(*Paper No. 3721.*)

"Aberdeen Main-Drainage Works: Girdleness Outfall Scheme."

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THE City of Aberdeen, with the exception of the district of Torry in the County of Kincardine, lies wholly between the estuaries of the Rivers Dee and Don, on the shore of the North Sea, and at the extreme south-east corner of Aberdeenshire.

The situation is within the area of the metamorphic rocks of the Highlands; and these rocks range southwards for a short distance, being exposed at Girdleness Point and along the coast to the south-east of the city. The metamorphic rocks with later intrusive masses form the geological foundation of Aberdeen and its neighbourhood. For the most part up to about 100 feet above sea-level they are overlain by a mantle of later accumulations, such as glacial clays,[1] fresh-water alluvium, blown sand, and ancient and modern beach-deposits. In the suburban and residential parts of the city to the north-west and west, the rocks are exposed at the surface, consisting generally of a fine-grained granite of a bluish-grey colour, extensively quarried at Rubislaw and well known as a valuable stone. The elevation of the city extends to over 400 feet above sea-level at the western boundary, but the greater part of the area built upon lies below the 120-feet line. There are two natural drainage-areas to the city; the southern part, with an area of 4,856 acres, drains to the River Dee, and the northern, 1,838 acres in extent, drains to the River Don. A plan of the city is shown in Fig. 1, Plate 5.

General Drainage Schemes.—Before the year 1866 the city cannot be said to have had any real system of sewerage. In that year, Mr. Robert Anderson, the Burgh Surveyor, designed an entirely new scheme, which was carried out under his direction during the

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[1] See "The Glacial Period in Aberdeenshire." Quart. Journ. Geological Soc., vol. xii (1906), pp. 13–39.

years 1866–70. This scheme, which at that time was called upon to deal with a municipal area of only 1,280 acres, had as its leading features two independent points of outfall: one providing for a high-level sewer discharging sewage on to an irrigation-farm of 45 acres at Spital, near the Old Town or King's Links; and the other providing for an outfall at Abercrombie's Jetty, near the mouth of the River Dee in tidal waters, the discharge into the latter being from both a middle-level and a low-level district. The low-lying areas near the quays and harbour being tide-locked, a small pumping-station was subsequently constructed at Clarence Street to pump the sewage into the Abercrombie's Jetty outfall. Owing to the rapid growth of the city since 1870 and to the extension of the boundaries on three different occasions—notably to include the large districts of Old Aberdeen, Woodside and Torry—these works proved quite inadequate for dealing with the added areas, and the consequent recurrence of serious floodings in the low-lying parts called for a remodelling of the whole system.

The following Table shows the growth in population and area since the year 1866, when the original scheme was designed :—

Population and Area of City.

Year.	Population.	Area of Police Burgh.
		Acres.
1866	63,500[1]	1,280
1871	67,102[2]	1,280
1871	76,348[3]	1,780
1881	87,220	1,780
1883	90,000[2]	1,780
1883	100,000[3]	2,681
1891	110,173[2]	2,681
1891	124,600[3]	6,694
1901	153,108	6,694
1907	170,000[1]	6,694

As this development took place and the new areas were added, new sewers were constructed at different points, having their outfalls direct to the burns or to the Rivers Dee and Don, without any purification whatever. The area of the Spital irrigation-farm, although

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[1] Estimated.

[2] Before extension of boundaries.

[3] After extension of boundaries.

originally sufficient for the population provided for by the high-level sewer, was rendered practically useless, and a new gravitation outfall-sewer was constructed along the Queen's Links to Abercrombie's Jetty in 1885. This intercepted the bulk of the sewage, the tenant of the irrigation-farm merely using sufficient sewage for agricultural purposes.

In 1886 Mr. Baldwin Latham, M. Inst. C.E., was asked by the Town Council to report upon the best method of intercepting the existing sewers and draining the new areas. In a valuable report, dated August 1886, Mr. Latham pointed out the advisability of establishing a new point of outfall, and gave it as his opinion that the two most suitable points for discharging the sewage into the sea without causing nuisance were: (1) a site on the coast of Aberdeen Bay midway between the estuaries of the Rivers Dee and Don, and (2) a point on the south-east of Greyhope Bay north of Girdleness Point, a rocky promontory on the coast south of the River Dee. Of these two points Mr. Latham favoured the former, and advised the construction of new intercepting sewers to discharge the sewage into a large storage tank at the Old Town Links, with an outfall laid into the bay; the sewage being thus stored during the rising tide and discharged during 5 hours on the ebb-tide, when the tidal currents were favourable for carrying it off the coast.

Nothing, however, was done towards obtaining a new outfall, and from 1894 to 1898 the subject of main drainage caused the Town Council considerable anxiety, owing to frequent flooding in the lower parts of the city. During these years the existing conditions were carefully investigated by the Burgh Surveyor, Mr. William Dyack, M. Inst. C.E., who in 1896–98 prepared various reports upon a new scheme.

In connection with these reports Mr. Dyack had an extensive series of float observations carried out at Girdleness and Nigg Bay to determine the best point of discharge, and to ascertain under what conditions of tidal flow the discharge could take place most favourably, without causing nuisance to the neighbourhood. The chief series of observations was carried out in May and June 1898, and a further series again in September of that year. These observations, together with those previously taken, gave very reliable information for determining the best point of outfall.

In carrying out these observations the type of float adopted was that known as the "double float." It consisted of a surface float about 9 inches in diameter and 6 inches deep, which was made of two flattened hemispherical parts of sheet-iron soldered together; to the bottom was attached a brass swivel carrying a light brass

TABLE I.—CURRENT OBSERVATIONS AT GIRDLENESS, 1898.

Number of Observation on Diagram.	Date.	Float placed in Sea.	Float taken out.	Time of High-Water.	Direction of Wind.	Remarks.
1	5th September	8.10 a.m.	11.30 a.m.	4.3 p.m.	S.S.E.	Neap-tide ; wind blowing moderately ; sea choppy.
2	6th ,,	12.10 p.m.	2.40 p.m.	4.50 p.m.	S.S.E.	Neap-tide ; stiff breeze with heavy ground-swell.
3	6th ,,	8.45 a.m.	12.0 noon	4.50 p.m.	S.S.E.	Neap-tide ; stiff breeze with heavy ground-swell.
4	7th ,,	3.40 p.m.	4.35 p.m.	5.43 p.m.	S.E.	Neap-tide ; light breeze with heavy ground-swell.
5	7th ,,	9.30 a.m.	12.10 p.m.	5.43 p.m.	S.E.	Neap-tide ; light breeze with heavy ground-swell.
6	8th ,,	10.40 a.m.	1.40 p.m.	6.48 p.m.	S.	Neap-tide ; stiff breeze lessening during afternoon ; sea choppy.
7	8th ,,	4.30 p.m.	6.0 p.m.	6.48 p.m.	S.	Neap-tide ; stiff breeze lessening during afternoon ; sea choppy.
8	15th ,,	11.15 a.m.	2.20 p.m.	12.39 p.m.	W.S.W.	Spring-tide ; sea very smooth.
9	21st ,,	8.55 a.m.	12.25 p.m.	4.27 p.m.	W.N.W.	Neap-tide ; strong breeze ; sea smooth.
10	14th June	1.25 p.m.	6.55 p.m.	9.26 a.m.	E.N.E.	Neap-tide ; light breeze ; swell on sea from north east.
11	16th ,,	12.0 noon	3.15 p.m.	11.14 a.m.	N.E.	Spring-tide ; moderate wind.
12	17th ,,	11.40 a.m.	4.25 p.m.	12.0 noon	N.E.	Spring-tide ; light breeze, sea smooth.

chain for suspending the under part. This was of zinc, in the form of a cylinder 16 inches in diameter and 16 inches long, perforated at close intervals with 1-inch holes. The total weight was 10 lbs.

Altogether 120 observations were taken in 1898 at Girdleness; Fig. 1, Plate 5, and Table I, give typical examples ; and Table II indicates the direction of prevailing winds at Aberdeen for the 5 years following that in which the observations were taken.

These observations suggested that the outfall should be fixed at the extreme point of Girdleness, immediately to the east of the lighthouse and running north-north-east out into deep water. Here sewage could be discharged under the most favourable conditions possible, that is, at all states of the tide, as the ebb currents flowed north-east off the coast and the flood currents south-east; this is clearly shown in the Figure. The strong current of the River Dee, it was found, would also assist in carrying the sewage into deep water. Comparing this point with that originally proposed at Aberdeen Bay, there is no doubt about its great advantages: it avoided the construction of large and costly storage-tanks, and the new proposal recognized the strong public feeling against the possibility of any sewage flowing back on to the bathing-grounds at the bay. For this reason, and also because a large and continually growing population had sprung up during the past 15 years on the south side of the River Dee at Torry (a place which could easily be drained by gravitation to the same outfall), it was considered that Girdleness was the most favourable point.

TABLE II.—DIRECTION OF PREVAILING WINDS AT ABERDEEN, 1899-1903.

Year.	*Number of Days.*							
	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.
1899	22	5	22	39	87	84	48	58
1900	30	12	40	47	65	60	48	63
1901	23	20	19	39	87	46	59	72
1902	37	5	26	46	67	67	34	83
1903	14	11	19	61	97	59	53	51
Total No. of days	126	53	126	232	403	316	242	327
Average for 5 years	25·2	10·6	25·2	46·4	80·6	63·2	48·4	65·4

Mr. Dyack's scheme therefore included as its essential feature the provision of an outfall at Girdleness, and in October 1898, the late Mr. James Mansergh, F.R.S., M. Inst. C.E., reported in favour of the scheme, after suggesting several detail modifications.

Powers were accordingly sought from Parliament during the session of 1899, and the Aberdeen Corporation (Sewage) Act was passed in that year, authorizing the Town Council to carry out the works, which were estimated to cost £187,000. The main features of the scheme, which have been modified in some particulars since the passing of the Act, are (Fig. 1, Plate 5):—

(1) The Girdleness high-level outfall sewer (A), 5,527 yards in length, commencing at Skene Street and continuing viâ Golden Square, Crown Street, Portland Street and North Esplanade to Point Law; thence passing under the River Dee to the south side of the river and along Greyhope Road, St. Fitticks Road and the foreshore of Nigg Bay to Girdleness Point.

(2) A northern district high-level intercepting sewer (B), 6,940 yards in length, commencing near the Grandholm Bridge over the River Don at Woodside, and passing along the south banks of the river to the boundary of Seaton House policies; thence through Old Aberdeen to the Old Town Links and through Park Street, Justice Street, Castle Street, Shiprow and South Market Street to Victoria Bridge, where it will join the main Girdleness outfall-sewer.

(3) A high-level intercepting sewer at Hutcheon Street (C), 1,880 yards in length, commencing at Westburn Road and connecting to and utilizing an existing main sewer in Urquhart Road; to be intercepted by the northern-district drainage sewer.

(4) A low-level storage sewer, 762 yards in length, laid along the North Esplanade to drain a low-lying district of 162 acres near Poynernook Road, and discharging direct into the River Dee 95 yards below Victoria Bridge.

(5) A storm-water culvert (D), 3,086 yards in length, commencing at King's Gate and passing along Fountainhall Road, Stanley Street, Union Glen, and the route of the Ferryhill Burn, discharging into the River Dee near Old Ford Road. The essential feature of this storm-water culvert is the utilizing of the existing natural water-course called the Ferryhill Burn for storm-water purposes; this has been diverted through a new culvert for the purpose, and the open parts of the existing burn have been covered in.

Powers were also obtained under the 1899 Act to discharge storm-water into the River Dee at various points, in accordance with the terms of an agreement entered into between the Dee District Fishery Board and the Town Council. This agreement provided

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that no storm-water should be discharged unless the sewers were two-thirds full, but in designing the new works allowance has been made for overflow to take place only when the sewage is diluted by an excess of 5½ times the dry-weather flow.

These new sewers enable the whole of the sewage of the city to be drained to Girdleness, with the exception of that from two low-lying districts, the one near Victoria Bridge having an area of 162 acres, and the other near Abercrombie's Jetty with an area of 270 acres. There are also several small areas adjoining the River Don and on the south side of King Street, amounting to 187 acres, that are unlikely to be built upon for many years; these cannot be drained by gravitation, but will require to be pumped into the new outfall-sewers. With these exceptions, which make up a combined total of 619 acres, practically the whole of the available building area (excluding the Old Town and Queen's Links) within the parliamentary and municipal boundary can be drained to Girdleness.

The main outfall-sewers below overflows are designed to discharge a quantity equal to 300 gallons per head per diem, on the estimated future population of the city in 1941, which has been liberally estimated at 270,000 persons. This quantity is slightly in excess of six times the average dry-weather flow of the future population. The present average dry-weather flow is equal to nearly 45 gallons per head, taken over the whole city, but the average dry-weather flow in different districts ranges from 30 gallons per head per diem in Woodside to 80 gallons in Rubislaw.

Provision for Rainfall.—The average yearly rainfall at Aberdeen amounts to 30·4 inches, but frequently very heavy falls are experienced, particularly during the months of June, July and August, falls at the rate of 1·5 and 2 inches per hour being recorded over periods of 20 and 30 minutes' duration. Owing to this fact, and taking into consideration the number of streets paved with granite and the rapidity with which the storm-water reaches the sewers, it was deemed desirable to allow for 1 inch of rainfall per hour as the quantity to be dealt with. A coefficient ranging from 0·2 to 0·75 was taken for different areas within the city, the latter coefficient being used in the fully built-over and paved areas near the centre. In the suburban districts practically all the storm-water from the streets is carried direct to the burns and natural watercourses.

Girdleness Outfall-Sewer: Upper Section.

The Girdleness outfall-sewer (A, Fig. 1, Plate 5) was constructed under two contracts, the upper section, extending from Skene Street to Point Law, being undertaken first, so as to provide a temporary relief from floods, and also to avoid opening up several main streets after the laying of a new tramway system. The sewer intercepts the whole of the sewage lying to the west of its route, and its invert level at Skene Street is 60·5 feet above Ordnance datum. It ranges in size from 3¾ feet by 2½ feet egg-shaped at the highest points, to 7½ feet diameter circular at the outfall. The gradients of the upper section range from 1 in 23 to 1 in 760, while the ruling gradient from Victoria Bridge to the sea at Girdleness, a distance of 3,474 yards, is 1 in 2,000. A section of the sewer line is shown in Fig. 2, Plate 5.

The sewer throughout the upper section was constructed within tunnels, and in open cuttings up to 30 feet deep. The tunnel through Golden Square to Crown Street was driven partly through disintegrated granite, overlying solid rock, and partly through fine running sand, which required particular care in tunnelling owing to the proximity of high buildings on either side. The headings were closely boarded throughout, 1½-inch poling-boards carefully caulked with straw being used, and the presence of large water-worn boulders, weighing in many cases up to 10 cwt., further added to the difficulties of tunnelling.

The deep open trenches were closely timbered in two settings with 2-inch and 2½-inch runners packed with straw, the upper setting being about 2 feet wider than the lower. Practically the whole of the timbering was allowed to remain in position after the work was completed.

The forms and dimensions of sewer are shown in cross-section on Figs. 3, Plate 5, the general type being of concrete with an inner lining of double-pressed red bricks. Where the velocities are high, the sewers are provided with solid blue-brick invert-blocks and the first six courses on either side are of specially-radiated blue bricks. The concrete was composed of crushed grey granite (1-inch mesh), and clean sand chiefly excavated from the trenches, mixed with Portland cement in proportions to form 5-to-1 and 6-to-1, and in some cases 4-to-1, concrete.

In Crown Street, on the top of a part of the main sewer, a cable subway[1] was constructed for the City Electrical Department. This

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[1] Proceedings of the Incorporated Association of Municipal and County Engineers, vol. xxx, p. 129.

subway was not decided upon until the sewerage works had begun, and was carried out simultaneously with the new sewer, which formed its foundation, so as to avoid opening up the street afterwards.

From the Crown Street sewer the bulk of the storm-waters are discharged at the top of Portland Street, over an overflow weir into an existing stone sewer 3½ feet by 2½ feet in size; this was repaired and plastered inside with cement, so as to be utilized as a permanent overflow sewer discharging direct into the Ferryhill Burn near Dee Village. The overflow is designed to discharge storm-waters at the rate of 35 million gallons a day.

Where the outfall-sewer passes under the Caledonian Railway main line it is constructed in two lines of 32-inch diameter cast-iron pipes; and for a short length when the cover above was limited, a special flat section, 6 feet 6 inches wide and 4 feet high in concrete, was used (Fig. 4, Plate 5).

Along North Esplanade West the outfall sewer is 5 feet in diameter, and it joins the main sewer from the northern district at Victoria Bridge.

Junction Chamber and Overflow at Victoria Bridge.—This chamber, which is fully detailed in Figs. 5, Plate 5, receives the 5-foot diameter sewer from the Esplanade, and the 6½-foot diameter sewer which drains the Northern district of Woodside, Old Aberdeen, Spital, etc. The junction of the two sewers is formed by means of a trumpet-shaped arch which terminates in a chamber with a concrete roof; the walls of the chamber are formed of 8 to 1 concrete lined with red brickwork 4½ inches thick, with headers every fifth course. The floor of the chamber at this point is 6·22 feet above Ordnance datum, and the stone overflow-weir, which is 15 feet long, is fixed at a point 11¼ feet above Ordnance datum, or about 18 inches above the level of the highest recorded tides. From the weir is constructed a concrete overflow-culvert, with its invert at mean-tide level and its outlet on the river-bank, where it is finished within an ashlar-faced concrete retaining-wall. A wrought-iron gate is placed across the culvert within a chamber, to prevent access to the main sewer from the river-bank.

From this overflow chamber the sewer is continued to Point Law in duplicate, 5¾ feet in diameter, owing to the fact that there was insufficient depth below the surface to make it the full 7½ feet in diameter. At Point Law the sewer is taken under the River Dee through a tunnel.

RIVER DEE TUNNEL.

This tunnel (Figs. 6 and 8, Plate 6), which forms one of the chief features of the new scheme, is constructed at right-angles under the river about 770 yards immediately east of Victoria Bridge, and is designed to form duplicate siphons for conveying the sewage to the outfall sewer at Torry, on the south bank of the River Dee. The depth from high-water mark of ordinary spring-tides to the top of the tunnel was fixed, by agreement with the Harbour Commissioners, at 41 feet, so as to allow a future dredging depth of 38 feet.

Tunnel Lining.—The tunnel is 344 feet in length, measured from centre to centre of the shafts (Figs. 6, Plate 6). Its external diameter is 8½ feet, and it is formed of rings of cast-iron segments 1 inch in thickness and 18 inches in length, each ring being made up of five segments and a special key-piece. The following Table gives the weight of one ring:—

	Cwt.
Key-piece	2·68
Two upper segments	9·03
,, lower ,,	9·06
Bottom segment	5·49
Total	26·26

The whole of the flanges are machined throughout and are provided with a caulking space. Each segment is tapped and fitted with screw-plugs for grouting purposes. The bottom segment and the key-piece have cast upon them special machined flanges, 10 inches wide, to receive the vertical steel diaphragm, which was placed in position after the tunnel was driven. The tunnel has a fall of 12 inches from Point Law to Torry.

Shafts.—At the Torry and Point Law sides of the river cast-iron shafts were sunk; these were 13 feet in external diameter, the metal being 1¼ inch in thickness; the ordinary rings were 6 feet in depth, made up of seven segments with 6-inch bracketed flanges. All the flanges were machined for a distance of 3½ inches from the outside, leaving a caulking space for rust of 2½ inches horizontally and vertically.

The Torry shaft was sunk to a depth of 62½ feet below high-water mark of ordinary spring-tides, or 70 feet below the finished wharf-level, a depth sufficient to form a permanent drainage sump below the level of the tunnel. In sinking this shaft no special difficulty was experienced until the level of the top of the tunnel was reached, the method adopted being to dig the material out by hand and to load the shaft internally with kentledge. The upper 10 feet of the ground passed through consisted chiefly of a fine red clay, used locally in former times for brickmaking. Underlying this was an impervious bed of grey clay, and the shaft passed through the upper 40 feet without any trouble. When, however, that depth was reached, the clay was found to contain numerous pockets of sand, and water burst into the shaft very rapidly, soon filling it up; pumps were then placed in the shaft and the excavation was continued by hand and by means of grabs under difficulties for the remaining 23½ feet. The quantity of water dealt with amounted to between 60 and 80 thousand gallons per hour. Great care had to be exercised in preventing the shaft from sinking too far, as the segments on the line of the tunnel had been placed vertically without breaking joint, in order that a horizontal and a vertical joint should fall exactly in the centre line of the tunnel. When the shaft had been sunk to the exact depth and hung from large balks of timber at the top, considerable difficulty was experienced in obtaining a suitable foundation to prevent it from settling. The surrounding ground had also been disturbed by the operation of sinking the quay-cylinders, referred to later, which was being carried on simultaneously with the sinking of the tunnel-shafts. The method adopted to plug the shaft and to form a foundation was as follows: it was allowed to fill with water, which rose to slightly above high-water mark, the rise and fall of the tide, normally about 12¾ feet, making practically no difference to this level. A diver was then sent down to excavate the ground below the bottom of the shaft, and a little beyond the side (the cutting edge had previously been taken off and a special ring with a bracketed lower flange, 12 inches wide, had been substituted in its place). By excavating an additional 3 feet below the shaft a solid foundation was reached consisting of hard boulder-clay overlaying the rock. The space excavated was then plugged with 2-to-1 concrete, which was lowered in closed skips and placed carefully in position by the diver. This concrete was continued up 21 inches above the lower flange of the shaft, giving an average depth of foundation concrete of 4¾ feet. The shaft was then allowed to stand full of water for a fortnight, when it was pumped out and found to be perfectly watertight.

Practically the same course had to be adopted in sinking and plugging the Point Law shaft on the north side of the river; exactly the same strata were met with, and the difficulties were accentuated by the closer proximity of the quay-wall cylinders and the presence of large water-worn boulders in the shaft, some of them several tons in weight. The shaft was sunk to a depth of 53 feet below high-water mark and the excavation for the foundation was carried about 4¾ feet below this level, when a firm foundation of very hard boulder-clay was reached.

Quay-wall Abutments for Tunnel.—In connection with a scheme then in progress on the River Dee for constructing docks (now completed), a joint arrangement was entered into with the Aberdeen Harbour Commissioners to substitute for the proposed timber wharfing a permanent abutment on either side of the river. This was formed of granite-faced concrete retaining-walls, laid on a foundation of concrete cylinders and sunk to give a clear navigation space of 250 feet (Figs. 6, Plate 6). This proposal was adopted to prevent any disturbance to the tunnel in the future, a proportion of its cost being borne by the Town Council. The plan, designed and carried out under the direction of Mr. R. Gordon Nicol, M. Inst. C.E., the Engineer to the Commissioners, was for the construction of a 70-foot length of quay-wall on either side of the river. Two pilot cylinders were first sunk 21 feet off the centre-line of the tunnel; these were 14 feet square and were formed of concrete blocks faced with granite dowelled and bonded together, with a well-hole measuring 7½ feet by 8½ feet. They were sunk to a depth of 48 feet below low-water mark by means of grabbing, about 400 tons of kentledge being used; at this level they reached a firm foundation on the boulder-clay. A large cylinder was then sunk between them, 38½ feet long by 14 feet wide, and having three well-holes.

In the large cylinder on either bank an opening for allowing the tunnel to pass through was provided, but for facility in sinking this was temporarily faced on the outside with an outer skin of 14-inch brickwork stiffened by concrete piers within the well-holes. When these cylinders were sunk to the required depth, a circular tunnel was constructed within them exactly on the line of the tunnel, and 9½ feet in internal diameter, thus allowing a clear space of 6 inches on all sides for surrounding the tunnel with concrete, as it was driven through. The well-holes were afterwards filled up with 6-to-1 concrete to the tops of the cylinders, which were at the level of low-water mark, and the quay-walls were then constructed on these as foundations.

Tunnelling.—Upon the completion of the quay-wall cylinders, a commencement was made to drive the tunnel from the Torry side. It was at first proposed to do the work without the aid of compressed air, but the experience gained in sinking the shaft and in an attempt to drive a small heading to discover the actual conditions of the strata, led to the adoption of compressed air; the presence of large quantities of water under pressure rendering satisfactory work impossible otherwise.

The air-lock of the Torry shaft, designed to suit the existing conditions, consisted simply of two circular steel floors supported upon girders, which in turn were suspended from the cast-iron flanges. The lower floor was placed 12 feet above the centre-line of the tunnel, with the upper floor 6 feet above it; this allowed a depth of 4½ feet inside between the main girders, but the full height was available between the decking. To render the floors air-tight, the floor-plates, etc., were bolted together with canvas and red-lead, and the clearance space between the shaft and the outer skin of the floors was grouted with plastic bitumen. In the lower floor was provided a cast-iron hinged door, and in the upper floor a sliding door that could be operated from either inside or out. On the top floor and immediately over the lower door a steel tube 18 inches in diameter was fixed; this was 12 feet long, and was fitted with an air-tight cover opening externally, so as to permit of rails, bars, etc., being passed through the air-lock.

For the purpose of lowering material into the tunnel from the air-lock, an electric hoist was provided, the motor and switches being fixed to the upper floor. The air-lock was fitted with a ¾-inch inlet and outlet air-tap, controlled only from the inside, and for passing through materials a 2-inch tap controlled from the outside was provided. Telephonic communication was arranged from the top of the air-lock to the compressor station and also to the tunnel.

The air-compressing plant was laid down on the Torry side about 200 yards west of the shaft, and adjoining the old Torry brickworks, the engine- and boiler-house of which were utilized as far as possible. Two Ingersoll-Sergeant horizontal air-compressors were used; these were provided with piston inlet-valves and water-jacketed air-cylinders and heads; the steam-cylinders were 16 inches in diameter and the air-cylinders 18¼ inches. Each machine was capable of supplying 37,800 cubic feet of free air per hour to the tunnel. The usual custom was to run the two machines at a low speed simultaneously, except during cleaning and repairs, when one compressor run at a higher speed was sufficient. Steam was supplied to the compressors from a Lancashire boiler having a working-pressure of 80 lbs. per square inch. The air was supplied to the tunnel through 7-inch diameter steel pipes, which were reduced to 5 inches at the air-lock.

Before erecting the steel floors to form the air-lock, the shield was lowered into the Torry shaft in a position to commence driving. This shield (Fig. 7, Plate 5) was 6 feet 9¾ inches long and 8 feet

8½ inches in external diameter. The shell was composed of two ¼-inch steel plates riveted together, the cutting edge being formed of eighteen steel knives. The diaphragm was double, being composed of two ¾-inch steel plates, and had an opening 4 feet 9 inches by 4 feet 2 inches with steel channels riveted on to permit of planking being used to close up the space. The shield was fitted with six hydraulic rams, 6½ inches in diameter, having a 22-inch stroke; the working-pressure was 1 ton per square inch, but the actual pressure used never exceeded ½ ton per square inch. The rams had forged cross-heads. In the diaphragm fourteen holes were tapped to 2¼ inches gas-thread and fitted with screw-plugs; these holes were occasionally used for passing a drill through where the cutting edge struck large boulders.

After the fixing of the air-lock and applying the pressure, operations were begun by driving a tunnel to form a shield-chamber to the back of the quay-wall cylinder—a distance of 33 feet 6 inches. This tunnel was driven in the ordinary way by means of 10-inch bars and poling boards, and was sufficiently large to permit of its being lined up with four rings of blue brickwork within the bars and to leave an internal chamber of 9 feet. The ground being in such a dangerously disturbed condition, the whole of the timber was left in and the back of the brickwork was packed with concrete. An air-pressure of 17 lbs. per square inch was required to keep this length clear of water. The space between the shaft and the quay-wall was taken out in three lengths and lined up immediately each length had been dug out. Upon completion of the short length of brick tunnel, the shield was moved along to the back of the quay-wall; the outer skin on both sides of the cylinder was then removed, and the shield was set into position to start under the river. After this the brick tunnel was lined with cast-iron segments up to the shield, and 6 to 1 concrete was packed in at the back of the plates.

A small heading, measuring 5½ feet by 3½ feet, was driven in advance of the shield exactly on the centre-line of the tunnel; this heading was timbered, generally for about 12 feet in advance of the cutting edge, with 9-inch by 4-inch side and head trees and sills, placed close together without poling-boards. The ground kept perfectly dry and firm under the air-pressure, and as the shield was driven forward and the segments were erected, the timbering in the advance heading was removed and used over again.

No further difficulty was experienced in tunnelling under the river until the quay-wall at Point Law was reached. Great care, however, had to be taken to prevent the lining from "corkscrewing" owing to the necessity of having the special flange in the key and bottom segments in accurate alignment for the erection of the steel diaphragm; the progress of tunnelling was consequently slow, never exceeding three rings a day, generally two. The actual driving from quay-wall to quay-wall occupied from the 14th March to the 14th June, 1905.

When the Point Law quay-wall was reached, the work of tunnelling was carried on by similar operations to that on the Torry side, a blue-brick tunnel being formed in the space of 19½ feet between the north side of the concrete cylinder and the Point Law shaft. To prevent the air from escaping up the Point Law shaft and to allow of a proper watertight connection being made between the tunnel and the shaft, a very satisfactory air-tight floor was constructed as follows: timber planking supported upon old tram-rails was placed above the level of the top of the tunnel, upon this came 7 feet of well-rammed clay, and the shaft above was then filled to the top with water.

In driving the tunnel, there was little or no escape of air at the face, except in passing through the quay-wall cylinders, but the purity of the air was maintained by always delivering it at the shield and exhausting it at the air-lock. The air was frequently analysed in the tunnel by means of a Haldane apparatus for determining the amount of CO_2, and larger samples drawn from the tunnel were also examined in the chemical laboratories of Aberdeen University. The amount of CO_2 varied at different times between 10 parts and 14 parts in 10,000. As far as possible, a supply of 5,000 cubic feet per hour was allowed for each man. Electric light was used throughout.

The entire tunnel was grouted with Portland cement grout (1 of cement to 1 of sand), and before the removal of the air-pressure it was carefully rust-jointed.

Forming the Sewage-Siphons.—To permit of cleaning operations being carried on at all times, duplicate siphons were formed, the tunnel being divided by means of a ⅝-inch steel-plate diaphragm (Figs. 8, Plate 6). The diaphragm was stiffened every 18 inches by two vertical angle-stiffeners on each side, and the steel plates were placed in position in 6-foot widths, templates being used to obtain the exact size. The stiffeners were hydraulically riveted to the plates above ground, and the sections were riveted together with wrought-iron ship-rivets below ground; all the joints were carefully arranged to break bond, and were packed with two layers of canvas and red-lead. The diaphragm was secured by steel angles to the special flanges on the cast-iron lining, the steel angles being also bedded completely with canvas and red-lead.

After the steel diaphragm had been completed the west siphon was closed temporarily at the ends by steel plates, and the work was tested for watertightness under a pressure of 25 lbs. per square inch. Beyond a few leaks through the bolt-holes connecting the steelwork to the cast-iron flanges, the diaphragm was found to be quite watertight, and the leaky bolt-holes were remedied by placing lead washers round the heads and nuts.

The two siphons were then lined with concrete to the required shape (Figs. 8, Plate 6), each being 6½ feet high by 3 feet wide on the centre-line of the tunnel; this gave a total thickness to the diaphragm of 14 inches. The concrete for this lining was composed of 2½ parts of crushed granite (¾-inch mesh), 1½ part of pit-sand and 1 part of Portland cement. The concrete was well rammed against planed laggings, the fine stuff being worked with specially-shaped iron tools to bring it to the face, thus leaving a perfectly smooth surface without any plastering. The inverts of either siphon were slightly flattened to allow of easy walking during the operations of cleaning.

The two siphons are connected to the outfall sewer on either side by means of cast-iron flanged pipes 51 inches in diameter with special bends at the top. At the bottom of each shaft these pipes were connected to either half of the tunnel and also to the vertical shaft by special junction castings (Figs. 6, Plate 6).

On the Torry side the 51-inch pipes are fitted with doors at the tunnel-level, so as to allow of access to each siphon; they are also provided with 8-inch sluice-valves for draining the siphons into the sump below the tunnel-level. At Point Law access-doors are also provided together with sluice-valves for draining into either siphon when not in use any water which may gather on the floor of the shaft. The bottoms of the 51-inch castings are closed with ribbed cast-iron plates, which at Point Law are encased in concrete and at Torry rest upon rolled steel joists and the concrete roof of the drainage sump.

Siphon Inlet- and Outlet-Houses—Point Law and Torry.—Over the top of the Point Law shaft is constructed a chamber to connect the outfall-sewer to the tunnel siphons (Figs. 6, Plate 6). The chamber is provided with two sets of 51-inch circular penstocks fitted with gun-metal facings, these penstocks being raised by means of 10-inch diameter hydraulic cylinders; for this purpose a pressure of 40 lbs. per square inch is obtained from the Corporation water-main. Over the top of the shaft is a small house in grey granite for containing the hydraulic cylinders, etc., and from which access to the siphons can be obtained.

On the Torry side two sets of penstocks and hydraulic cylinders are also provided, and by closing the respective penstocks on both sides of the river either siphon can be thrown out of use. A very effective method of flushing is obtained, by allowing the sewage to accumulate in the sewer at Point Law and then raising the penstocks on one siphon rapidly. The actual fall between the inlet at Point Law and the outlet at Torry is 16 inches, giving a hydraulic gradient of 1 in 250, and if sewage were running at its maximum depth in the outfall-sewer, a velocity of 7 feet per second would be obtained.

For cleaning purposes the contents of either siphon can be pumped out in 2 hours by means of a $4\frac{1}{2}$-inch high-pressure centrifugal pump placed on the roof of the drainage-sump at the tunnel-level. This pump is driven by a 30-B.HP. electric motor, compound-wound, and placed vertically in the floor of valve-house; the connection between the motor and pump is by means of a vertical steel spindle, $2\frac{1}{4}$ inches in diameter, which is supported by special bearers fixed to girders placed across the shaft.

The siphon inlet house is octagonal in plan and is built of grey Kemnay granite with fine-axed dressings. An overhead travelling crane is fixed in the roof, with quick and slow motions for raising and lowering skips to remove the silt in the siphons. Ventilation is obtained by means of an 18-inch Blackman electric fan fixed in the roof. A 36-inch electric fan, fitted with an enclosed motor, is also provided in the roof of this house for special ventilation during the cleaning operations; this fan runs at a speed of 800 revolutions per minute and gives a velocity of 600 feet per minute in each siphon.

LOWER SECTION: RIVER DEE TO GIRDLENESS.

From the Torry siphon outlet-chamber the main sewer for a distance of 34 yards is constructed on a timber grillage, supported by 12-inch pitch-pine piles driven down through the 40-foot bed of clay. This was necessary as the ground had settled considerably during the pumping operations in connection with the sinking of the Torry shaft, the beds of sand underlying the clay being drawn away. The sewer, which is here $7\frac{1}{2}$ feet in internal diameter, is constucted of 6-to-1 concrete, the lower half being lined with red bricks. From the north corner of Sinclair Row to Greyhope Road the sewer is in duplicate; at Sinclair Road it is joined by the $4\frac{1}{2}$-foot by 3-foot Torry outfall-sewer, which has been reconstructed and intercepted from its original outlet into Torry harbour. Along Torry quay, the complete scheme provides for two sewers, only one of which has been constructed, namely, the 6½ feet internal diameter sewer, the other, which will be constructed later when the necessity arises, is to be 5¾ feet in diameter. The former sewer is continued as far as the Torry overflow chamber, the existing outfall into Torry harbour having been abandoned except as an outlet for storm-water. The overflow chamber has its sill, which is 12 feet long, fixed at 8 feet above Ordnance datum level, i.e. slightly above high-water mark of ordinary spring tides, but the outlet which discharges slightly below mean-tide level, has an automatic tidal valve fitted with a penstock to prevent the influx of tidal water during exceptionally high tides. From this chamber to the north end of St. Fitticks Road, provision has been made in the junction chambers, etc., for two 5¾-foot sewers, one only having been laid down at the present time.

St. Fitticks Tunnel.—This tunnel was driven under St. Fitticks Road to carry the sewer through the high ground to the foreshore of Nigg Bay. It is 725 yards in length and 7½ feet in internal diameter, and was constructed of 5-to-1 concrete. The minimum thickness of concrete was 15 inches, the lower half being lined with red bricks. The tunnel was driven in two straight lines joined in the centre by a curve of 200 feet radius. The shafts are three in number, one at each end 30 feet deep and the Balnagask shaft 90 feet deep in the centre. This last shaft was sunk through gravels and boulder clay, and was timbered in the usual way with walings and poling boards, 9 feet by 8 feet clear inside the timbering. After the tunnelling was completed, it was lined with brickwork, and domed over the top to form a ventilator, a side-entrance manhole being provided.

The section of tunnel between the north end and the Balnagask shaft was driven entirely through boulder clay. Tunnelling by means of bars was adopted, the ground being taken out to the exact shape in lengths of 12 feet, and lined up as the excavation was carried forward. The concrete arch was put in position on planed laggings, supported on four semicircular steel angle-ribs to each 12-foot length; these being wedged up from similar steel ribs placed over the brick invert. By adopting this method, all materials were easily handled, as plenty of head-room was available. Throughout this length, the whole of the bars were removed, a few poling boards only being left in where a wet spot was encountered. A length of 12 feet at each face was completely lined and finished in 5 days.

Between the Balnagask shaft and the southern end of the tunnel the strata varied considerably, and half way through this length a full face of rock was met with—chiefly gneiss of a very contorted nature—rendering blasting necessary. Farther south the tunnel passed through what was practically a mass of granite boulders, necessitating very stout timbering, and owing to the enormous weight upon the arch the concrete was increased at some points to about 20 inches in thickness. The progress in this section was very slow and occupied nearly 18 months, from March 1902 to August 1903, the difficulties being further increased by the presence of large quantities of water.

Foreshore of Nigg Bay.—From the south end of the St. Fitticks tunnel the sewer crossed arable land to Nigg Bay. Provision has been made for two 5¾-foot diameter sewers, but for a distance of 430 yards only one was constructed, the general principle adopted throughout the construction of this outfall sewer being, that in places where duplication could be carried out easily in the future one only should be laid down, but in tunnelling and through rock cuttings the full size to deal with the future growth of the city should be constructed at once. When therefore the sewer reached the foreshore of Nigg Bay and passed through rock, the full size was again adopted and continued for the rest of the way to Girdleness Point.

Along the foreshore this sewer was constructed during the spring and summer of 1902, the cuttings ranging from 10 feet up to 36 feet deep; the rock passed through was principally granite, gneiss and hornblende schist, full of joints and very contorted. Steam rock-drills were used for a section of the work, but owing to the disintegrated and jointy nature of the beds, it was found more economical and expeditious to resort to ordinary hand-drilling. For the purpose of carrying on this work, a railway was put down along the foreshore from the south end of St. Fitticks Road to Girdleness Point, the rock having to be cut through at several points, and at others temporary embankments having to be made. In excavating the trenches five 3-ton steam travelling cranes were used, running on embankments on the south side of the trench; these embankments in some cases were puddled with clay, so as to form a watertight coffer-dam to prevent the sea from flooding the trenches. During heavy storms the cranes were run back on to the railway out of danger. The trenches were kept clear of water with 5-inch centrifugal pumps, and during calm and dry weather hand diaphragm-pumps were largely used.

At one point along the foreshore the top of the sewer for a distance of 68 yards was exposed to very rough seas; it was therefore carried in a heavy retaining-wall. The outfall-sewer terminates at Girdleness in a penstock-chamber and valve-house, with its invert at Ordnance datum level.

Penstock and Valve-House.—This house, indicated on Figs. 9, Plate 6, is 29 feet long by 19 feet wide internally, and contains two sets of cast-iron penstocks 6½ feet square, fitted with gun-metal facings throughout; these are fixed to concrete walls 4½ feet thick, built across the chamber. One set is designed for closing against the incoming sewage, and the other to shut back the sea coming up the outlet when necessary for cleaning and repairing the tidal valve, etc. Between these penstocks is placed an automatic tidal flap with double cast-iron doors, covering an opening of 5½ feet by 6½ feet; the doors are balanced so that they open immediately the pressure within the sewer exceeds that on the sea side. Each penstock is fitted with hydraulic cylinders 30 inches in diameter for raising and lowering it, the water-pressure of 35 lbs. per square inch being obtained from the Corporation service at St. Fitticks Road. The hydraulic cylinders are of similar design to those at the Dee Tunnel, and all the pipes and fittings are of copper and gun-metal to prevent corrosion. The upper penstocks are utilized for flushing the outfall during low water, and experience in its working has proved that the outfall-sewer as far back as Torry quay can be effectually flushed by shutting the penstock until the sewage rises to a depth of 5 or 6 feet, and then raising it quickly. In case of any accident to the tidal flap, two overflows are provided in the upper division wall, having their lips at 11½ feet above Ordnance datum.

The lower part of the penstock-house, which was excavated to a depth of 20 feet in rock, is constructed of 8-to-1 concrete, the walls being rendered internally with 2-to-1 cement plaster ¾ inch thick. Above the ground-level the building is of grey Rubislaw granite ashlar, dressed inside and rock-faced outside, with Kemnay granite dressings. The roof is carried on two simple steel trusses and lined inside with V-jointed match-boarding. A large louvre ventilator, 10 feet long, is framed in the roof and covered with lead, and the roof of the house is covered with green Westmorland slates. A 2-ton overhead travelling crane is provided in this house for handling the heavy parts of the cylinders, tidal valves, etc.

The penstock-house is protected from the sea by a heavy retaining-wall of concrete. This wall is pitched with Kemnay granite 15 inches thick on the sea side, and on the inside is faced with Rubislaw rock-faced ashlar to correspond with the penstock-house. The coping measures 3 feet 3 inches by 1 foot 6 inches and is formed of dressed Kemnay granite in heavy blocks, weighing about 1½ ton each.

The surrounding embankments on the land side have granite retaining-walls at their toes, and the roadway round the house is paved with 4-inch granite cubes laid on a bed of concrete. A cart-road was also made from the top of the embankment to the penstock-house.

Sea Outlet.—From the penstock-house, the sea outlet (Figs. 9, Plate 6) is laid in a north-easterly direction for a distance of 571½ feet. It is constructed of cast-iron pipes 7 feet in diameter encased in a heavy sea-wall. The outlet has its invert at the lower end of the penstock-house 2·25 below Ordnance datum, and terminates in the sea at a point 13·50 feet below Ordnance datum level, or 20·85 feet below H.W.O.S.T., advantage being taken at the extreme point of a deep natural channel on the rocks, running into very deep water in a north-easterly direction. The outlet laid at this level will always be covered at low water, the average range of spring-tides being 12·75 feet.

The outlet pipes were cast in 9-foot and 6-foot lengths (Figs. 11 and 11*a*, Plate 6). The 9-foot lengths are 1½ inch thick with 6½-inch by 2⅛-inch flanges, and are stiffened with brackets 1½ inch thick between each bolt-hole, twenty-eight 2-inch steel bolts being used for connecting up. Two annular stiffening flanges 2½ inches deep and 2 inches wide are carried round the body. The weight of these pipes is approximately 6½ tons each.

The 6-foot lengths of cast-iron pipe, nine of which ordinary lengths were laid at the extreme point, are 2¼ inches thick in the body, and have one annular stiffening flange to each pipe 5 inches deep by 2½ inches wide. The extreme outlet pipe was cast the same thickness, but with the addition of a bull-nose. The weight is approximately 7 tons each.

For a distance of 336½ feet from the internal north wall of the penstock-house, the pipes were laid in a trench 9 feet wide and from 10 feet to 20 feet deep, as shown in the Figure.

The first pipe was laid at the north end of this length in the third week of November 1902, and the work was continued inwards to the penstock-house, so that operations could be carried on during the winter without being influenced greatly by the storms. The bell-mouth pipe at the penstock-house, the last laid in this length, was fixed in the second week of February 1903. At the extreme end of the section the outside of the trench was protected by a temporary coffer-dam; this was constructed of bags of clay, with its top level about 4 feet above Ordnance datum, the rock excavation being pumped dry after the tide had receded. A crane road was laid along the seaward side of the trench, carried up to a level of about 5 feet above high water, to form a protection from the sea, and the pipes were lowered into the trench by means of a 10-ton steam travelling crane. The method adopted to handle and adjust these pipes ready for bolting up was, to use a framed timber stool, securely and strongly braced, after each pipe had been lowered into the trench; the stool had long and short legs, the latter being shaped to form a saddle-back to rest upon the previously-laid pipe. On the longitudinal bearer, two 5-ton chain-tackles were used to adjust the pipe to the proper level; it was then firmly blocked up from below and the joint was made with red-lead and canvas, the pipe being finally packed at the bottom with 6-to-1 concrete. By adopting this method, a pipe could be lowered from the top and firmly bolted up in about 1½ hour. From the 240-foot to the 336½-foot point the concrete was packed round the pipes and over the tops to a width of 20 feet, forming a heavy protecting wall from the sea; the rock beyond the sides of the trench for this length was carefully cleaned and excavated, so that the sea-wall could be dovetailed into it. The sea-wall had a batter on the sides of 1 in 12 and was finished with a heavy bull-nose. The thickness of concrete over the pipes from the penstock-house to 170 feet was 12 inches, and from 170 feet to 240 feet it was 2 feet; at the 190-foot point a concrete retaining-wall was built across the trench to prevent the action of the sea from scouring out the rock-filling on the beach above high-water mark.

The upper section of this work from 0 to 170 feet was carried on irrespective of the tides by constructing a temporary dam across the trench, but from 170 to 336½ it was wholly tide-work, about 5 hours' work on each favourable tide being obtained. The trenches and coffer-dams were pumped dry when the sea was fairly calm, and after it had fallen sufficiently. Though the average range of spring-tides is 12·75 feet, they frequently rose to 9 feet above and fell to 6·5 feet below Ordnance datum; while the neap-tides occasionally had a range of only 6 feet.

Upon the completion of this length, a start was made at the end of May 1903 to work outwards. A crane-road for carrying the 10-ton travelling crane was laid immediately on top of the finished sea-wall, and over the centre-line of the pipes. This road consisted of 12-inch squared timber logs laid longitudinally to carry 60-lb. rails; the logs were supported upon 10-inch by 10-inch sleepers laid 4 feet apart and secured by iron bolts dowelled to the permanent sea-wall. The rock was excavated in advance of the crane for short lengths within temporary concrete coffer-dams, the foundations of which were placed in position by divers. Two or three pipes were then laid at a time, and the concrete was placed in position with vertical joints and bonds to form large monoliths. The construction of this work was retarded by very rough seas experienced during the summer and autumn seasons of 1903–05, operations having to be suspended sometimes for many weeks at a time; Girdleness Point is one of the most exposed on the east coast of Scotland, and on several occasions much of the temporary plant was washed away or seriously damaged. During some periods owing to the heavy ground-swell work could only be carried on, even in fine weather, for about 2 or 3 hours in each spring-tide, no work at all being possible during neap-tides.

The chief difficulty experienced was in constructing the last length from 500 to 571½ feet. The sea-wall on this section was increased in width from 20 feet to 30 feet for the last 53 feet, and its height was raised to 5 feet above Ordnance datum level. This length was constructed in the following manner: after the rock had been carefully cleaned and all jointy rock removed on each side of the centre-line, a section of the permanent wall 6½ feet wide was constructed on either side and in advance of the portion already completed; a space 17 feet wide thus being left for the excavation of the 9-foot trench. The foundations of these walls were placed in position by divers below low-water level, the walls being carried up to 3·25 above Ordnance datum level with 4-to-1 concrete. The concrete was placed in position between a timber framing, secured to 7-inch square timber posts fixed to the rock below with iron dowels; the framing had 2-inch planking nailed to the inside and was lined for the outside of the walls with canvas. These walls, on the inside had deep channels left in them for bonding the internal hearting. When the walls had reached a distance of 30 feet in advance of the work already finished, they were closed by placing across them a temporary concrete wall 4 feet thick, strengthened by old steel rails. The excavation and the pipe-laying was then carried on in a dry trench after the water had been pumped out. The method adopted for placing the last five pipes into position is shown in Figs. 10, Plate 6. The temporary wall was built 3 feet beyond the termination of the sea outlet, being laid on a foundation of bag concrete, this allowed room for setting the pipes and for properly framing the sea-wall to the required batter. This wall was afterwards removed by blasting, holes, carefully plugged, having been placed in convenient positions during its construction. To prevent the concrete-work in the trenches from being washed away by the tide flowing over the top of the concrete coffer-dams, a 12-inch iron pipe fitted with a sluice-valve was always placed at the lowest possible level, and as the level of the tide approached the top of the coffer-dam the sluice was opened and sea-water was allowed to enter gradually. To add to the strength of the concrete wall over the top of the pipes in the last 53 feet, it was reinforced with 12 rows of 4-inch iron bars curved as shown in the section XX, Figs. 9. The specific gravity of the hearting of the wall at its extreme point was increased by building into the concrete mass large granite displacers, some of which weighed 5 or 6 tons.

The rock immediately in front of the outlet for about 15 feet was excavated to 15 feet below Ordnance datum level, to allow the sewage to flow into the natural channel, which ran into deep water immediately north-east of the outlet. By the methods adopted every pipe was laid in position in a dry trench, and satisfactory work that could be carefully inspected was obtained.

Northern District Drainage.

It has already been pointed out that the Girdleness outfall-sewer was designed to deal with the sewage and storm-water of the whole city, and the intention is eventually to take the sewage from the northern district of the city to Girdleness Point. In the meantime the work is being proceeded with in sections, so as not to throw too great a burden upon present-day ratepayers. The chief sections which have already been undertaken to drain the northern half of the city are the Hutcheon Street intercepting sewer and the main intercepting sewer from Woodside through Old Aberdeen as far as the Old Town Links.

Hutcheon Street Intercepting Sewer.—This sewer (C in Fig. 1, Plate 5) has been constructed from the east end of Westburn Road along Hutcheon Street to George Street, intercepting along its route the sewage flowing down Mount Street and Skene Square, and its construction has been the means of relieving serious floodings that were constantly recurring to the south of its route. The sewer, which ranges in size from 3¾ feet by 2½ feet to 4 feet by 2 feet 8 inches, is egg-shaped, and forms the upper part of a main intercepting sewer which continues along Nelson Street and Urquhart Road, discharging at present into the existing Links outfall-sewer. The intention is to intercept this sewer again by the proposed main northern district sewer to Girdleness, when that has been completed. The only feature calling for special remark in the construction of this sewer is the siphon passing under the tunnel of the Great North of Scotland Railway. This siphon is formed of two lines of cast-iron flanged pipes 18 inches in diameter, which are carried through a cast-iron tunnel driven about 40 feet below the surface of the roadway. The tunnel is 33¼ yards in length to allow for doubling the line, and is formed of cast-iron segments 5½ feet in external diameter. The top of the tunnel was driven about 8½ feet below the brick invert of the railway-tunnel through old red sandstone conglomerate. It was taken out by hand to the exact circular shape without blasting, in lengths sufficient to insert two tunnel rings at a time, and as the segments were bolted in position they were grouted immediately with Arden lime, by means of a Greathead grouting-pan. The cast-iron pipes were laid upon a concrete bed in the tunnel, and were carried up vertically in the inlet and outlet shafts, which were formed of 13½-inch brickwork, rendered with cement-plaster at the back. These pipes at their inlets have sluice-valves fitted with bevel gearing and headstocks, a catch-pit is also placed in front of the inlets for intercepting sand and other solid matter, which is taken out by a small chain-bucket pump. The siphon has a fall between its inlet and outlet of 3¼ feet, giving a hydraulic gradient of 1 in 34. No difficulty is experienced in keeping this siphon clean, as flushing by means of the sluice-valves is sufficient to scour out the contents, one siphon being cleaned at a time. A sump is provided in the lower shaft for draining the siphons through a branch-pipe fitted with a sluice-valve, and the contents can then be pumped out by a pump temporarily placed in the shaft. The siphon has been in operation since June 1904, but has not required any special cleaning except from that obtained by flushing. The siphon inlet- and outlet-chambers are ventilated by means of two 30-foot columns, 10 inches in internal diameter, carried up outside on the edge of the street footpaths.

Northern District Intercepting Sewer.—The section of this sewer that has been constructed up to the present, comprises a length of 4,202 yards (B in Fig. 1, Plate 5), extending from Grandholm Bridge over the River Don at Woodside, to the Old Town Links north of the Broad Hill, where it discharges temporarily into the original 4½-foot Links outfall-sewer. At its junction with this sewer a storm overflow and a junction chamber have been constructed, the object being to utilize the old outfall-sewer as a storm-water culvert discharging at Abercrombie's Jetty, when the new main northern outfall-sewer has been completed as far as the Victoria Bridge junction chamber.

The new sewer, which has its invert at an elevation of 30·5 feet above Ordnance datum at Grandholm Bridge, has gradients varying from 1 in 500 at the upper end to 1 in 1,000 at the lower. It ranges in size from 3¾ feet by 2½ feet to 5 feet by 3 feet 4 inches, is egg-shaped, and was carried out in a similar manner to the works already described. Great difficulty was experienced in constructing the sewer between Tillydrone Road near the River Don and Old Aberdeen. The sewer for this length was constructed within a tunnel 1,245 yards long, at a depth of 40 to 70 feet below the surface of the ground, the tunnel being driven partly through boulder clays, and partly through fine running sand containing enormous quantities of water. Throughout this latter part, which was on the site of an ancient loch, the ordinary methods of tunnelling had to be abandoned, and for a length of 1,100 feet compressed air was used. A cast-iron shaft 6 feet in diameter was sunk, and a vertical air-lock being placed on top, tunnelling then proceeded in two directions in the ordinary way. By constructing this sewer the whole of the sewage has been taken away from the River Don and carried temporarily to the mouth of the River Dee at Abercrombie's Jetty. Storm overflows are provided into the River Don, and one main overflow (Fig. 12, Plate 6) is allowed for in the line of a proposed new road east of School Road, Old Aberdeen, to discharge storm-water into the Tile Burn, a natural water-course flowing across the Links to Donmouth.

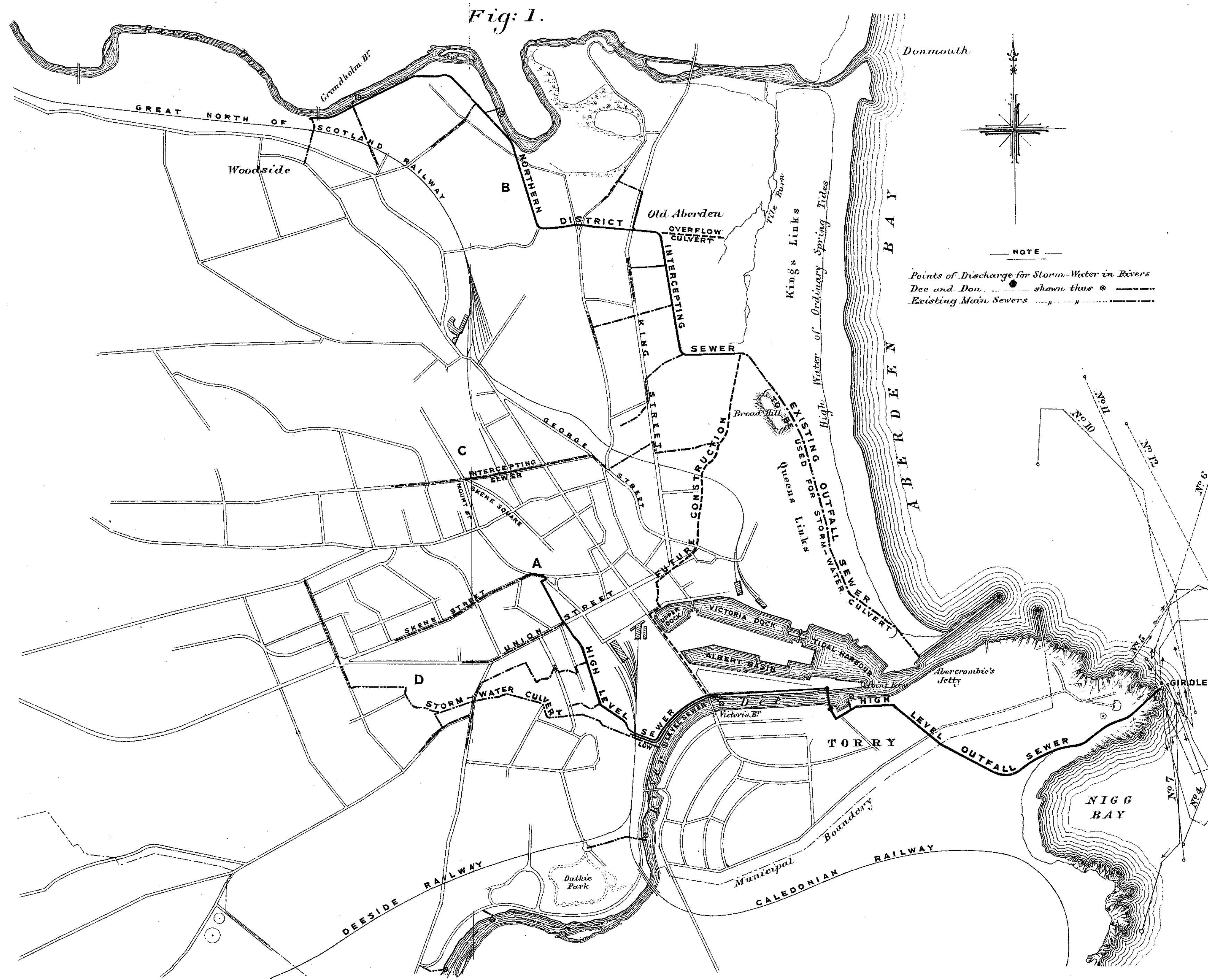
In carrying out the new works for the city a large number of branch sewers and storm-water culverts have been constructed. The interception of many existing sewers has called for their improvement, and in several cases, new fireclay pipe-inverts have been constructed within them at improved gradients, so as to provide more satisfactory velocities, with the consequent reduced flow below the points of interception. The general problems of local drainage arising out of the construction of the new intercepting sewers are being carefully dealt with, and a considerable sum of money will have to be spent annually for a number of years upon the general improvement of the internal drainage.

The works were designed by Mr. William Dyack, M. Inst. C.E., Burgh Surveyor to the City of Aberdeen, and were carried out under his supervision, the Author acting as Resident Engineer, assisted by Mr. Henry Gregory. The Contractor for the works was the late Mr. Peter Tawse, of Aberdeen.

The Paper is accompanied by twenty-one drawings, from which Plates 5 and 6 have been prepared, and by a number of photographs.

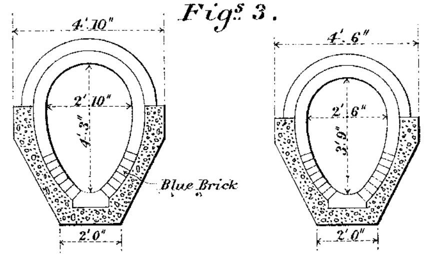
ABERDEEN MAIN-DRAINAGE WORKS.

Fig: 1.



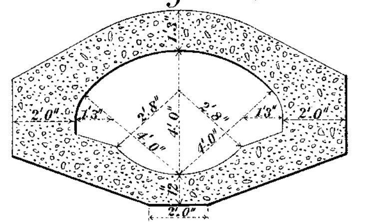
PLAN SHOWING THE ARRANGEMENT OF SEWERS AND ALSO THE CURRENT OBSERVATIONS TAKEN AT GIRDLENESS JUNE & SEPT 1898.

Figs 3.



SEWERS IN CROWN ST & PORTLAND ST

Fig: 4.



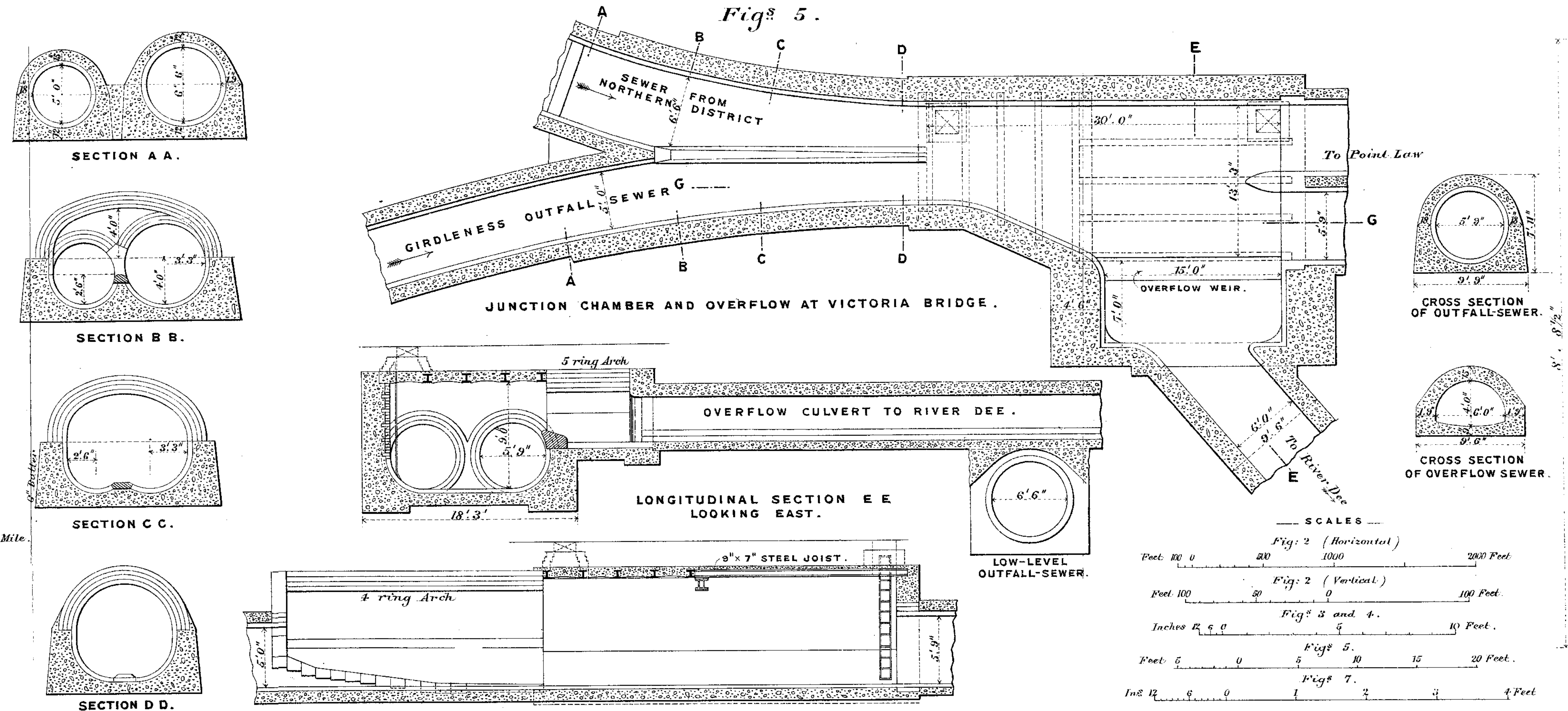
HIGH LEVEL SEWER_SPECIAL LENGTH UNDER RAILWAY.

— SCALE —

Fig: 1 ..... 2 Inches = 1 Mile.

Mile 0 ¼ ½ ¾ 1 Mile.

Figs 5.



— SCALES —

Fig: 2 (Horizontal)

Feet 100 0 500 1000 2000 Feet

Fig: 2 (Vertical)

Feet 100 50 0 100 Feet.

Figs 3 and 4.

Inches 12 6 0 5 10 Feet.

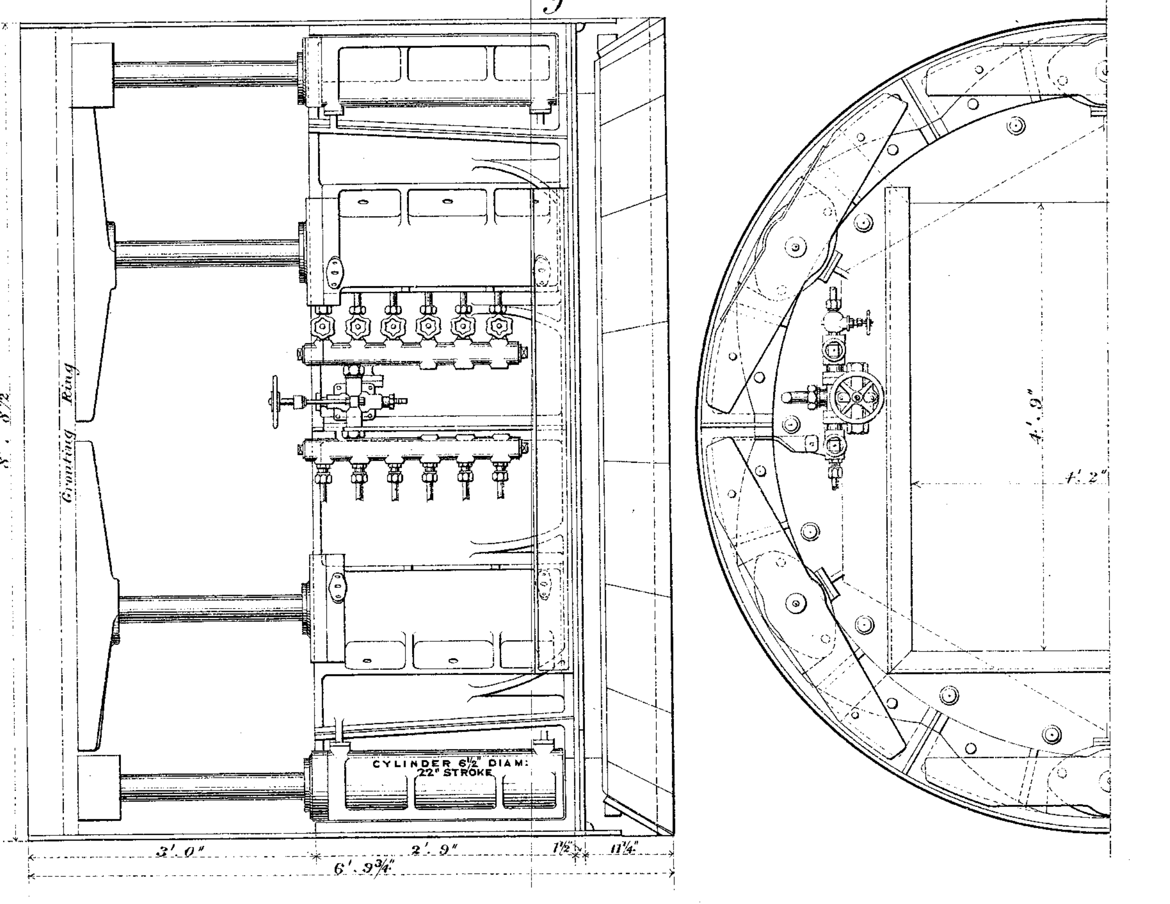
Figs 5.

Feet 5 0 5 10 15 20 Feet.

Figs 7.

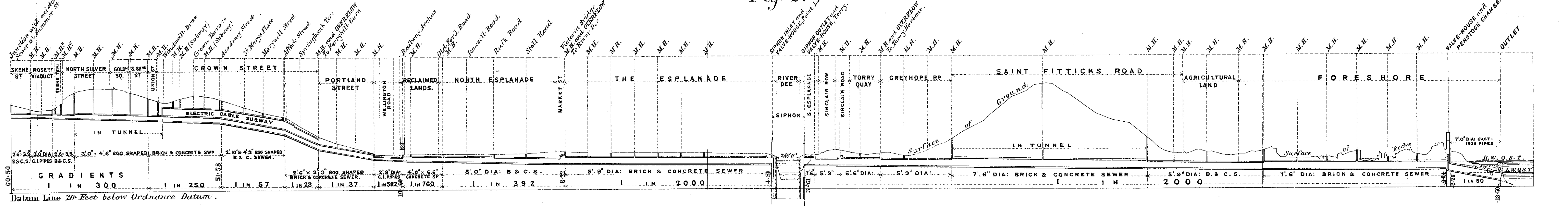
Ins. 12 6 0 1 2 3 4 Feet

Figs 7.



SHIELD FOR DRIVING RIVER SIPHON.

Fig: 2.



GIRDLENESS OUTFALL SCHEME — LONGITUDINAL SECTION

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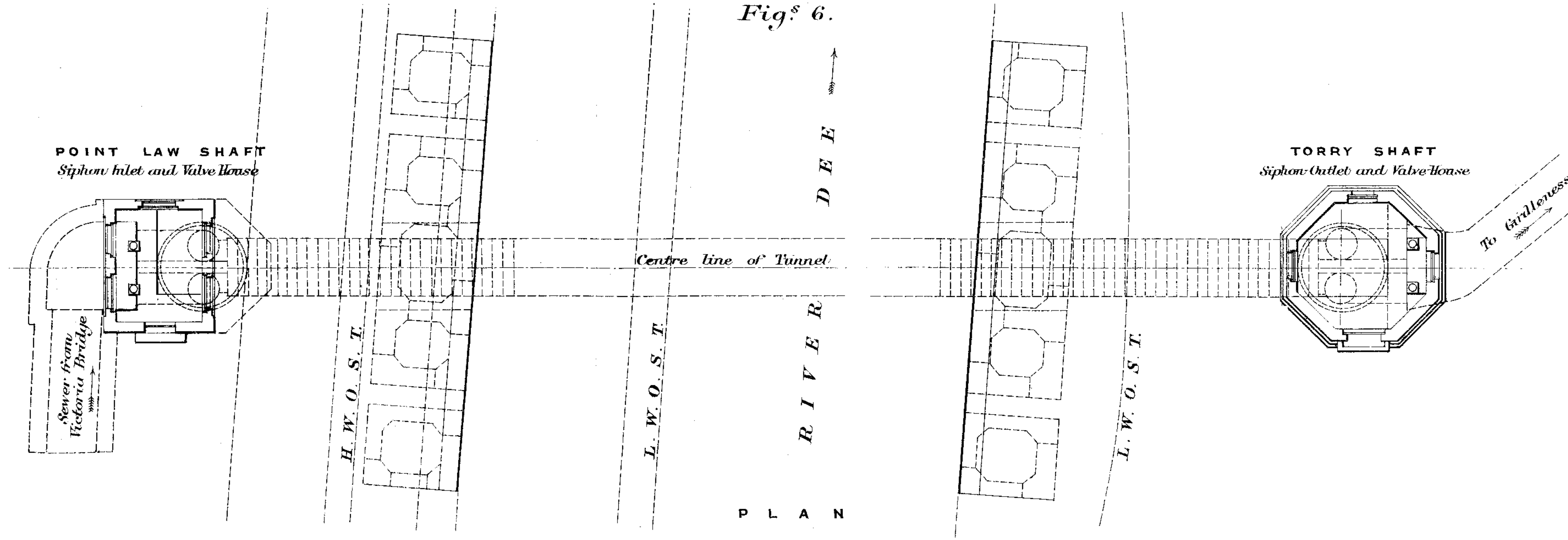
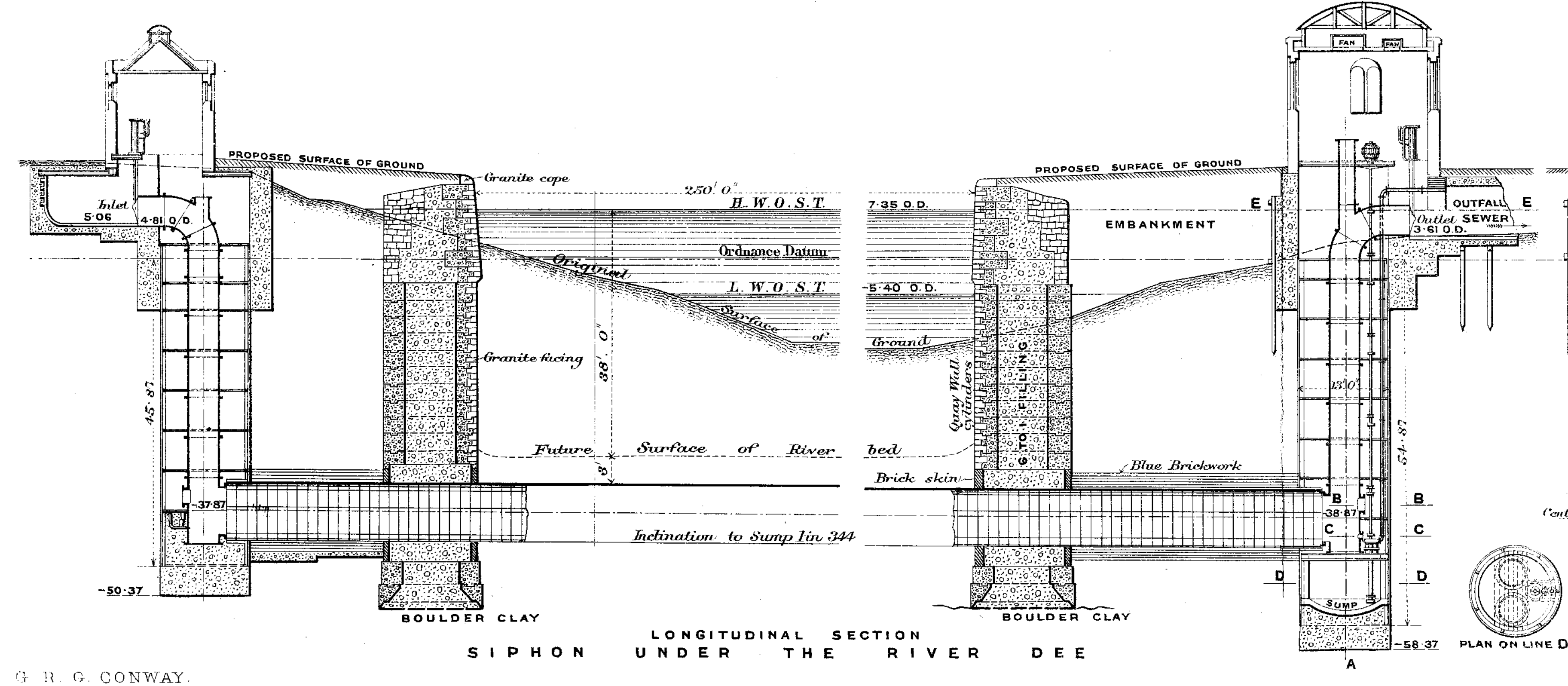
ABERDEEN MAIN-DRAINAGE WORKS.

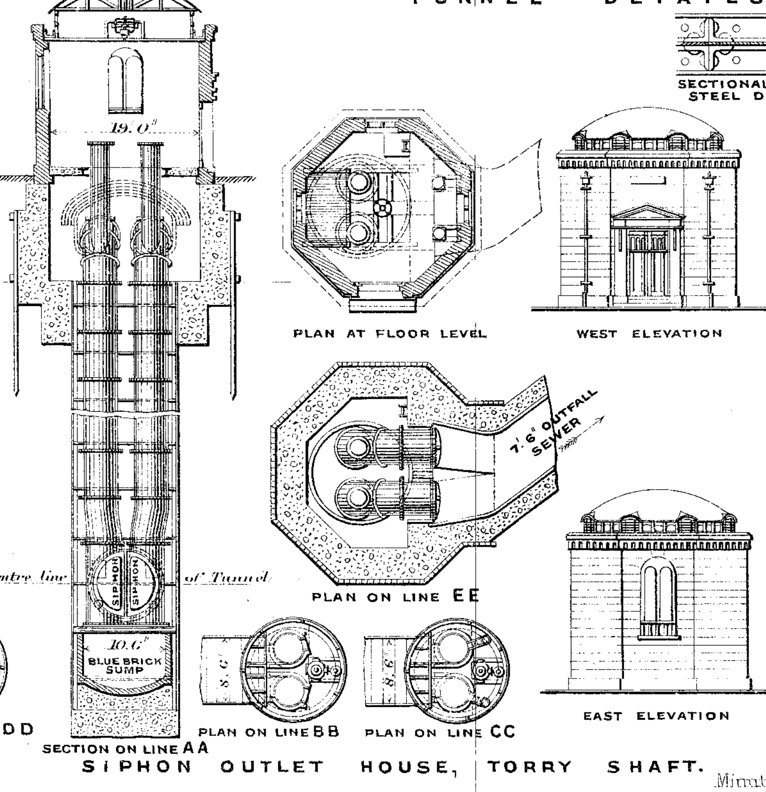
Figs. 6.



PLAN



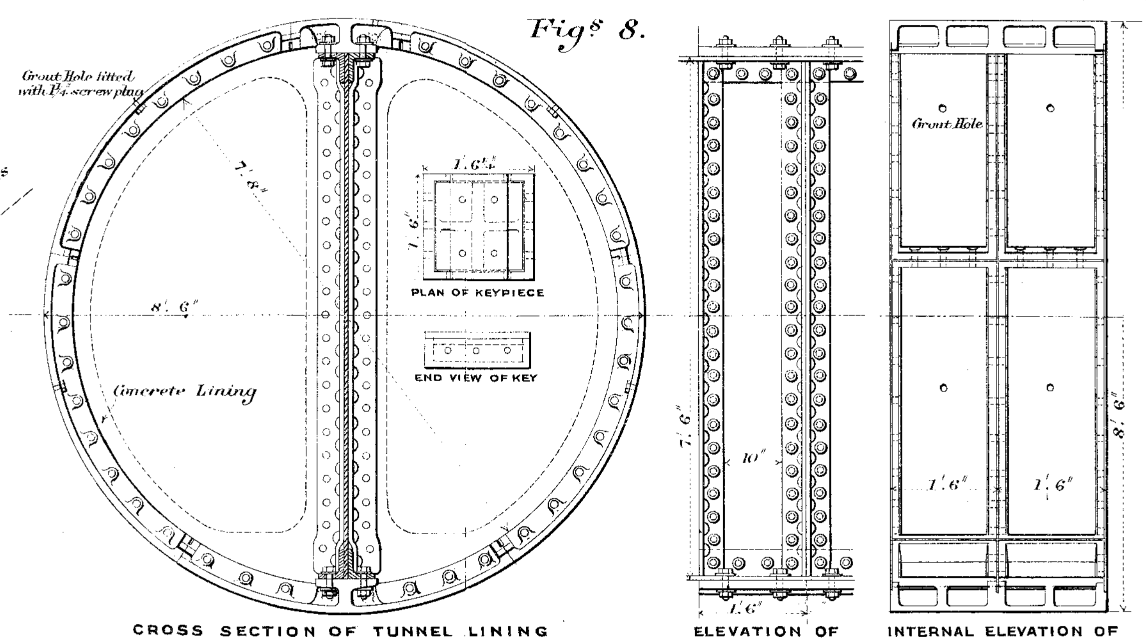
SIPHON LONGITUDINAL SECTION UNDER THE RIVER DEE



SECTION ON LINE AA

SIPHON OUTLET HOUSE, TORRY SHAFT.

Figs. 8.

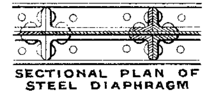


CROSS SECTION OF TUNNEL LINING UNDER RIVER DEE

ELEVATION OF STEEL DIAPHRAGM

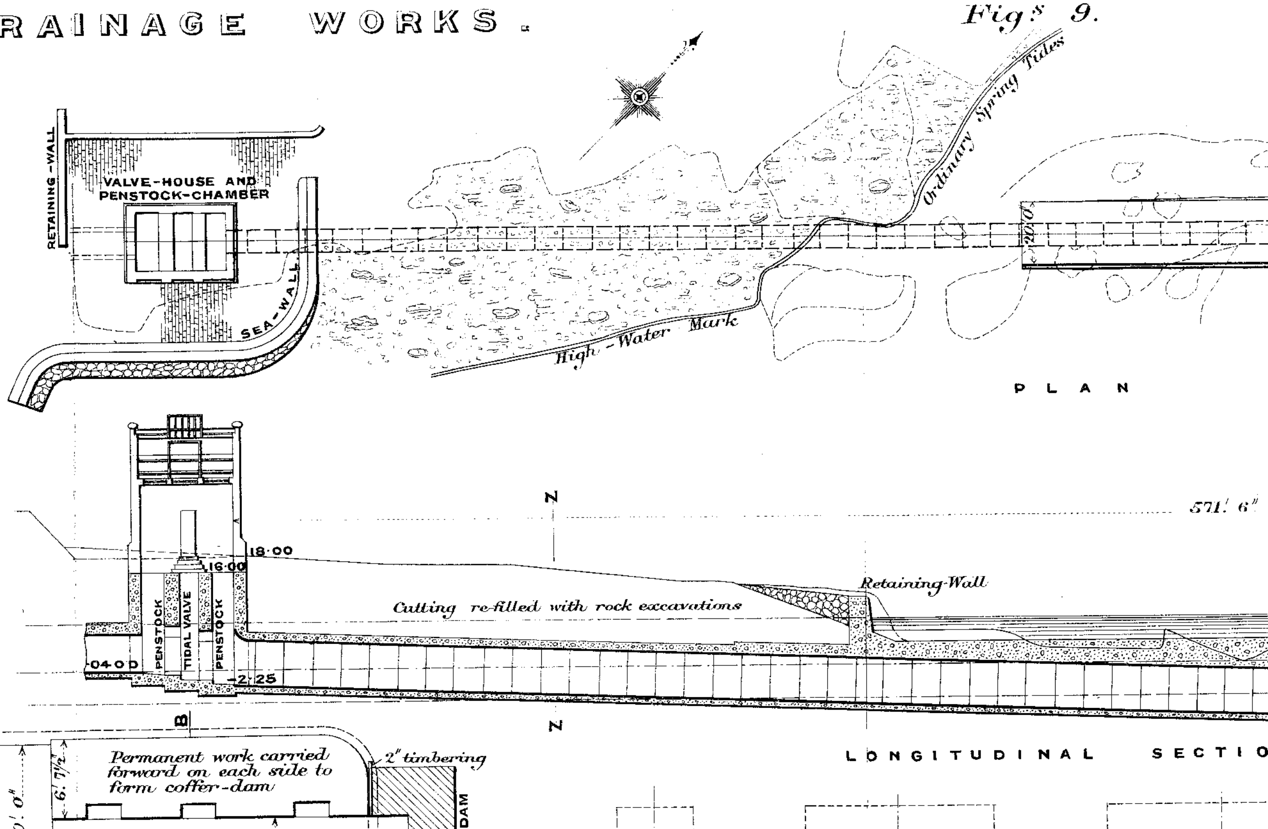
INTERNAL ELEVATION OF CAST-IRON LINING

TUNNEL DETAILS



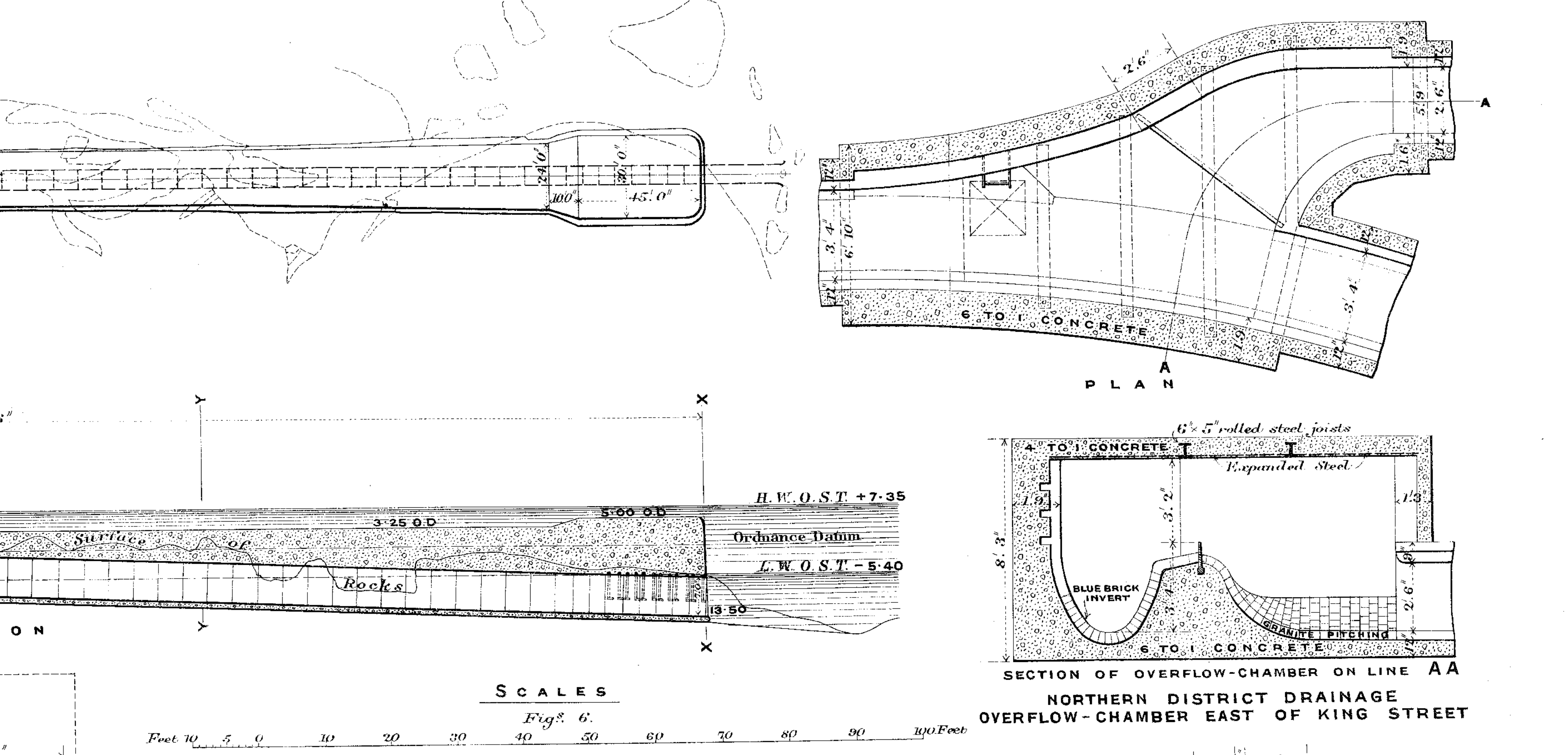
SECTIONAL PLAN OF STEEL DIAPHRAGM

Figs. 9.



LONGITUDINAL SECTION

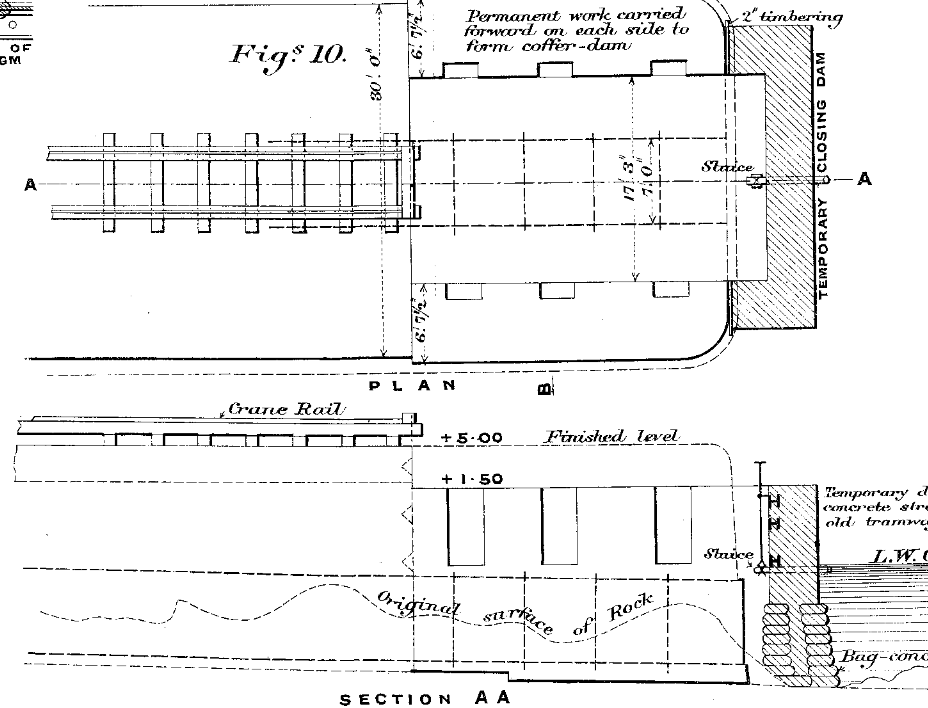
Figs. 12.



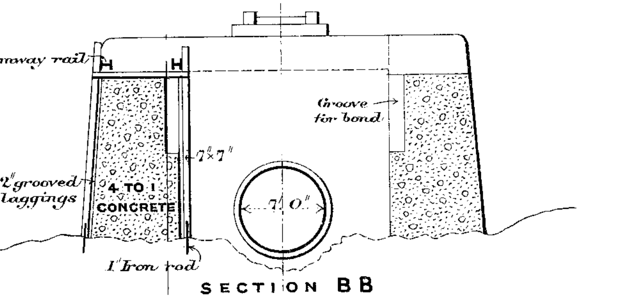
SECTION OF OVERFLOW-CHAMBER ON LINE AA

NORTHERN DISTRICT DRAINAGE OVERFLOW-CHAMBER EAST OF KING STREET

Figs. 10.

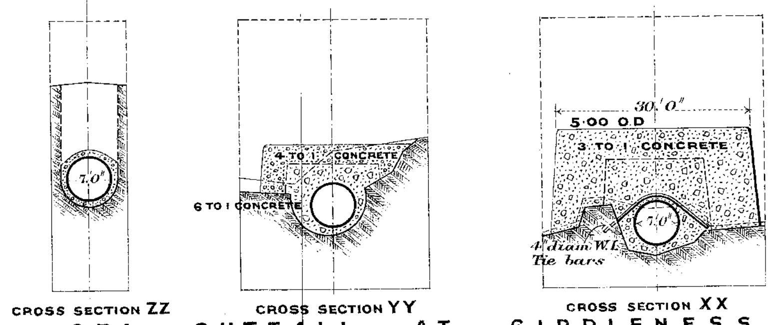


SECTION AA



SECTION BB

METHOD ADOPTED FOR LAYING OUTFALL-PIPES IN THE LAST LENGTH



CROSS SECTION ZZ CROSS SECTION YY CROSS SECTION XX

SEA OUTFALL AT GIRDLENESS

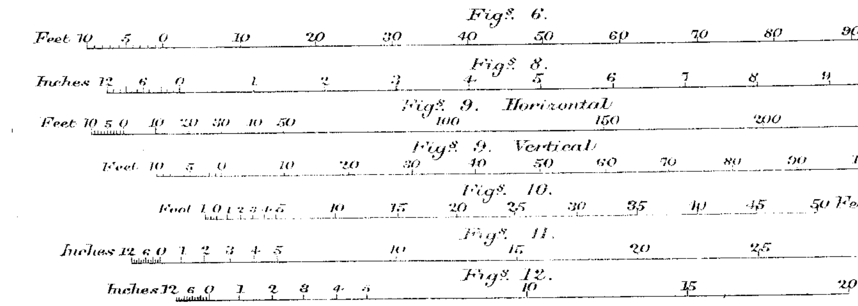
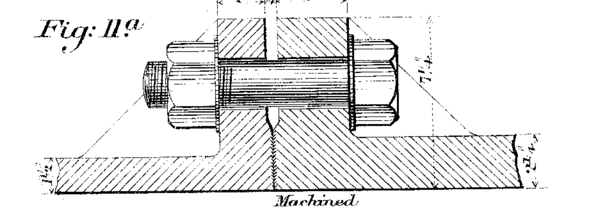
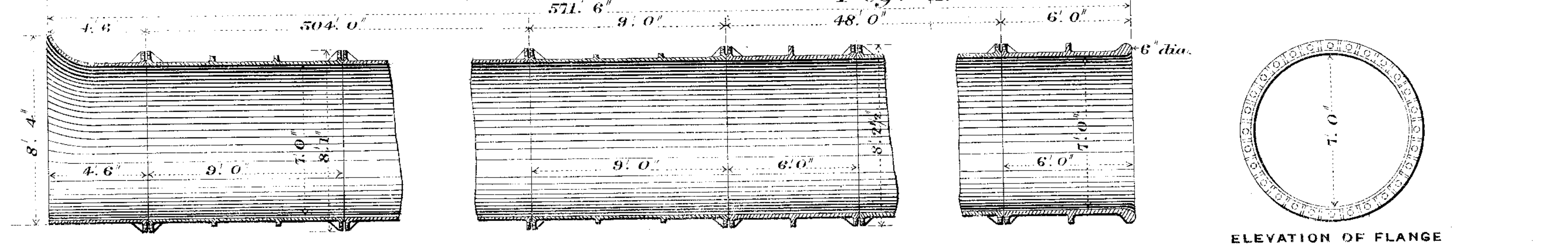


Fig: 11a



DETAIL OF FLANGES

Figs. 11.



7-FOOT CAST-IRON PIPES AT SEA OUTLET

ELEVATION OF FLANGE

G. H. G. CONWAY.

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