World's longest pumping distance of macro synthetic fibre reinforced concrete to build Perth's Forrestfield-Airport Link tunnel track slab

Todd Clarke[1], Des Vlietstra[2], Sarvesh Mali[3], Justin Rapp[4], Murray Simcock[5], Chris Rakich[6], Robert Sturgeon[7], Jack Bull[8], Gian Vicchi[9] and Dave Deakin[10]

[1]Engineering Manager, BarChip Australia Pty Ltd
[2]Global Technical Services Manager, BarChip Australia Pty Ltd
[3]Technical Services Manager – Concrete, Boral Construction Materials Australia
[4]Senior Project Engineer, Martinus Rail
[5] Work Health and Safety Advisor, Meales Concrete Pumping WA
[6] Managing Director, Meales Concrete Pumping WA
[7]Track Form Specialist, Mott MacDonald UK
[8]Materials Specialist, Mott MacDonald UK
[9]Project Engineer, Salini Impregilo-NRW JV
[10]Senior Project Engineer, Whittens

Abstract: The growing scale and volume of modern infrastructure requires innovation in design, construction processes and concrete technology. The Forrestfield-Airport Link tunnel required each of these aspects in combination to deliver a vital piece of Perth's infrastructure. The design of the tunnel track slab evolved from a conventionally reinforced design to a macro synthetic fibre reinforced concrete track slab, enabling significant construction efficiencies and program savings. Further efficiencies can be observed in the method of placement, which eliminates a significant amount of in-tunnel truck movements by pumping the track slab concrete from the top of each station box along the tunnel alignment. This meant that in some sections of the tunnel, concrete was being pumped almost 2 kilometres.

Pumping of this magnitude requires significant collaboration between the contractor, pump operator and concrete supplier, to ensure high-quality concrete, consistent supply, best practice pumping practices and accurate planning of the construction schedule. This paper discusses the adoption of macro synthetic fibres for the track slab, as well as the concrete technology and pumping practices required to achieve the world's longest single pump of macro synthetic fibre reinforced concrete.

Keywords: track slab, long-distance pumping, macro synthetic fibres, tunnel, fibre reinforced concrete

1. Introduction

The $1.86 Billion Forrestfield-Airport Link is a 7m diameter twin bored railway tunnel situated in Perth, Western Australia. The tunnels are 7.5km in length with a maximum depth of 26 metres. Included in the tunnels are three emergency egress shafts, 12 cross passages and two underground stations at Redcliffe and Airport Central with a third station, High Wycombe on the surface just beyond the dive structure. (1)

Boring of the tunnels started in July 2017 and was completed in April 2020. The Forrestfield-Airport Link is delivering a new rail service to the Perth Eastern Suburbs and spurs off the existing Midland line at the Bayswater Junction just past the Bayswater station.

"The rail link forms part of the METRONET vision to create liveable communities connected by world-class public transport" (2) jointly funded by the Australian and Western Australian governments and overseen by the Public Transport Authority (PTA).

The design, construct and maintenance contract for the Forrestfield-Airport Link was awarded to Salini Impregilo – NRW Joint Venture (SI-NRW JV) in April 2016.

SI-NRW JV contracted Martinus Rail to deliver track and overhead wiring works. These works include the construction of the 16.7km track slab, 3 km of ballasted track, supply and installation of all overhead wire and overhead conductor system for the tunnel and ballasted track works, brownfield track and OLE works at Bayswater. It also included the supply and installation of a concrete embedded rail scissor crossover also known as a diamond crossing at a slope of 1:10 and ballasted rail turnouts from the tunnel structure at a slope of 1:25.

Boral Concrete was contracted to develop and supply the concrete mixes for the project, where the track slab concrete contains macro synthetic fibres, supplied by BarChip Australia. Concrete pumping, which included an effective horizontal pump of 1970m in length, was delivered by Meales Concrete Pumping.

This paper reviews the construction processes adopted for the rail proponent of the project, as well as design changes made that significantly improved efficiency and sustainability.

2. Track Slab Design

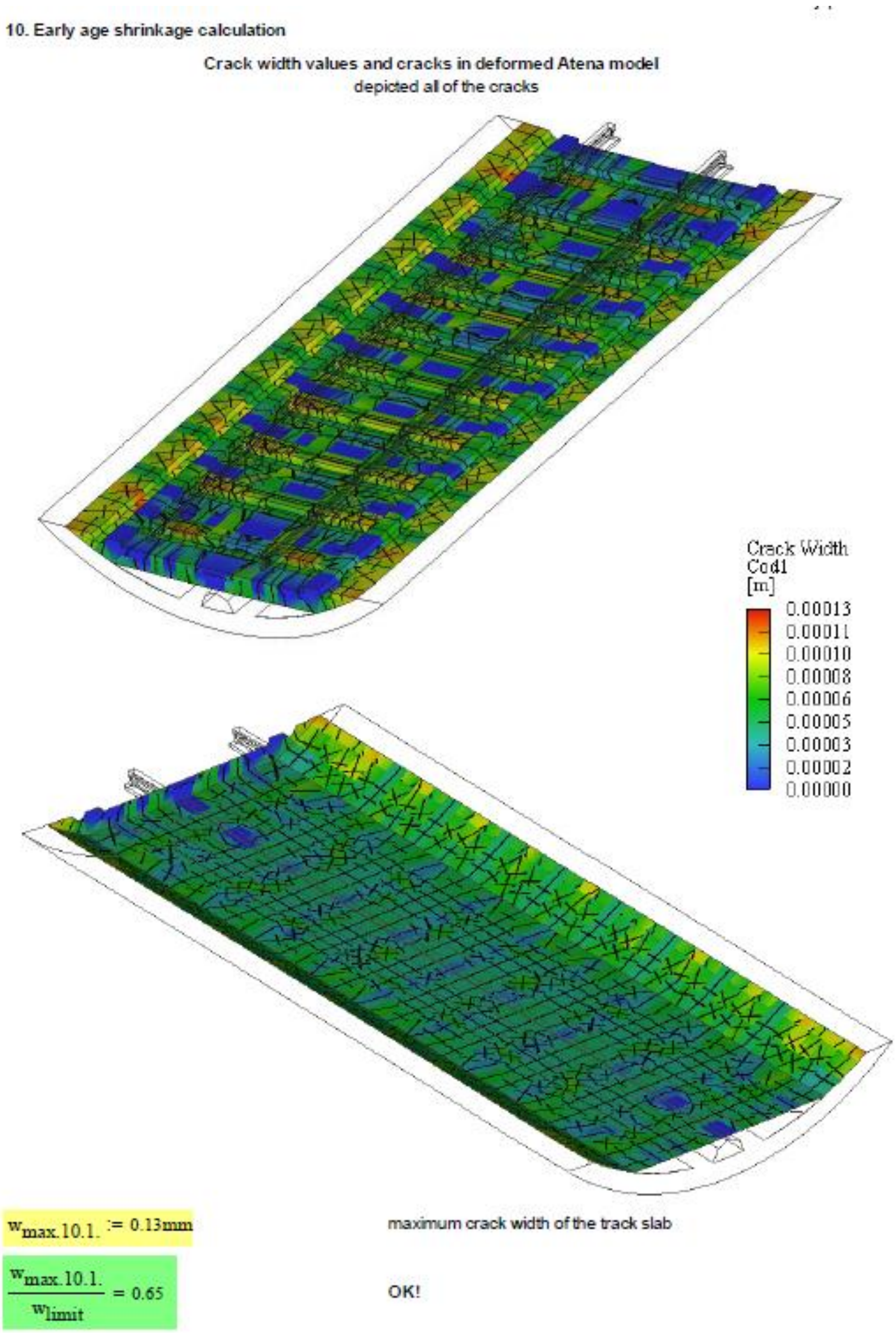
Typical concrete track slabs within a tunnel are formed from two components, consisting of an invert slab overlain with a reinforced concrete track slab. The tunnels of the Forrestfield-Airport Link (FAL) are formed of precast reinforced concrete segments, onto which the invert concrete was poured directly. The track slab concrete is constructed directly overlaying the invert concrete. This supports the sleepers in their permanent positions, maintaining line and level of the track, whilst distributing the loads to the structural supports. This concrete must withstand the loadings imparted on it and resist cracking from early age and shrinkage effects.

The track slab selected for the FAL is a fibre reinforced concrete track slab overlaying an unreinforced concrete invert. Indeed, the initial Scope of Works and Technical Criteria (SWTC), Section 32.4, required the track slab for the FAL to be a reinforced rigid concrete continuous slab using either steel reinforcing bar, steel fibres, or a combination of both. Due to the low construction depth of the concrete and the presence of the sleepers, it was decided traditional reinforcing bars would not be viable for the project. Therefore, this requirement was amended to allow the use of macro synthetic fibre reinforced concrete (MSFRC). Macro synthetic fibres were considered a far more suitable option given the significant pumping distance proposed on the project. This was proven as a good choice during pumping trials, as steel fibres dosed in the same mix increased the pumping pressure significantly and caused blockages during the trials. Also from the pumping contractor's experience, steel fibres have a propensity to escalate the chances of blockages and increase the wear on the equipment, thus increasing maintenance costs. The ease of pumping synthetic fibre could be attributed to their flexible nature allowing sympathetic alignment with the concrete flow through a pump line,

As there are no “traditional” reinforcing bars within the track slab, jointing is required at regular intervals to control cracking. Joints are formed by the introduction of two-part crack inducers in the track slab concrete, with a bottom crack inducer cast into the concrete and a top crack inducer placed in the concrete shortly after pouring. These will promote the track slab concrete to crack at these locations, relieving tensile strains developed within the slab. These crack inducers were placed every 4.2 metres throughout the tunnel track slab, except at construction joints which were required to separate each day’s pour.

The key aim of the design was to simplify the geometry to provide a constructible track form. To do this the design sought to minimise the amount of traditional reinforcement within the track slab. The use of macro synthetic fibre (MSF) reinforcement within the slab will save programme on the fabrication and placement of steel cages, whilst providing sufficient structural performance for the loads imparted on the slab.

The design has considered there to be no flexure acting on the track slab. Therefore, the design checks were carried out with the track slab concrete and invert concrete only supporting direct compression load paths and considering the invert and the track slab concrete working monolithically. This is a reasonable philosophy for the design of such a system as the slab track is cast directly against the tunnel structure, which will be uniformly supporting all the structural loads. Hence the only major stress in the slab to consider is the early age and long-term drying shrinkage. The adoption of macro synthetic fibres was aided by the provision of analyses and pre-construction trials. These demonstrated their ability to limit and control these cracks. Figure 1 below illustrates an excerpt from a finite element analysis that was conducted using ATENA, which demonstrates the capabilities of macro synthetic fibres for limiting crack widths due to drying shrinkage.


10. Early age shrinkage calculation

Crack width values and cracks in deformed Atena model
depicted all of the cracks

$w_{max.10.1.} := 0.13mm$ maximum crack width of the track slab

$\frac{w_{max.10.1.}}{w_{limit}} = 0.65$ OK!

Figure 1. Finite element analysis of shrinkage crack development in MSFRC for FAL track slab (3)

Figure 2 depicts photos taken from pre-construction trials (both at the time of the trial and 1 year after the trial) that confirmed the excellent behaviour of the MSFRC mix in limiting shrinkage cracks. These slabs were cast on polyethylene sheet, were stripped the day after being cast, and were unrestrained.

(a) Pre-construction trials (b) Finished slab in pre-construction trials

(c) MSFRC slab after 1 year

(d) Plain concrete slab after 1 year (e) SFRC slab after 1 year

Figure 2. First pre-production pumping and placement trials for FAL track slab (Author's photos)

The rails are supported on precast reinforced concrete mono-block sleepers, which are cast directly into the track slab concrete. These sleepers do not have any positive shear connection with the track slab, so to ensure that they are properly embedded the side faces were roughened to expose the aggregate. This promotes aggregate interlock when the track slab is poured around the sleepers and ensures that they work monolithically with the track slab.

3. Construction Methodology

The track slab was poured in two stages:

1. The primary pour (invert concrete) was unreinforced mass concrete, which contains the subsurface drainage. The surface of the primary pour was set out parallel to the track throughout the tunnel alignment, including matching the track superelevation/cant around curves. Before placement of the track slab, the surface of the invert concrete was scabbled.
2. The secondary pour (track slab) was fibre reinforced concrete, with the trackwork being installed using a top-down methodology. The precast sleepers were hung from the rails at the correct alignment and embedded during the second stage pour. The second stage pour incorporated surface drainage features, pits for access to the subsurface drainage and ducts forming under track crossings (UTXs). The setting out of the primary pour parallel to the track allows the second stage concrete to be a constant thickness, which has been seen on previous projects to aid setting out of the track elements for the top-down construction and reduces the potential impacts of early age thermal and differential drying shrinkage effects. The use of precast embedded sleeper blocks assists in reliably maintaining the correct rail gauge, inclination, and position, prior to the concrete placement, which is critical to providing the high accuracy of track line and level that is needed for rail track construction.

The techniques for top-down construction of concrete track slabs are generally well established and pose few issues when undertaken by experienced and competent installation teams. However, for any given track design, different sensitivities and aspects require increased vigilance to ensure that construction is completed in a satisfactory manner. From experiences on past projects, the key aspects identified for this trackwork construction included:

- **Quality of preparation and materials**: with the fibre reinforced design, the capacity and longevity of the track structure is more heavily dependent on the workmanship during construction than may be the case in equivalent conventionally reinforced designs, where increased reinforcement can be used to compensate for any anticipated poor workmanship. To mitigate any potential issues in this regard, the materials and workmanship specification for the track slab included detailed requirements for aspects such as surface preparation (to ensure adequate bond), quality control of materials and trialing of the construction methodologies.
- **Minimisation of voiding beneath sleepers**: the placement techniques and properties of the concrete are critical to ensuring that air entrapment, leading to voiding beneath the sleepers, is minimised to provide a good load-bearing path and minimise the potential for damage at the interface due to water ingress. The specification provided guidance on the concrete properties and placement techniques required to achieve a satisfactory outcome. Principally, a placement technique to flow the second stage concrete below the sleepers in a single direction to expel air using vibration was recommended. Pre-construction trials were used to refine the concrete mix design and placement methodology and train key operatives prior to construction. These trials accounted for required transportation and pumping distances to ensure similar performance could be realised within the tunnel environments. The distance between the base of the sleepers and the invert slab, combined with the slump retention and flowability of the concrete, and the use of vibration ensured that voiding was minimised, if not eradicated. Coring was carried out in the mock-up trial to confirm that this system worked.
- **Water management within tunnels**: as part of the required preparation steps, water will be required for wash-downs and pre-soaking of interface elements. Within the tunnel environment, management of this water can be particularly challenging as any standing or surface water should be removed prior to placement of concrete.

The adopted construction sequence is outlined below:

1. Surface preparation of the tunnel lining. Thorough washing down of the surfaces which will form the interface with the in-situ concrete. Cleaning of the tunnel segment joint recesses of any slurry to allow the installation of the pressure relief system.
2. Installation of the pressure relief system within the circumferential joints of the tunnel lining surfaces, followed by placement of the subsurface carrier drain, bedded on a geotextile wick.
3. Setting-out and placement of the first stage concrete. Finishing of this concrete to provide a laitance-free and roughened top surface, suitable for bonding to the second stage concrete pour.
4. Introduce crack inducers within the first stage concrete at designated locations. Either by guillotine through fresh concrete or saw cutting of initially set concrete.
5. Placement of track componentry, including rails and sleepers, along with other elements, such as ducts for UTXs.
6. Thorough wash down, to remove all loose dirt and debris, oil and other contaminants.
7. Install bottom crack inducers.
8. Adjustment and survey of track line and level.
9. Pre-soak the surfaces which will form the interface with the second stage concrete. Ensure no excess or pooling water on the surfaces.
10. Placement of second stage concrete, flowing beneath the sleepers to minimise air entrapment. Top surface to be finished to the appropriate levels, with top sections of crack inducers placed or tooled into the fresh concrete.
11. Curing measures applied, as required.
12. Removal of excess fibres protruding from the surface, if required.
13. Final clean of rail componentry and finishing of interfacing elements.

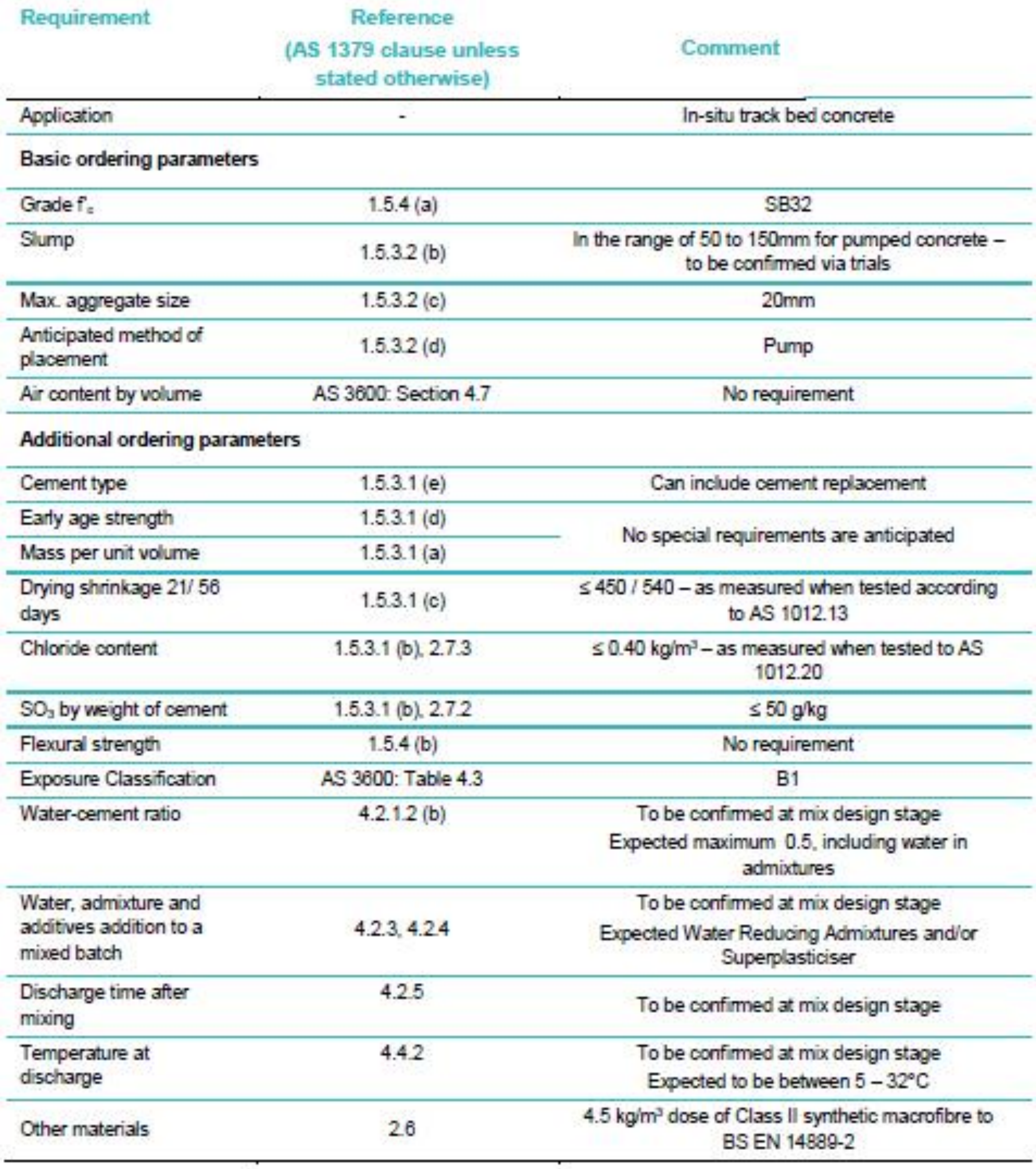
4. Concrete Technology to Achieve Pumping Distances

The pumping of concrete for long distances requires substantial planning and coordination. This required all stakeholders to be involved in the process to achieve the desired outcome. The required outcome on the FAL project being the delivery of macro synthetic fibre reinforced concrete pumped through a pipeline was planned to be up to 2000m in length. The concrete had to meet certain requirements in both its fresh and hardened state, consider various weather conditions and meet the 120-year design life. (4)

This section describes the challenges of materials for developing the concrete, taking into consideration the pumping was planned to take place at the beginning of summer and be completed at the end of Autumn.

The initial requirement in the SWTC called for a minimum concrete strength of 40MPa. However, in discussion with the contractor, and considering previous project experience, this was believed to be an excessive requirement. Initial calculations showed 32MPa concrete was sufficient to meet the structural requirements of the project for the track slab. As such, the proposed mix requirements specify a 32 MPa mix design after a concession from the SWTC was agreed with the PTA. The mix would have remained largely similar, but with additional cement and/ or a plasticiser to achieve the 40 MPa required strength class if a concession had not been reached. The contractor’s mix design and trialing had to consider the planned construction processes, batching arrangements that were to be used in the permanent works and to ensure the mix would retain sufficient workability to allow the final placement of the concrete.

Table 1. Specimen details and test strength.



Requirement	Reference (AS 1379 clause unless stated otherwise)	Comment
Application	-	In-situ track bed concrete
Basic ordering parameters		
Grade f'_c	1.5.4 (a)	SB32
Slump	1.5.3.2 (b)	In the range of 50 to 150mm for pumped concrete – to be confirmed via trials
Max. aggregate size	1.5.3.2 (c)	20mm
Anticipated method of placement	1.5.3.2 (d)	Pump
Air content by volume	AS 3600: Section 4.7	No requirement
Additional ordering parameters		
Cement type	1.5.3.1 (e)	Can include cement replacement
Early age strength	1.5.3.1 (d)	No special requirements are anticipated
Mass per unit volume	1.5.3.1 (a)	
Drying shrinkage 21/ 56 days	1.5.3.1 (c)	≤ 450 / 540 – as measured when tested according to AS 1012.13
Chloride content	1.5.3.1 (b), 2.7.3	≤ 0.40 kg/m^3 – as measured when tested to AS 1012.20
SO_3 by weight of cement	1.5.3.1 (b), 2.7.2	≤ 50 g/kg
Flexural strength	1.5.4 (b)	No requirement
Exposure Classification	AS 3600: Table 4.3	B1
Water-cement ratio	4.2.1.2 (b)	To be confirmed at mix design stage Expected maximum 0.5, including water in admixtures
Water, admixture and additives addition to a mixed batch	4.2.3, 4.2.4	To be confirmed at mix design stage Expected Water Reducing Admixtures and/or Superplasticiser
Discharge time after mixing	4.2.5	To be confirmed at mix design stage
Temperature at discharge	4.4.2	To be confirmed at mix design stage Expected to be between 5 – 32°C
Other materials	2.6	4.5 kg/m^3 dose of Class II synthetic macrofibre to BS EN 14889-2

It is common practice to reduce the risk of early-age cracking in concrete by using a blended cement with slag in the range of 21-50%, subject to slag supply and cost. The same approach was suggested and used in this track slab. Strength gain in slag cement is initially slower when compared with Portland cement. The fact that opening to traffic was not programme sensitive on this project, gave full advantage of being able to achieve the required properties at 56 days instead of the normal 28-day strength requirement.

The concrete mixture requires to be integrated and robust for long-distance pumping. To achieve these properties, the rheology of the fresh concrete determines the desired elastic and viscous properties of the fresh concrete as shown in figure 3.

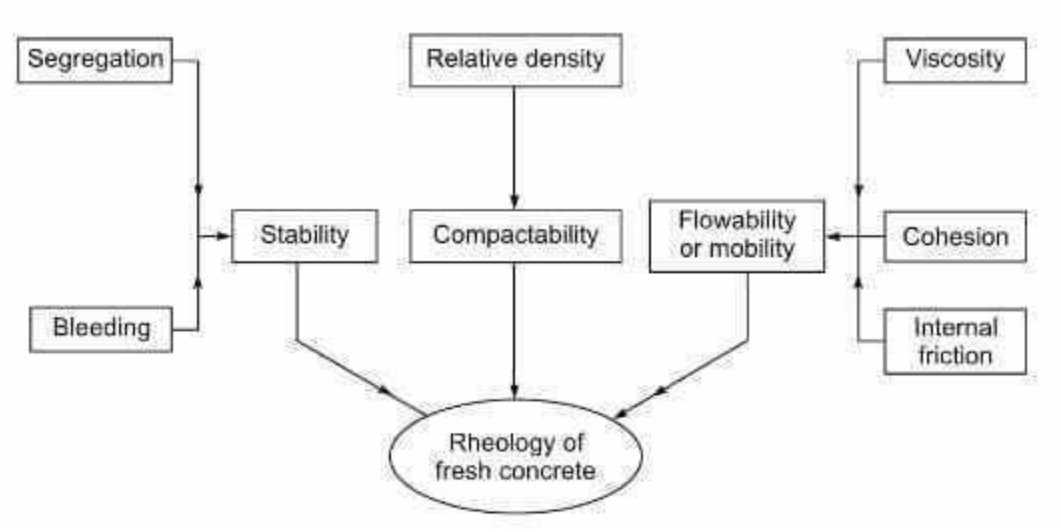


Figure 3: The rheological parameters of fresh concrete (6)

This requirement necessitates the understanding of the size and shape of the aggregates, the paste quality and quantity in the mixture, the fines content and the admixture system requirement, to develop a consistent, homogenous and workable mixture.

The other challenge while considering the mix design was the workability once macro synthetic fibres were incorporated at a dosage of 5kg/m^3, to meet the specification.

Designing concrete with suitable workability and finish ability was integral to the success of the project. While highly workable concrete (flowable) is ideal for long-distance pumping, it would be difficult to place due to the many places where the tunnel either slopes upwards or downwards and includes many bends where there is significant superelevation. The initial development of the mix was done in the laboratory, with the final mix being confirmed after a total of 14 mixing trials. A further 6 field trials which included an 800m and a 1500m long pump on the surface was performed with the proposed equipment to ensure the mix was suitable.

To aid the pumpability and final workability of the concrete, the maximum aggregate size was reduced from 20mm to 14mm. The initial mix proportioning created a highly viscous mix leading to high pumping pressures. The Envisia mix using the Zep technology system was adopted to soften the mix and achieve lower pumping pressures, while additionally lowering drying shrinkage of ≤ 450 με at 21 days and ≤ 540 με at 56 days. This was observed during the 1500m pump trial, where the Envisia mix using the ZEP technology had a pump pressure 20 bar lower than the standard concrete mix. Adoption of the Envisia mix with ZEP technology also meant achieving a low carbon concrete with a 50% replacement of ordinary Portland cement, which alongside the replacement of significant quantities of reinforcement through the adoption of macro synthetic fibres, led to significant reductions in the embodied CO$_2$eq of the FAL track slab.

5. Long Distance Pumping

5.1 People

To achieve the requirements of the pumping works, Meales engaged their most experienced pump operators. It was essential for them to judge the correct amount of slurry to avoid blockages, determine if a mix would pump without issue, and be a good communicator to others in the team.

To ensure the works maintained a constant momentum, communication between the operator and the discharge crew in the tunnel was imperative. 2-way radio communications were adopted, which were supplemented with mobile telephones.

The tunnel team were required to spend their full day in the tunnel, taking all their requirements with them. With enough people in the crew and a schedule of job rotation and rest breaks, the potential of work fatigue was avoided. The scheduling also contributed to mitigating program slippage, as the crew set up the pipe at the end of each shift in readiness for the next day's pour.

The Meales work crews included three teams.

- The set-up team for fixing pipe and moving equipment;
- The pumping team; made up of the group in the tunnel (for concrete placing and moving pipes and hoses, etc), the above-ground group including the operator, supervisor, traffic manager (to direct trucks onto the hopper), and an HSE advisor; and
- The removal team, dedicated to demobilize, clean-up and relocate equipment out of the tunnel.

5.2 Equipment

In the forward planning period, Meales worked closely with the construction and engineering teams to select the right equipment and design the piping layouts.

The importance of having the correct reliable pumping setup was imperative. In planning the setup areas, they ensured there was a dedicated area adequate for truck movement, concrete testing equipment, equipment storage, pipe layout and pedestrian circulation space. A purpose-built slab on ground to ensure stability of pumps and the first stage pipework was used, which was located adjacent to a dedicated testing bay. Also, thanks to the site safety team, people were kept separated from mobile plant using hard barricading.

With the requirements to maintain the workflow, Meales were confident in the performance of their machines. This was achieved by maintaining an inspection regime and only using state-of-the-art, well-maintained and serviced pumps. The main pump used was a double piston line pump with a hydraulic rating of 350 Bar and capable of continual pumping of concrete with a line pressure of 260 Bar. The line was a 125mm internal diameter high-pressure line that used high-pressure clamps and the line was well anchored along its length to ensure no movement of the line could occur during pumping. All equipment selected was more than capable in their capacity to perform.

5.3 Safety

An independent review of the pipeline setup and fixing was undertaken to confirm compliance to AS 2550.15:2019 and engineering calculations were undertaken to review forces acting on the line as well as the thrust blocks and fixings to ensure the safety of these pumping works.

Meales concrete pump was equipped with a safety cut-off switch to ensure pressures did not exceed safe working limits of the pipeline setup. Ultrasonic wall thickness of the high-pressure pipes was taken for each setup and wear rates calculated to confirm the integrity of the line for operation. The line was inspected and signed off by Meales' competent personnel prior to use and all details of inspections were maintained in an updated logbook. The calculated average wear on the pipeline was approximately 0.4mm per 1000m^3 of concrete pumped

5.4 Pumping

Through close collaboration with the rest of the team, two major challenges were overcome. These included the need to deliver the engineered performance requirements of the concrete, and to use the right slump which would pump the distance.

The longest recorded pumping distance was over 1,900 metres. This included 1,810 metres along the tunnel plus another 4 storeys down from the pump station. Considering this distance, it required over 25 cubic metres of concrete just to fill the pipe, taking an hour and ten minutes from entering the pump to delivery at the end of the hose into the track slab. Therefore, five trucks were required to fill the pipe and to starting the pumping for the work, each of which had to be tested prior to discharging into the pump.

To achieve the distance and deliver a constant volume of concrete, maintenance of a safe concrete pressure was required. Using the 125-millimetre internal diameter high-pressure pipe fixed to the wall, then reduced to a 20-metre long 100mm rubber hose, Meales effectively achieved an average pumping rate of 5 cubic metres every 9 minutes. With testing, cleaning and setup times consuming some of the work period, this equated to achieving approximately 160 cubic metres of concrete pumped per day or 180 linear metres of track slab cast. At the longest distance, the maximum pump pressures were in the order of +/- 220 Bar which was well below the pump threshold which had a capacity to pump concrete with a line pressure of 260 Bar.

The method of cleaning after each pumping shift resulted in numerous benefits to the project. Using a separate pump for this process, Meales flushed water through the pipe and returned it for recycling. Water and slurry were captured in bags, to prevent it from flowing onto the recently poured slab making clean-up of the work area a simple process, allowing more effective movement of the job front.

The water cleaning method enabled pushing of the entire volume of 25 cubic metres of concrete remaining in the pipe, into the job. This process resulted in zero-waste and water recycling contributed greatly to meeting commitments for the project's environmental sustainability targets.

5.5 Observations

There were several interesting observations made during the final 1500m pumping trial. The 1500m trial had a pipeline that ran up and down the yard several times, as seen in figure 3, resulting in the discharge point being close to the pump making it easy to access both the hopper and the discharge point. Also, the fact that in the 1500m trial both a conventional pump mix and an Envisia pump mix were tested, allowed comparisons between the two to be drawn.

Figure 3. 1500m of pump line set up for the trial

A commonly asked question is whether pumping long distances increases the temperature of the concrete. In this trial, approximately 3 m^3 of slurry was discharged into the line, followed by five truckloads of concrete (approx. $25m^3$), before anything came out of the discharge end. Concrete temperatures taken from those 5 different loads gave a range of temperature readings varying between 20°C - 23°C and the range of temperatures taken at the discharge end of the pump were between 21°C - 24°C. This could indicate a possible average of 1°C increase in concrete temperature, however the time difference of approximately 1 hour also needs to be taken into consideration, suggesting that there was very minimal increase in the concrete temperature due to this long pumping distance.

Of much more interest was the air content, where the conventional mix had an average of 2.72% air over 5 tests when taken from the truck, while at the discharge from the pump, the average result was 3.54% giving an increase on average of 0.82%. The Envisia mix, on the other hand, showed a decrease in air after pumping from an average of 2.8% before pumping to 2.14% air content after pumping, exhibiting an average reduction of 0.66% in air content.

Strength tests showed the compressive strength after pumping compared to the non-pumped concrete had a slightly higher early strength at 7 days, but this balanced out and the final 56-day compressive strengths were the same, so it could be concluded that the pumping had no effect on the ultimate strength of the concrete.

6. The Importance of Collaboration

Communication and planning of such a project is key to its success and with the number of stakeholders, collaboration and working together to achieve a common goal is key.

The stakeholders included:

Table 2. Forrestfield-Airport Link project stakeholders

Client	Public Transport Authority – METRONET
Lead FAL Contractor	Salini Impregilo – NRW Joint Venture
Designer	Mott MacDonald
Concrete Pumping Contractor	Meales Concrete Pumping WA
Concrete Placement Contractor	Martinus Rail
Concrete Supplier	Boral Concrete
Macro Synthetic Fibre Supplier	BarChip Australia

The responsibility of the client (PTA) is to provide the SWTC. This must be managed and complied with by the lead contractor SI-NRW JV. Mott MacDonald provided the design for the concrete track slab.

The role of the pumping contractor Meales was to provide the required pump, and pipeline, associated equipment and skilled personals to manage the pipe installation, maintenance, and removal as well as oversee and manage the long-distance pumping.

The concrete supplier Boral provides a continual supply of concrete during the shift which is suitable for pumping the required long-distance, as well as permanent onsite testing and quality control of the mix.

Martinus has overall responsibilities for the fit-out of rail infrastructure, including installing the track slab and rail. They needed to ensure there was sufficient track aligned and prepared ready for concrete placement. They employed Whittens to assist with the concrete finishing and overseeing the finish quality.

BarChip Australia supplied the macro synthetic fibre and their main responsibility was to assist with product technical support, ensure best practice for mixing fibre to eradicate issues such as balling, while maintaining a continuous supply to the concrete batch plant.

Collaboration between each of these parties (and others) was necessary to bring this project from its SWTC beginnings to fruition. Change from the original continuously reinforced concrete track slab to a MSFRC track slab required close collaboration between the PTA, SI-NRW JV, Mott MacDonald and BarChip Australia. Once the change was agreed, collaboration between SI-NRW JV, BarChip Australia, Boral Concrete and Meales Concrete Pumping took place to develop a concrete mix design that would meet all of the hardened property requirements (which allowed the realisation of a reduced concrete strength). This mix could also maintain its integrity while being pumped up to an effective length of 1970 m. Further cooperation took place between Martinus, Meales and Boral to ensure the concrete was not only pumpable but could also meet the properties necessary for correct and accurate placement of the concrete. This close collaboration between all parties has been and continues to be, essential.

7. Conclusions

While construction of concrete track slabs is not a new undertaking, the uptake of concrete track slabs within a tunnel environment is still in development. It is clear that general practices from design of above ground track slab are not so easily adopted in construction of underground track slabs. Minimal workspace and clearance underneath sleepers create difficulties and significant labour requirements if attempting to construct a conventionally reinforced concrete track slab within a tunnel. An innovative solution, macro synthetic fibre reinforced concrete, was adopted on this project after significant pre-construction trials and analyses proved the option was a suitable one. This led to significant cost and programme savings for the project when compared to the original design.

Learnings from this project have further enthused Meales to develop their techniques in readiness to tackle even greater challenges. With the aim to pump concrete from a surface-mounted pump 2 kilometres down into a tunnel, the team needed to work collaboratively and effectively to meet target deadlines without incident.

This project is an excellent example of true collaboration between all stakeholders to ensure and achieve a successful outcome.

8. References

1. Kajastie N. Future of Tunnelling | Challenges on Perth’s Forrestfield-Airport link in Australia. New Civil Engineer [Internet]. 2020 8 April 2021. Available from: https://www.newcivilengineer.com/the-future-of/future-of-tunnelling-challenges-on-perths-forrestfield-airport-link-in-australia-18-09-2020/.Rezansoff, T., Akanni, A. et al., “Tensile lap splices under static loading: A review of the proposed ACI 318 Code provisions”, ACI Structural Journal, 90(4), 1993, pp 374-384.
2. PTA. Forrestfield- Airport Link, Tunnel fit-out and track laying. In: METRONET, editor. Perth: Public Transport Authority; 2020. p. 4.
3. Juhasz KP, Schaul P. FEA design report #513: macro synthetic fibre reinforced cast in situ concrete track slab. Budapest, Hungary: JKP Static Ltd; 2018. Contract No.: 513
4. Authority PT. Volume 3 of 6 Exhibit 1 - Scope of Works and Technical Criteria. Perth: Government of Western Australia; 2016.
5. Authority PT. Volume 4 of 6 Exhibit 1 Scope of Works and Technical Criteria Appendices Perth: Government of Western Australia; 2016.
6. Neenu SK. Rheology of Concrete- Rheological Parameters of Fresh Concrete. The Constructor [Internet]. 2017. Available from: theconstructor.org/concrete/rheology-of-concrete/15319.