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Design and Construction of Sewer Tunnels for the Deep Tunnel Sewerage System Phase 2 Project - Contract T-07

Report – Low Carbon foot print concrete

Introduction

The Public Utilities Board (PUB) intends to implement the Deep Tunnel Sewerage System (DTSS) Phase 2 project in Singapore. DTSS Phase 2 project (the Project) extends the existing deep tunnel system to collect used water from the western and southern parts of Singapore.

Used water from municipal and industrial sources will be transported by gravity separately by the conveyance system to the new Tuas WRP. Tuas WRP will be able to treat the two streams of used water separately, with a total treatment capacity of 800,000 cubic meters per day.

Contract T-07

In September 2017, PUB awarded the T-07 contract to Ed. Züblin AG - Singapore Branch. Subsequently, Ed. Züblin AG - Singapore Branch engaged Arcadis Design & Engineering Limited with support of Jacobs International Consultants Pte. Ltd. to undertake the Detailed Design Services.

The project is located in western Singapore. The overall key plan for T-07 is shown below.

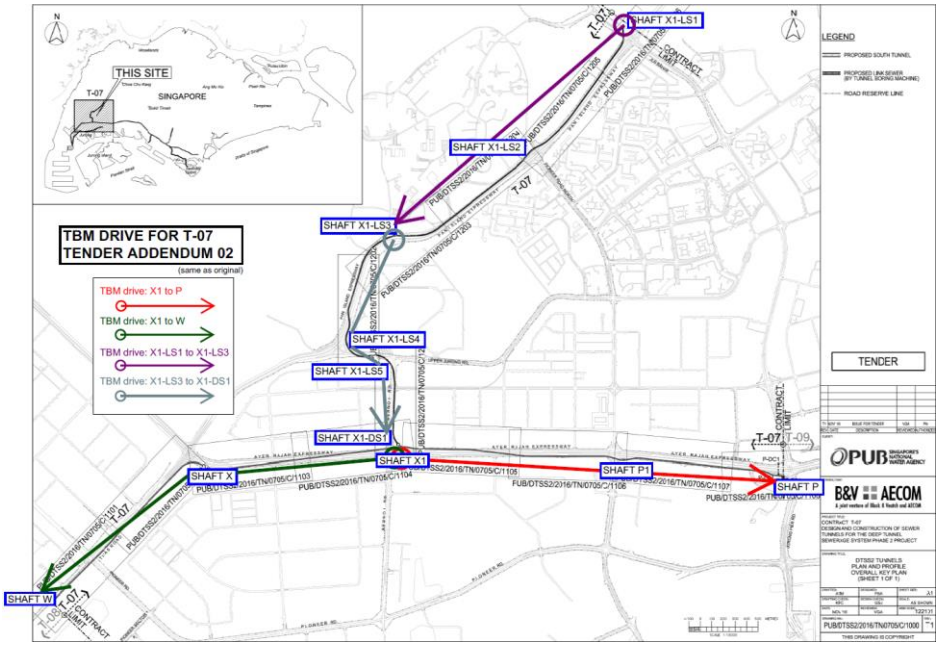


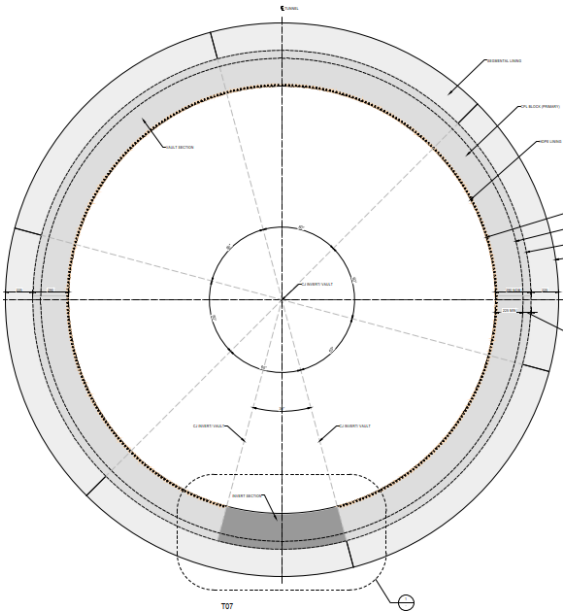
Figure 0-1 Overall key plan for Contract T-07

The 6.9km long South Tunnel will run in a westerly direction parallel to the Ayer Raja Expressway (AYE) between Jurong Pier Road (shaft P) and Tuas Road, before turning south-west for a short stretch parallel to Tuas Road.

The 5.1km Northwest Link Sewer Tunnel will run in a south-westerly direction parallel to the PIE between Jalan Bahar and Upper Jurong Road (shaft X1-LS1), before a dog-leg turn to head south parallel to Benoi Road and meet the main DTSS south tunnel at the AYE junction (shaft X1-DS1).

Lining Design

The south and northwest connecting tunnels are designed as drilled segmental tunnels with an additional corrosion protection lining of 225 mm microbiologically induced corrosion (MIC) concrete.



Concrete design

The actual concrete mix design was created by **TPA GmbH (department of Ed. Züblin AG)** in partnership with MC-Bauchemie Singapore Pte Ltd. (admixture) and KrampeHarex GmbH & Co. KG (Steel fibre):

Ingredient	Percentage per cubic meter
Cement OPC / CEM I	6%
GGBS	11.2%
Water	14%
Air	1
Microsilica	3.5%
Admixture	1.6%
Steel fibres	0.4%
Sand	31.4%
Aggregates	31%

- Design life 100 years

Microbiologically influenced corrosion (MIC) resistant concrete shall meet the following requirements:

- A volume of permeable voids of less than 10.0% when tested according to ASTM C642.
- Corrected water absorption of less than 1% when tested in accordance with BS 1881: Part 122. Where MIC resistance is to be achieved using hydrophobic pore-blocker, the absorption limit must be achieved within 7 days.
- A pressure penetration of less than 10 mm when tested in accordance with BS EN 12390-8.

- A permeability coefficient of less than 5 X 10'13 m/s. when tested in accordance with HDB permeability coefficient test.
- An electrical indication of resistance to chloride ion penetration of less than1000 coulombs when tested according to ASTM C1202.
- A shrinkage limit of less than 0.01% in 28 days when tested according to
- ASTM C1698
- Resistance to designated microbiological / chemical exposures in the sewage or in the atmosphere above the sewage flow with resistance to hydrogen sulphide concentration not less than 100 ppm in order to achieve the design life of 100 years.
- A combination of approved methods of achieving the required resistance to corrosion shall be by one or more of the following:
    - (i) The addition of a hydrophobic pore-blocker with a minimum active ingredient of 1.2% by weight of binder.
    - (ii) Replacing 80% or more of Ordinary Portland Cement (OPC) with Ground Granulated Blast furnace Slag (GGBS);
    - (iii) Replacing 15% or more of OPC with Silica Fume.

Hardened concrete requirements:

- Compressive strength after 56 days bigger than 60 MPA
- Tensile splitting strength over 4.6 MPA
- Flexural strength after EN 14951:2005
    - LOP 6.0 MPA
    - $f_{R,1}$ 5.0 MPA
    - $f_{R,4}$ 2.0 MPA

The initial results for flexural strength with 40 and 35 kg/m² steel fiber were overfilled, resulting in a reduction of the steel fiber to 31 kg/m². All test results from the production of the concrete meet the requirements.

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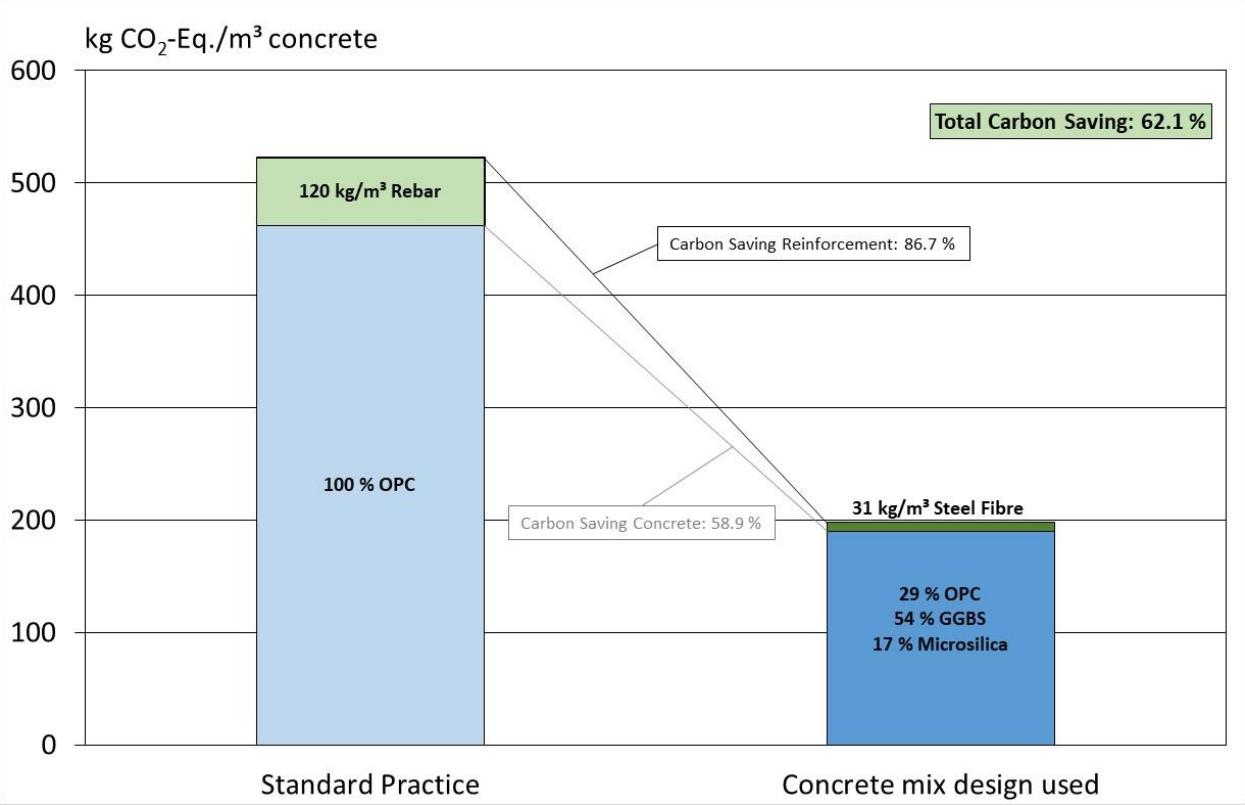
Carbon Saving compared to Standard Practise



Concrete Mix	CEM I		GGBS		NC II		Rebar	Steel Fibre	Total Binder	Total reinforcement	Total
	% by mass	kg/m³	% by mass	kg/m³	% by mass	kg/m³	kg/m³	kg/m³	kg CO_2/m³	kg CO_2/m³	kg CO_2/m³
Standard Practice	20.7	496.8	-	-	-	-	120.0	-	**462.0**	**60.0**	**522.0**
Concrete mix design used	6.0	144.0	11.2	268.8	3.5	84.0	-	31.0	**190.0**	**8.0**	**198.0**
Savings									**58.9%**	**86.7%**	**62.1%**

Materials	A1 to A3	Sources	
	kg CO_2/kg		
CEM I Singapore	0.930	One Click LCA 2022	Portland cement, generic, CEM I, 0% recycled binders (One Click LCA 2022)
CEM III 65 % GGBS - (CEM III 60 % GGBS + CEM III 70 GGBS, Singapore)/2	0.440	One Click LCA 2022	Blast furnace cement, generic, CEM III/A, 60% GGBS content (One Click LCA 2022) & Blast furnace cement, generic, CEM III/B, 70% GGBS content (One Click LCA 2022)
Microsilica	0.100	MC-Bauchemie	Manufacturer´s information
Stahl Singapore, 97 % Recycling	0.500	One Click LCA 2018	Reinforcement steel (rebar), generic, 97% recycled content (typical), A615
KrampeHarex Steel Fibre	0.257	EPD International	https://api.environdec.com/api/v1/EPDLibrary/Files/04764257-e5f6-4df0-f5a5-08dcece3a830/Data

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Lessons Learnt

- Good **communication** within the "**project team**" (Züblin, TPA, MC-Bauchemie, KrampeHarex) is key
- **Round Table Approach** is important!
  - Sharing Expertise, Knowledge, Experience from the beginning
- **Comparison of Solution** with similar Projects
- The ambition of all parties to reduce CO_2 emissions