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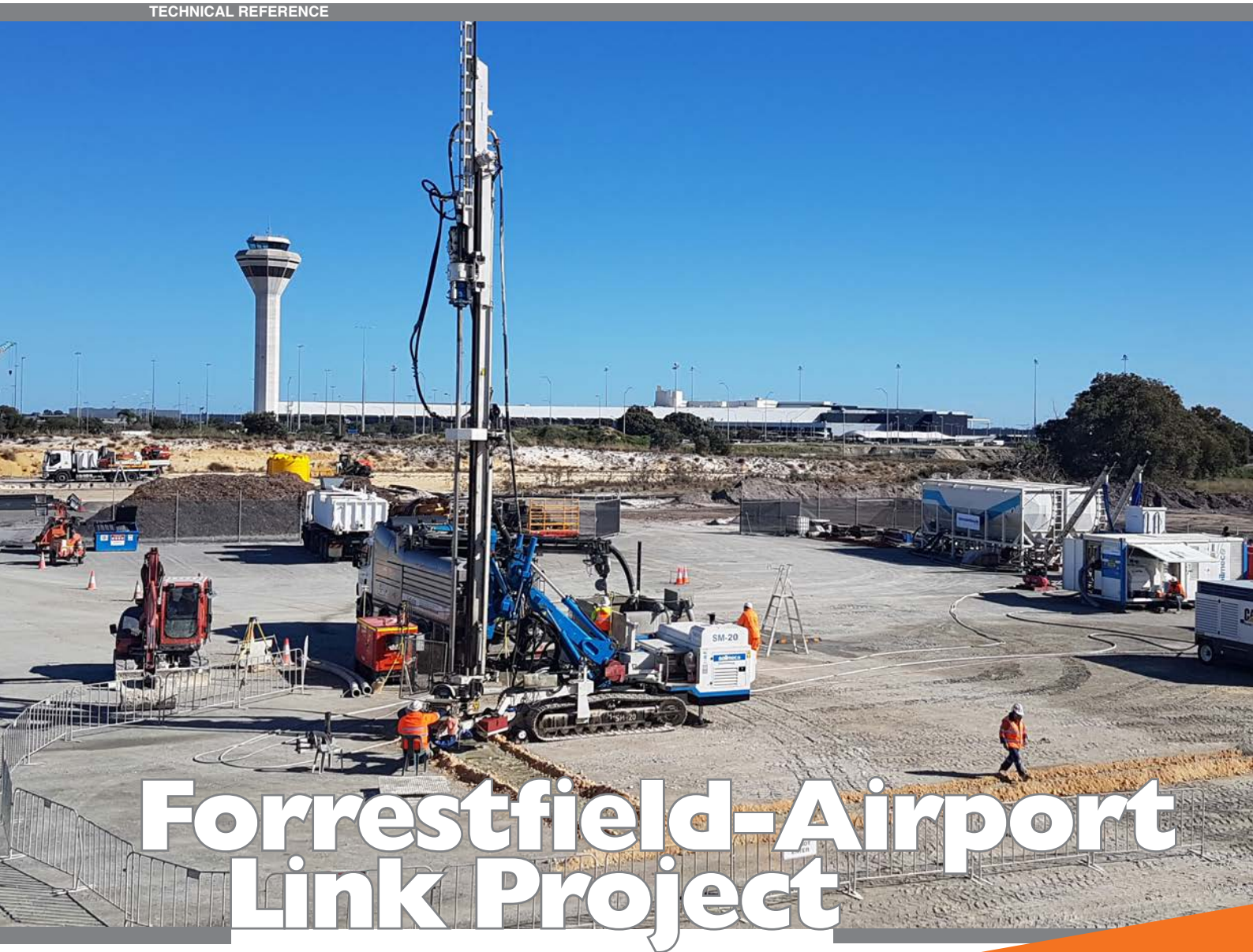
TECHNICAL REFERENCE



Forrestfield-Airport Link Project

Perth, Western-Australia

Jet Grouting

Artificial Ground Freezing

Owner:	Public Transport Autority of Western Australia (PTA)
Main Contractor:	**Salini Impregilo and NRW Pty Ltd (SI-NRW)**
Duration of works:	**2016 - 2021**

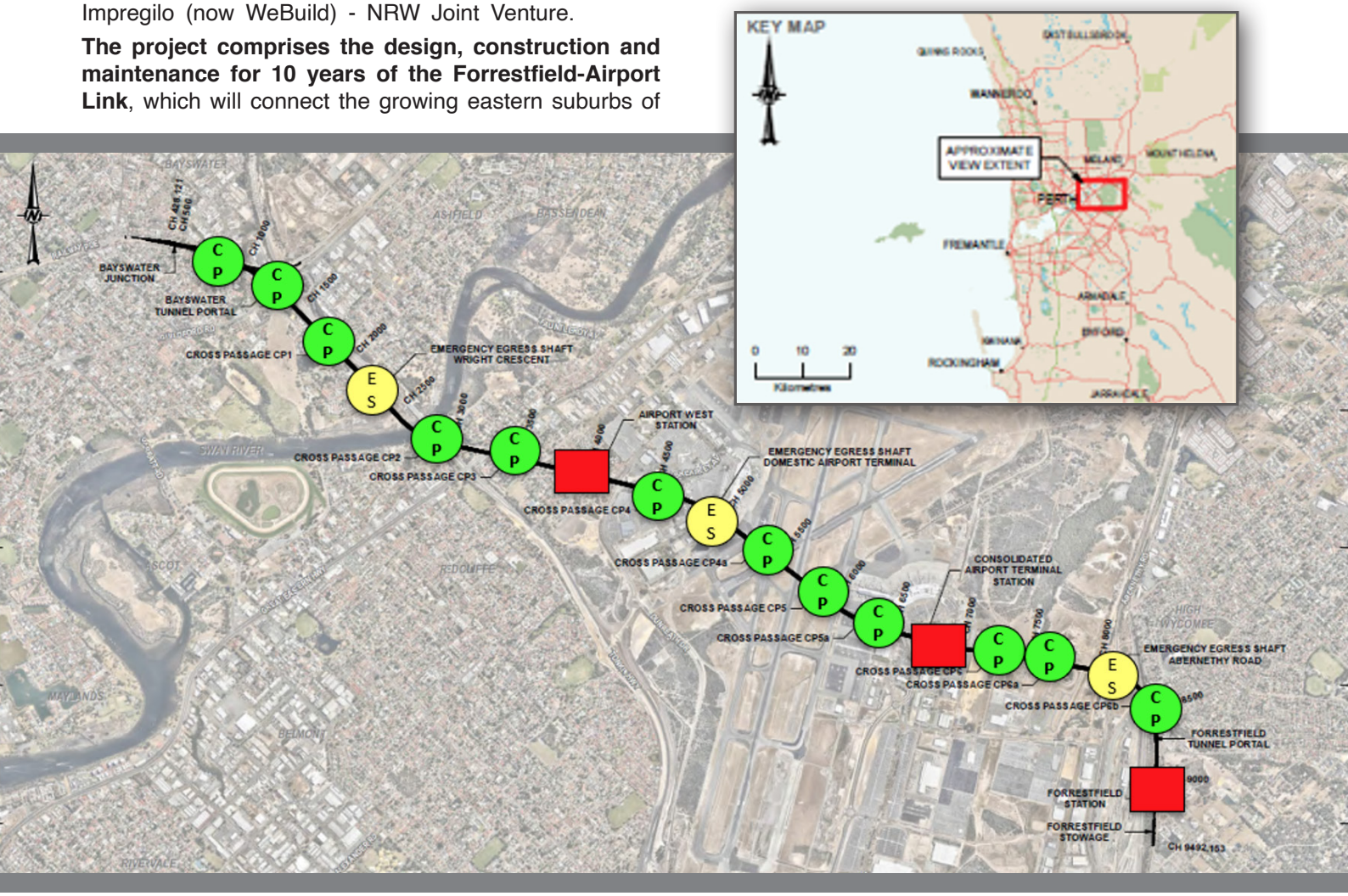
Introduction

Trevi Australia The Forrestfield Airport Link in Perth is a A$1.9B project that will deliver an **8.5 km extension of the existing urban rail network connecting the Midland Line, just past Bayswater Station, toHigh Wycombe, running underground in twin bored tunnels underneath the Swan River, Tonkin Highway and Perth Airport.**

In April 2016 the Public Transport Authority awarded the design, construct and maintenance contract to Salini-Impregilo (now WeBuild) - NRW Joint Venture.

The project comprises the design, construction and maintenance for 10 years of the Forrestfield-Airport Link, which will connect the growing eastern suburbs of

- **Three new railway stations**:
  - Redcliffe Station,
  - Airport Central Station,
  - Forrestfield Station,
- **Two dive structures, at Bayswater and Hig Wycombe**;
- **Twelve Cross Passages**;
- **Three Emergency Egress Shafts.**



Perth with the existing suburban rail network as well as the airport.

In the first year of operations the Airport Line is expected to generate 20,000 passengers trips on the network every day, as well as reduce road traffic and travel times.

The Project

The project works:

- **7.14 km of twin underground rail tunnels, with an external diameter of approximately 7 m. The tunnel separation, measured from the centre of one tunnel to the centre of the other tunnel, typically varies between 13 m and 15 m with a maximum depth Ground Level-Rail Level of about 32m;**

Trevi scope of works:
Jet Grouting

The Jet Grouting soil improvement technique was an allotted work for Trevi Australia.

The scope of work includes the installation of jet grouted columns to create a consolidated block in correspondence with the cross passages, having both structural and hydraulic purposes, in order to allow the safe excavation of the connecting tunnels.

All JG columns were set in place prior to the passage of the TBM using both double fluid system, where the grout jet is assisted by an air shroud, and single fluid system, where only high-pressure grout is used.
The diameters achieved were 2.2 m and 1.0 m respectively.
The jetting-drill string was composed of specially designed

rods with two concentric coaxial, the inner for high-pressure grout and the outer for compressed air.

Pre-washing *(or pre-cutting)* **technique**, in which water is used to pre-erode the soil, was performed either during the drilling phase or in a separate phase prior to jetting. Maximum installation depth was up to 32 m using a triangular grid spacing from 1.35 m to 1.75 m, according with the column diameters and depths of the treatment.

Prior to execution of the JG works three Field Tests were carried out in order to:

- Test the effectiveness of the JG Parameters and methodology
- Set the operating modalities
- Acquire data to optimize the work methodologies

Dundas was the first location of the JG production works.

The JG treatment within the Bassendean Sand from approximately 7 to 18 meters deep was quite superficial. The particularity of the treatment was the geometry with the installation of inclined columns of up to 36 degrees from vertical and the use of the mono-fluid system for the columns with a greater inclination.

These solutions were implemented due to the presence of a gas pipe line and Fiber Optic Cabling in close proximity to the treatment area.

During execution of JG works a dedicated monitoring system was in place to ensure a safe working-condition and to avoid any damage to these utilities.

As in CP10 Manheim, CP06 Car Park C and also in CP05

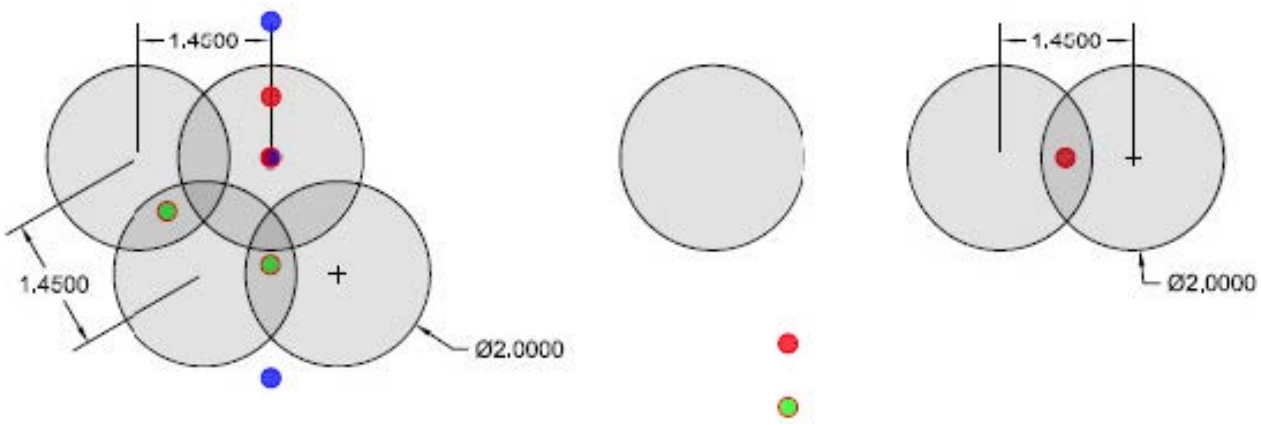
Test field

FORRESTFIELD DIVE

Columns diam. = 2.00 m
Triangular pattern = 1.45 m side
JG length = 12.0 m
Blind boring length = 8.0 m
Drilling length = 20.0 m

- Coring and sample recovery for UCS test in laboratory
- Coring and sample recovery for UCS and permeability test lab/field
- Boring for cross hole

Isolated JG column for visual exposure



To produce the most reliable data, the trials were carried out according to the project technical specifications in areas and at depths where the geology reflects as much a s possible the characteristics of the soil to be treated.

The trials were carried out with different sets of JG parameters and subsequent post installation tests including Coring, UCS and Modulus lab tests, Sonic Logging Testing and Permeability tests.

There were six **Cross Passages (CP)** and two **Emergency Egress Shafts (EES)** where Jet Grout treatment was required, as listed below:

- CP01 Tonkin;
- CP05 Brearley;
- CP10 Manheim;
- EES Abernethy;
- EES Wright Crescent;
- CP06 Car Park C;
- CP11 RAC;
- CP12 Dundas.

Brearley AV a top layer of very fine sand was encountered which influenced the treatment by the impossibility to use the Pre-Washing technique due to the risk of forming sink holes on the surface.

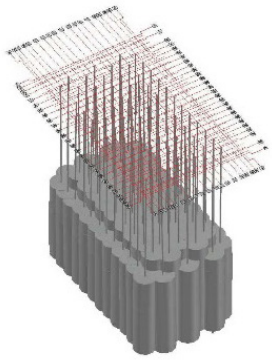
To reduce the risk of collapsing and overturning of the rig two actions were adopted:

- Removal of the Pre-Washing phase, to reduce the siphoning effect
- A Pre-Treatment phase with mono-fluid columns, this to consolidate the upper portion of the ground assuring the stability of the working platform.

Geological units treated by Jet Grouting

Bassendean Sand **(BS)**	SAND – brown to pale grey typically fine to coarse grained sand. It is encountered across the entire FAL
Ascot Formation **(AF)**	Carbonate Sandy GRAVEL/Gravelly SAND – fine to coarse grained carbonate sand and fine to coarse grained carbonate gravel, generally medium dense to dense.
Osborne Formation **(OF)**	The Osborne formation was encountered as the base layer along the entire alignment. This member can be divided in to three units - Mirrabooka Member (OFm) - Sand - Kardinya shale (sand dominated) (OFs) - Kardinya shale (fines dominated) (OFf)

3D TOP VIEW BEFORE INTEGRATIVE COLUMN



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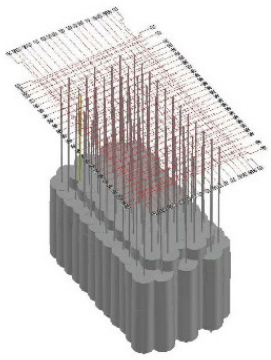
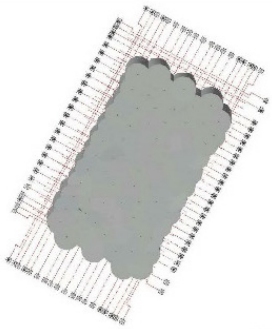
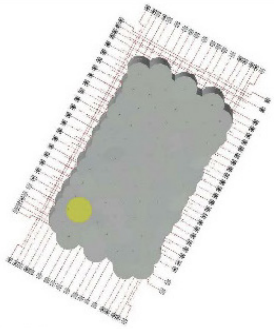


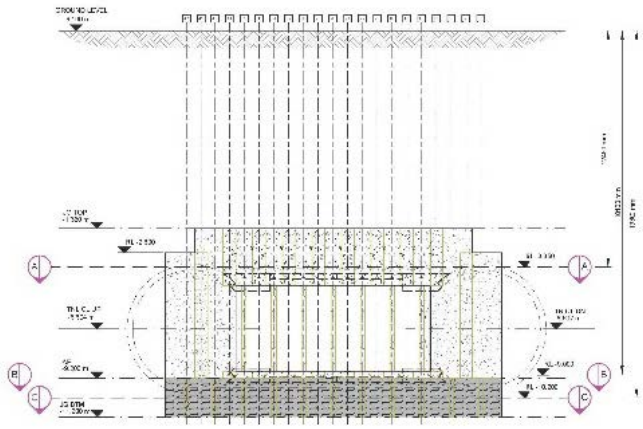
3D BCTTOM VIEW BEFORE INTEGRATIVE COLUMN



3D BOTTOM VIEW AFTER INTEGRATIVE COLUMN



CROSS SECTION ELEVATION



Equipment for Jet Grouting works

The main equipment used for the site activities as listed below.

- **Drilling Rig *(Soilmec SM-20)***
- **High Pressure Pump *(Soilmec 7T-600J)***
- **Batching Plant**
- **Drilling and Jetting Control System**

The boreholes were drilled using a rotary drilling methodology with drag/tricone bit using water as a circulating fluid to remove the cuttings. To prevent the borehole from collapsing casing was used (in some locations the casing was up to 9 meters long) and also a diverter to facilitate the spoil removal from the site.

The Jet Grouting parameter used in the project required a flow of 450 l/min with a pressure of 420 bar. The air pressure range was between 9 to 12 bar.
The capacity of the grout plant was up to 30 m³/hr and was connected to two cement silos with a capacity of 50 Ton each. To assure the necessary continuous flow of grout to the pump, an agitator with the capacity of 5 m³ was used also.

Both the operational phases (drilling and jetting) were monitored by recording the principal parameters such as drilling speed and torque, rotation per minute (RPM), grout and air pressure and lifting speed. Verticality control was performed on 100% of installed columns; the data was plotted in 3D as built drawings, in order to evaluate the need for integrative columns to close any potential gaps.

Trevi scope of works:
Artificial Ground Freezing

The Artificial Ground Freezing soil improvement technique was an allotted work for Trevi Australia.
The scope of work includes the application of a soil-improvement technique, having both structural and hydraulic purposes, to create a consolidated block in correspondence with the cross passages in order to allow the safe excavation of the connecting tunnels.

The technique consists of freezing the water inside a volume of soil, according to a known geometry, by subtracting heat from the ground through special heat exchangers.
The frozen soil, where soil grains represent the aggregates and the binder is the frozen water, is 100% water-tight, whereas other consolidation methods can only reduce the

natural permeability of the soil *(i.e. jet Grouting).*

Treated soil is also homogeneous, with no weak points or planes and a high mechanical resistance is achieved, according to soil type and temperature. Last but not the least the technique of freezing is environmental-friendly as no products are injected into the ground, the refrigerant fluids never come directly in contact with the ground or with the ground water.

In the first stage just three cross passages *(CP07, CP08 and CP09)* were to be excavated under AGF due to the inapplicability of consolidation by means of Jet Grouting from the surface: The CP were all located below main runway of Perth airport with no possibility to work from the surface with heavy long mast equipment during landing and taking-off.

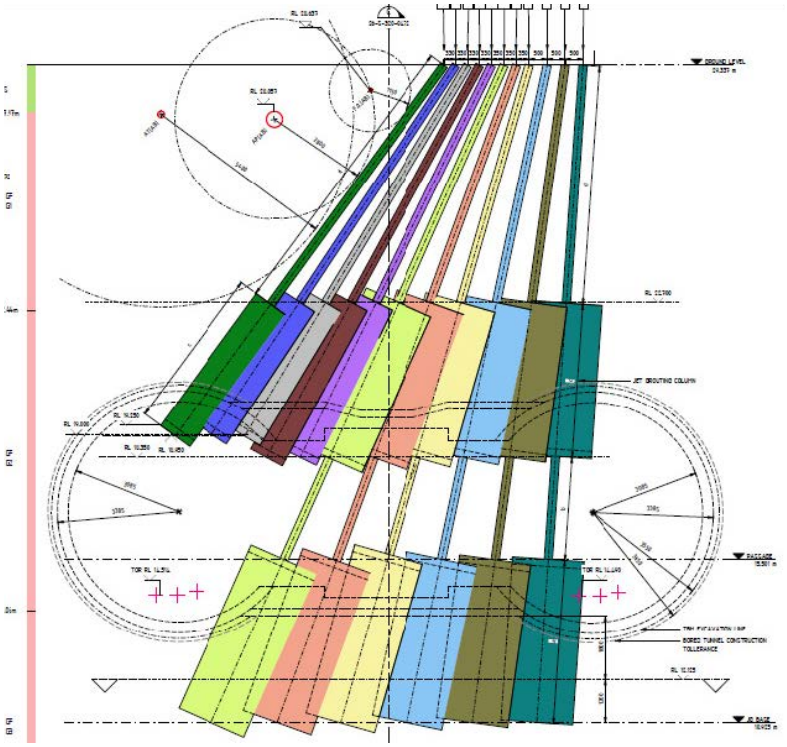
Drilling Activities and Equipment

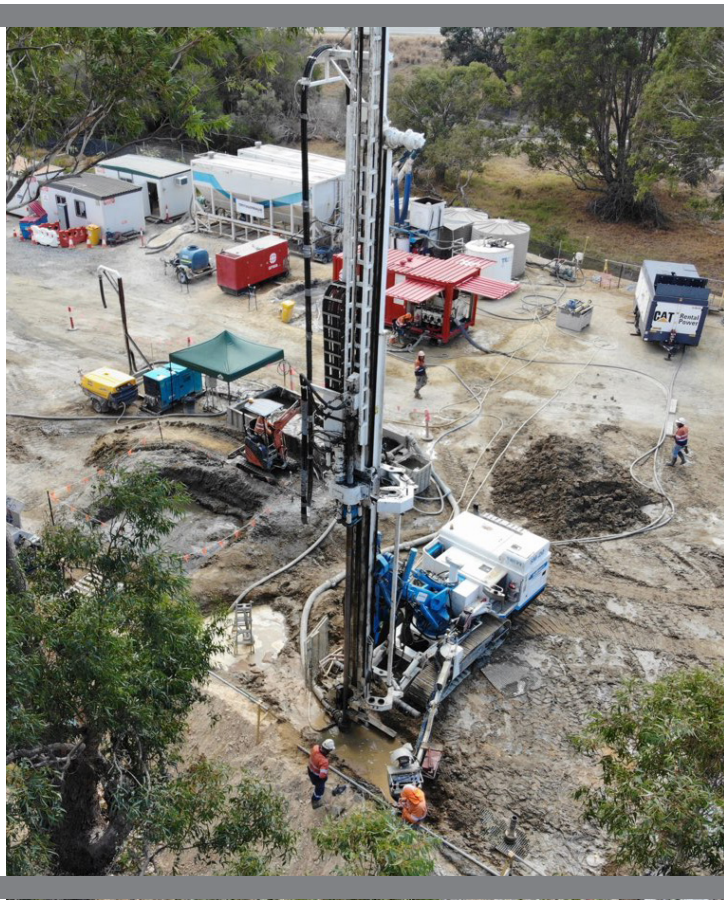
The **Soilmec SM-5** and Drill mast Ripamonti EX300DTH set on an excavator were used to drill both freezing and control pipes.

Every single set up of the drilling equipment was previously checked by CAD due to the tunnels small diameter and due to the presence of slurry pipelines and ventilation system of the TBM in operation.

To efficiently and precisely set the drilling position a special aligner was adopted, all pipes were finally set in place with an average deviation from the design less than 1%.

To monitor the actual position and deviation of the installed pipes a special cylindrical device equipped with a LED was





In the second phase the client gained confidence after the successful application in the first three CP, decided to consolidate through AGF also CP10 due to unexpected soil condition.

Geological units involved in the AGF works along the FAL project

Ascot Formation **(AF)**	Carbonate Sandy GRAVEL/Gravelly SAND – fine to co-arse grained carbonate sand and fine to coarse grained carbona¬te gravel, generally medium dense to dense.
Osborne Formation **(OF)**	The Osborne formation slightly silty gravelly Sand that can be divided in to following three units - Mirrabooka Member (OFm) - Sand - Kardinya shale (sand dominated) (OFs) - Kardinya shale (fines dominated) (OFf)

fabricated and placed within the borehole casing. A theodolite was installed on a fixed support at the tunnel end to site down the casing .

All measured deviations were then used to build a 3D drawing which could be checked anytime to measure the actual distance between every thermocouple and the closest freezing pipe.

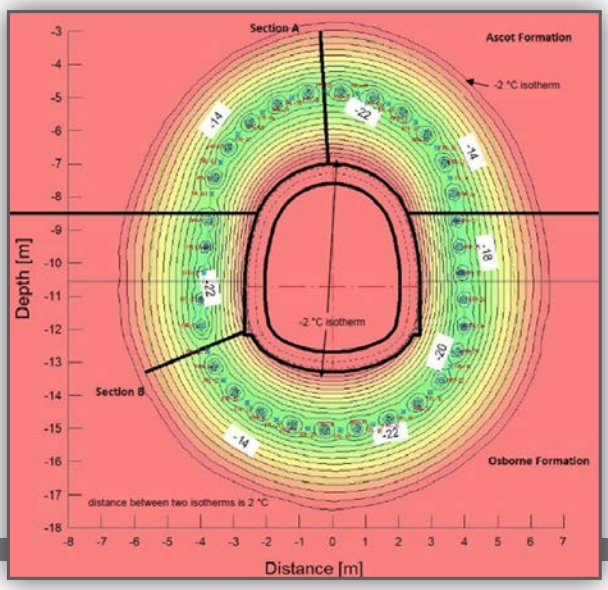
Freezing Phase and Equipment

The Brine method was the deployed on the FAL project with brand new 100 kW chillers installed within the tunnel close to each CP to be excavated.

The Chillers were all installed within tunnel 1 only, using two horizontal service holes at each CP to bring brine back and forth to Tunnel 2 also. These Chiller were specially designed

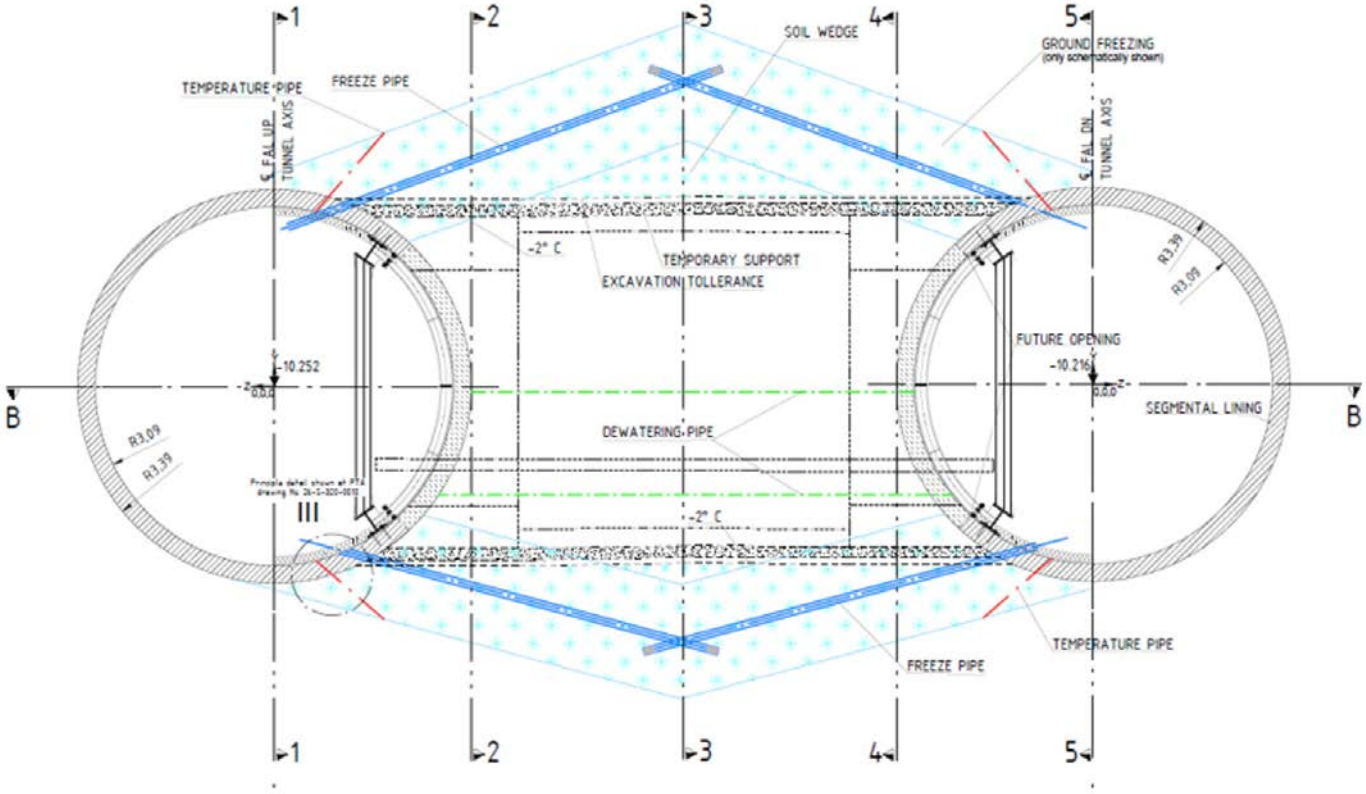
for this tunnel diameter by having a maximum width of 1.80 m, allowing the clients plant and equipment to pass through either tunnel at any time. The water line connecting the chillers to the cooling towers (located at ground level at the closest available shaft) was more than 1.5 km long.

Design goals, in terms of both thickness between two isotherms at -2°C and average temperature within the frozen volume, have been achieved in 40-45 days for all treated CPs.



Monitoring

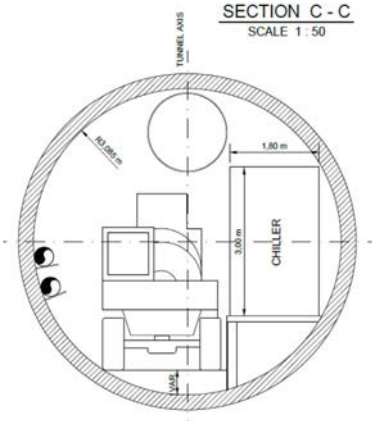
The implemented dedicated monitoring system allowed the analysis of ice wall formation. Due to this monitoring system it was possible to analysis, design and realize interventions

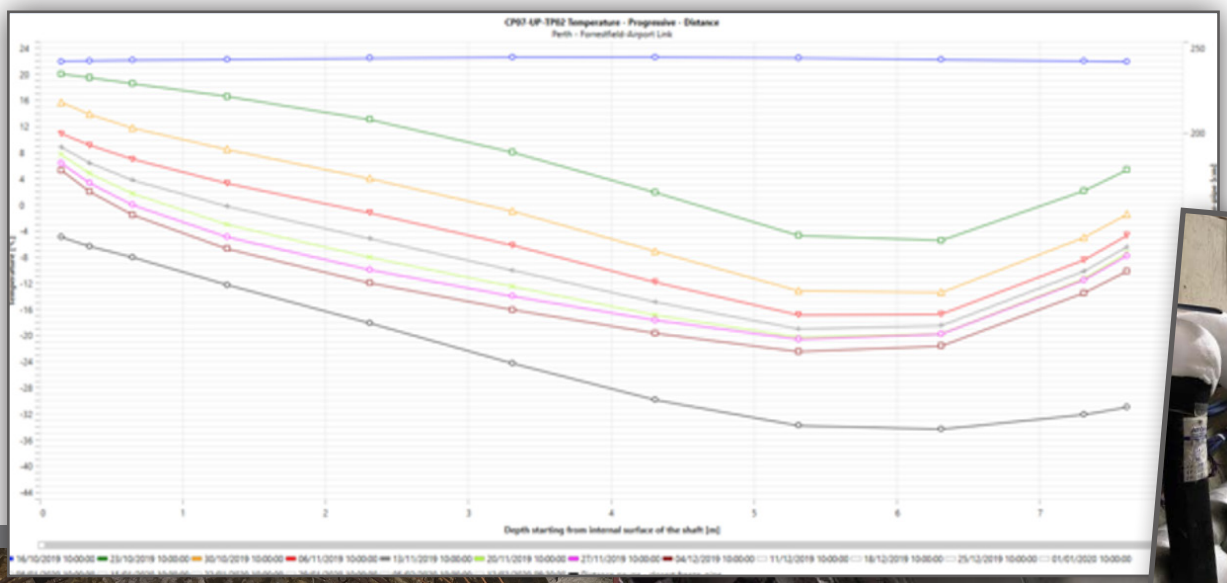


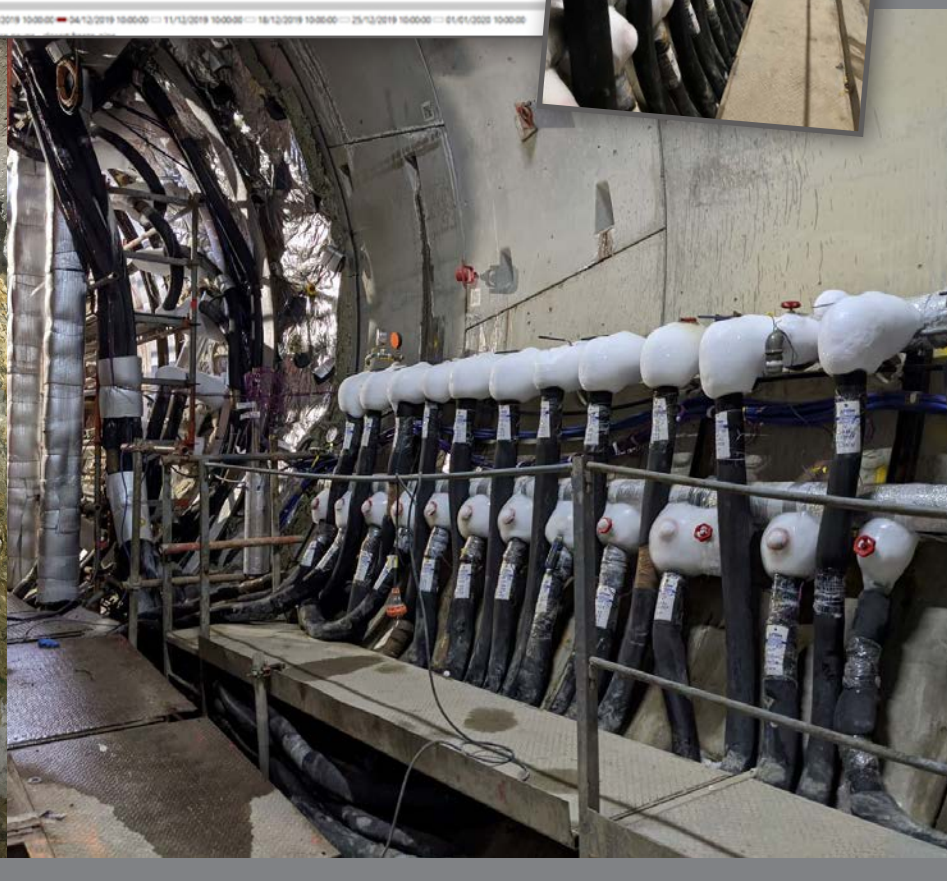
during all phases (including the excavation phase) in areas where an increase of cooling power was necessary to avoid the formation of possible defects.

All data was shared within a daily report as well as on a dedicated “web monitoring system” implemented to give all key personnel the opportunity to check on any smart-device the soil temperature development at any time.

A surface laser survey system was also implemented in order to monitor the heave at ground level where planes were continuously landing and taking off. Recorded heave was within a range of 3 mm and 8 mm significantly less than the 15mm which was the max allowable heave.







Safety

Around the site there was a very good and positive attitude towards safety, during inspections positive feedback was recorded.

Safety procedures were implemented during the project to maintain a safe working area with focus on each individual's safety performance and the overall safety on site:

- Daily pre-start with discussion of the site activities and hazard reports;
- Monthly training for all the crew;
- Site inspections

The following main topics have been developed and monitored to achive the sustainability program:

- *Choice of equipment and utilization;*
- *Efficiency of plant and equipment;*
- *Careful utilization of natural resources;*
- *Recycling;*
- *Continuous control/inspection of performance;*
- *Monitor energy use*
- *Monitor water usage*

Quantity of works

Area	Columns	Volume	Drilling Length
	nos.	Vol. Theor. (m^3)	Linear Meter
CP12 Dundas (95 col. with monofluid)	149	1.370	2.246
EES Abernethy	172	3.313	4.175
CP11 RAC	70	1.392	1.548
CP10 Manheim	93	1.629	2.452
CP06 Car Park C	70	1.031	1.534
CP05 Brearley	77	1.424	1.584
EES Wright Crescent	168	1.871	5.005
CP01 Tonkin	70	1.039	1.692
TOTAL	**869**	**13.069**	**20.236**

TREVIAUSTRALIA PTY LTD

Head Office:
CALL 1300 019 679

19 Precision Place
Mulgrave NSW 2756 - Australia
e-mail: **info@treviaustralia.com.au**
www.treviaustralia.com

TREVI
a TREVIGroup company

5819, via Dismano - 47522 **Cesena** (FC) - Italy
Tel. +39.0547.319311
Fax +39.0547.318542
e-mail: **intdept@trevispa.com**
www.trevispa.com