysis are given under the following heads:—

1. Appearance.
2. Total Solids or Residue on Evaporation.
3. Loss on Ignition.
4. Chlorine.
5. Albuminoid Ammonia.
6. Free Ammonia.

7. Nitrogen as Nitrites.
8. Nitrogen as Nitrates.
9. Oxygen absorbed, or consumed.

Under "Appearance" are noted the turbidity, colour, etc., which are expressed in terms of some standard, depending upon the method of observation.

The amount of the total solids is obtained by evaporating a portion of the sewage to dryness, and weighing the residue. The latter will be partly organic and partly inorganic. By carefully heating it to a low red heat a portion of it will be driven off in the form of gases. The remainder is weighed, and is called the "fixed residue," while the part which passes off is called the "loss on ignition." The amounts indicate roughly the relative proportion of the inorganic and organic matters respectively. Sometimes the sewage is first filtered, and the above determinations made separately for the "dissolved" and "suspended" matters.

Common salt is one of the characteristics of domestic sewage, and it is very largely from it that the "Chlorine" in the analysis is derived. It is thus a measure of the strength of the sewage, and is useful in determining the identity in this respect of a sample of a putrified effluent with the original sewage.

The most important information, however, which a chemical analysis furnishes, with regard to the relative purity of sewage, and effluent, and of the manner and rate at which the process is taking place, is that given under the next five headings,—"Albuminoid Ammonia," "Free Ammonia," "Nitrogen as Nitrites and Nitrates," and "Oxygen Absorbed."

We recall that organic matter is composed almost entirely of carbon, hydrogen, oxygen and nitrogen, combined in various ways, and produced by the agency of green plants by processes of *deoxidation*; and that, therefore, the reverse process of decomposition is one of *oxidation*, requiring a supply of oxygen from external sources, taking place in a variety of ways, but always depending upon the activities of the bacteria. Also that the result of the first step, is the oxidation of carbon, and the formation of various compounds of nitrogen, such as ammonia, ammoniacal salts, etc.; and that then other bacteria bring about the oxidation of the nitrogen also, forming first nitrites, and lastly nitrates, which are mineral substances, and capable of no further oxidation.

If water or sewage containing organic matter in process of decay, is boiled, the ammonia which has been produced, either in the free form, or as salts, will be driven off, and may be obtained by distillation. The amount (which is given in the analyses as "Free Ammonia") is thus a measure of the extent to which the first step in the decomposition has taken place. The nitrogen of *fresh* organic matter may also be obtained in the form of ammonia if it is boiled in an alkaline solution of permanganate of potash. The quantity of ammonia obtained in this way, after the "Free Ammonia" has been driven off, is given in the analysis as "Albuminoid Ammonia." It is thus a measure of the amount of organic matter present, which has not yet begun to decay, and it is thus shown in the diagram. A decrease in the amount of albuminoid ammonia with a corresponding increase in that of free ammonia would indicate progress in the first stages of purification.

The amount of nitrogen present in the form of "Nitrites" is determined, and, being so given in the analysis, represents the beginning of the oxidation of the nitrogen, and hence further progress in decomposition, while the "Nitrates" represent the completion of the final step in the process of purification.

There is another determination which is useful in ascertaining the degree of purification, viz., the "Oxygen absorbed." This is obtained by treating the sewage with an acid solution of permanganate instead of an alkaline, as in obtaining the amount of albuminoid ammonia. The oxygen of the permanganate attacks the organic matter, and combines with the carbon. The total quantity of oxygen so absorbed in a given number of hours, is measured, and will be greater or less in proportion to the amount of unoxidised organic matter present. Since in this process the oxygen given up does not combine with the nitrogen, the "Oxygen absorbed" will correspond to the carbonaceous organic substances rather than to the nitrogenous, which are represented by the albuminoid ammonia. The refuse from manufactories often contains mineral substances, which absorb oxygen very readily. In such cases the "Oxygen absorbed" would be no indication of the quantity of organic matter. The determination is of greatest use in comparing the quality of an effluent with the raw sewage. The percentage reduction in the "Oxygen absorbed" will be then a measure of the degree of purification, which latter is usually thus stated, in terms of either the "Albuminoid Ammonia," or the "Oxygen absorbed," or both.

Under ordinary circumstances, pure water contains a certain amount of atmospheric oxygen in solution. If decaying organic matter is mixed with it, oxidation would take place, provided the bacteria were present, at the expense of the dissolved oxygen, and hence the diminution in the amount and the rate would furnish some information as to the condition of the organic matter, and the changes taking place in it. In watching the progress of purification, therefore, the determination of the amount of "Dissolved oxygen" is often of great importance.

In making the Manchester experiments, which will be referred to further on, an "Incubator Test" was employed to test the quality of the sewage effluents, canal water, etc. It is thus described in the experts' report:—

"A very valuable indication of the degree of impurity of any sewage or effluent is afforded by the so-called incubator test. To carry out this test a determination is first made of the oxygen absorbed from potassium permanganate by the sample in three minutes. A bottle is then completely filled with the sample and closed, and placed in the incubator at 80° Fahr. for six or seven days. The three minutes' absorption is then again determined. If any putrefaction has taken place, the oxygen absorbed in three minutes will exhibit a decided increase in amount, owing to the more ready oxidizability of the products of putrefaction, such as sulphuretted hydrogen, etc. On the other hand, if the sample keeps sweet, the three minutes' absorption remains practically unchanged after incubation, or there will be a slight decrease, owing to slight oxidation of the impurities which has taken place during the period of incubation at the expense of the nitrate or dissolved air present in the sample."

In the Diagram (A) the determinations "Albuminoid Ammonia," "Free Ammonia," "Nitrites" and "Nitrates" have been placed so as to indicate as nearly as possible the various stages in the process to which they correspond. The "Oxygen absorbed" is placed where it is, because the fresher the organic matter the higher will be the amount.

The above determinations furnish the means by which the action of sewage purification processes are tested and compared, and are therefore of the greatest importance; but unless care and judgment are exercised in collecting representative samples for analysis the results may be without value, or entirely misleading

We are now in a position to refer briefly to the various methods which have been devised since the necessity for sewage treatment first became evident, to accomplish that end, and to describe the principal features of those which, being based on true principles, have proved their practicability and efficiency.

ARTIFICIAL DISPOSAL.

After the report, in 1870, of the Royal Commission, mentioned above, a very great number of methods were invented, most of which were based on the idea that the process of decomposition was purely chemical, and could therefore be effectively promoted and carried through by methods entirely artificial. It was also thought that substances incidentally produced would have high fertilizing qualities, and that, by utilizing them as manures the purification of sewage might be carried on without cost, or even at a profit.

The extreme variety in the nature and condition of the organic matter in sewage, and the large proportion of water, rendered any process which aimed at its oxidation solely by chemical means while thus diluted, entirely impracticable. The same may be said of attempts in the direction of disinfection or sterilization, with the object of arresting decay, or rendering the products innocuous. Chlorine in various combinations was used for this purpose, principally in the form of chloride of lime or bleaching powder. The so-called electrolytic processes are of this nature. By electrolyzing a mixture of sewage and sea-water, or a solution of common salt, a result is produced similar to that of the action of bleaching powder. The oxidation produced, which is limited, is due to the nascent oxygen set free by the action of the chlorine in decomposing water. The Webster process of England, and the Hermite of France, are among the most important of these processes.

The effluents from such processes are very imperfectly purified, and the germicidal action is a direct hindrance to the work of the bacteria, which must ultimately complete the decomposition.

CHEMICAL PRECIPITATION.

The chief difficulty in any method of treating sewage is with the "sludge," or the portion composed of the solid matter, and the larger and heavier of the suspended particles, which tend to separate from the rest by subsidence. Those chemical processes which have survived the experimental stage had for their object the production of a clear effluent by the removal of the sludge, and as nearly as possible all of the suspended matter. This was effected by mixing certain chemicals with the sewage, and running the mixture into large tanks, where it remained long enough to permit of the precipitation of the suspended matter. A great number of chemicals have been employed for this purpose, which accounts for the hundreds of patents granted at the time these methods were first being tried, but experience has shown that lime and sulphate of aluminum or sulphate of iron are the most satisfactory from the point of view of economy and efficiency. In the settling tanks the action of these chemicals upon certain substances always present in sewage, and upon each other, results in the formation of insoluble flocculent precipitates, which, as they fall, entangle and carry down with them almost the whole of the suspended matter. There is very little reduction, however, in the quantity of dissolved substances, so that the effluent liquid, which is drawn off from above, while clear, still contains nearly half the organic matter of the raw sewage, which is subject to putrefaction, and which must still pass through the various processes of decomposition before it can be said to have been purified. Of course, such an effluent is much less liable to cause a nuisance when discharged into a stream than the raw sewage, and the quantity of organic matter being reduced by a half, it may often be discharged with safety into a much smaller stream. But the large quantity of sludge from the bottom of the tank has yet to be disposed of, and it is here that the great objection to chemical precipitation exists. It also is subject to putrefaction, though the process has been hindered by the destruction of a great number of the bacteria. But their destruction is not complete, and they soon reassert themselves, so that the sludge soon becomes very foul. It still contains a large proportion of water, and is thus very difficult to deal with. Sometimes this water is partially removed by filter presses, or by allowing it to drain away and evaporate in shallow sludge basins, or on gravel filter beds. The remainder is sometimes used as manure, either as it exists, or after being mixed with other material to improve its quality. It has been used with clay to form cement and bricks. Often the sludge is taken directly from the tanks and spread over large areas of loose soil into which, when dry, it is ploughed. The manurial value is low, since the fertilizing elements in sewage are largely in solution. In London and Manchester it is pumped into tank steamers and carried out to sea. In adition to the difficulties in conducting the process, such as properly proportioning the quantity of chemicals to the varying strength and character of the sewage, the disposal of the sludge is always an expensive matter, not to speak of its disagreeable features. Besides this, in many cases the effluent does not satisfy the local requirements as to purity, and has to be further treated by irrigation or some other process in which the bacteria—the true purifiers—are enabled to act. Hence, in the light of what is now known of the true processes of decomposition, it is evident that the treatment of sewage by chemical precipitation is not a process of purification at all, but merely a separation of it into two portions, both of which are still to be disposed of.

Nevertheless, a great number of such plants have been built in Europe, chiefly in England; and a few in America. In nearly every case they have proved unsatisfactory, and have been abandoned, or are being abandoned in favour of processes which work with nature instead of against her. An excellent example of such a plant, both as to construction and operation, is that of the Worcester, Mass., sewerage system. The reports of the department contain much detailed information as to efficiency, cost, management, etc.

SEWAGE FARMING.

Another method that was early employed with the object of disposing of sewage, and at the same time obtaining a return from its manurial qualities, is known as Broad Irrigation, or Sewage Farming. This is to a certain extent a natural method, and consists in applying the sewage to large areas of cultivated land, in such small quantities that the supply of air in the pores of the surface soil is always sufficient for the conversion by the bacteria of the organic matter to inorganic, in which form it is available for plant food. The action is thus chiefly aerobic. Unless the subsoil is very porous the surplus water must be removed by under-drainage.

With favourable soil, and careful and intelligent management, the method is satisfactory. Some of the difficulties connected with it are the tendency of the particles of sludge to choke up the surface; the variable needs of the crops for water depending on the rainfall, the season of the year, etc., the effects of frost and snow; and the tendency to become at times a nuisance to people living in the neighbourhood, even at a considerable distance. It requires large areas of land often very expensive or impossible to obtain; but when well and carefully managed, it is a decided success as a purifying process.

It was at first undertaken with the idea that plant life of itself was capable of decomposing the organic compounds contained in sewage. Later, however, it was discovered that they had nothing to do with it, and could make no use of these materials until the decomposition had been first brought about by the bacteria. Still it was thought that such soil, teeming as it is with bacterial life, would be the best material to employ. But it was soon found out that quartz sand or any such porous material would acquire the same purifying power simply by dosing it with the sewage for a period of two or three weeks. Not only that, but the amount which it could purify in a given time was found to be very much greater.

INTERMITTENT FILTRATION.

The sand itself has no purifying power, but the sewage comes laden with bacteria which find on the surface of the sand grains an extensive area upon which to establish themselves, the air in the spaces between the grains supplying them with the necessary oxygen. If the application of the sewage is continuous, this air is soon used up, and then purification becomes very imperfect, putrefaction ensues, and the sand becomes foul and choked up. But if the sewage is applied intermittently, it draws in after it, as it sinks, a new supply of air, which becomes available for the next dose, and so on. Worked in this way, the arrangement is called an Intermittent Filter. It is not a filter at all, of course, since when properly working the action is entirely biological; that is, carried on by living organisms. It is shown on the right side of diagram A, beginning with decomposition by aerobic bacteria, and ending with the completion of nitrification. The degree of purification under favorable circumstances cannot be surpassed, the effluents from the under drains of the "filter beds" being often chemically purer than many domestic water supplies. In practice the area is divided up into beds, upon any of which the sewage may be turned at will, from the distributing pipes or channels, which are placed in the embankments separating the beds. Under-drains at a depth of four or five feet collect the purified effluent. In some exceptionally favourable situations, where the subsoil is coarse sand and gravel, and near a valley or depression, the natural underdrainage is sufficient.

With good material as much as 100,000 gallons per acre per day can be purified. If much more than this is applied, even under the best conditions, the capacity of the bacteria will be overtaxed. and an imperfectly purified effluent will be the result. In most cases, however, the amount per acre is very much less than this, on account of the inferior nature of the material usually available, and by the choking of the surface by sludge.

The heaviest and coarsest portion of the suspended matter is usually removed by screening and simple subsidence for a short time in small tanks. The rest can usually be disposed of by the beds, if they are not overworked, and if the surface is dug over and loosened up when signs of clogging appear. The surface should be ridged and furrowed before cold weather, so as to allow the ice which forms to rest upon the ridges, roofing over the hollows, and preventing the sewage from freezing. Crops of vegetables are often grown upon the beds successfully. This is not a part of the purification process, and is therefore of secondary importance.

Intermittent filtration is therefore in accordance with the methods of nature, and the comparatively high rate at which these filter beds may be worked, is obtained, 1st, by selecting material the most favourable for the action of the bacteria; 2nd, by applying the sewage so as to always maintain a sufficient air supply; 3rd by removing the coarse solids, etc., from the sewage before it is turned on the beds; 4th, by careful personal attention to the working of the plant and prompt correction of any wrong tendency as soon as it appears. In principle, however, it is an aerobic process, and therefore does not provide adequately for the disposal of the sludge. This is usually, when it is settled out, run on to sludge beds, where, after drying, it is composted or otherwise disposed of. The amount requiring such treatment is, of course, much less than that from a chemical precipitation plant. Nevertheless, it may become a nuisance to the neighbourhood, and will necessarily accumulate during cold winter weather; so that the lack of provision for it constitutes a defect in the system, though a comparatively slight one, when its superiority to the majority of other systems in use is considered. The advisability of employing it depends largely upon the existence of suitable material, since, on account of the great area necessary, it would be a very expensive matter to construct such beds of material transported from a distance.

In the State of Massachusetts, for instance, this method is in favour because suitable material is available in nearly every locality. The beds are prepared by stripping off the surface soil and levelling up the beds of sand and gravel thus exposed. On account of the prevalence of these favourable conditions, the experimental work of the Board of Health experts has been largely with this method of purifying sewage. In England, on the other hand, clayey soils predominate, and hence neither intermittent filtration nor sewage farming have been very successful. Land treatment of the effluents from chemical precipitation plants is not uncommon, and it is required at the present time by the Local Government Board for those of the Bacterial Systems to be referred to presently. Hence, in England, particularly during the last ten years, many investigations and experiments have been made upon the purifying action of other material than sand, such as coke breeze, cinders, ashes, burnt clay, etc. The object was to discover some method by which these materials could be utilized to purify the sewage at such a rate as would keep the first cost within reasonable limits. Such experiments have been carried on by the Main Drainage Committee of the London County Council at Barking and Crossness, and by the authorities of Sutton, Exeter, Leeds, Sheffield, Manchester, Birmingham, and other places. These investigations, which have been watched with the greatest interest by the many other places with similar problems to solve, have been remarkably successful, and have resulted in the discovery of more than one system in which the whole of the sewage,—not the finer and liquid portions only, but the sludge as well—may be purified from first to last by natural processes and at a comparatively low cost.

NEW BACTERIAL METHODS.

The distinguishing feature in these processes is the recognition of the work of the anaerobic bacteria, whose development and activity depends upon the exclusion of air and light. In other bacterial processes constant and abundant aeration is provided to as great an extent as possible. The aerobes, which develop under these encouraging conditions are very effective in purifying the organic matter in solution, but are less successful with even the finer matter in suspension, and fail altogether to deal with the larger solids and such substances as paper, rags, strings, etc., which must be separately disposed of. By the new methods, however, it is shown that this separation is not necessary if the whole of the sewage is first worked over by anaerobic bacteria. The result of their action is to bring the organic matters, solids as well as liquids, into such a condition that they can be readily disposed of by the subsequent action of the aerobes, and at a much greater rate. In so doing they furnish the best solution so far known of the difficult problem of the disposal of sludge.

When sewage is first discharged from the houses, streets, etc., into the sewers, it contains a considerable amount of dissolved oxygen. During the time the sewage is flowing through the mains toward the outlet, the aerobic bacteria, in the presence of the oxygen, begin their work of decomposition, which, as we have seen, results in oxidation of carbon and the formation of ammoniacal substances. This action will proceed until the dissolved oxygen is all used up, which it soon will be, but in the meantime very little putrefying action will have taken place, and that is the reason why the sewage in the pipes of a well-designed system is comparatively free from offensive odours. Chemical analysis would show during this period a slight decrease in the albuminoid ammonia, with an increase in the free ammonia, and perhaps in the nitrates. When the oxygen is exhausted, anaerobic action begins, resulting, as we have seen, in the breaking down and liquefaction of a portion of the solids, and the production of various gases, some of them very foul-smelling. This action will sometimes have begun before the sewage reaches the outfall, the degree of which has taken place depending upon the length and inclination of the mains.

The fact of the disappearance of the solids in sewage under circumstances in which aeration is impossible, was known many years ago. About twenty years ago there appeared in the French *Cosmos les Mondes* references to what was called the "Mouras Automatic Scavenger." This was described as consisting of a closed vault with a water seal, in which all the excrementitious matters were rapidly transformed into a homogeneous fluid; and it was stated that in time kitchen refuse, onion peelings, paper, etc., also dissolved and disappeared. It was said to be automatic in action, and to have been in operation for twenty years.

In 1870 Frankland experimented on London sewage by causing it to flow continuously upward through sand, and his analysis of the effluent showed a considerable liquefaction of the suspended solids as well as a reduction in the total quantity of organic matter. But as the cause of such action was not understood (though suggested in the description of the Automatic Scavenger), and the effluent so much fouler than the fresh sewage, and still in need of treatment, little interest was aroused at the time.

SCOTT-MONCRIEFF METHOD.

In 1891, Mr. Scott-Moncrieff constructed at Ashtead, in England, a bacterial tank, in which the crude sewage was admitted from below and made to pass gradually upward through a bed of stones. The reports of the chemists who examined it showed it to be capable of liquefying the solids of the sewage passing through it, and of causing incidentally a disappearance of a portion of this in the form of gases. The effluent from this tank, of course, contained a large quantity of matter in solution, but in a condition which rendered it readily oxidizable. By alternating periods of rest and use, Mr. Moncrieff tried to complete the decomposition by bringing about the oxidation of the result of the anaerobic liquefaction, but without much success. Later, after it became evident that the preliminary anaerobic action and the subsequent oxidation were entirely separate processes, he perfected his system by causing the effluent to pass through layers of coke placed vertically over one another, with intervals of about three inches between. The layers are nine inches thick, and the coke is broken to a diameter of one inch. By this means the bacteria corresponding to the different phases of the oxidation processes are kept separate from each other, and a remarkable degree of purification is the result.

The system is said to work satisfactorily at rates of from 500,000 to 1,000,000 gallons per acre of coke bed per twenty-four hours. The cost of construction must be considerable, and obviously it requires protection from cold, which would add to the expense and prove a serious objection to its use in many places.

CONTACT BEDS.

Another bacterial system which includes the destruction of the bulk of the sludge is known as the Bacterial or Contact Bed System. This method was developed by W. J. Dibdin, while conducting experiments for the London County Council, the town of Sutton, and other places. The average flow of sewage at Sutton is about 500,000 gallons per day, and chemical precipitation with subsequent land treatment was the method of disposal employed. This proving unsatisfactory, Mr. Dibdin was engaged in 1896 to advise with regard to the construction of a bacterial system. The methods suggested by him have proved successful there, as they have since in several other instances. In the short description which follows, the plates and photographs of the Manchester experimental plant will be used to illustrate the method of working. The materials used in constructing the tank as well as that used in filling it, vary considerably, but their mode of action is the same.

The beds are constructed and worked in pairs in the Double Contact System, the sewage passing first through one and then the other, which must thus be at a lower level. The rate of inflow and outflow is controlled by valves, sometimes worked automatically.

The depth of the filtering material is in each case usually about three and a half feet. In depressions in the bottom of the tank are perforated pipes for draining off the filtrate, which, by an arrangement of the outlet, remain full after the bed is emptied. Immediately around these pipes coarse material is placed, but the material in the body of the bed is usually of uniform size. The upper of the two beds is the coarser. The general arrangement is shown in Diagram 1.

The sewage is first to be passed through a revolving self-cleaning wire screen, which removes rags, paper, etc., and the "grosser solids." It should, especially if from a combined system, be also made to pass through a small detritus or sand tank, which intercepts heavy matters, such as sand, gravel, etc., which do not require treatment, and would choke the bed. It is then run on to the first or coarse bed, called sometimes the "roughing" filter. The method of distributing the sewage uniformly over the surface of this bed is a matter of considerable importance in the case of large beds. When the bed is filled to within a few inches of the surface, it is held so for two or three hours, or for a time depending upon the rate at which the system is to be worked. This period of "resting full," during which the sewage is in "contact" with the surfaces of the filling material, gives the system its name.

The outlet valves are then opened, and the bed is emptied at any desired rate. It is then allowed to rest empty for a definite period, at the end of which the process is again repeated. The time of a complete cycle thus includes the time of filling, resting full, emptying, and resting empty, and depends upon the number of complete cycles to be made in twenty-four hours. This is usually not more than three or four at most. At regular intervals of a week or longer the beds are left empty for a whole day. The process taking place in this coarse filter, especially when standing full, is largely anaerobic, as shown by chemical analysis of the effluent. The sludge disappears in the beds, and does not accumulate, being broken down and liquified by bacterial action. The completion of the process,—the oxidation of the effluent from the coarse filter, is accomplished by the second or finer bed. When the coarse bed is emptied, the effluent is run into the fine one, which is worked in the same way as the first. The organic matter being in a suitable condition, the process here is chiefly oxidation by the aerobic bacteria.

The effluent from this bed has a good appearance, is free from all objectionable odour, and keeps perfectly sweet in open or closed vessels.

The percentage purification shown in the Sutton experiments is given by Dr. Rideal as follows:—

	Oxygen Absorbed.	Free Ammonia.	Albuminoid Ammonia.	Suspended Matter.
By the coarse bed..	53	69	47	94.0
By the fine bed....	29	21	25	4.4
Total purification.	82	90	72	98.4

A third bed of still finer material may be added, if a higher degree of purification is desirable, which will rarely be the case.

The filtering material may be coke, clinker, broken stone, broken bricks, burnt clay, slag, ashes, etc., according to the cost, which will vary with the locality. Of these coke seems to have some slight advantage over the others, and is more generally used. At Lichfield coal has been used, with good results. In fact, one of the great advantages of the system is, that material that will serve the purpose can be found in some shape or other in almost every locality. The construction of the tanks need not be expensive. The sides may be sloping, which favours cheap construction. In any case, the beds are usually quite shallow. Experiments have been made with filters as deep as 13 feet, but the tendency seems to be towards three and a half feet beds, and several cycles in the course of 24 hours. The tanks will usually be built of concrete or brick, though one of the Dibdin tanks at Sutton was made in heavy clay by digging a pit about three feet deep, burning the excavated clay, and using it for the filtering material to fill the pit with, after the collecting drains for the effluent had been put in place.

This system requires a fall somewhat greater than the combined depths of the beds, which may in some cases necessitate pumping. The preliminary digesting bed of the Scott-Moncrieff system, on the contrary, requires only the very slight fall necessary to overcome the resistance to the flow through the beds.

The process is not completely anaerobic at any stage, hence the necessity for screening, and also the tendency to loss of capacity from the accumulations among the particles of the bed of fragments of straw, chaff, etc. This reduction of holding capacity proceeds rather rapidly at first, but seems in many (but not in all) cases to finally reach a maximum which is permanent. The time occupied in filling, resting full, etc., the length of the cycle, the length of the interval between the lengthened periods of rest and aeration, vary with the quantity of sewage, the rate of flow, material, etc. The system is already in use in several places, and is working satisfactorily.

Whether such materials as burnt clay, coke, etc., will be permanently effective, and not disintegrate, is yet to be proved.

SEPTIC TANK.

The invention of this system is claimed by Mr. Donald Cameron, city surveyor of Exeter, England. A plant built by him for the disposal of a portion of the sewage of that city has been in operation since 1895. Diagram 3 shows a sketch plan, and Photograph 3 a view of the works.

In this system, as in Moncrieff's, the purely anaerobic part of the decomposition process is kept quite separate from the aerobic.

After passing through a small "grit chamber," which intercepts sand, gravel, etc., the sewage, without further preparation, enters one end of a long, narrow tank, seven or eight feet deep, through which it flows very slowly, finally escaping at the other. In the Exeter plant, this tank is 56 feet 10 inches long, 18 feet wide and 7 feet 6 inches deep. The grit chamber is 7 feet long, the same width as the tank, and 10 feet deep. The sewage flows from this chamber into the tank over a bridge wall one foot below the level of the sewage which is kept constant. The outlet consists of a horizontal slotted pipe extending the width of the tank, and also situated a foot below the surface. The object of this relation of inlet and outlet to depth and width of tank, is to cause as little disturbance as possible to the contents of the tank, and to produce a uniform flow in all parts of it. The rate of flow will be very slight, not averaging as a rule more than one inch per minute. A certain amount of mixing which takes place has the effect of rendering the sewage which escapes from the tank more uniform in quality than when it arrives.

This tank is built of concrete, and is arched over and covered with turf to exclude light and air. The conditions are thus essentially anaerobic, and the process, which has probably already begun in the outfall sewer, is carried on under the best possible circumstances. It does not reach its full intensity for some weeks after being put into use, during which time the bacteria are developing and establishing themselves. The changes which take place are, according to Dr. Rideal, of the nature of the hydrolytic ones already referred to, and indicated by the inner path on the diagram (A), connecting "Fresh Organic Matter" with "Free Ammonia, etc."

In the Exeter tank there is a glass inspection well, from which the action going on in the tank may be observed. When the sewage enters the tank any light fatty matter it contains rises to the surface, while the heavier sludge falls to the bottom. Here there is great bacterial activity. Anaerobic bacteria begin to break down and liquify the solids, liberating various gases, which, appearing as bubbles in the body and on the surface of the masses of faeces, etc., cause them to float to the surface, where they soon form a leathery-looking scum from two to six inches thick, in which the processes of decomposition and liquefaction go on with undiminished activity. The greater part of the solid matter is thus thrown into solution during the slow progress through the tank, but a considerable portion is converted into gas, the bubbles of which, continually rising and carrying up bits of solids from below, keep up a constant mixing of the contents of the tank.

The location of the inlet and outlet prevents the layers on the surface and bottom from being disturbed. The effluent, which is drawn from between them is dark in colour and offensive in odour. It contains more matter in solution, but has lost on the whole a considerable percentage of organic matter,—chiefly matter in suspension. The percentage purification is given by Rideal as 29, measured by oxygen absorbed, and 46 by organic nitrogen removed. Corresponding figures from Dr. Dupre, chemist to the Medical Schools, Westminster, are 63.5 and 27.7. As we have seen, much of this has been converted into gas, largely methane or marsh gas, (CH_4), which renders it inflammable. This is collected at Exeter and used for lighting about the works.

The active decomposition going on at the bottom of the tank prevents the accumulation there of much organic matter. After being in operation for three years, the deposit at the bottom of the Exeter tank had not accumulated to such an extent as to make its removal worth while. When this becomes necessary, it is drawn off through a sludge pipe under the bottom. It is a dark, peaty-looking substance, about one-third organic. It may be used for filling, as the smell is not disagreeable, and it is to outward appearance, very much like ordinary prairie soil.

The surface layer at first increases in thickness, owing to the accumulation of the more resistant materials; but they also finally succumb to the intense bacterial action, and, after that, the depth of this scum, though fluctuating somewhat, remains fairly constant. It is an interesting fact that full bacterial activity may be set up in a new septic tank in a very much shorter time if it is "inoculated" with a portion of the scum from a working tank.

As has been said already, the effluent from this tank has already been considerably purified. The total amount of organic matter has been greatly reduced, and what remains is largely in solution, and in a condition which renders it very easily oxidized. Hence, in some cases, it may be turned at once without further treatment into a body of water. But usually further treatment will be required, and this is provided for in the system by contact beds, into which the effluent from the tank is run after passing over aerating weirs. These beds of the Exeter plant, shown in Diagram and Photograph 3, are each 36 feet long by 20 feet wide, and filled to a depth of 4½ feet with crushed furnace clinker, resting on 6 inches of coarse gravel. In filter No. 3 coke breeze is used instead of clinker. The filtrate is collected by a system of underdrains. The flow through the septic tank is continuous, but the filters are worked in much the same way as the contact beds already described; that is, they are first filled, then held full for a time, then emptied, and after resting empty for a time have the same process repeated. In the Exeter plant the opening and closing of the necessary valves is effected by an automatic arrangement, which causes the beds to act in rotation, thus securing great regularity with very little attention. Some such device is necessary in any system of beds operated in this way.

In these aerobic beds the products of the fermentation which has taken place in the septic tank are acted upon in the presence of oxygen by aerobic bacteria, and a very high degree of oxidation takes place. The total percentage purification effected by tank and filter, as shown by analysis, is as follows:—

Authority.	Albuminoid Ammonia.	Oxygen Absorbed.
Dibdin and Thucidum	63.2	80.9
Dupré	84.9	88.3
Pearman and Moor	80.0	90.0
Perkins	64.4	78.7
Rideal	77.0	82.0

The effluent is clear in appearance, with very little colour, and without any offensive odour. It keeps well without showing any tendency to putrefy, and is said to be quite as satisfactory as that obtained from well-managed sewage farms. An advantage of the system is that there is almost no loss of head in the tank, and that therefore the only fall necessary is that required by the beds.

The three processes described above are the most important of those which separate the process into an anaerobic and an aerobic portion. The order of the operations is shown by the inner path on the left side of diagram (A), the "partial aeration" step corresponding to the changes between the completely anaerobic and oxidizing stages.

There are also the Lowcock, Waring and Ducat processes, which are chiefly aerobic at all stages. The object of these methods is, by bringing large quantities of air in contact with sewage by mechanical means, to enable the filters to be worked continually.

LOWCOCK'S SYSTEM.

In the Lowcock system the beds consist of a bottom layer of coarse coke, a body of coke breeze, and a top layer of broken stone and sand. The air enters at a low pressure through the outlets, which are always kept open. In the plants in operation at present, however, daily periods of rest are said to be found necessary as well as preliminary sedimentation.

DUCAT'S SYSTEM.

In Col. Ducat's system the beds are composed of layers of ¼ to ½ inch vitrified clinker, alternating with thin layers of coarse pebbles. The walls are composed of short lengths of 6 inch drain pipes set in mortar, with an upward tilt towards the outside to prevent the escape of the sewage as it trickles through the bed, and at the same time to provide for its aeration.

WARING'S SYSTEM.

The method devised by the late Col. Waring at Newport consists of a screening tank of broken stone, through which the sewage sinks in one part of the filter and rises in the other, after passing under a dividing wall. This bed removes the coarser suspended matter, which eventually clogs it. It is then thrown out of use, and a current of air from a blower is made to pass upward through it, and maintained for a few days, until the accumulated solids disappear, as they are said to do, under bacterial action. The effluent from these "strainers," as they are called, is run on to beds of crushed coke, covered with sand, through which it passes downward, meeting air currents, which are forced in through the collecting pipes which cover the floor. The system is in operation at Willow Grove Park, Philadelphia, where it is said to work satisfactorily, the effluent being used to sprinkle the roads and lawns in the park and the neighbouring residence avenues.

With these methods, besides the cost of artificial aeration, protection from cold is necessary in winter, which adds to the expense.

MANCHESTER EXPERIMENTS.

About the middle of 1898 the Council of the City of Manchester, England, engaged Messrs. Baldwin Latham, Percy Frankland and

W. H. Perkin, Jun., three of the most distinguished experts on the subject in England, to advise them as to the choice of a new system of sewage disposal for the city. The dry weather flow of sewage amounted to 30,000,000 gallons per day, and the method of disposing of it was (as now) by chemical precipitation and partial land treatment. The effluent from the precipitation tanks was discharged into the Ship Canal, but the purification was so inadequate that the fouling of the canal water was the cause of frequent complaints, which finally led to the employment of the board of experts mentioned above. In making their investigations and reports they had the advantage of the experience of a great many plants in operation, including most of the new bacterial systems described above. After visiting and examining many of these plants, and carefully considering various processes, the board decided that the most promising method of disposal would be by one of these bacterial processes. And to verify this view, and at the same time to indicate which would prove most suitable for Manchester, they undertook a series of experiments, 1st, with bacteria or contact beds; 2nd, with the septic tank system, and 3rd, with the Roscoe filters. As it was a combination of the first two methods that was finally recommended, a short description of the plants used, and some of the conclusions arrived at, will now be given.

Diagram and Photograph 1 show the contact bed plant. The tanks, situated as shown, were constructed of concrete 6 inches thick, and plastered with half an inch of cement mortar. They are 33 feet 6 inches square on top, and 17 feet 6 inches on the bottom, and 4 feet deep. The bottoms are channelled to receive the 6-inch and 2-inch perforated pipes for drawing off the filtrate. The filtering medium is composed of clinkers laid to a depth of 3 feet. With the exception of the rough material immediately surrounding the pipes, the size of the clinkers is uniform throughout the bed. Five beds were used, the material being of a different size in each bed. In the finest it was from ⅛ inch to ½ inch; in the coarsest from 1 inch to 3 inches.

These beds were worked in pairs, according to the method already described, of periods of filling, resting full and emptying. They were worked with raw sewage, sewage settled in a comparatively small tank, and sewage which had undergone anaerobic action in one of the large open precipitation tanks.

The septic tank plant is shown in Diagram and Photograph 2. The tank is constructed of concrete plastered on the inside with cement mortar. It is 40 feet long, 12 feet wide, and 9 feet 2 inches high, having an arched roof, in which air-tight manhole covers are placed for inspection. There is a grit chamber, and the effluent passes in thin sheets over the sides of an aerating trough, before it goes to the filter beds, which are six in number, and of the average area of 294 square feet. Two-inch and four-inch butt-jointed perforated drains are laid on the bottom to collect the filtrate.

The filtering material is 4 feet deep, and is composed as follows from the bottom upward:—

1 foot in depth of clinker, 1 inch to 3 inches.

2 feet 9 inches screened clinker, ⅛ inch to ¾ inch.

3 inches of residue from above, which will pass a ⅛ inch mesh.

These beds are filled and discharged automatically.

It was found in the course of the experiments, as it has in other places, that the open septic tanks produced results equal to those of the closed tanks; the amount of air or light which can be absorbed when the scum covers the tank not affecting the action. The mixing of the sewage in the tanks, which renders it more uniform in character is regarded as being of great importance in the further purification in the beds.

The system finally recommended by the experts, was treatment by an open septic tank and two contact beds. A satisfactory effluent can be obtained in this way at the rate of about 700,000 gallons per acre per day. The sewage of Manchester contains an unusually large proportion of trade wastes, which it was at first thought would render bacterial treatment unsuitable, but the results of these experiments have removed all doubts as to its capability in this respect.

The plant, which is to deal with a daily dry weather flow of 30,000,000 gallons is recommended to consist of 60 acres of contact beds, which are thus to be capable of purifying at the rate of 500,000 gallons per acre per day, allowing one day a week for rest. The system is also to be capable of dealing with a storm water flow of 90,000,000 gallons per day. This is effected by storing the first flush of storm water for regular treatment, since it is almost as foul as the sewage; and then disposing of the rest, which will be greatly diluted, by an accelerated bacterial treatment of short double contacts, or, where the dilution is great, by single contacts. Experiments were made with the storm water to show this to be possible; and an additional area of 25 acres was estimated to be necessary for the purpose. The material recommended for the contact beds is ½ inch to 1½ inch clinker.

The experts express their confidence in the capability of this method to produce an effluent which will not only not pollute the canal water, but will materially improve its condition; and they further expect that the saving in the expense of operating the system when compared with that necessary in connection with the present plant, will offset to a very considerable extent the cost of constructing the present works.

The data in regard to the cost of construction of bacterial systems, is as yet necessarily rather limited. In any case, it would be impossible to give any statement or estimate of cost which would be generally applicable. The cost of constructing the beds and tanks will depend upon the price of the materials used, and the nature of the site available. But in comparing such systems with sewage farms or intermittent filter beds, there are other things to be taken into account besides the first cost of the plant itself. The great area of land required for the latter methods necessitate their location at a considerable distance, and as this land must also be of special quality, pumping will often be required. With bacterial plants, on the contrary, the choice of a location is not limited by the necessity of finding proper material, the area required is relatively small, and their operation, especially when the tanks are covered, does not cause a nuisance even in the immediate neighbourhood. They may therefore be placed to suit the natural outfall of the system, and usually so as to receive the sewage by gravitation. It sometimes happens that a partial purification only is all that is necessary, such as the removal of sludge and floating material. In such cases treatment in the septic tank alone will be sufficient. For these and similar reasons the adoption of this method may result in a considerable saving in the expense of constructing long outfall sewers, pumping plants, etc., which should be credited to it when making comparative estimates of cost.

The operating expenses will certainly be less than for any of the artificial processes, and will probably not be greater than for land treatment.

In conclusion, it may be stated that the experience of the last four or five years seems to indicate that the main problems in the disposal of sewage have been solved; and that further progress will be in the direction of improvements in the methods of applying the principles, and in the details of operation.

Whether the preliminary liquefaction, which is the distinguishing feature of these new bacterial methods, is essentially anaerobic or not is not certain, in view of the action which takes place in the coarse bed of the Dibdin system. In any case preliminary treatment in an open or closed septic tank seems advisable.

A system of this kind is especially adapted for isolated plants such as for large country houses, hospitals, schools, etc., being compact in arrangement, and, when covered, free from nuisance, while at the same time protected from the effects of cold.

The degree of purification effected by such methods has been already referred to, and the effluents have been shown to be entirely satisfactory, both from the point of view of their chemical purity, and of their freedom from putrescible material. The bacterial efficiency is, however, very low, the number of bacteria in the effluent not being very greatly less than in the raw sewage. This is, of course, an advantage rather than an objection if the discharge is into a stream not used lower down as a water supply; since the bacteria will tend to bring about the further oxidation of any organic matter which may still remain in the sewage. The possible presence of pathogenic organisms among the rest would seem to constitute a danger if the water were subsequently used for drinking. The opinion of those who have investigated this subject seems however, to prove that the conditions in the sceptic tank and filter beds are decidedly antagonistic to the existence of the typhoid germ, for instance, and that the chances of pathogenic bacteria surviving the passage through tank and beds are small. Dr Rideal has suggested sterilizing the effluent, in cases where it is necessary, by chemical means.

In considering this matter, however, it must be remembered that the object of purifying sewage is not to produce a drinking water. Such a result is, of course, often desirable if it can be obtained without undue expense. But when a community has purified its sewage by the methods just described, before discharging it into a water course, it would seem as if all reasonable precautions had been taken, and its duty in that respect had been fulfilled. If the water is subsequently required for a domestic supply, it should be the part of the community so using it to provide any further guarantee as to its wholesomeness and freedom from danger. Such a mutual arrangement between places thus situated with reference to each other would ensure greater efficiency, more satisfactory results, and at the same time an equitable apportionment of the cost of the necessary sanitary works.

DISCUSSION.

Mr. W. M. Davis The paper by Mr. Lea on Sewage Disposal is a concise history of bacterial treatment of sewage up to the present time, written in such a clear, logical manner as to make it very interesting ; the graphic illustration of changes in living and dead organic matter is very ingenious.

Mr. Lea makes the statement that the new bacterial methods solve the problem of sludge disposal ; it appears, however, to the writer that this is going rather farther than the facts would justify. The experience of places where these methods have been tried is that about 20 per cent. of the suspended matter in sewage is deposited as sludge ; this sludge is composed chiefly of inorganic matter and is inoffensive in character, but still provision must be made for its removal.

In the contact bed system lack of permanency must be a serious objection ; the clogging is by inorganic matter, and prolonged aeration does not relieve it ; preliminary sedimentation would apparently remedy this.

The septic tanks constructed at Urbana and Champaign, Ills., by Prof. Talbot were installed about the same time as those built by Donald Cameron in England, the chief difference being in the capacity, the English tanks being about twelve times the size of the American tanks. It would be interesting to know whether the difference in the character of the sewage necessitates so great a difference in the capacity of the tanks.

The presence in tank effluents of elements, which are absolutely necessary to the growth of the plants, would suggest the economy of utilizing the effluent where practicable for the irrigation of a sewage farm. It is probable that the revenue from the farm would materially reduce the expense of management of the disposal plant.

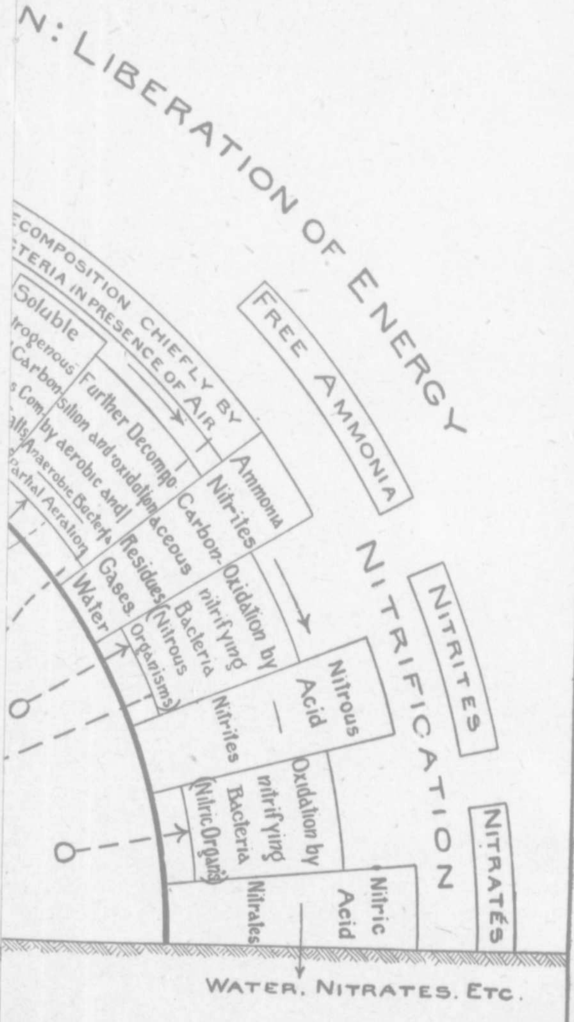
Mr. R. S. Lea Mr. Lea in reply to Mr. Davis said his paper was read from the manuscript in April, 1900, and hence no proofs were sent out in advance as is customary. As published in the Transactions of the Society, it is considerably extended, and some slight modifications have been made in accordance with further experience in the working of bacterial methods of disposal.

Regarding the statement referred to by Mr. Davis, that these methods solve the problem of sewage disposal, what the author means is that the utilization of the action of the anaerobic bacteria as a prelimary to the subsequent oxidizing processes furnishes the true solution of the problem. There is, of course, still much to learn regarding the details of the process under different circumstances, but, if the results obtained by Prof. Talbot in the Champaign tank, which Mr. Davis refers to, could be depended upon in all cases, the chief difficulties in the disposal of sludge would be removed.

There is no doubt that the proper capacity and method of working the septic tank depends to a great extent upon the character of the sewage, and it is not reasonable to expect satisfactory results unless this is taken into account. In any case the sewage should remain in the tank ten or twelve hours in order that septic action should take place.

Diagram A to accompany Paper on
Sewage Disposal by R.S. Lea.

D ORGANIC MATTER



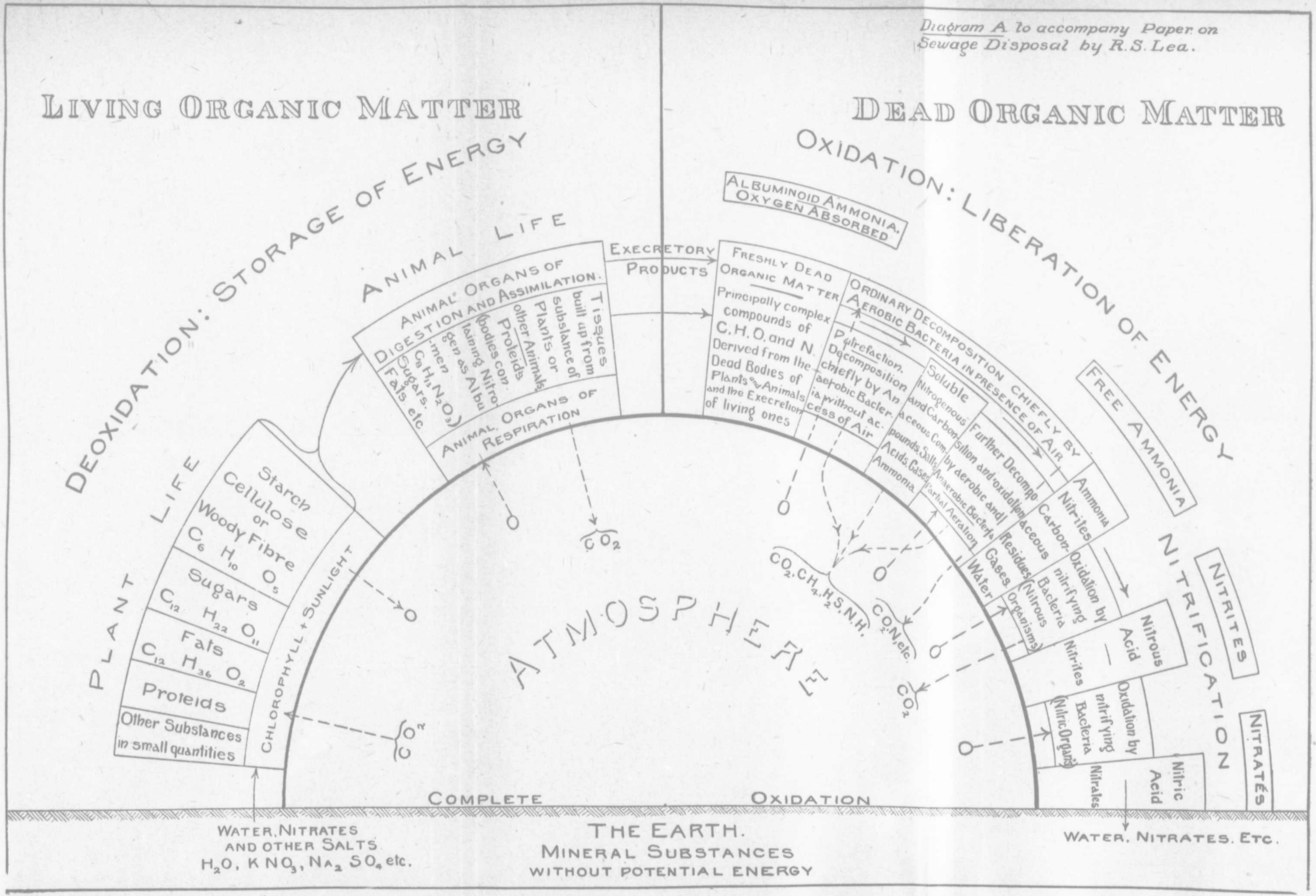
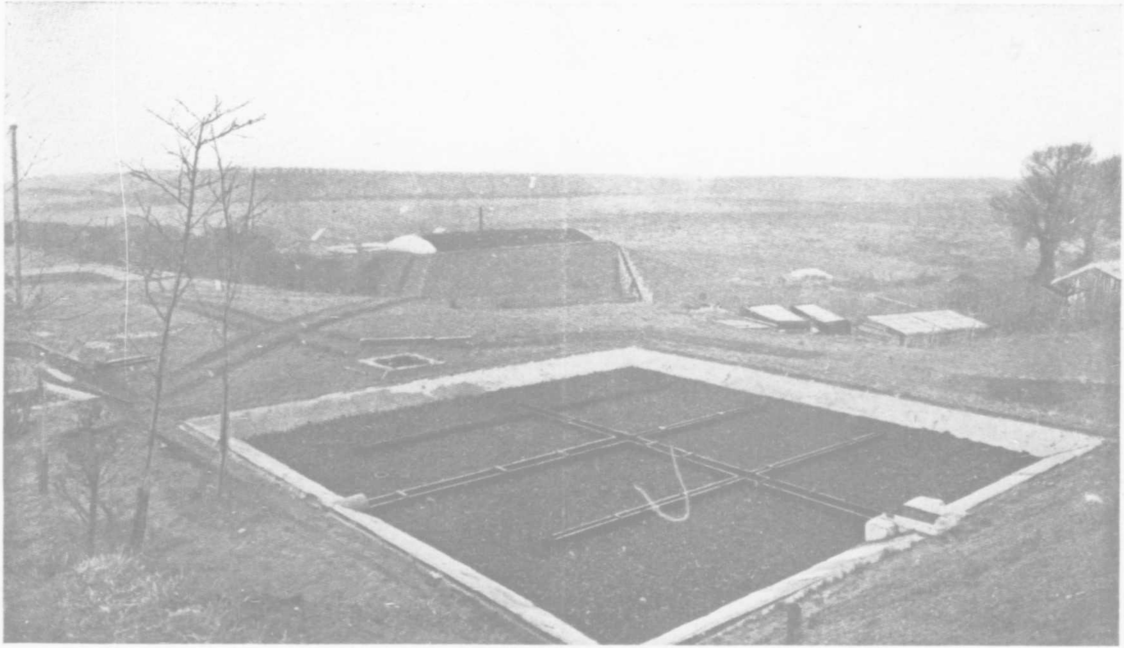


Diagram A to accompany Paper on Sewage Disposal by R.S. Lea.

Mr. W. M. Davis

Mr. R. S. Le

Photograph I



GENERAL VIEW SHEWING BACTERIA BEDS A AND B. MANCHESTER (ENG.) EXPERIMENTS.

Mr
Da

Mr.

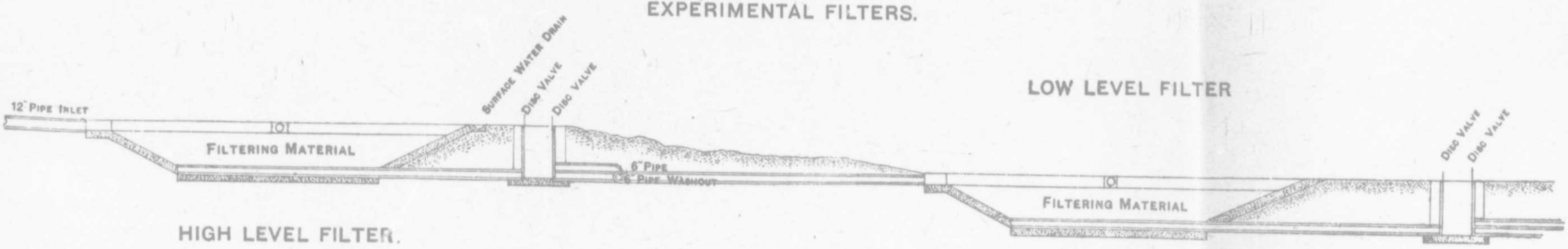
MANCHESTER

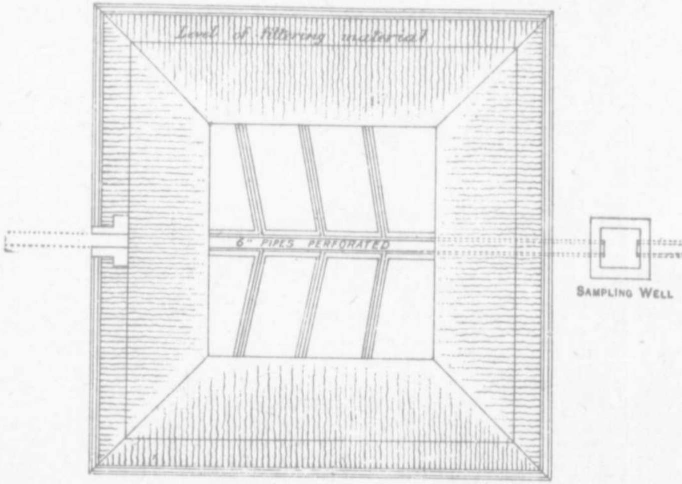
EXPERIMENT

Diagram I

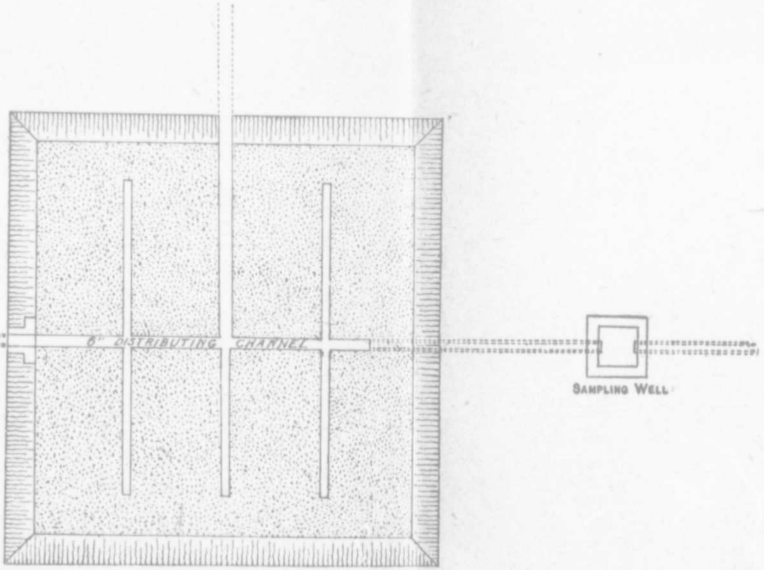
MANCHESTER CORPORATION.

EXPERIMENTAL FILTERS.





Plan without filtering material

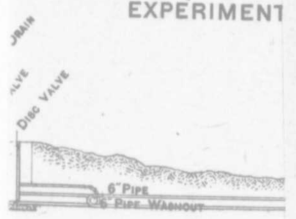


Plan shewing filtering material

Mr
Dr

MANCHESTER

EXPERIMENT



Mr

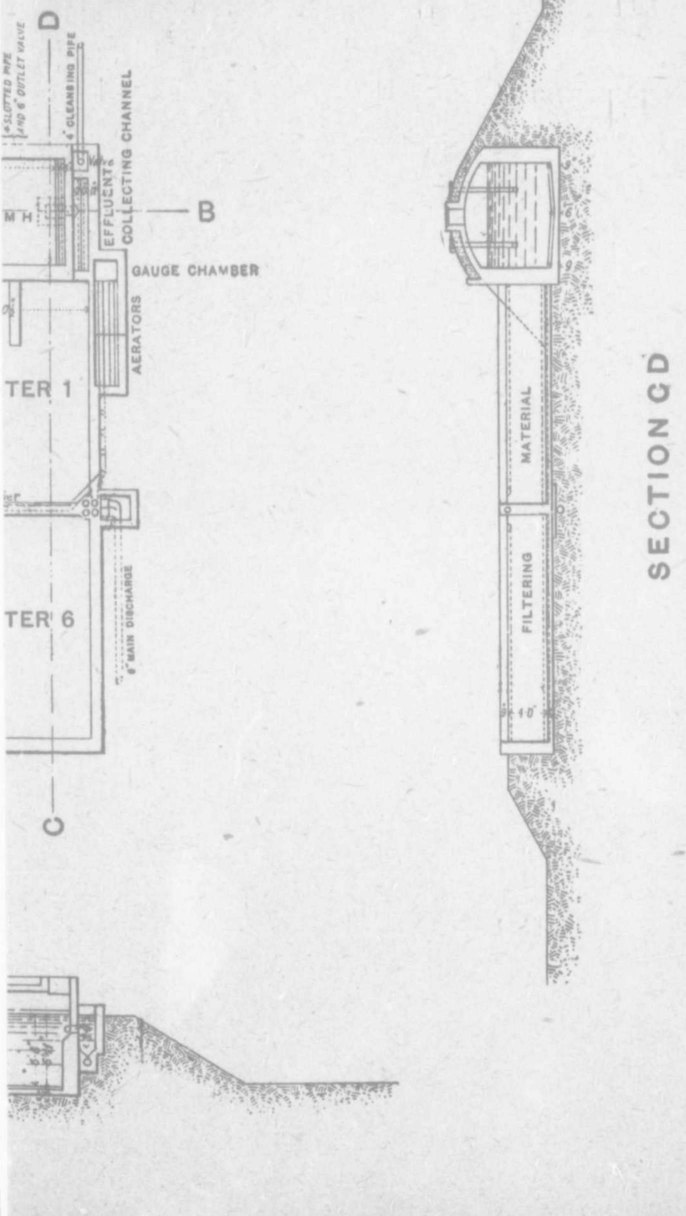
Photograph 2

VIEW SHEWING SEPTIC INSTALLATION. MANCHESTER (ENG.) EXPERIMENTS.

Diagram 2

SEWAGE TREATMENT.

L INSTALLATION.

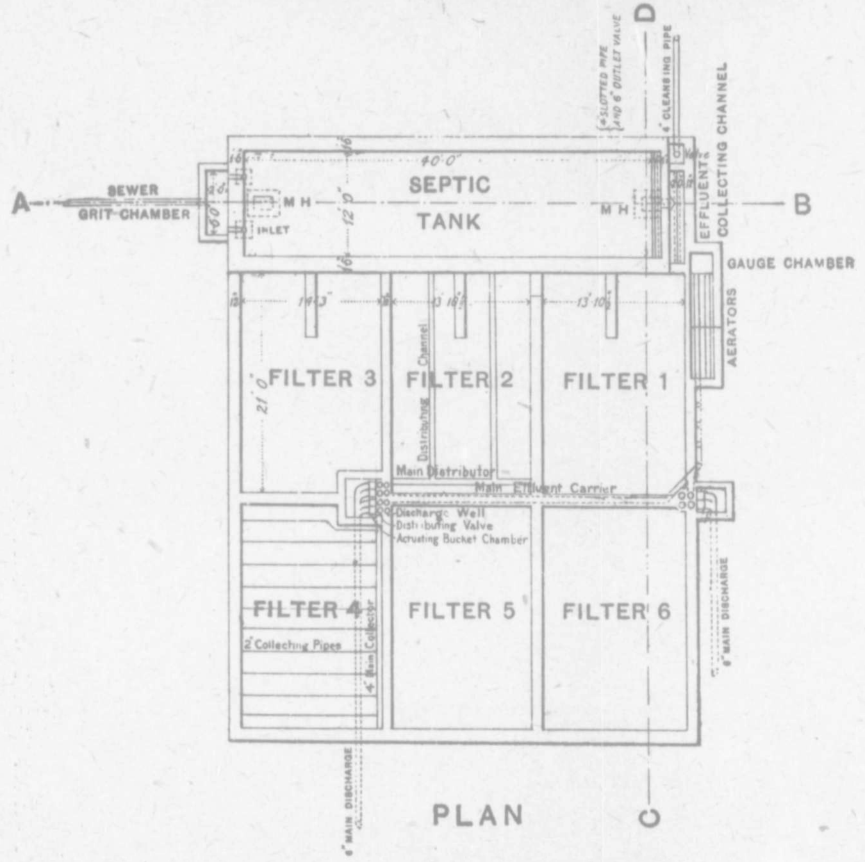


EXETER (BELLE ISLE) INSTALLATION. (SEPTIC TANK SYSTEM.)

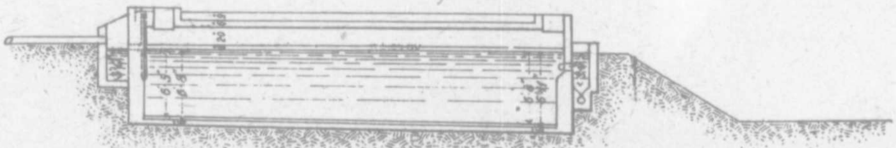
Diagram 2

THE SEPTIC TANK SYSTEM OF SEWAGE TREATMENT.

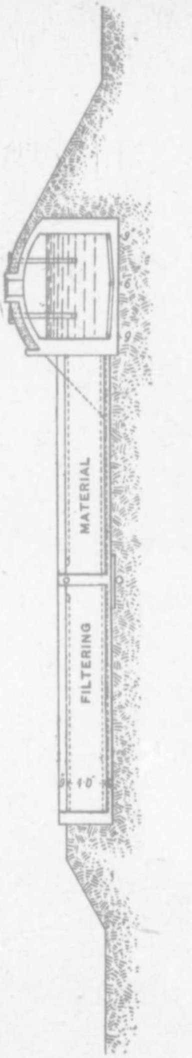
MANCHESTER EXPERIMENTAL INSTALLATION.



PLAN



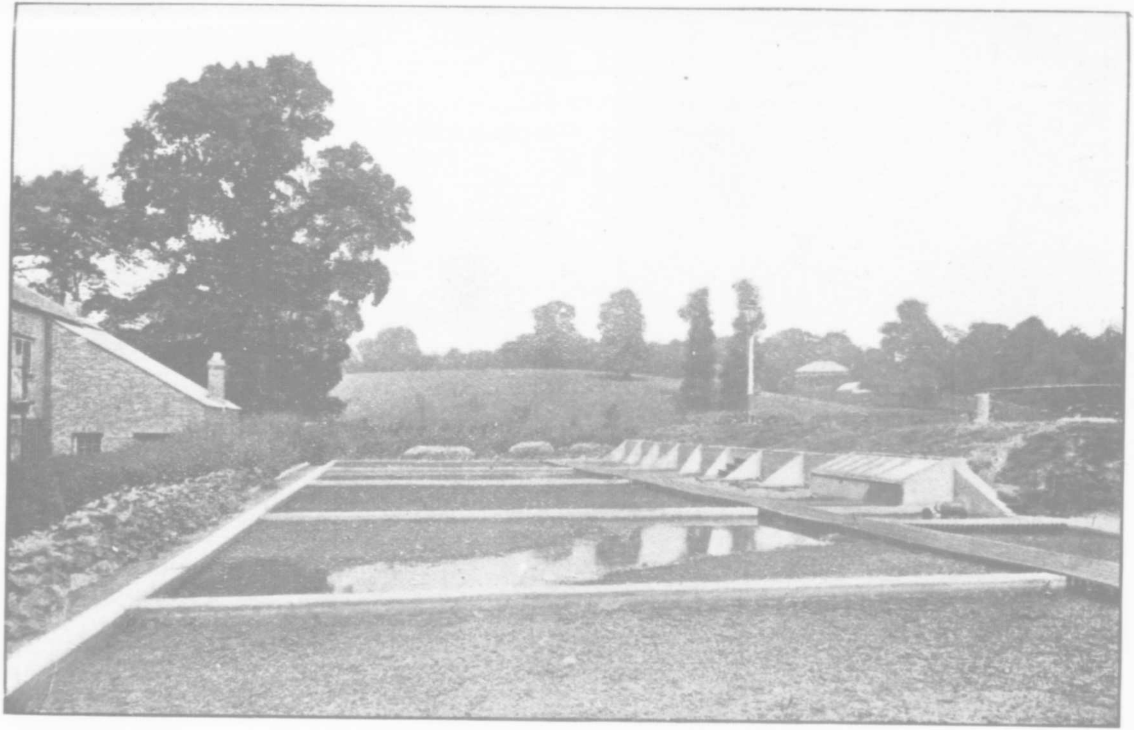
SECTION AB



SECTION CD

Photograph 3

Photograph 4

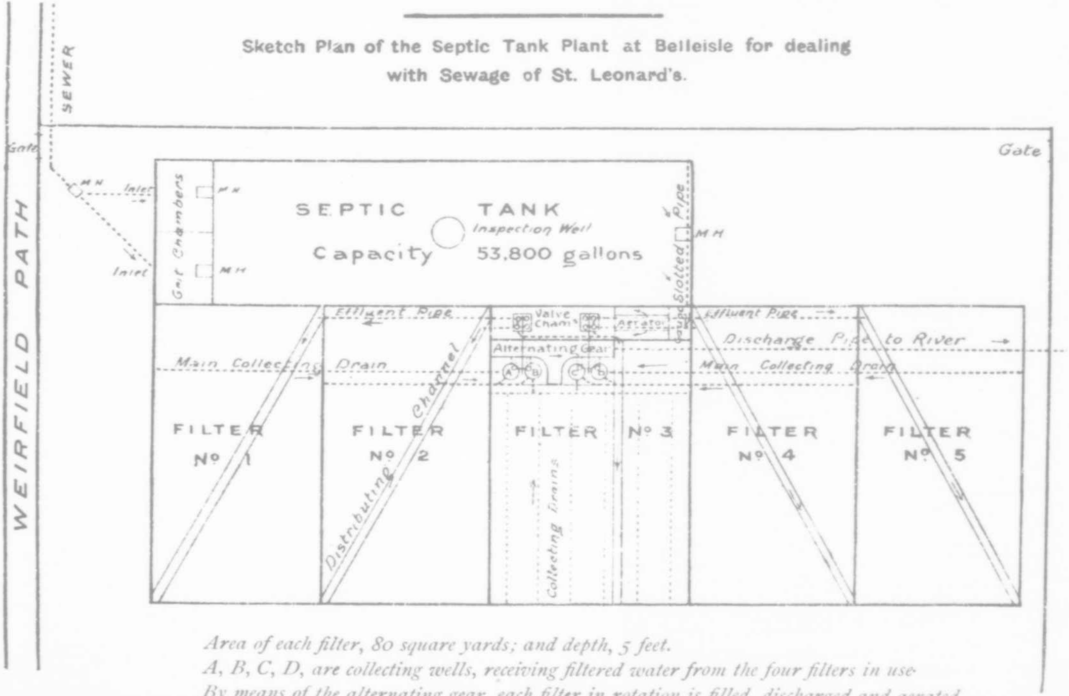


EXETER (BELLE ISLE) INSTALLATION. (SEPTIC TANK SYSTEM.)

Diagram 3

EXETER SEWAGE DISPOSAL

Sketch Plan of the Septic Tank Plant at Belleisle for dealing with Sewage of St. Leonard's.



Area of each filter, 80 square yards; and depth, 5 feet.

A, B, C, D, are collecting wells, receiving filtered water from the four filters in use

By means of the alternating gear, each filter in rotation is filled, discharged and aerated automatically.

Thursday, 31st May.

G. H. Duggan, Vice-President, in the Chair.

Donations to the Library were reported as follows:

Forty-six volumes, Report of Chief of Engineers, U. S. Army, from Mr. P. W. St. George, M.Can.Soc.C.E.

"Induction Coils and Coil-Making," from Mr. H. L. Shepherd.

The following letter, addressed to Dr. Bovey, was read:—

"Dear Sir,—

Your letter of May 23rd, addressed to W. H. Wiley, at hand. In reply, we mail you this day our catalogue. Please mark to the amount of $50 the books you would like, except those that are starred, and we will send them.

Hoping this is satisfactory, we are,

Yours truly,

JOHN WILEY & SONS."

On motion of Mr. L. Skaife, seconded by Mr. G. H. Duggan, it was resolved: "That the thanks of the Society be transmitted to Messrs. Wiley & Sons for their gift to the Library."

Messrs. W. C. Thomson, E. S. M. Lovelace and S. F. Rutherford, having been appointed scrutineers of the ballot, reported the following as elected:—

MEMBER.

CHAS. FERGIE.

ASSOCIATE MEMBERS.

W. E. MANN, G. STEAD.

Transferred from the class of Associate member to the class of Member:

W. CHASE THOMSON.

Transferred from the class of Student to the class of Associate Member:

E. LOIGNON, W. A. MACDONALD,
A. J. MACDOUGAL, J. L. TIGHE.

STUDENTS.

D. M. CAMPBELL, J. A. CAMPBELL,
L. B. CHUBBUCK, G. G. GRUNDY,
E. P. JOHNSON.

Paper No. 151

ENGINEERING RECORDS IN THE RAILWAY OPERATING DEPARTMENT.

By C. E. Cartwright, M. Can. Soc. C. E.

When, on completion of construction, a railway is turned over to the operating department, it is generally found that the maps, profiles and other records are far less complete than generally supposed. Even with very careful location, the unevenness of the ground, obstructions from trees and changes made during construction, introduce inaccuracies in distance, breaks in chainage caused by changes of alignment increase or decrease length of line and are difficult to keep account of.

The profiles also have been made with differing datum and changes of grade made at the last moment. are often unrecorded.

Sidetracks, buildings, water tanks, etc., are seldom definitely located until construction is nearly complete, and not generally until after the general construction work is finished.

Altogether, even at the best, the plans and records are more or less deficient.

Sometimes, also, a railway company acquires an old line from another company, or several short lines are amalgamated; in these cases it is often found that the records are almost altogether lacking, or are in a very incomplete and unreliable condition. Often the engineer in charge will find that he will have to get along the best way he can with the information available, making special surveys as the necessity arises; these surveys will be made in a hurry for some special purpose and will be of little or uncertain value for other uses. Surveys of this kind accumulate, made by different parties for different purposes, with varying degrees of accuracy. and after a time it is seldom known how much reliance can be placed in them; in consequence it is often necessary to revisit the ground and make new surveys; a great amount of work has to be done, which would have been unnnecessary if reliable plans existed.

The remedy for this state of affairs is a complete re-survey of the whole road, especially when it is an important road in a thickly settled country, with towns and villages at short intervals.

On a railway in the Central States, with which the writer was employed, it was decided to make a complete re-survey, the line having been recently acquired from another company; the few existing plans were incomplete and disconnected, a great amount of uncertainty existed as to the company's title to right of way and other property, and it was also proposed to expend a considerable sum in improving alignment and grades, accurate plans and profiles being needed for this purpose.

The railway was first carefully measured from end to end, starting with zero at one terminus; a 100-foot steel tape was used; each hundred-foot station was marked with white paint on the inside of the rail; every tenth station was referenced by an oak stake, 3 inches square, set 7½ feet from the centre line; stakes were also set at every mile, to be afterwards replaced by standard mile posts. After the measurement was completed, the line was gone over by the transit party. This party made a traverse of the line, not stopping to run tangents to intersection and put in curves, simply getting a record of the centre line of the track, as they found it on the ground. On tangents, a sight would be taken on the track ahead as far as visible, and a straight line run, any deflection in the track being noted.

The intersection of all township, section, quarter-section and property lines were obtained, the angles recorded, and distances measured to the nearest section or quarter-section corners, one member of the party being employed most of his time in looking up monuments.

Plusses to points of intersection were obtained from the stations marked on rails by the measuring party.

A record was made of the fences on each side of the right of way, and distance from the centre line, this being often important as a means of determining a disputed boundary, where the fence had been in existence for a long period, as many deeds did not state the width of the right of way.

In villages and towns, the streets and lots adjacent to the company's property were located; all important factories, with the tracks leading to them, even if on a foreign railroad, and all sidings and structures on the company's property, particular attention being given to apparent encroachments, it being often found that buildings were wholly or partially on the company's property without any lease having been made. In making a survey through a village or town, the transit party was furnished with copies of the official plates, previously obtained at the county seat, to aid them in locating lines and streets.

The transit party measured all bridges, buildings, culverts and other structures, located all "Y" and railroad crossings, and public and private road crossings.

The level party followed, taking levels at every hundred-foot station, on top of tie, at ends of bridges, on railway crossings, of level of water in streams, and approximate levels of adjacent ground. Check levels were run and bench marks established at about half mile intervals, and oftener at places likely to be needed. Levels were connected with sea levels taken from United States Government surveys. The plans were drawn on white drawing paper in sheets, on a scale of 400 feet to an inch, each sheet showing the line across a square mile section of land, a whole section or two adjoining half-sections being shown on the sheet.

The top of sheet was north in every case, all distance and angles obtained on the ground to section and property lines were recorded on the sheets.

On top of each sheet was a plain title giving number of section, township and range.

All deeds and agreements were carefully gone over and compared with the plans, right of way coloured in red, with name of grantor, page, and number of record book, and any conditions in deeds noted on plans. Villages and towns, where the scale of 400 feet to an inch did not allow sufficient detail to be shown, were drawn also on a scale of 100 feet to an inch, a large town often requiring several sheets, the same ground being covered, with less detail, on the smaller scale.

The sheets, when completed, were numbered and bound together by counties, the first page being devoted to title and the second to an index map of the county, showing the route of the railway.

The centre line was drawn in red ink, all station numbers and plusses being also in red; distances and all lettering were shown in black.

Before binding, all the plans were copied on tracing linen.

The profiles were drawn on the usual scales of 400 feet to an inch horizontal, and 30 feet to an inch vertical.

In cases where the engineer is unable to have a complete resurvey made, it will be advisable, as time permits, to make accurate surveys of all yards and station grounds, depending for general details of alignment outside these limits on the existing right of way maps.

If an accurate set of yard and station ground plans are obtained to start with, it will be a comparatively easy matter to keep them correct as changes are made.

A statement should be prepared, giving length of all sidings, spurs and "Ys," made from actual measurements, and not from foremen's reports. The form can be made with several blank colums to be filled in from time to time, with "Track laid during ——." "Track taken up during ——," "Total length on ——." This statement will show at a glance length of track on any siding, and avoid a search on plans and profiles for the information.

A chart, showing graphically the different makes, weights and date when laid, of the rails in use should be made, and corrected as new rails are laid.

A bridge book should be kept, devoting a page to each bridge or trestle, giving style, spans, size of stringers, when built, when repaired or rebuilt, conditions when inspected, etc.

A record should be kept of all leases of the company's property, a copy of lease and plat filed.

Detailed statements should be kept of the actual cost of all structures built, and, on completion, plans made showing the structure actually as built, showing depth and character of foundations of bridges, retaining walls, etc., and all differences from the original designs. A condensed plan and profile may be prepared when time permits, showing a great amount of general information, useful in the track and operating departments. The scale will depend somewhat on the length of line it is desired to represent, but, even on a scale as small as one mile to an inch horizontal, and 100 feet to an inch vertical, the principal grades, sections, mileage, water tanks, sidings, railway crossings, etc., can be shown.

The plan will probably have to be somewhat distorted in order to keep it on same paper as the profile, and lengths of sidings and size of structures exaggerated. The arrangement can be somewhat as follows:

On top a series of lines showing number of telegraph wires; lines showing the fencing, the mileage and the track sections; below this, a plan or graphical chart of the line, showing general geography and alignment, degree of each curve being shown by figures. Then the profile, showing bridges, grades, stations, etc.; below the profile a series of lines showing rails, joints, ballast, and new rails, new joints, new ballast.

An important matter is a system of filing plans so they can be quickly found when needed. When blue prints are much used, it is best to file the tracings. When plans are numerous a card index will be found most convenient. A plan can be indexed on the cards under several headings, and new plans can be added and changes made without spoiling the index.

DISCUSSION.

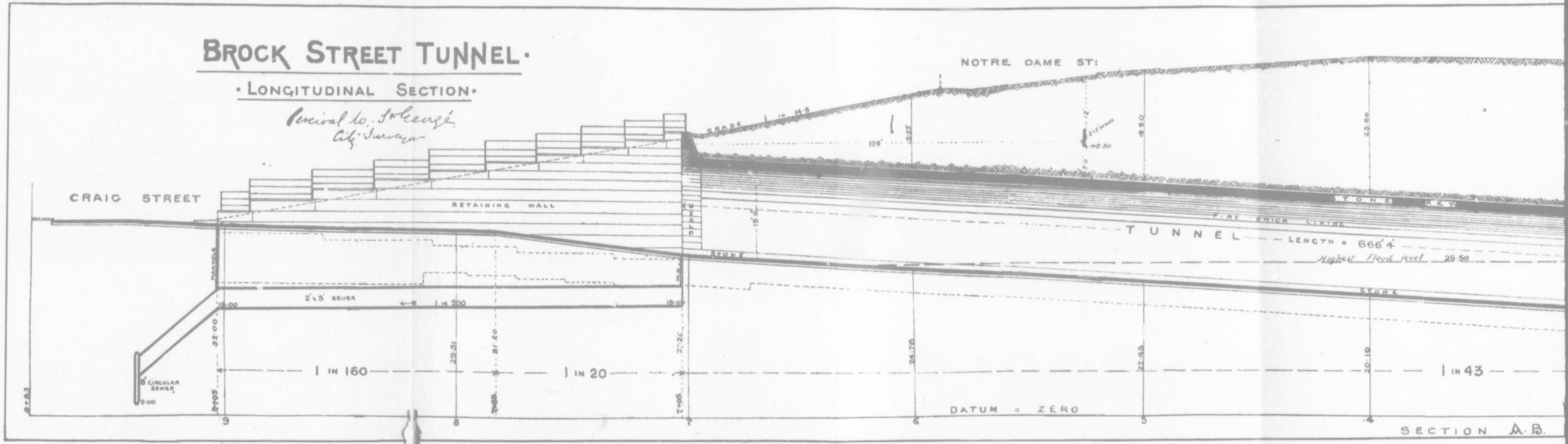
Mr. W. T. Jennings

Mr. Cartwright's paper on "Engineering Records in the Railway Operating Department" contains numerous good suggesstions to young engineers or those untrained in or unaccustomed to the usages of a large and well regulated engineering office.

The Railway Act of Canada contains sections clearly defining the records, plans and profiles required for registration and other purposes in this country, and which largely cover the useful requirements in this branch of engineering.

The lack of method, through want of proper apprenticeship or training, is one of the conspicuous features among our engineers, and until the Society maps out a course of procedure for the guidance of the engineers of the future we need not expect any great improvement.

The desire to "save?" money, as so often seen in the conduct of railway "promotion" and construction work, especially if of the "bonus" description, is not conducive to good engineering results. On the contrary, it has to answer for many of the so-called shortcomings of engineers in the matter of general and final working plans and records.



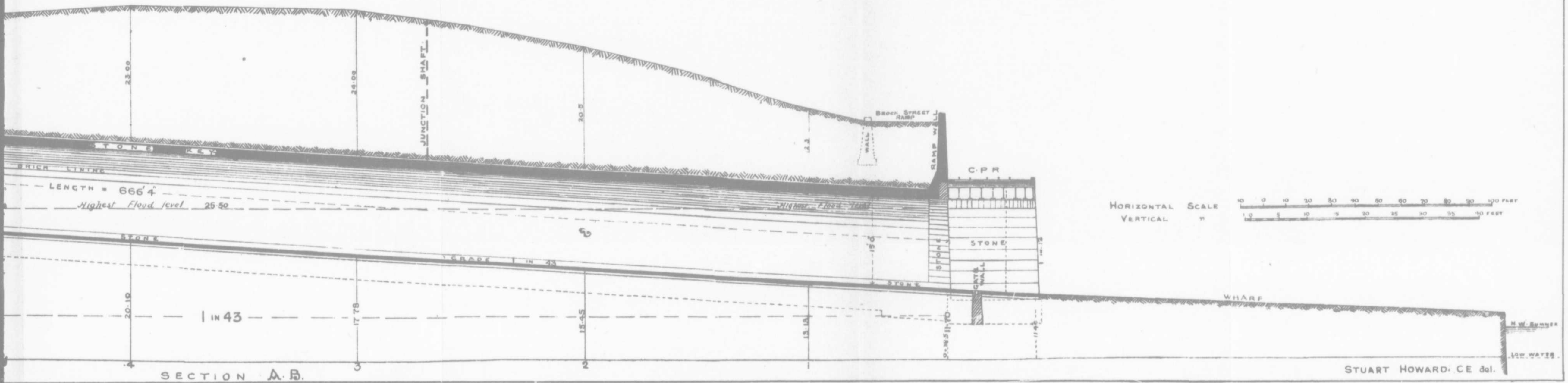
BROCK STREET TUNNEL·

·LONGITUDINAL SECTION·

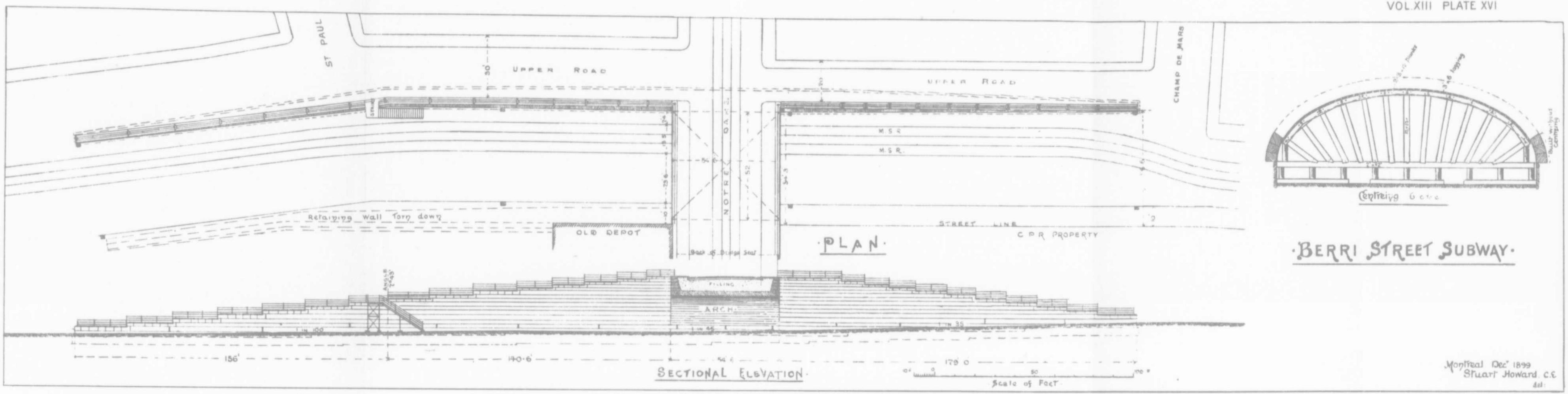
Percival to St George
City Surveyor

STUART HOWARD C.E.
Del.

TRANSACTIONS CAN. SOC. C. E.
VOL. XIII PLATE XVII

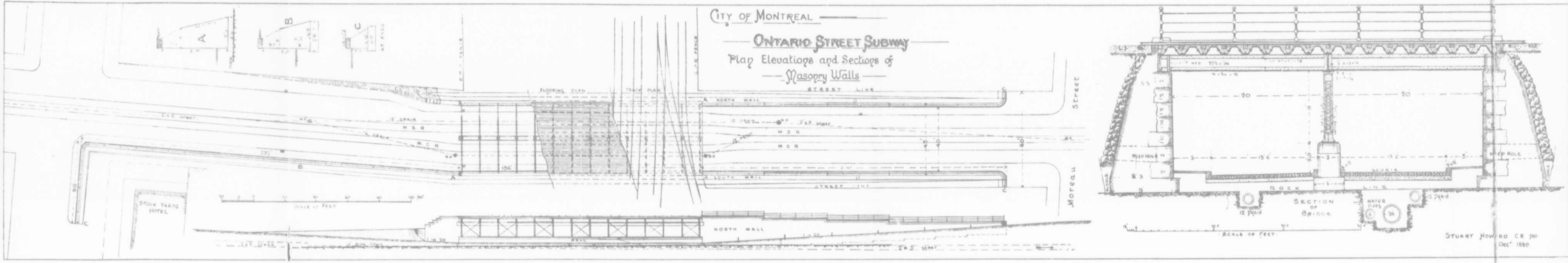


SECTION A.B.



·BERRI STREET SUBWAY·

Montreal Dec^r 1899
Stuart Howard C.E.
del.



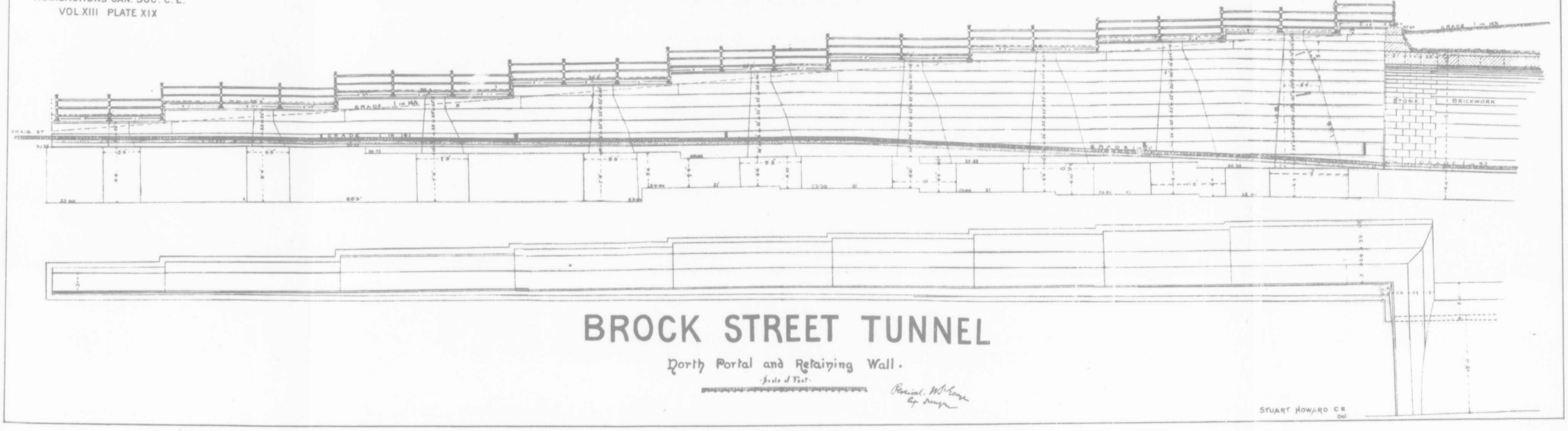
City of Montreal

Ontario Street Subway

Plan Elevations and Sections of Masonry Walls

Stuart Howard CE del
Dec^r 1880

TRANSACTIONS CAN. SOC. C. E.
VOL XIII PLATE XIX



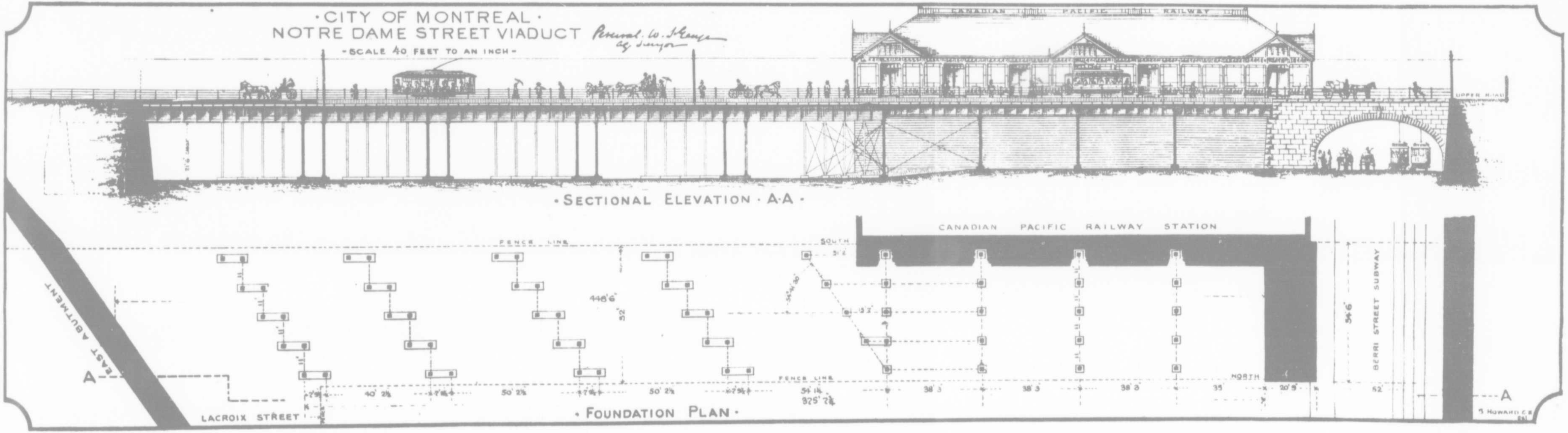
BROCK STREET TUNNEL

North Portal and Retaining Wall.

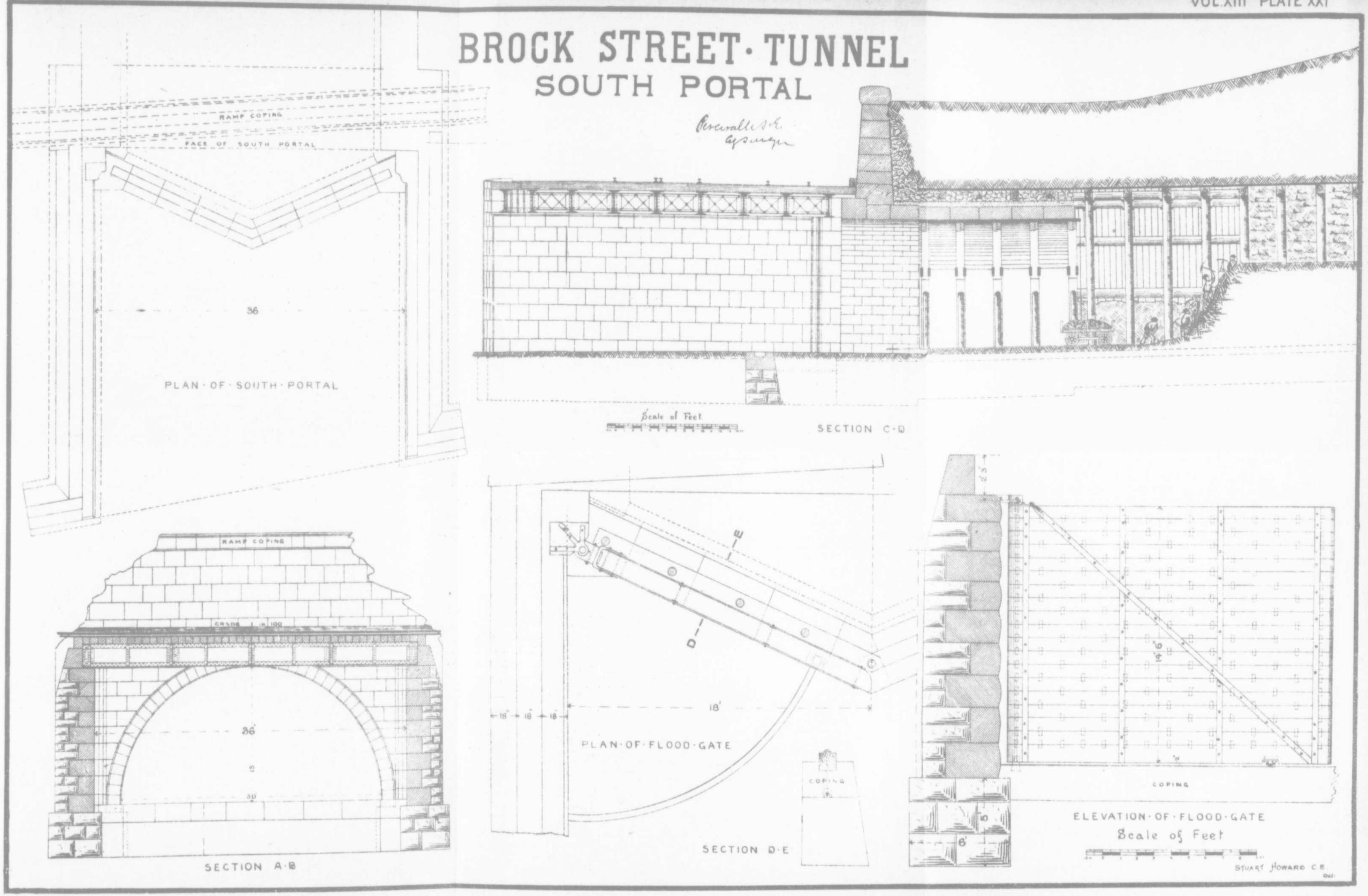
Scale of Feet.

Percival W. St. George
Cy. Engr

STUART HOWARD C.E.
Del.


·CITY OF MONTREAL·
NOTRE DAME STREET VIADUCT
Percival. W. St George
Cy Surveyor
-SCALE 40 FEET TO AN INCH-
CANADIAN PACIFIC RAILWAY
UPPER ROAD
·SECTIONAL ELEVATION·A·A·
CANADIAN PACIFIC RAILWAY STATION
FENCE LINE
SOUTH
NORTH
EAST ABUTMENT
BERRI STREET SUBWAY
446' 6"
52'
54' 6"
40' 2½
50' 2½
50' 2½
54' 1¼
325' 7¾
38' 3
38' 3
38' 3
35'
20' 9"
52'
A
A
LACROIX STREET
·FOUNDATION PLAN·
S. HOWARD C.E.

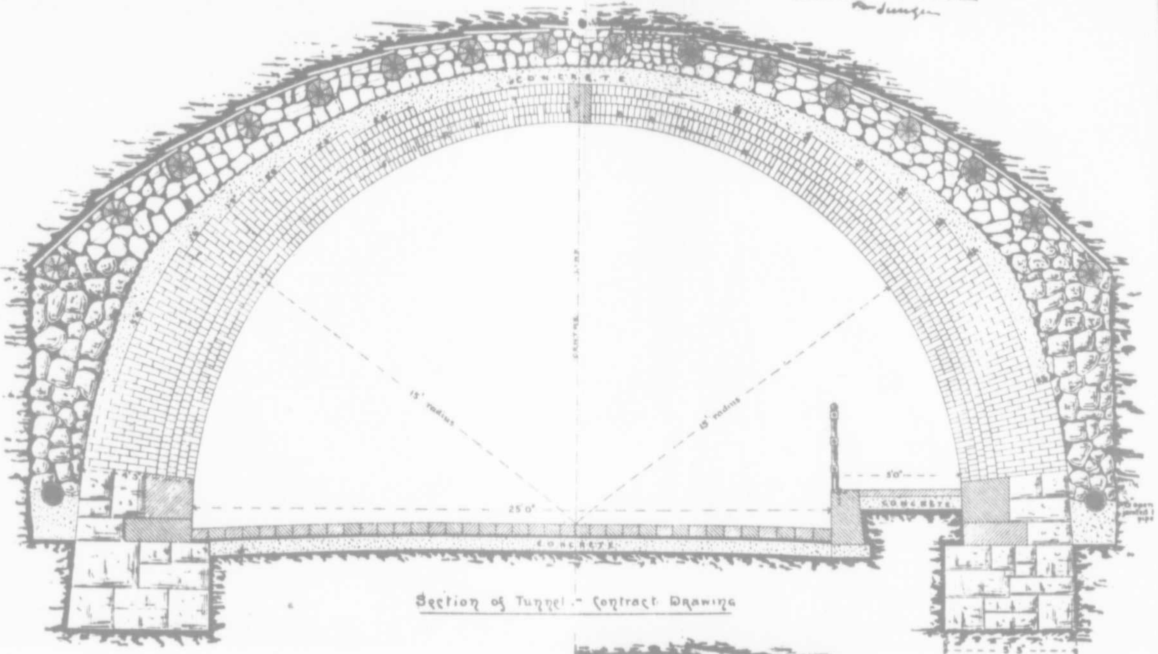
BROCK STREET · TUNNEL
SOUTH PORTAL



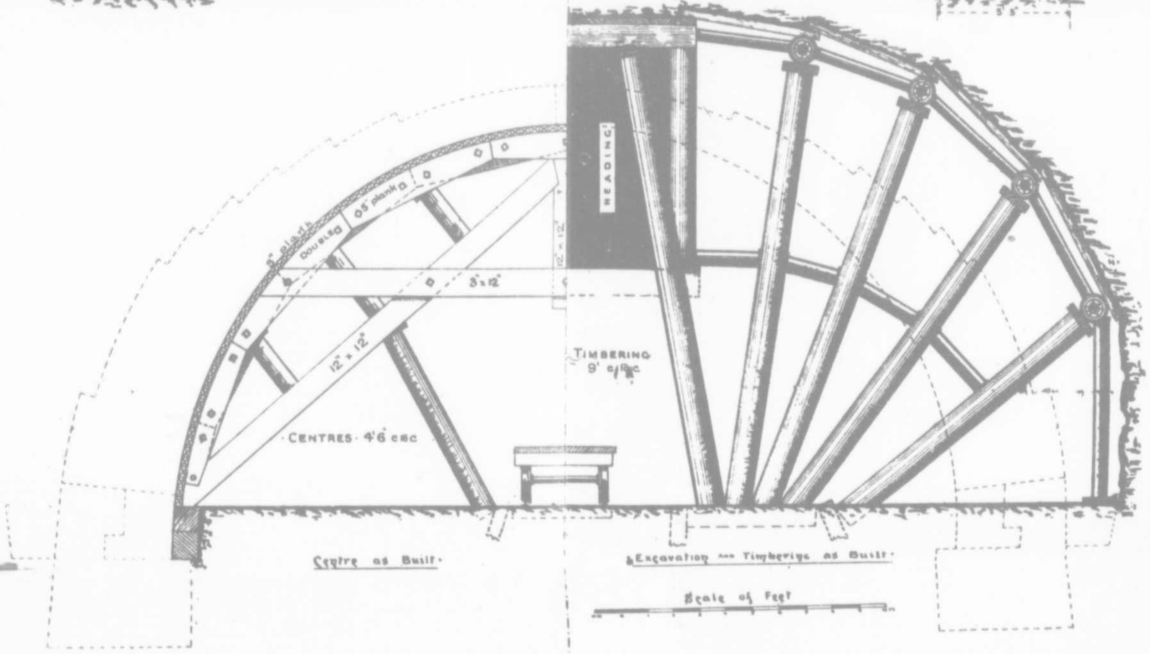
TRANSACTIONS CAN. SOC. C. E.
VOL. XIII PLATE XXII

BROCK STREET TUNNEL

Reversal [illegible] drawings



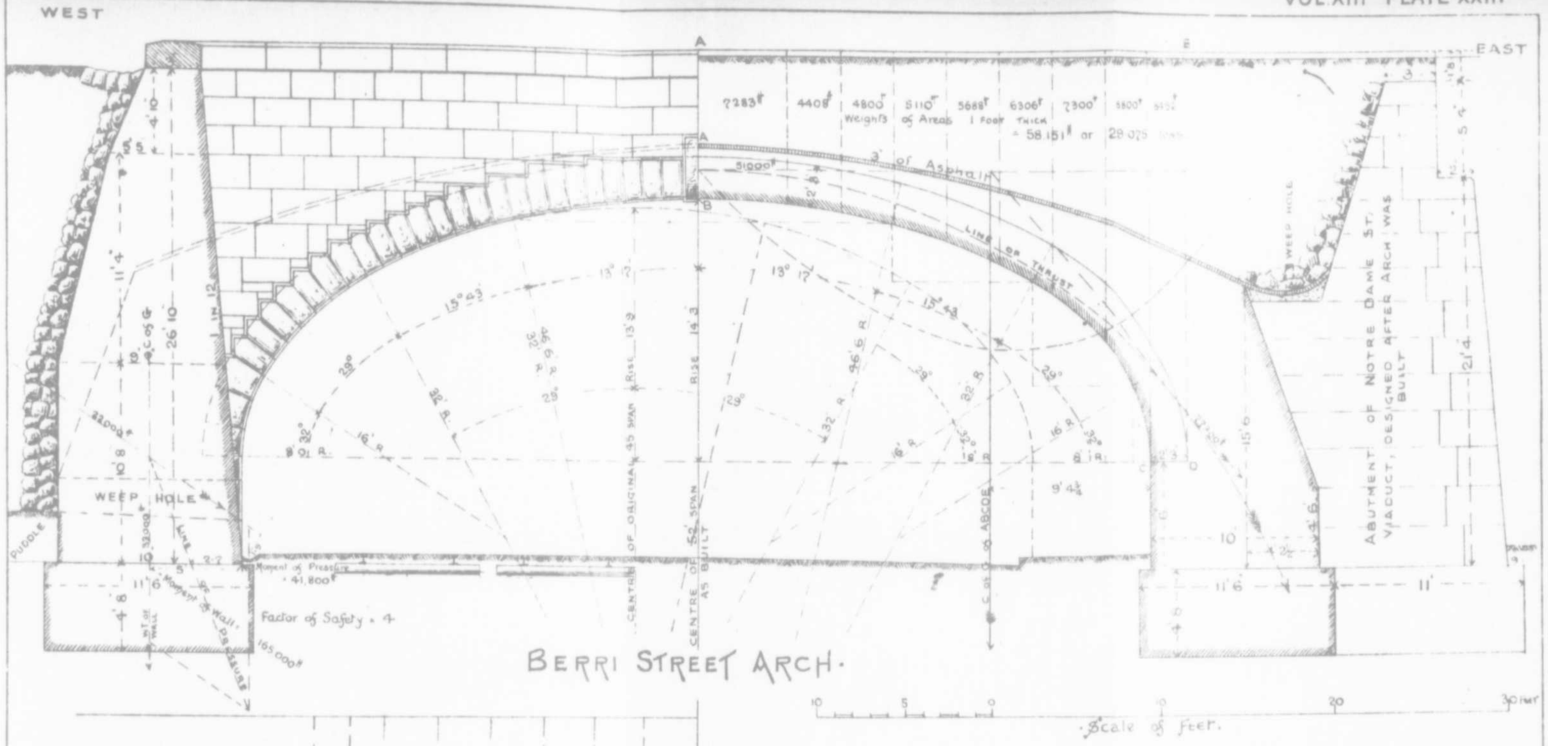
Section of Tunnel. - Contract Drawing



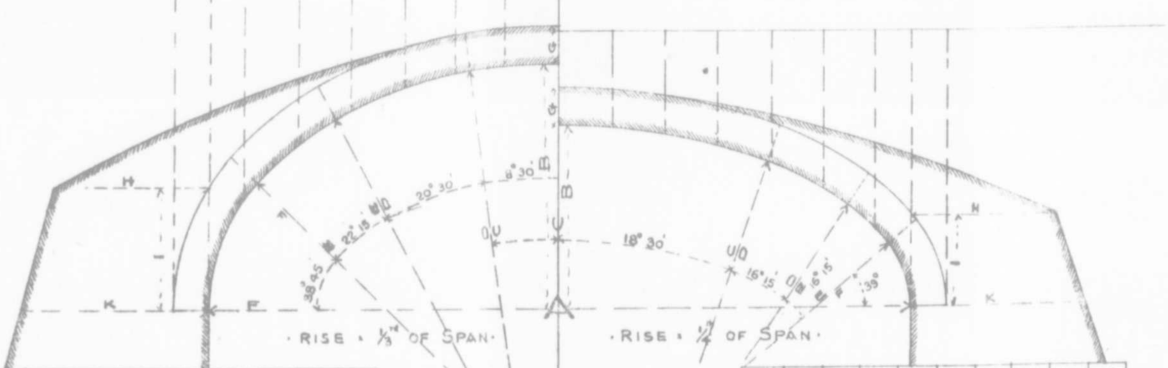
Centre as Built.

Excavation and Timbering as Built.

STUART HOWARD C



BERRI STREET ARCH.

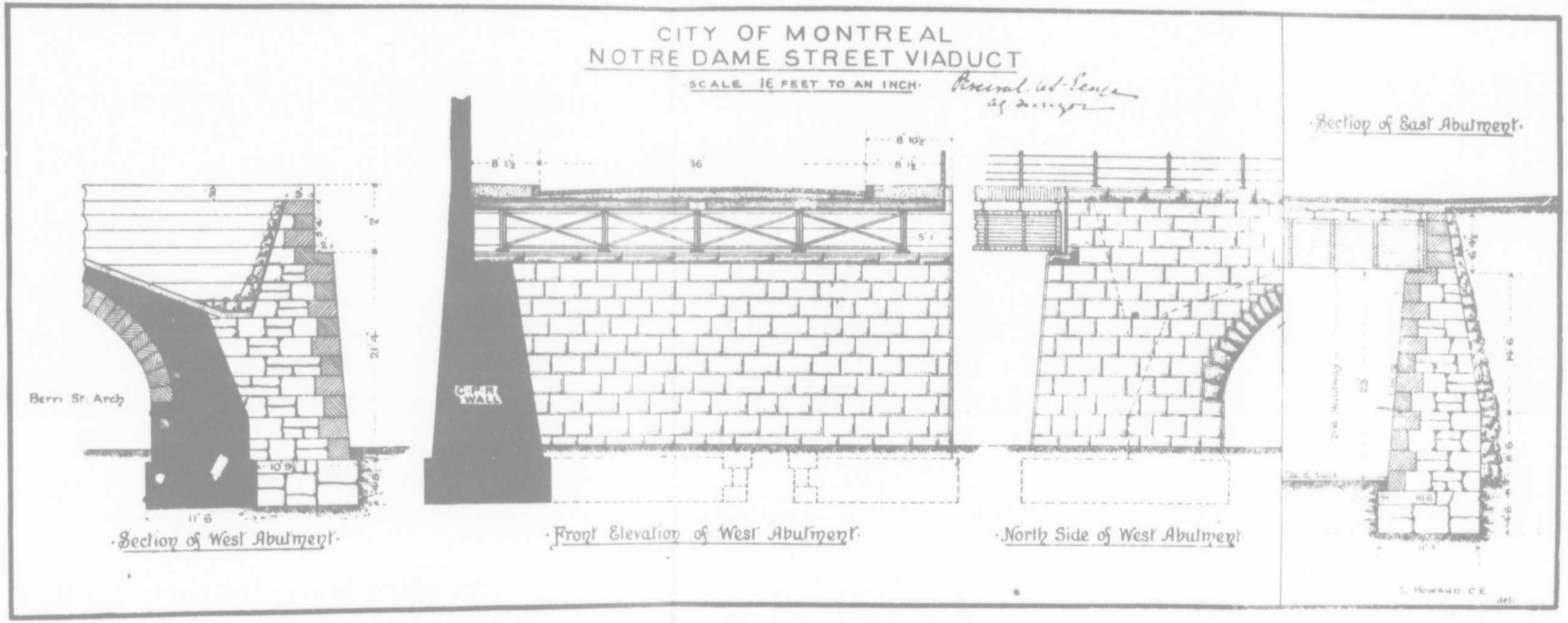


SPAN A	RISE B	RAD. C	RAD. D	RAD. E	RAD. F	KEY G	WIDTH H	HEIGHT I	WIDTH K
60'	20'	52.5	34.5	24.75	15	2.42	13.05	10	15.45
55	18.33	48.125	31.625	22.7	13.75	2.33	11.96	9.17	13.16
50	16.66	43.75	28.75	20.63	12.5	2.25	10.87	8.33	12.87
45	15	39.37	25.875	18.56	11.25	2.16	9.78	7.5	11.58
40	13.33	35	23	16.5	10	2.08	8.7	6.66	10.3
35	11.66	30.625	20.125	14.438	8.75	2	7.61	5.83	9
30	10	26.25	17.25	12.375	7.5	1.92	6.52	5	7.73
25	8.33	21.875	14.375	10.318	6.25	1.83	5.44	4.16	6.44
20	6.66	17.5	11.5	8.25	5	1.75	4.35	5.	5.15

DIAGRAM OF ELLIPTICAL ARCHES

SPAN A	RISE B	RAD. C	RAD. D	RAD. E	RAD. F	KEY G	WIDTH H	HEIGHT I	WIDTH K
60'	15'	53.76	30	16.8	8.4	2.5	12.25	7.5	15.25
55	13.75	49.28	22.5	15.4	7.7	2.37	11.7	6.87	13.93
50	12.5	44.8	25	14	7	2.25	10.63	6.25	12.71
45	11.25	40.32	22.5	12.6	6.3	2.16	9.57	5.63	11.44
40	10	35.84	20	11.2	5.6	2.08	8.5	5	10.17
35	8.75	31.36	17.5	9.8	4.9	1.92	7.44	4.37	8.90
30	7.50	26.88	15	8.4	4.2	1.83	6.37	3.68	7.63
25	6.25	22.40	12.5	7	3.5	1.75	5.31	3.13	6.35
20	5	17.92	10	5.6	2.8	1.66	4.25	2.5	5.08

Montreal. Decr 1899.
Stuart Howard. C.E.
M.C.S.C.E.



CITY OF MONTREAL
NOTRE DAME STREET VIADUCT
SCALE 16 FEET TO AN INCH.

Percival St. George
Cy. Surveyor

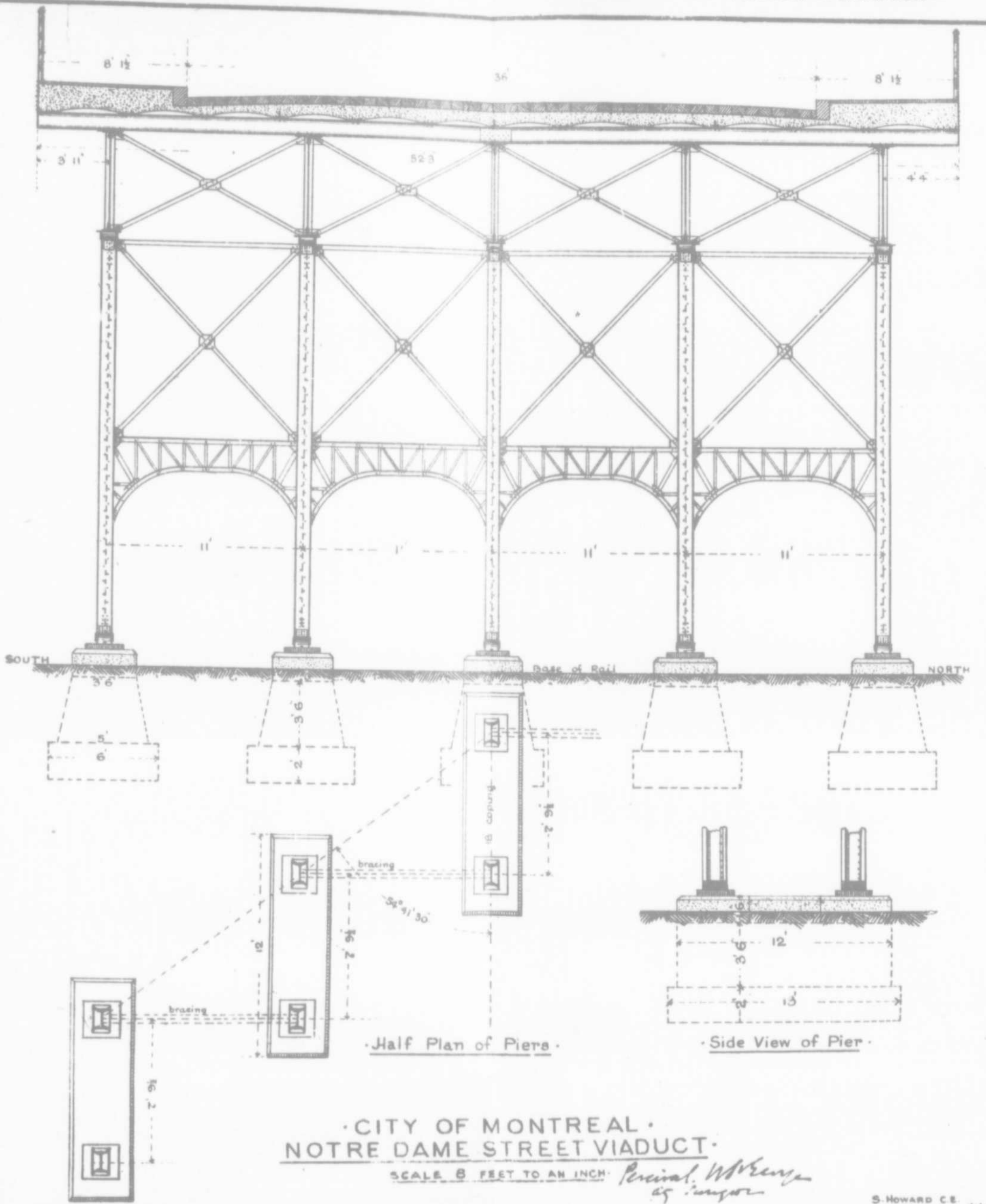
·Section of West Abutment·

·Front Elevation of West Abutment·

·North Side of West Abutment·

·Section of East Abutment·

L. HOWARD C.E.
del.



·Half Plan of Piers·

·Side View of Pier·

·CITY OF MONTREAL·
NOTRE DAME STREET VIADUCT·
SCALE 8 FEET TO AN INCH· Percival W St George
Cy Engineer

S. HOWARD C.E.
del.