be passed upon some such analytical conditions. With regard
to brick walls for new buildings, he was rather of Major Mon-
ash’s opinion, that they would soon be a thing of the past, but
there were hundreds of brick buildings in Melbourne waiting to
be raised, and they could be raised without difficulty if a sensible
schedule of thickness was adopted.

PAPER.

RECENT TUNNELLING OPERATIONS FOR THE SEWER-
ING OF THE CITY OF MELBOURNE.

By Major H. V. Champion.

On deciding to extend the Melbourne sewerage system from
Richmond to Hawthorn it became necessary to once more cross
the river Yarra.

Several sections of sub-aqueous work had already been con-
structed, the first being the inverted siphon under Stony Creek,
on North Yarra main section No. 1 (see Minutes of Proceedings
The Institute of Civil Engineers, vol. cxxxiii., pages 351 to 362,
inclusive), closely followed by the tunnel on the Hobson’s Bay
main under the Yarra at Spotswood, where the disastrous inburst
occurred which caused the death of the engineer, Mr. Buchanan,
and several men. This contract was then abandoned by the con-
tractor, and the work was re-let to Mr. A. G. Shaw, C.E., who
successfully completed it.

The Melbourne main sewer crossed the Yarra at Dudley street,
and was constructed within a steel tube, which was floated out
into position and sunk on a prepared bed. It again crossed the
river at South Yarra near the Cremorne railway bridge, and was
constructed in a similar manner, except that the tube was sunk in
sections, which were joined together afterwards at the bottom
of the river.

The North Yarra main sewer crossed the Saltwater river near
Dyonon-street, and was also constructed of a steel tube sunk in
sections on a prepared bed.

All these works having been completed, considerable expe-
rience had been gained by designers and constructors in the meth-
od of overcoming the difficulties incidental to such operations, and
the design adopted at Hawthorn was an inverted siphon to get
cover enough to tunnel under the stream.

This, however, was merely one section of the contract let to
Mr. A. G. Shaw, and known as section No. 1, Hawthorn Main
Sewer. The contract extended from the corner of Burnley and Mur-
phy-streets, Richmond, to Lynch-street, Hawthorn, and traversed Murphy-street, Denham-street, Power-street, and Lynch-street.

Geological Nature of Country.

The part from Burnley-street to a point between shafts No. 4 and No. 5 consisted of solid bluestone or basalt, thence to No. 5 of schisty clay. No. 5 shaft went down to the invert of the siphon and bottomed in solid clay slate or schist rock (Lower Silurian). This formation continued through the section under the river, getting softer as the sewer reached the clayey country near the bottom of the old valley. The course of the river is in alluvium, not over the centre of the original valley. On the left bank, or Hawthorn side, the whole of the work was in schist country except a short length at No. 10 shaft, where basalt again occurred in mass, quickly dying out towards No. 9, but continuing up to and beyond No. 11 in boulders and basaltic clay. Beyond this the ground consisted of sandy clay, alternating with schist rock up to No. 13 at Power-street, where the work entered and remained in schist rock to the end.

Ground under River.

It was originally intended to construct the tunnel for the siphon 9ft. higher than was actually done. In that case the tunnel for a short distance would have been above the bottom of the ancient valley in clay and silt, necessitating the use of a shield, patent Dunlop wooden lining, and probably compressed air. By locating it 9ft. lower these accessories, the contractor believed, could be dispensed with, and his proposition was accepted.

Conduct of the Work.

Shafts.

Shaft sinking was begun simultaneously at all points up to No. 10. At No. 1 a whip horse was used. Nos. 2, 3, and 4 were served by a crane travelling on a railroad extending between these shafts. At Nos. 5 and 6, the river shafts, proper winding plants were established with powerful steam pumps. At Nos. 7 and 8 winding engines and pumps were installed, and No. 9 was served by a crane. A whip horse was used at No.10. At the shallow shafts, Nos. 1, 2, 3, 4, and 10 water was removed by jet pumps, usually called siphons here, actuated by water from the mains of the Melbourne and Metropolitan Board of Works.

Shafts Nos. 11, 12, 13, and 14 were not started until the driving had been completed at some of the earlier shafts. At Nos. 11 and 12 a crane was used, at No. 13 a winding engine and at Nos. 14 and 15 a crane travelling between the shafts.

Little or no timber was used for the shafts in the basalt, but the river shafts were close timbered throughout with 9 inch sets about 6ft. apart and 2in. laths. The sets were of round timber with the bark trimmed off, and the laths split slabs about 8 or 9 inches wide. All the remaining shafts were timbered more or
less closely except No. 10, in basalt, where little or no timber was necessary.

The timber used was Australian hardwood. The explosive used in shafts was rack-a-rock.

**Drives.**

In basalt the drives were made, if anything, larger than was necessary, and were kept low. This diminishes the cost of trimming after breaking through, and the bottom is solidly filled up by the chips left during the excavation and the subsequent trimming. No timbering was required in the basalt, and the soft part of the drive between 4 and 5 was driven without any timber. The size of the drives was about 6ft. x 4ft., the top being left arched and the sides brought in approximately to the shape of the oval section. The explosive used in drives was gelignite.

**River Section.**

The ends of the river section were driven 9ft. in diameter in solid schist rock.

A drain was cut in the bottom, in which was placed a 9 inch vitrified stoneware pipe with socketted joints left open, and made to fall to a pump well in each shaft. On nearing the bottom of the original schist valley the ground became softer, and large quantities of water were met with. The tunnel was then reduced to a drive, which was heavily timbered, the water being diverted from overhead by sheets of galvanised iron. Just before reaching the soft ground from the Richmond side, on firing a charge 12ft. of the roof came away, leaving only about 13ft. of cover, and the water came in in great volume, one stream being as thick as a man’s arm. The cavity was blocked up with timber with great difficulty, and no further driving was done from that end.

During the progress of this excavation considerable quantities of sulphuretted hydrogen prevailed in the tunnel, the men suffering severely from sore eyes. Silver sometimes turned black in one’s pockets.

The small drive joining the two larger sections was put through from the East, and was afterwards opened out to the required size, the end sections being first made good with the concrete lining.

In opening out this drive the work had to be heavily timbered with crown bars. The roof was arched over with sheet iron and the water thus diverted conveyed to the 9 inch drain at the bottom through a bed of bluestone metal broken to a 3in. gauge, carried up to springing level.

By this means the water was perfectly controlled and the whole work was lined throughout with 15 inches of cement concrete, and then rendered with 3/4in. cement rendering. As long as the pipe was kept open and the pumps in operation no great diffi-
culty was experienced in finishing the rendering, and a first-class job was completed.

_Hawthorn Side._

The driving on the Hawthorn side was mostly in soft schist and sandy clays, except for the part near 10, in hard basalt and basaltic clay. Where the basalt country joined the schist soft country was met with, necessitating a square section in construction.

Generally speaking in the schist the drive, being East and West, was at right angles to the strike, the most favourable direction. But in Power-street, where the country was harder, the drive being N. and S. was in the line of the strike and the ground much more difficult to remove. This part had to be driven large, as owing to the situation of the rock it was impossible to preserve the proper shape of the drive.

Alignment and Levels.

An ordinary Troughton and Sims 5in. transit theodolite was used throughout, the ranging rods for surface work being made of steel 3-8th inch diameter, and painted red and white in alternate bands.

For transferring the line from the surface the method described in Minutes of Proceedings of the Institute of Civil Engineers, Vol. CXVI., p. 122, was adopted, copper wire being used for the lines.

![Fig. 1](image.png)

By means of the apparatus shown (see sketch) the lines could be brought into position with greater accuracy.

The plummets were steadied by being suspended in buckets of water.
Gear for lowering material.

Carrier for placing siphon pipes in position.

Siphon pipes in tunnel under Yarra River.
TUNNELLING OPERATIONS FOR MELBOURNE SEWERS.
The line was produced below by using the theodolite on short legs, with the sliding plate exhibited. By this means it is possible to move the theodolite short distances in azimuth without disturbing the level, and thus the instrument is much more rapidly brought into the alignment.

The instrument was set up at such a distance from the wires that when focussed for the furthest wire the near wire could not be seen.

After the instrument had been brought into alignment the line was produced by turning the telescope round on its horizontal axis, the mean of two observations being taken with the instrument in reversed position.

Wooden plugs were driven into holes bored in the roof, and the line marked by cuts in horseshoe nails bent round at right angles. In subsequent contracts a horseshoe nail with the head flattened and a small hole punched through it was used. This was found easier to drive into the wood plug. Three points were put in every drive, so that there would be a check on the position at any time, and the line would still be maintained if one were knocked out.

The chainages of the nails were then fixed by measuring from one of the plumb lines the chainage of which had already been fixed from a known point on the surface.

The levels were taken by levelling to a nail driven into the timbers at the top of the shaft and measuring therefrom with a 100 feet tape to a nail fixed at the bottom so that it would be visible from the drive.

The reduced level of this point being thus found it was used as a datum to determine the levels on the bottoms of the nails, the staff being placed bottom up against the nails.

The heights of these nails above springing line were then computed, and short boning rods hung from them so that the bottoms of the T's were all on springing line. By using any two with a forward boning rod cut the proper height of springing above invert the level of the invert could be fixed at any point.

For long drives such as the one under the river the line was extended from the fixed points near the shafts to points nearer the face as the work progressed, by using the instruments.

All the drives met with considerable accuracy. The one under the river was the longest and most important, and the lines diverged from each other at the junction by one inch, the true line passing between both points. The error in level was practically nil.

In connection with driving the greatest difficulty is experienced in making the miners keep down to the proper levels, especially when driving down hill. In the latter case, if there be water, and and there usually is even in the apparently dry clay slate country, the miner keeps up to keep dry and has to be repeatedly corrected.

To the contractor an error in levels is far more important than
an error in the alignment, which can be rectified by introducing a
curve; but an error in level can only be put right by excavating
the second time what should have been done at the first opera-
tion. On this contract the whole of the underground surveying
was checked by Mr. J. L. Nolan, for the Board of Works.
As soon as the drives were broken through they were carefully
trimmed to the necessary cross section. As the bluestone drives
were kept large, very little trimming was necessary there.
When the trimming was finished and it was necessary merely
to lower material, the steam plant was taken away from each
shaft and the windlass shown in photographic illustration used
instead.

Construction.

The various types of sewers constructed are shown on cross
sections. The greater part of the work was type 2 or 2a, but it
was found necessary in two places, one near shaft 11 and one
near shaft 14 to use type 1 or 1a, owing to the wet and soft char-
acter of the country.
In the case of type 2 or 2a the ground is first drained by the
open jointed agricultural pipe covered over with metal and laid
in the bottom of the excavation. In all ordinary country as
soon as this is done there is a dry bottom to start work upon.
The invert blocks shown form a further means of draining the
work as the joints are left open, except at the top in the invert of
the sewer. These blocks and the drain beneath afford such ample
means of draining the work that it is possible to get the render-
ing on the side sectors.
The side sectors of the oval-shaped sewers were, in Hawthorn
main, section 1, formed of cement concrete of the following
composition, viz., 1 part of Portland cement, 3 parts of sand, 4
parts bluestone screenings, \( \frac{3}{4} \) in. gauge.
After completion they were covered with \( \frac{3}{4} \) in. cement render-
ing, 2 to 1.
The arch was constructed of brick in cement, with \( \frac{3}{4} \) in. cement
rendering over the top, and the space left overhead carefully filled
in with spalls, hand packed, except in the case of type 1 or 1a,
when the filling was sand.
The bricks were radial, and were specially made in Hawthorn
for this contract.

Construction of River Section.

The drainage of the river section was accomplished as already
described, on the same principles as those used for the ordinary
types, but the pipe, 9 inch, was very much larger.
After the tunnel was completed, concrete bearers to carry
the siphon pipes were constructed at intervals of 9 ft., centre to
centre.
These pipes were 21 in. internal diameter and heavy and awk-
ward to handle in a confined space. They were slung from
a truck designed to move freely on rails laid on top of the concrete bearers, and lowered into position by easing off the suspending wire rope which had been made secure round red gum barrels bolted on to the crossbars (see photograph).

The siphon was completed according to drawings, and has been in satisfactory operation for some time.

The amount of water met with was considerable on this section, and was gauged at one time at 22,000 gallons per hour. It was, however, delivered to the surface by direct acting steam pumps without allowing any pressure on the work.

HAWTHORN MAIN SEC. 4.

This section was driven through the clay slate country of Prospect Hill, Camberwell, and contained no special features of interest except that under the crown of the hill the sewer was constructed at considerable depths, reaching to 115ft. or more. No timbering was required in the drives.

Alignment.

In this case the alignment was transferred from the surface to the drive by using fishing lines passed over grooves cut in the head of ¾ in. W.I. spikes. These spikes were driven into the top sets, and could be tapped gently with a hammer to bring the lines into position. The ends of the lines were secured to nails driven into the top sets at a convenient distance from the spikes.

This was found to be quite accurate enough for the purpose, and very much quicker than the method used in the preceding case. There was trouble at first owing to the lines stretching, but this was only for the first time of using.

Vanes were used with the plumb bobs, but the author discarded them as they seemed rather to accentuate than to diminish the rotation.

The methods of constructing the sewer and the type used were similar to those on the Hawthorn side of section No. 1, for good ground, which have been already referred to.

An improvement on the sliding plate for bringing the theodolite into line was used in this case and hereafter. In the former method the movement of the sliding plate was universal in a horizontal plane, but the instrument had to be moved by hand. In the new system a traversing bar was substituted. This was screwed on the legs and the instrument then screwed on to the carrier of the bar. Transverse movement only was thus given to the theodolite by means of a screw, the motion being much more regular and the instrument brought into the alignment more certainly and more quickly.

HORSE’S BAY MAIN SEC. 6.

This section extended from near the corner of Acland and Barkly streets, St. Kilda, along Milford-street across the Elwood swamp to Glen Huntly-road, and thence to St. Kilda-street, Elsternwick. Total length of contract, 6,600 feet.
Nature of Country.

The first part of the section for about 3,000 feet was a red marl, similar to that of the well known Red Bluff, St. Kilda, with horizontal ironstone layers about 2in. thick each running through it at intervals of about two feet vertical distance apart.

The flat bottom type of cross section was adopted throughout this contract, and in the red marl the excavation was taken out the full size of the drive, 7ft. x 5ft., without timber, the ironstone layers forming a sufficient support.

In the swamp the formation changed from the red marl to silt, sand and sandy clays; the part nearest the surface being loose silt and sandy clays, which had been deposited for reclamation purposes by the Von Schmidt dredge some years before.

From the red marl to the end of the contract the drive was taken out the full size, but had to be heavily timbered (with 2in. diameter sets and 2in. laths.

In order to get through this section quickly excavation was pushed forward as rapidly as possible, but some delay occurred in the delivery of materials and it was impossible to keep the brick work up to the excavation, which advanced far ahead of it across the swamp.

Floods.

In this condition heavy rain fell on the 9th April and the Elwood Canal overflowed its banks and flooded the whole of the low lying surface of the swamp. The author was ranging lines at No. 14 shaft, and made his way with instruments in water knee deep across the swamp to the office. Owing to the looseness of the country and its friable nature the water quickly found its way through it to the drive and filled up and wrecked considerable lengths of it. In some places great chasms appeared in the surface through which the water poured into the drive.

After the flood subsided the extent of the damage could be ascertained and work resumed. Engines and plant which had sunk down had to be restored to their positions, portions of the wrecked drive reached by open cut close sheeted with timber and the whole of it cleaned out. The bench marks for levels had to be re-determined, as a general subsidence had taken place along the sewer, and the whole of the lines and levels fixed below had to be checked. In many cases the subsidence was considerable, as much as 18 inches.

Eventually order was restored and work resumed, to be interrupted again by a flood on the 9th May. The damage on this occasion was not so great, as the contractor had taken extra precautions since the previous flood, and the permanent work was further advanced.

The contractor held and claimed that these floods were accentuated, if not actually caused by the erection of a brick wall across the Elwood Canal. This wall was erected to hold back water from the canal and enable the bottom to be filled in with
concrete, a work which was then being carried out by another firm.

**Alignment by Eye Below.**

In connection with the alignment of the drive in the latter part of the section along Glen Huntly-road and St. Kilda-street, the distance between shafts was not great and the shafts were of considerable dimensions. A good base line, some 7 or 8ft. long between wires, was established in the shaft by the theodolite from the surface, and the author produced this line by eye below without using the theodolite, and obtained good results. This system has been used in much longer drives with good results by Mr. Trethowan, of the M. and M. Board of Works, and certainly saves time, although requiring practice and good eyesight.

**Alignment and Levels for Trimming and Construction.**

After the drives had been broken through the author's practice throughout all these contracts was the same. The instrument was set under the nearest point to one shaft and directed to an illuminated mark set directly under the nearest point to the adjoining shaft. A simple means of making a point easily visible up to 400 or 500 feet was to fix a 3/4in. steel bar under the point to be used and place a candle box in rear of it with four or five candles lit. The candles are protected from draught and the point is clearly defined in the telescope.

For illuminating the cross wires the author always found it enough merely to hold a candle near the object glass without using any means of reflection.

Plugs and nails were then fixed in the roof along the whole length of drive at intervals of 50 feet. The chainages were fixed by measuring from one shaft to the other, and the reduced levels of the nails determined by measuring down one shaft from a known point, levelling along drive and measuring up further shaft to a known point. This formed a check on the previous work, and determined the closing error. The height of each nail above invert was then computed and results handed to the manager.

The type of sewer built was the same throughout. First the 12in. x 4in. R.G. planks were laid down longitudinally, and 3in. R.G. planking laid transversely over them. Then three rows of bricks laid dry, the first two with 2½in. spaces between them, the last or top row laid close to take the concrete bottom of the sewer. The concrete bottom and invert blocks were then put into position and the haunches constructed. The outside of the latter was composed of rubble concrete. The side sectors in this case were composed of brick in cement as well as the arch. The three-quarter inch rendering of side sectors was dispensed with, and the whole of the interior of the sewer finished in brickwork in cement with struck joints, except the invert blocks in the bottom.
The ground was very wet in the bottom, especially through the swamp, where it was exceedingly slushy and treacherous. Before the work through the swamp started a trial shaft was sunk at No. 10 and this filled up with water as soon as the pumps were removed. Steam pumps had to be used at nearly every shaft.

As soon, however, as the planks and dry bricks had been laid a perfectly dry floor to work on was obtained, the open joints in the dry bricks forming an effective drain to the shafts.

In excavating the shallow ground through the swamp one or two dummy shafts were opened between each pair of manhole shafts so as to increase the number of working faces. These shafts were made as small as possible and filled in after the work was finished.

In the design submitted to tenderers by the Board of Works the choice of various methods for getting over the bad ground was allowed the contractor. These included, besides the method adopted, Dunlop’s patent wood lining, the drive to be done by using a shield, and open cut from the surface with continuous sheeting. The contractor, however, determined to tunnel throughout and use the square bottom type of section. He took the risk of floods, and there is no doubt it was the most economical method.

The plant used in this contract was of similar character to that described for Hawthorn main section 1.

**South Yarra Main Sec. No. 4.**

This contract extended from the corner of Bruce-street and Williams-road along Bruce-street to Grange-road, thence along that road to Struan-street, thence along Struan-street to “The Towers,” thence through private property to Heyington Place, thence along Princes-street to Kooyong-road, and some distance beyond that road into the valley of Gardiner’s Creek.

The main features of interest in this contract were the depth at which a great part of the sewer was located, and the fact that a considerable length passed through private property.

**Nature of Country.**

For a length of about 1,200 feet along Bruce-street the sewer was in decomposed granite. The quartz grains and mica were easily distinguishable in the decayed felspathic matrix. In some parts the colour was a light French grey, in others yellow and brown, while here and there masses of almost white felspar were met with. This material would have made excellent fire clay—and some of it was good enough for pottery ware.

Near the end of Bruce-street the country changed to clay slate, and a close examination beyond the main body of granite showed intrusive veins of this material forced between the joints of the Silurian formation, clearly indicating that the granite had burst through the Silurian.
Excavation.

For the part in the decomposed granite the square type of section was adopted and the ground taken out the full size required and heavily timbered.

After two or three days' exposure, the granite, though easily worked and timbered at first, began to exert very great pressure on the timbers, which it crushed in some cases, and came into the drive in large masses, sliding off irregular joints.

It was found to be impracticable to close lath and keep the granite back, so the laths were spaced with 6 inch openings and the ground allowed to come away between them. This necessitated frequent cleaning up, but was quite satisfactory in preserving the timbers and the drive.

After excavation the flat bottom type of cross section was constructed without the timber and bricks.

Flood.

During excavation, the works in this portion were flooded by water backing up from the existing main sewer when the recent great flood occurred in the Saltwater River. Considerable damage was done to the drive and shafts, the decomposed granite coming away in great quantities of slurry, almost filling up the drives.

The part driven in the Silurian was done without great difficulty and the oval type of section was adopted.

Alignment.

The parts of the drive in private property were very deep, as much as 150 feet or more, and in one case, from No. 10 to No. 11, owing to buildings and other obstructions, it was impossible to observe or to measure on the surface direct from one shaft to another, the length between shaft centres being 802 feet.

In this case a traverse was made round St. George's-road, Torresdale-road and Heyington Place, and the length and bearing of the line between shafts computed. Independent traverses by Mr. Breen, of M. and Metrop. Board of Works, and by the author were made, and a close agreement of the result obtained.

The computed line was then laid out from each shaft on the surface as far as possible and permanent marks fixed for reference.

This surface line was laid out by observing the included angle between it and the adjoining traverse line at each shaft. Eight readings of this angle, four on each vernier, were taken and the mean adopted.

The angle given by this mean point was then read on the same part of the plate with the telescope in reversed positions, but it was not found necessary to make any correction on account of errors of adjustment, which had been carefully eliminated before using the instrument. Moreover, the ground was not very steep at each shaft.
The lines were then dropped down the shaft in the manner already described, the iron spikes and fishing lines being used.

It was not possible owing to the timbering to get more than 4 feet 6 inches between the plumb lines, and, owing to the depth it took a long time to get the lines steady.

The method of prolonging the line was as has been already described, the theodolite with traversing bar being used.

On breaking through, it was found that the lines diverged 2½ inches at the centre, but the true line between shafts passed half way between the two points, giving an error of 1½ inches in the alignment.

The error in level was ¼ inch.

Between shafts 9 and 10 the distance was 895 feet, and direct observation from shaft to shaft was not practicable. The line had, therefore, to be computed as before, but the computation could be checked on the surface by ranging the line through on intermediate points. This was also the case between 8 and 9, a shorter drive than the preceding, but was impossible between 10 and 11.

All the drives on this contract met with considerable accuracy.

To put in the trimming and construction points for the long drives the instrument was set up half way between shafts and brought into line by the traversing bar. The exact position was determined by sighting to the illuminated point at one shaft and turning the telescope over twice with the instrument in reversed positions until the mean of two sights intersected the illuminated point at the other shaft. The distances given between shafts 9 and 10 and 10 and 11 are slightly different from the lengths shown on longitudinal section, as the shafts were not sunk in exactly the positions shown.

The drives were trimmed and the brick and concrete sewer constructed as in preceding cases.

Practically no timber was required in the Silurian country.

The total cost of the works herein described was nearly £80,000, and the total length of the sewer about 23,000 feet.

All these works were constructed by Mr. A. G. Shaw, C.E., contractor, the author acting as his engineer.
Mr. H. M. Trethewan said in the case of the longer ranges below ground Major Champion had chiefly advocated the use of the theodolite, dropping the surface lines by two wires and producing them. He had had a good deal of that work to do under varying conditions, and had found that the use of the theodolite caused difficulty at times. For instance, there were spoil banks and other obstructions at the surface which made it difficult to get a line through from the instrument to the shaft. He had often, by suspending the wires above the surface high up on poppet legs, dropping them down the shaft, and sighting to a point, above and below ground, got very good results without the use of instruments.

He had one case in mind where the distance between two shafts was nearly 800 feet, and the base line was not more than 3 feet, and yet the total error was something under 4 inches. They could not get a much better result than that, under the conditions, with the theodolite. The theodolite was difficult below because there was not much room. They had to spread the three legs in the shaft, and frequently a labourer coming along would knock it over. He thought that with care and practice they could take the lines at the surface by the eye, transfer them below, and carry out the same process, and get very good results.

Mr. Jas. Alex. Smith asked what was the nature and size of the wire used?

Mr. Trethewan said the wire he used was ordinary plaited picture wire, not more than 1/20th of an inch in total diameter, and the plumb bobs, which were suspended in buckets of water, weighed 28 lbs each.

Further discussion was postponed till next meeting.
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