Exempt

33(1)

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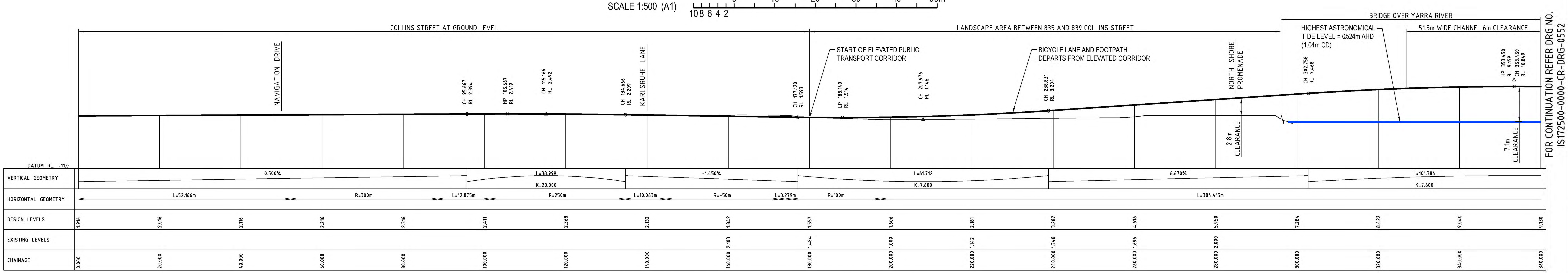
33(1)

Appendix B. Concept Design Drawings – Specific Route Elements

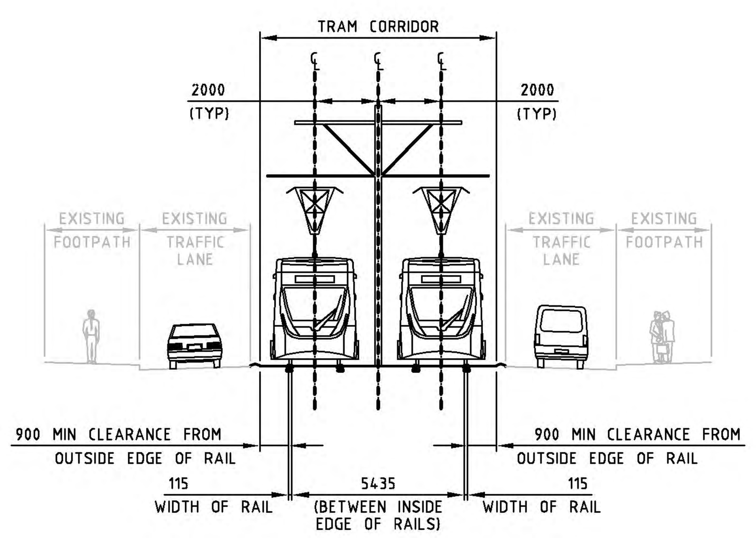
PLAN

SCALE 1:500 (A1)

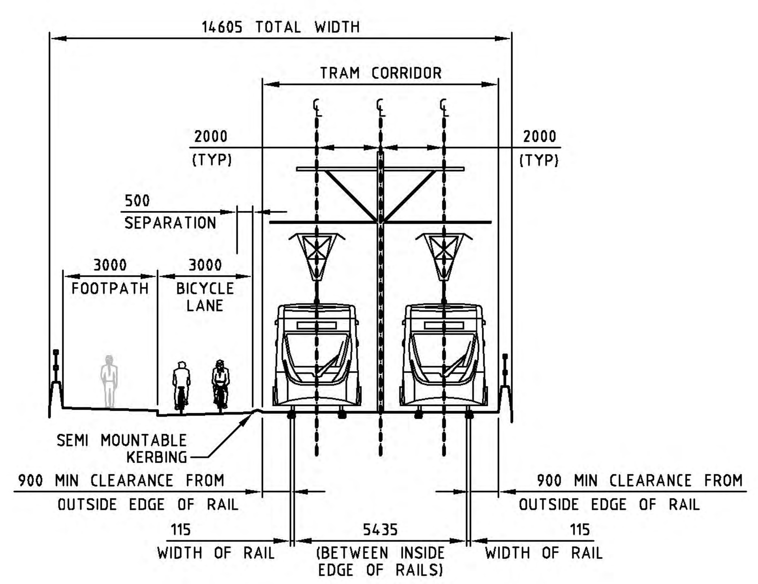


LONGITUDINAL SECTION - COLLINS STREET (MC501)

SCALE 1:500 (A1)



SECTION A
TYPICAL CROSS-SECTION
COLLINS STREET - CHAINAGE 100



SECTION B
TYPICAL CROSS-SECTION
ACROSS YARRA RIVER - CHAINAGE 300

SCALE 1:200 (A1)

LEGEND

- PUBLIC TRANSPORT CORRIDOR - ELEVATED
- PUBLIC TRANSPORT CORRIDOR - GROUND LEVEL
- SHARED USER CORRIDOR
- BICYCLE LANE
- FOOTPATH CORRIDOR
- APPROXIMATE BUILDING FOOT PRINT

ISSUED FOR REVIEW (DRAFT)

REV	DATE	DRAWN	REV'D	APP'D	REVISION
4	24.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)
3	15.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)
2	31.01.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)
1	30.01.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)

DRAWING NUMBER	REFERENCE DRAWING TITLE

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Web: www.jacobs.com

CLIENT: DEPART. OF ENVIRONMENT, LAND, WATER AND PLANNING
PROJECT: IMPROVING CONNECTIVITY IN FISHERMANS BEND STUDY

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
GCD	MM	MM	AN
DESIGNED	DESIGN REVIEW	DATE 30.01.17	DATE 30.01.17
GCD	MM		

TITLE: BRIDGE OVER YARRA RIVER (6 METRE) AND WEST GATE FREEWAY AT COLLINS STREET AND HARTLEY STREET - SHEET 01

SCALE: AS SHOWN | DRAWING No: IS172500-0000-CR-DRG-0551 | REV: 4

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DATE: 22/02/2017 3:46:55 PM LOGIN NAME
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Exempt

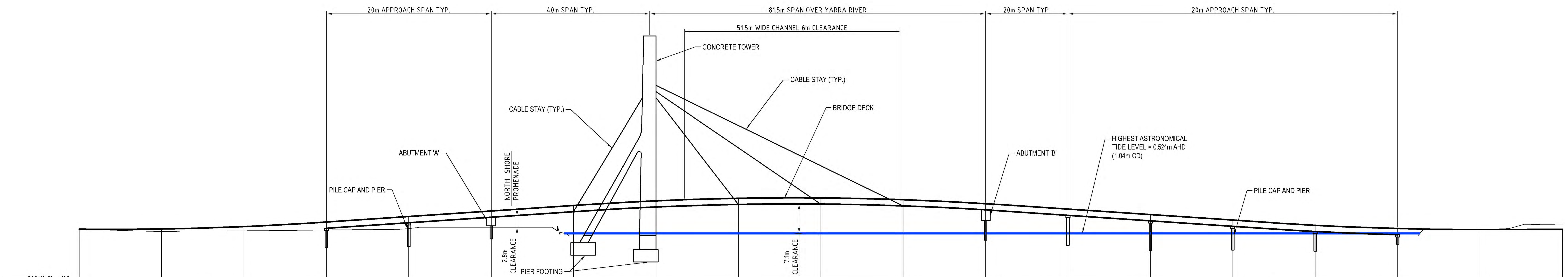
33(1)

Exempt

33(1)

PLAN

SCALE 1:500 (A1) 10 8 6 4 2 0 10 20 30 40 50m



DATUM RL. -11.0

VERTICAL GEOMETRY: L=61.712, K=7.600 | 6.670% | L=101.384, K=7.600 | -6.670% | L=53.732, K=7.600 | 0.400%

HORIZONTAL GEOMETRY: R=100m | L=384.415m

CHAINAGE	DESIGN LEVELS	EXISTING LEVELS
180.000	1.557	1.484
200.000	1.606	1.000
220.000	2.181	1.142
240.000	3.282	1.348
260.000	4.616	1.696
280.000	5.950	2.000
300.000	7.284	
320.000	8.422	
340.000	9.040	
360.000	9.130	
380.000	8.695	
400.000	7.733	
420.000	6.410	
440.000	5.076	
460.000	3.742	
480.000	2.488	
500.000	1.708	
520.000	1.453	1.523
540.000	1.528	2.769

BRIDGE ELEVATION - YARRA RIVER CROSSING (MC501)

SCALE 1:500 (A1) 10 8 6 4 2 0 10 20 30 40 50m

LEGEND

- PUBLIC TRANSPORT CORRIDOR - ELEVATED
- PUBLIC TRANSPORT CORRIDOR - GROUND LEVEL
- BICYCLE LANE
- FOOTPATH CORRIDOR
- APPROXIMATE BUILDING FOOT PRINT

ISSUED FOR REVIEW (DRAFT)

REV	DATE	DRAWN	REV'D	APP'D	REVISION
2	24.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)
1	15.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)

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DRAWN	DRAWING CHECK	REVIEWED	APPROVED
GCD	MM	MM	AN
DESIGNED: GCD	DESIGN REVIEW: MM	DATE 15.02.17	DATE 15.02.17

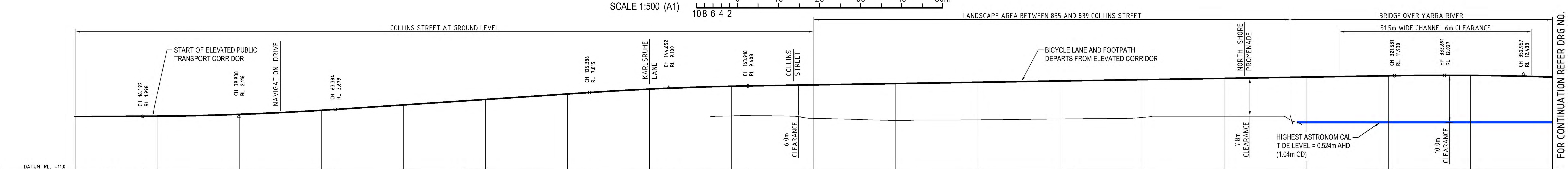
TITLE: BRIDGE OVER YARRA RIVER (6 METRE) ROUTE COMPONENT 1 BRIDGE ELEVATION

SCALE: AS SHOWN | DRAWING No: IS172500-0000-CR-DRG-0554 | REV: 2

A1

PLAN

SCALE 1:500 (A1) 10 8 6 4 2 0 10 20 30 40 50m



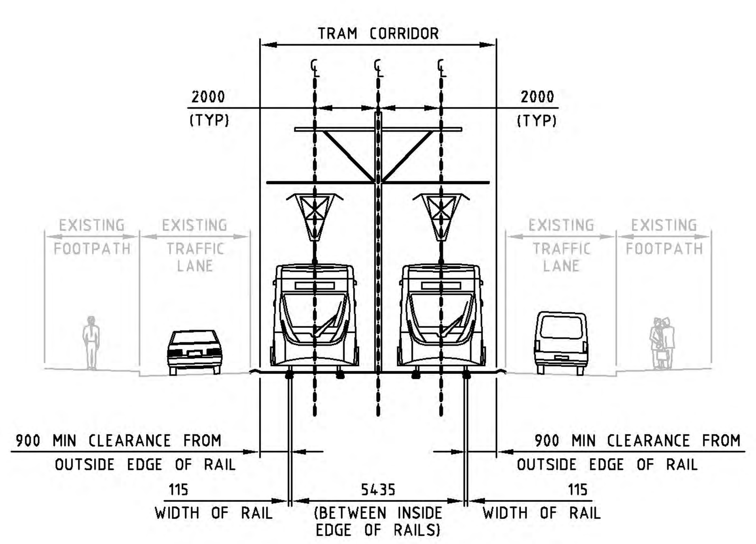
VERTICAL GEOMETRY	0.500%	L=46.892 K=7.600	6.670%	L=38.532 K=7.600	1.600%	L=62.852 K=7.600

HORIZONTAL GEOMETRY	L=52.166m	R=300m	L=12.875m	R=250m	L=10.063m	R=-50m	L=3.279m	R=100m	L=384.415m

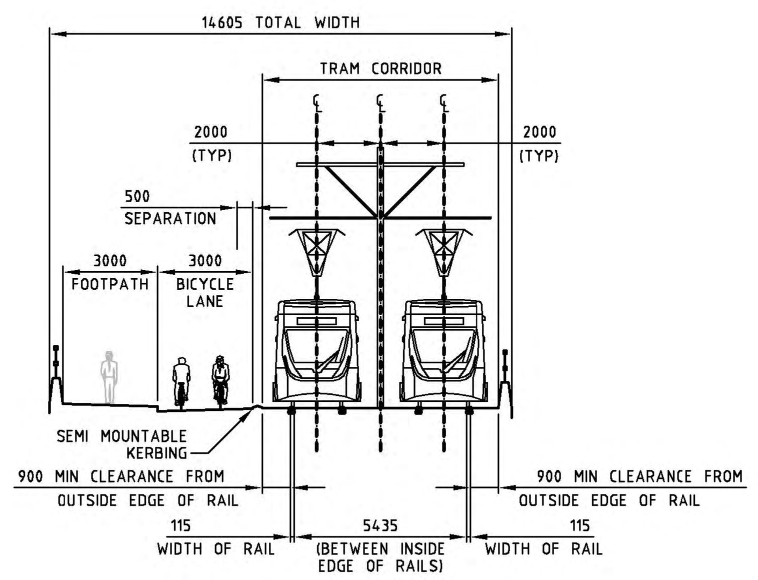
CHAINAGE	DESIGN LEVELS	EXISTING LEVELS
0.000	1.916	
20.000	2.024	
40.000	2.479	
60.000	3.461	
80.000	4.788	
100.000	6.122	
120.000	7.456	
140.000	8.649	
160.000	9.335	2.103
180.000	9.666	1.484
200.000	9.986	1.000
220.000	10.306	1.142
240.000	10.626	1.348
260.000	10.946	1.696
280.000	11.266	2.000
300.000	11.586	
320.000	11.906	
340.000	12.001	
360.000	11.572	

LONGITUDINAL SECTION – COLLINS STREET (MC502)

SCALE 1:500 (A1) 10 8 6 4 2 0 10 20 30 40 50m



SECTION A
TYPICAL CROSS-SECTION
COLLINS STREET – CHAINAGE 100



SECTION B
TYPICAL CROSS-SECTION
ACROSS YARRA RIVER – CHAINAGE 300

SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

LEGEND

- PUBLIC TRANSPORT CORRIDOR – ELEVATED
- PUBLIC TRANSPORT CORRIDOR – GROUND LEVEL
- SHARED USER CORRIDOR
- BICYCLE LANE
- FOOTPATH CORRIDOR
- APPROXIMATE BUILDING FOOT PRINT

ISSUED FOR REVIEW (DRAFT)

REV	DATE	DRAWN	REV'D	APP'D	REVISION
2	24.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)
1	15.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)

DRAWING NUMBER	REFERENCE DRAWING TITLE

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DRAWN	DRAWING CHECK	REVIEWED	APPROVED
GCD	MM	MM	AN
DESIGNED	DESIGN REVIEW	DATE 15.02.17	DATE 15.02.17
GCD	MM		

TITLE: BRIDGE OVER YARRA RIVER (9 METRE) AND WEST GATE FREEWAY AT COLLINS STREET AND HARTLEY STREET - SHEET 01

SCALE: AS SHOWN
DRAWING No: IS172500-0000-CR-DRG-0561
REV: 2

A1

DATE: 22/02/2017 3:50:40 PM LOGIN NAME
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Exempt

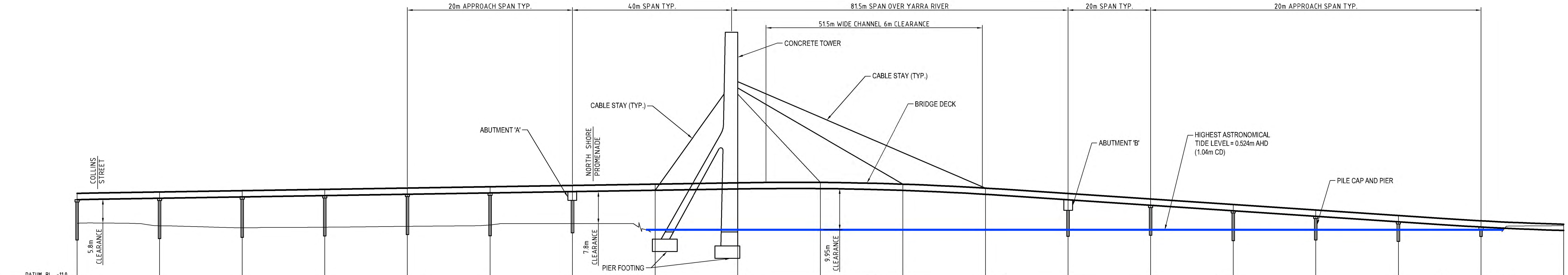
33(1)

Exempt

33(1)

PLAN

SCALE 1:500 (A1)



VERTICAL GEOMETRY: L=38.532, K=7.600; 1.600%; L=62.852, K=7.600; -6.670%; L=53.732, K=7.600

HORIZONTAL GEOMETRY: R=-50m, L=3.279m, R=100m; L=384.415m

CHAINAGE	DESIGN LEVELS	EXISTING LEVELS
160.000	9.335	2.103
180.000	9.666	1.484
200.000	9.986	1.000
220.000	10.306	1.142
240.000	10.626	1.348
260.000	10.946	1.696
280.000	11.266	2.000
300.000	11.586	
320.000	11.906	
340.000	12.001	
360.000	11.572	
380.000	10.616	
400.000	9.295	
420.000	7.961	
440.000	6.627	
460.000	5.293	
480.000	3.959	
500.000	2.680	
520.000	1.848	1.523

BRIDGE ELEVATION - YARRA RIVER CROSSING (MC502)

SCALE 1:500 (A1)

LEGEND

- PUBLIC TRANSPORT CORRIDOR - ELEVATED
- PUBLIC TRANSPORT CORRIDOR - GROUND LEVEL
- BICYCLE LANE
- FOOTPATH CORRIDOR
- APPROXIMATE BUILDING FOOT PRINT

ISSUED FOR REVIEW (DRAFT)

REV	DATE	DRAWN	REV'D	APP'D	REVISION
1	24.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)

DRAWING NUMBER	REFERENCE DRAWING TITLE

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PROJECT: IMPROVING CONNECTIVITY IN FISHERMANS BEND STUDY

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
GCD	MM	MM	AN
DESIGNED	DESIGN REVIEW	DATE 24.02.17	DATE 24.02.17
GCD	MM		

TITLE: BRIDGE OVER YARRA RIVER (9 METRE)
ROUTE COMPONENT 1
BRIDGE ELEVATION

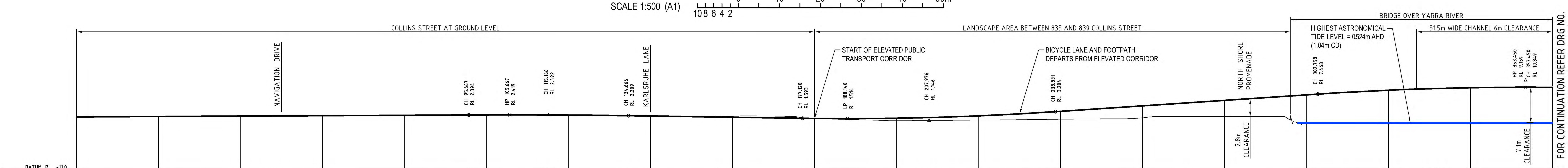
SCALE: AS SHOWN | DRAWING No: IS172500-0000-CR-DRG-0575 | REV: 1

A1

Exempt

PLAN

SCALE 1:500 (A1)



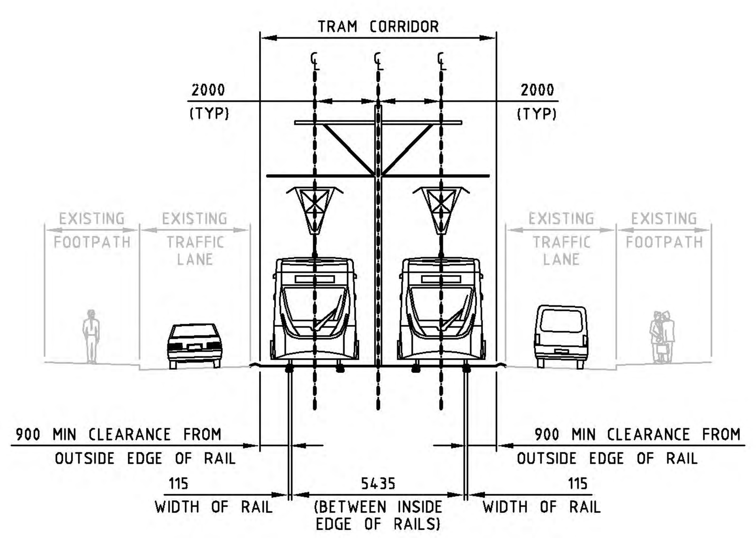
VERTICAL GEOMETRY: 0.500% | L=38.999, K=20.000 | -1.450% | L=61.712, K=7.600 | 6.670% | L=101.384, K=7.600

HORIZONTAL GEOMETRY: L=52.166m | R=300m | L=12.875m | R=250m | L=10.063m | R=-50m | L=3.279m | R=100m | L=384.415m

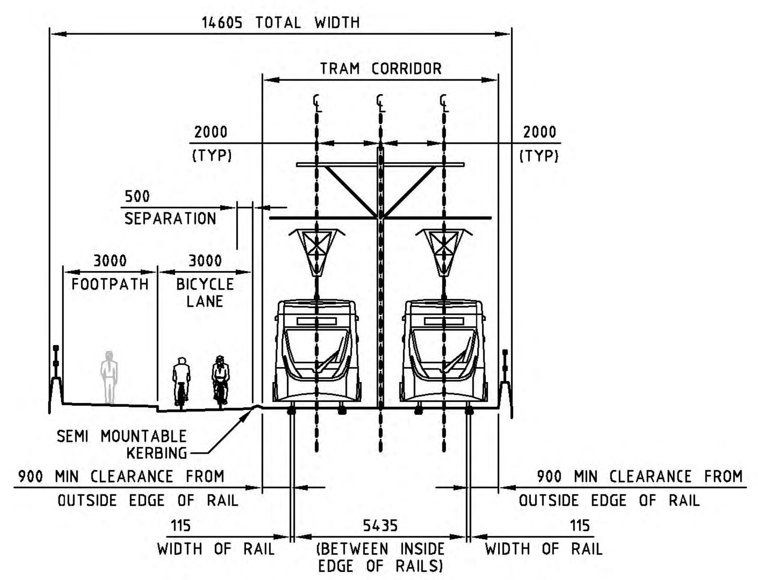
CHAINAGE	DESIGN LEVELS	EXISTING LEVELS
0.000	1.916	
20.000	2.016	
40.000	2.116	
60.000	2.216	
80.000	2.316	
100.000	2.411	
120.000	2.368	
140.000	2.132	
160.000	1.842	2.103
180.000	1.557	1.484
200.000	1.606	1.000
220.000	2.181	1.142
240.000	3.282	1.348
260.000	4.616	1.696
280.000	5.950	2.000
300.000	7.284	
320.000	8.422	
340.000	9.040	
360.000	9.130	

LONGITUDINAL SECTION - COLLINS STREET (MC503)

SCALE 1:500 (A1)



SECTION A
TYPICAL CROSS-SECTION
COLLINS STREET - CHAINAGE 100



SECTION B
TYPICAL CROSS-SECTION
ACROSS YARRA RIVER - CHAINAGE 300

SCALE 1:200 (A1)

LEGEND
- PUBLIC TRANSPORT CORRIDOR - ELEVATED
- PUBLIC TRANSPORT CORRIDOR - GROUND LEVEL
- SHARED USER CORRIDOR
- BICYCLE LANE
- FOOTPATH CORRIDOR
- APPROXIMATE BUILDING FOOT PRINT

ISSUED FOR REVIEW (DRAFT)

REV	DATE	DRAWN	REV'D	APP'D	REVISION
1	24.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)

DRAWING NUMBER	REFERENCE DRAWING TITLE

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PROJECT: IMPROVING CONNECTIVITY IN FISHERMANS BEND STUDY

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
GCD	MM	MM	AN
DESIGNED: GCD	DESIGN REVIEW: MM	DATE 24.02.17	DATE 24.02.17

TITLE: BRIDGE OVER YARRA RIVER (6 METRE) AND TUNNEL UNDER WEST GATE FREEWAY AT HARTLEY STREET - SHEET 01

SCALE: AS SHOWN | DRAWING No: IS172500-0000-CR-DRG-0571 | REV: 1

A1

DATE: 22/02/2017 3:54:41 PM LOGIN NAME
LOCATION: J:\IE\Projects\03_Southern\IS172500\...IS172500-0000-CR-DRG-0571-0573.dwg

Exempt

33(1)

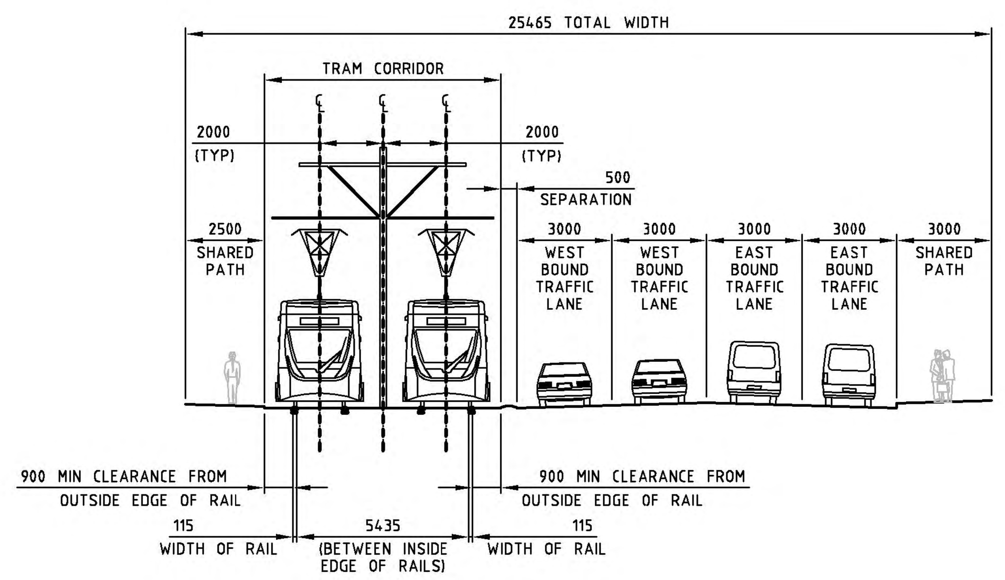
Exempt

33(1)

Exempt

PLAN

SCALE 1:250 (A1) 5 4 3 2 1 0 5 10 15 20 25m



SECTION H
TYPICAL CROSS-SECTION
LORIMER STREET - CHAINAGE 100

SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

LEGEND

- PUBLIC TRANSPORT CORRIDOR - ELEVATED
- PUBLIC TRANSPORT CORRIDOR - GROUND LEVEL
- SHARED USER CORRIDOR

ISSUED FOR REVIEW (DRAFT)

REV	DATE	DRAWN	REV'D	APP'D	REVISION
3	24.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)
2	16.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)
1	15.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)

DRAWING NUMBER	REFERENCE DRAWING TITLE

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PROJECT: IMPROVING CONNECTIVITY IN FISHERMANS BEND STUDY

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
GCD	MM	MM	AN
DESIGNED: GCD	DESIGN REVIEW: MM	DATE 15.02.17	DATE 15.02.17

TITLE: ROUTE COMPONENT 2 - OPTION 1A
LORIMER STREET TO HARTLEY STREET
INTERSECTION RECONFIGURATION

SCALE: AS SHOWN | DRAWING No: IS172500-0000-CR-DRG-0557 | REV: 3

A1

DATE: 22/02/2017 3:49:38 PM LOGIN NAME
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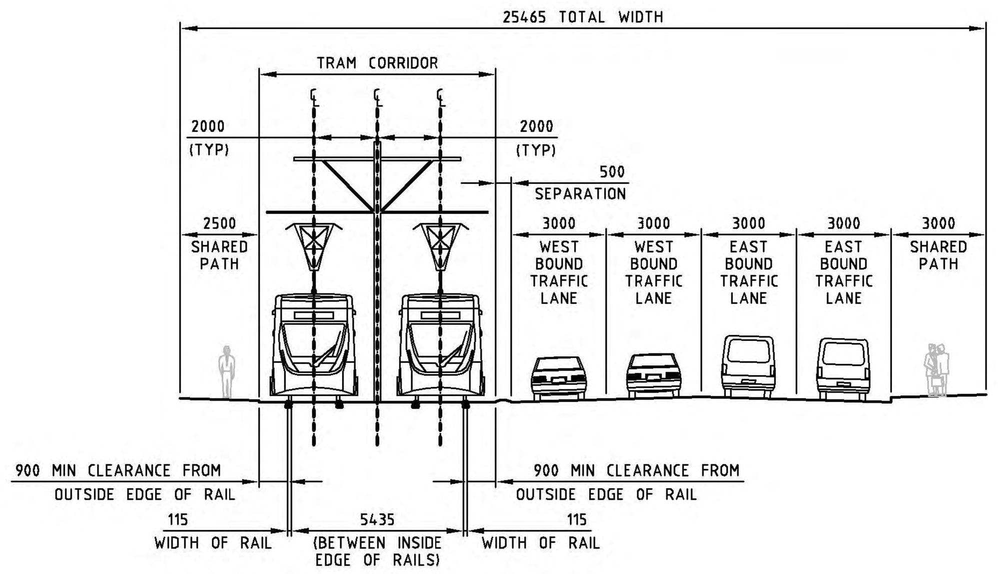
PLAN

SCALE 1:250 (A1) 5 4 3 2 1 0 5 10 15 20 25m



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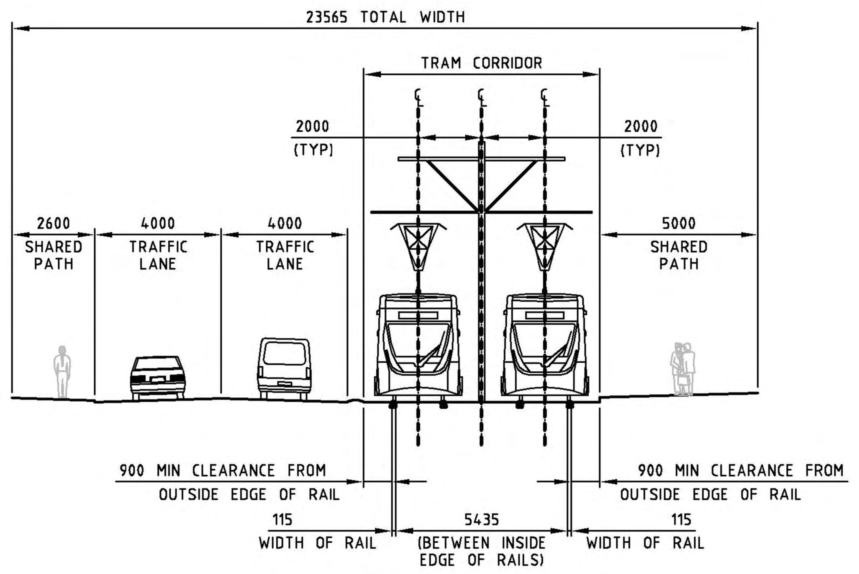
TYPICAL CROSS-SECTION
LORIMER STREET - CHAINAGE 200



SECTION K
TYPICAL CROSS-SECTION
ROGERS STREET - CHAINAGE 275

SCALE 1:200 (A1) 4 3 2 1 0 4 8 12 16 20m

LEGEND

- PUBLIC TRANSPORT CORRIDOR - ELEVATED
- PUBLIC TRANSPORT CORRIDOR - GROUND LEVEL
- SHARED USER CORRIDOR

ISSUED FOR REVIEW (DRAFT)

REV	DATE	DRAWN	REV'D	APP'D	REVISION
3	24.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)
2	16.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)
1	15.02.17	GCD	MM	AN	ISSUED FOR REVIEW (DRAFT)

DRAWING NUMBER	REFERENCE DRAWING TITLE

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PROJECT: IMPROVING CONNECTIVITY IN FISHERMANS BEND STUDY

DRAWN	DRAWING CHECK	REVIEWED	APPROVED
GCD	MM	MM	AN
DESIGNED	DESIGN REVIEW	DATE 15.02.17	DATE 15.02.17
GCD	MM		

TITLE: ROUTE COMPONENT 2 - OPTION 1A
LORIMER STREET TO ROGERS STREET
INTERSECTION RECONFIGURATION

SCALE: AS SHOWN
DRAWING No: IS172500-0000-CR-DRG-0558
REV: 3

A1

Exempt

Exempt

Exempt

Exempt

Appendix C. Design of options and alignment for Collins St – Hartley St Public Transport Route

Exempt

Exempt

Exempt

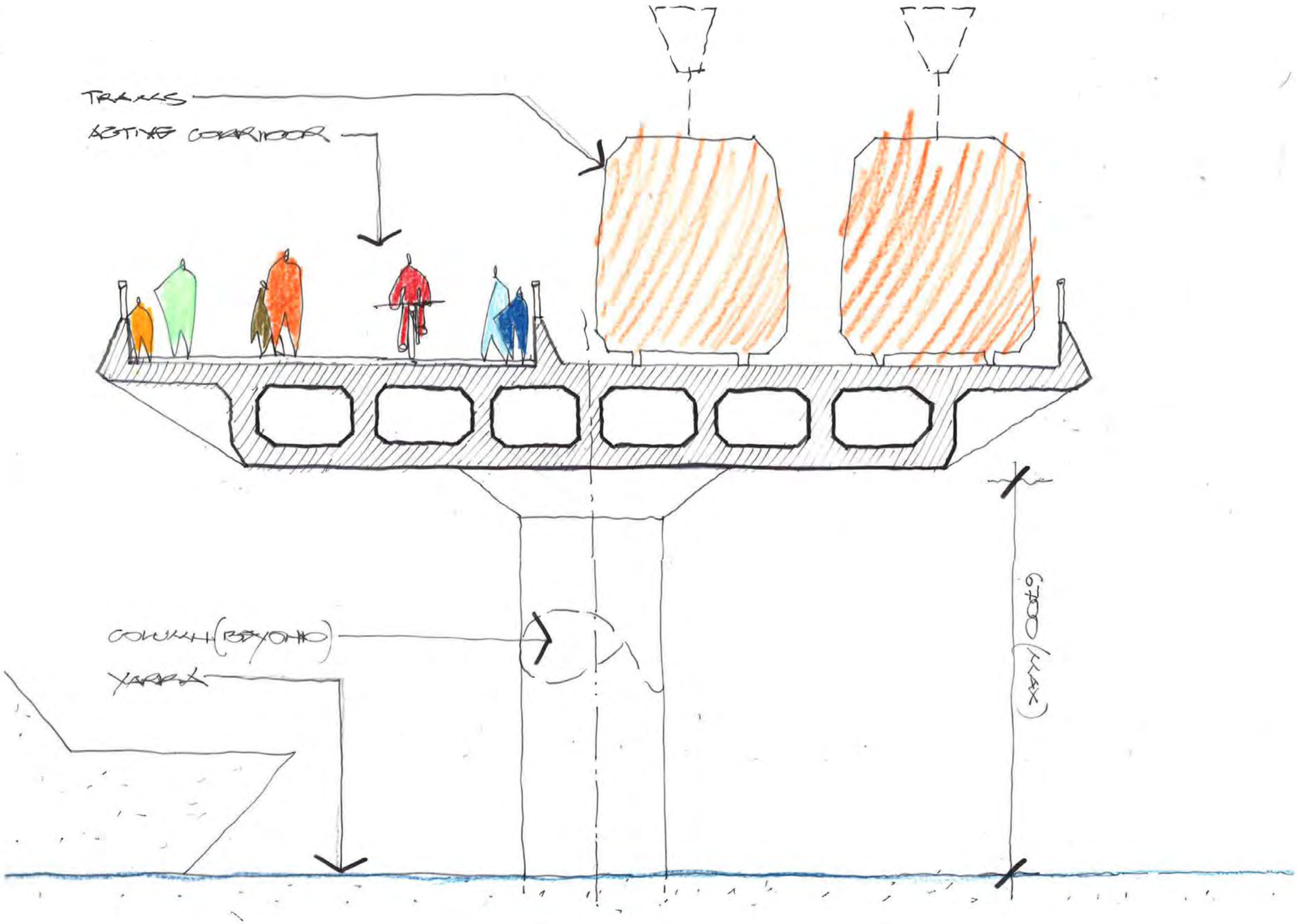
Exempt

Exempt

DRAFT
17.02.2017

Exempt

TYPICAL BRIDGE SECTION
6M CLEARANCE OPTION



SECTION

FISHERMANS BEND CONNECTIONS:
BRIDGES OVER YARRA RIVER & WESTGATE FREEWAY AT COLLINS & HARTLEY STREET

JACOBS

Appendix D. Detailed Costings for Phase 3 Feasible Options

Exempt

Appendix E. Detailed Notes Supporting Design of Option 3 (Tunnel Option)

1 Existing Geology

Summary of Existing Ground Conditions

Geological conditions in the vicinity of the proposed Yarra River and West Gate Freeway crossings have been inferred from published information from the area.

At the eastern end of the site, information is available from the area around Charles Grimes Bridge which has been inferred from geotechnical boreholes available from the adjacent Melbourne Main Sewer, reported by GHD in 2007. The sewer crosses the Yarra River to the east of Charles Grimes Bridge. Four geotechnical boreholes and four Cone Penetrometer Tests (CPTs) were undertaken across the river and at the river banks for the sewer. These holes identify a consistent ground profile comprising very soft Coode Island Silt and recent river muds, overlying firm to stiff Fishermen's Bend Silt and medium dense to dense Moray Street Gravel. Very dense sandy gravels and residually weathered siltstone of the Brighton Group and the Melbourne Mudstone formation respectively were encountered below the Moray Street Gravels. A summary of the materials to be encountered, and their depths where encountered near Charles Grimes Bridge, are summarised in **Table 1**.

Geological map code	Unit name: material description	Typical elevation (mAHD) to top of layer (GHD, 2007)		Strength information[1,2,3]
		From	To	
FILL	**FILL:** Concrete (north bank of river), Silty Clay (south bank of river)	1.2	0.9	N/A
RAMS	**Recent alluvial / marine muds:** Silty Clay, Clay, some organics	1.2	0.4	N=0
Qri / Qc	**Coode Island Silt:** Very soft clay and silt with some sand	0.4[4]	-9.4	N=0 to 1 s_u = 8 to 28kPa
Qi	**Jolimont Clay:** Firm to Stiff Clay	Not encountered at Charles Grimes Bridge		Su ~50kPa
Qpf	**Fisherman's Bend Silt:** Firm to stiff Clay with Sand, Sandy Clay, occasional pockets of silty sand and gravel	-9.9	-11.9	N = 0 to 16 Su = 12-49kPa
Qpg / Qm	**Moray Street Gravels**: Medium dense to dense sand and sandy gravel, generally well graded	-23.1	-24.4	N= 8 to 48
Tov	**Older Volcanics:** variably weathered	Not encountered at Charles Grimes Bridge		UCS: 1 to 90 MPa
Tew	**Werribee formation:** Very stiff to hard clay, dense sandy gravels	-26.6	-28.3	N = 5 to 39
Sud	**Melbourne formation:** Siltstone, residually to extremely weathered.	-29.5	-33.4	N/A

Notes:
(1) N – Standard Penetration Test 'N' value
(2) su = peak undrained shear strength measured by hand vane shear in U63 sample tube
(3) UCS = Uniaxial Compressive Strength
(4) interface between RAMS and Qri difficult to discern. Materials can be considered the same from an engineering point of view

Information to the west of the site is available from **Figure 1**, extracted from Neilson (1992). Figure 1 shows an indicative cross section which runs south to north along Graham St, Port Melbourne, and parallel to Citylink / Bolte Bridge, to the west of the project site. The section suggests between 10 m to 20 m of Coode Island Silt may be present, overlying up to 10 m of stiff clays of the Jolimont group, and up to 30 m of variable sequences of Older Volcanics Basalt, Moray Street Gravels, and Werribee Formation. Siltstone bedrock may be encountered from 50 m to 80 m below ground level.

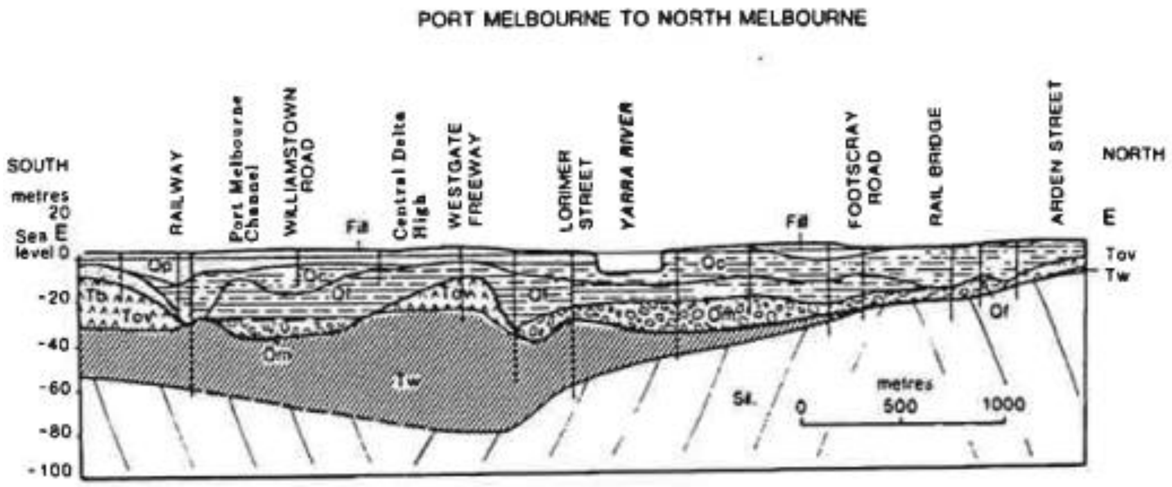


Figure 1 – indicative geological section through Graham St and Citylink (extracted from Neilson, 1992)

Implications for Development/Structure

We expect that any new foundations required to accommodate a new bridge over either the Yarra River or the West Gate Freeway would be piled, and it is likely that driven piles would be adopted, founded at least at the level of the Moray Street Gravels. Driven steel tubular piles have been used successfully to support structures at Webb Dock, and for pier piles for the Bolte Bridge. For smaller structures, concrete precast piles may be suitable. If design loads are very high, bored piles which are cased all the way to bedrock may be more appropriate. The surficial sediments of the Yarra Delta (ie river muds and Coode Island Silt) have low strength and are prone to significant consolidation and creep settlements, and shallow footings are not recommended. Elsewhere, where above-grade or elevated infrastructure is proposed, we consider that elevated structures founded on piles extending to the Moray Street gravels or deeper would be more appropriate than earth fill embankments or structures founded on shallow footings, which would be prone to extensive settlement over time.

If a tunnelled alignment beneath the West Gate Freeway is adopted, the design would need to consider the likelihood of encountering very soft, normally consolidated soils and a high water table (expected to be close to 0 mAHD). Groundwater inflows may be saline, due to proximity to the river and Port Philip Bay, and may also be contaminated, owing to the industrial nature of the site. Tunnelling would likely need to be via Tunnel Boring Machine (TBM) with earth pressure balancing or slurry to support the ground and minimise volume loss or settlement of the soft ground above. Any tunnel would also need to be permanently 'tanked' or sealed, to minimise groundwater inflows or regional drawdown of the groundwater table, which could result in regional subsidence extending towards South Melbourne or Port Melbourne in the south, or Docklands to the north.

References:

GHD (2007) Melbourne Water Melbourne Main Sewer Replacement Project Factual Report on Geological, Geotechnical and Hydrogeological Investigations (Phase 1 and 2)

Ervin, M.C., (1992) *Engineering properties of Quaternary age sediments of the Yarra Delta*, Engineering Geology of Melbourne, Balkema, Rotterdam.

Neilson, J.L., (1992) *Geology of the Yarra Delta*, Engineering Geology of Melbourne, Balkema, Rotterdam.

2 Site Ground Condition

The proposed public transport alignment crosses the West Gate Freeway (WGF) with Hartley Street at north and Winfield Automotive Service at south (Figure 1). The existing road surface level of the WGF has a level of approximately +2.0 mAHD, and must not be interrupted by the tunnel construction. Currently there is no ground information available along the proposed public transport alignment crossing the WGF, hence the geological conditions at the concerned area have been inferred from published information from the adjacent area.

At the eastern end of the site, information is available from the area around Charles Grimes bridge which has been inferred from geotechnical boreholes available from the adjacent Melbourne Main Sewer, reported by GHD in 2007. The four geotechnical boreholes and four Cone Penetrometer Tests (CPTs) indicate a consistent ground profile comprising very soft Coode Island Silt and recent river muds, overlying firm to stiff Fishermans Bend Silt and medium dense to dense Moray Street Gravel. Very dense sandy gravels and residually weathered siltstone of the Brighton Group and the Melbourne Mudstone formation respectively were also encountered below the Moray Street Gravels.

Information to the west of the site is available (Neilson 1992), which suggests Coode Island Silt may be present at a depth between 10 m to 20 m, overlying up to 10 m of stiff clays of the Jolimont group, and up to 30 m of variable sequences of Older Volcanics Basalt, Moray Street Gravels, and Werribee Formation. Siltstone bedrock may be encountered from 50 m to 80 m below ground level.

In general, the ground condition on site likely consists of a 2 m thick Fill at top, followed by a thick layer of very soft, normally consolidated Coode Island Silt and recent river muds, overlying firm to stiff Fishermans Bend Silt and medium dense to dense Moray Street Gravel. The groundwater table on site is high, expected to be close to 0 mAHD.

Although there is no information on the existing underground utilities, typical water mains, gas mains and electric and communication cables are expected at the top 2m depth below the WGF. These existing utilities must not be disturbed during the tunnel construction.

3 Tunnel Options Study

As showing in the Figure 2, in addition to the proposed public transport corridor, there are footpath and bicycle lanes at both sides of the proposed public transport corridor. The total width of the proposed cross section is approximately 16.9m. As the anticipated ground condition around the proposed tunnel alignment crossing the WGF is soft to very soft with a high groundwater level, a tunnelling method must be able to provide immediate effective support to the ground and groundwater cut-off around the tunnel crossing section. As the groundwater on site is expected to be high, resistance to buoyancy must also be considered in the tunnel design. Generally, buoyancy forces are resisted by increased dead load of the tunnel structure and/or weight of overburden above the tunnel. The minimum overburden depth of the tunnel required for buoyancy resistance would be 3m to 4m depending on the shape of the tunnel and the likely weight of the tunnel structures. Several tunneling options considering the tunnel dimension, site constraints and existing ground conditions, constructability and likely risks to the WGF and adjacent properties have been developed and discussed below.

Tunnelling Options

To tunnel underneath the live WGF, three tunnelling methods may be considered, namely the Box Jacking method, the New Austrian Tunnelling Method (NATM) and the Tunnel Boring Machine (TBM) tunnel construction method.

a) Tunnel Box Jacking

The box jacking method would first involve construction of jacking pit and receiving pit at each side of the WGF. A relatively large jacking pit can be constructed at Hartley street side where more space is available. The receiving pit can be located at existing carpark of the Winfield Automotive Service. To construct the jacking pit and receiving pit, relatively rigid earth supporting structures shall be installed to retain the ground and provide ground water cut-off, adopting such as secant concrete pile / bored pile wall.

Jacked box tunnels are often prefabricated box structures, jacked horizontally through the soil using methods to reduce surface friction; jacked tunnels are often used where the tunnel is shallow but the surface must not be disturbed, for example beneath highways /runways or railroads embankments. A purpose designed cellular tunnel shield shall be provided at its leading end of the box with thrust jacks mounted at its trailing end reacting against the jacking base. Internal equipment include face excavation and spoil handling equipment, ventilation fans and ducting, essential services and rear access for personnel.

As the tunnel box section to be jacked is over 80m long and has a relatively large cross section, significant jacking force is required. While intermediate jacks can be installed to overcome the jacking resistance due to the ground friction along the jacking box, top and bottom proprietary anti-drag systems can be installed to minimise both ground drag and friction developed on the box /ground interface during box installation.

Arching effects do not develop around a rectangular section at shallow depth. Instead, the box and shield carry the full overburden and superimposed loads on their flat roofs and transmit them into the ground below. Ground closure occurs along the side walls, hence there will be a tendency to drag the ground due to the development of skin friction on the shield and box external faces, particular at underside of the box, resulting in shearing and remoulding accompanied by a loss in soil volume which will cause the box to dive. However, the problems associated with ground drag can be largely relieved by a number of anti-drag measures developed including lubrication with bentonite slurry and the use of reinforced rubber 'drag sheets', or more recently used Ropkin's proprietary wire rope anti-drag system.

<u>Ground Strengthening and Control of Ground Disturbance</u>

Because the box/ground interface cannot be grouted until box installation has been completed there is a potential for increased time dependent settlement. This may be further increased by drag or shear effects causing remoulding of the ground with a subsequent loss in ground volume. To minimise the risk to disturbance to the WGF due to tunnelling construction in such soft ground with shallow depth of ground cover, ground strengthening measures are required to facilitate the tunnel box jacking work. Possible ground strengthen measures are discussed below.

A. Pipe-Roofing and Grouting,

Pipe roof, eg. adopting inclined 12m long 114mm Diameter steel pipes can be installed at spacing of 400mm at a stabilised tunnel face. The steel pipes shall be installed after 9m advance of the tune box jacking, such that a 3m overlapping of the pipe-roof can be maintained throughout the tunnel excavation and box jacking process. The steel pipes can also be slotted to facilitate the TAM pre-grouting around the tunnel box for groundwater cut-off and ground pre-treatment. To control excessive ground settlement in soft clay material, ground improvement work may be required.

The steel pipes may be installed by the direction drilling method, such as the steel pipes can be installed to its full length along the tunnel before commencement of tunnel excavation. Therefore a safer tunnelling face is provided, and less ground relaxation / less ground disturbance can be achieved by the direction drilling method for pipe roof installation. The pipe roof installation adopting conventional method or direction drilling shall be compared in detail at the detailed design stage, when further GI and existing utility information becomes available.

B. Control of Face Loss

Face excavation causes three-dimensional stress redistribution in, ahead of, and around the advancing face accompanied by ground relaxation, or face loss. The face loss can be controlled by buttressing the face using the purpose designed multi-cell shield. In particular, fibreglass reinforced pipes can be installed at tunnelling face together with grouting for groundwater cut-off to improve the face stability.

Figure 3 presents the scheme using box jacking method with ground strengthening by pipe-roof and face stabilisation.

C. Ground Freezing

Ground freezing method can be adopted for ground pre-treatment before commencing the tunnel excavation and box jacking. Ground freezing method can provide a safe tunnel excavation and groundwater cut-off while its mechanical properties are sufficiently increased to allow an efficient and safe tunnel excavation and support installation under the protection of the frozen soil body. Starting from one tunnel the freezing pipes are drilled surrounding the tunnel box in longitudinal direction at spacing of 1.1-1.2m. The ground is often excavated for the most part by high-powered purpose-designed roadheaders. As excavation advances, individual circuits in the freezing regime are decommissioned.

However, ground heaving is often associated with the ground freezing process, and subsequently settled during thawing of the frozen ground. Given the high groundwater table, small overburden and the likely very soft silty soils on site, significant ground heaving may occur during the ground freezing stage, and settle after thawing. Therefore, unless future project GI indicates a more preferable ground / groundwater condition, the ground freezing method is not considered a suitable ground strengthening method for the current tunnel option.

<u>General Construction Sequence using Box Jacking</u>

As discussed above, the general construction sequence is also summarised below:

1) Construct jacking pit and receiving pit - install secant pile /bore pile earth retaining wall (headwall), excavation and cast concrete base of jacking pit & receiving pit ; carry out grouting behind the constructed headwall;

2) Carry out pipe-roofing installation and pre-grouting around the tunnel box from the jacking pit side, and grouting the tunnel face;

3) Lowering the precast tunnel box section into the jacking pit and attach the jacking shield to the box structure;

4) Make opening on the secant pile / bored pile wall at the jacking pit to allow excavation;

5) Excavate 150mm from the jacking pit side. Staged partial excavation following the multi-celled box jacking shield shall be carried out; over excavation around the tunnel box structure must be prevented to minimise disturbance to the ground and subsequent ground settlements. Jacking the tunnel box after staged soil removal.

6) Carry out pre-grouting around the tunnel box position from the receiving pit side; make opening on the secant pile / bored pile wall at the receiving pit to receive the jacking shield.

7) Repeat the excavation and jacking process till specified over lapping pipe-roofing or the tunnel face stabilization works reached; carry out pipe-roofing installation work or face stabilization.

8) Continue excavation and box jacking, repeat 7) until the jacking shield of the tunnel box approaching the receiving pit.

9) Trim the opening (receiving eye) at receiving pit headwall if necessary for exact shield position;

10) Complete box jacking, remove the jacking shield;

11) Carry out cement-bentonite grouting to fill any voids around the completed tunnel box structure.

b) New Austrian Tunnelling Method (NATM) Construction

New Austrian Tunnelling Method (NATM) adopting effective pre-support measures can be used as one the tunnelling option method. Because of the ground's relatively short stand-up time and the shallow overburden involved, the full face heading is not applicable in the soft ground conditions expected on site. Thus, the top heading and bench excavation sequence, or sequential excavation method (SEM) should be adopted. Similar to the box jacking method, extensive ground improvement work may be required for the soft clay material in order to control the ground settlement.

Pre-support measures involve grouted pipe arch canopies that bridge over the unsupported excavation round. These longitudinal ground reinforcement elements are supported by the previously installed initial shotcrete lining behind the active tunnel face and the unexcavated ground ahead of the face. The grouted pipe arch canopies are used to:

- Increase stand-up time by preventing ground material from traveling into the tunnel opening causing potentially tunnel instabilities or major over-break, and subsequent excessive ground movements.

- Limit over-break

- Reduce the ground loads acting on the immediate tunnel face

- Reduce ground deflection and, consequently road settlements above.

Figure 4 presents the scheme using NATM with ground strengthening by pipe-roof and face stabilisation.

<u>Ground Strengthening and Control of Ground Disturbance</u>

The pipe arch canopy is formed by installing steel pipes of diameter typically between 300mm to 600mm at a spacing of 500 to 800mm (Figure 4). The steel pipes shall be installed from within the tunnel and at a 7-degree outwards angle. The lap length between successive pipe arches is 3m. After excavating a 9m long tunnel section the next grouted steel pipe arch in sequence is installed.

The tunnel shall be constructed following a top heading, bench and invert excavation with a shotcrete invert closure. Excavators can be used for the excavation of stabilised soils with round lengths limited to maximum 1 m. The top heading has a temporary shotcrete invert which is subsequently removed during the bench excavation. A layer of approximate 300 mm thick shotcrete lining reinforced by either welded wire fabric or steel fibres shall be installed after each round of excavation.

The tunnel excavation face can be stabilised by install fibreglass reinforced pipes together with grouting for groundwater cut-off to improve the face stability.

<u>General Construction Sequence using NATM</u>

1) Install secant pile /bore pile earth retaining wall at the proposed tunnel portal at each side of the WGF, carry out grouting behind the constructed headwall; excavation the cofferdam at each portal zone.

2) Install 12m long horizontal pipe piles at a 7-degree outwards angle around the tunnel perimeter, and glass fibre reinforced polymer (GFRP) reinforcements at the tunnelling face by drilling through the headwall and grouting.

3) Make opening on the headwall for top heading;

4) Excavate the first 750mm at the top heading and apply temporary shotcrete immediately after excavation including invert;

5) Install first steel rib around the exposed pipe piles.

6) Further excavate maximum 1000mm along the tunnel axis for top heading, and apply temporary shotcrete immediately after excavation including invert;

7) Install steel rib at a maximum spacing of 1000mm around the exposed pipe piles.

8) Repeating 6) & 7) for top heading excavation until minimum 6m length of top heading constructed; .

9) Repeat the step 4) to 8) for the excavate of the bench, and the top heading should maintain minimum 6m ahead the bench excavation;

10) Repeat the step 4) to 8) for the excavate of the invert, and the bench excavation should maintain minimum 6m ahead the invert excavation;

11) During the staged excavation stages, 12m long pipe piles shall be installed to maintain a minimum 3.5m overlapping of the successive pipe-roofing throughout the tunnel excavation; GFRP reinforcements together with grouting shall also be installed at the tunnelling face in stages such that a minimum 3m overlapping is maintained.

12) Install water proofing and construct permanent tunnel lining;

13) Void between the tunnel lining and the temporary support will be backfilled by mass concrete or sprayed plain concrete where necessary. Cement grouting may be carried out for small voids.

Again, the steel pipes may be installed by the direction drilling method rather than the conventional sequential installation method (see Pipe-Roofing and Grouting in 2.1.1).

C) Tunnel Boring Machine (TBM) Construction Method.

Tunnel Boring Machine (TBM) can also be adopted for tunnel construction. With earth pressure balancing or slurry to support the ground, the volume loss due to the tunnel boring can be controlled, hence to minimise settlement of the ground above. In particular, deep tunnel with a sufficient tunnelling length, TBM may offer a cost effective tunnelling option.

However, the proposed tunnel has a shallow depth to avoid construction of excessive length of the ramp at both ends of the tunnel. Large diameter TBM shall be necessary given the cross section required for the proposed public transport corridor and foot path. The existing WGF may experience unacceptable disruption during the TBM tunnelling with small overburden. Furthermore the total tunnel length crossing the WGF is just over 80m only. Therefore the TBM method is not recommended here considering the risk to the above live WGF associated with the TBM tunnelling at shallow depth and its uneconomical short driven length. The TBM scheme shall not be discussed further unless the tunnel length is extended.

4 SUMMARY AND RECOMMENDATION

Several tunnelling schemes are presented in detail in the section 2.0. The construction sequences, temporary supporting / pre-strengthening of the ground conditions, constructability and risks associated with each tunnelling method are discussed. The tunnelling schemes are summarised below with recommendations made to the proposed tunnel option.

Option No.	Tunnelling Method	Constructability / (Complexity)	Risk to WGF disruption	Cost effective
1	Box jacking with pipe-roofing and face stabilised with GFRP	Medium to high /(medium); obstructions encountered can be easily removed;	medium	medium
2	Box jacking with Ground Freezing	Low to medium /(high); obstructions encountered can be easily removed;	high	Medium to high
3	New Austrian Tunnelling Method (NATM) with pipe roofing & GFRP for tunnelling face stabilising	Medium to high/(medium); obstructions encountered can be easily removed;	medium	medium
4	Tunnel Boring Machine (TBM)	Low to medium / (Medium to high), obstruction encountered could be very difficult to remove;	high	high

From the summary table above, it can be seen that options 1 and 3 would provide an acceptable level of complexity in terms of constructability since they are conventional and have been widely used in many successful cases; the construction risk to disturbing ground and above WGF and utilities is also more controllable compared with other methods. Further, the options 1 and 3 may provide a relatively more cost effective tunnelling solution than other options. Therefore tunnelling method using box jacking method together with pipe-roofing and GFRP at tunnelling face (option no.1), and the New Austrian Tunnelling Method (NATM) with pipe roofing and GFRP for tunnelling face stabilizing (option no.3) are recommended for the construction of the proposed tunnel.

The following measures are recommended for consideration in next design stage:

- Carry out additional GI to verify the ground condition (by horizontal direction coring / inclined boreholes);
- Review of the extent of ground improvement base on the ground condition;
- Consider the use of interlocking pipe roof to reduce the need of ground treatment;
- Optimise the mined tunnel construction sequence in a safe and ease of excavation manner; and
- Carry out detailed tunnel space proofing and determine the ventilation area required.

a) Fishermans Bend - Ventilation and Fire Safety Requirements

The overall objectives of the fire safety strategy will follow the applicable Australian codes of practice and guidelines. Reference will also be made to guidelines and recommendations from professional institutions and internationally recognised standards.

A tunnel with a length of 85m is proposed to be built underneath the West Gate Freeway. The tunnel will be divided into two cells with each consists of a public transport corridor and a 4m width shared path for pedestrians and cyclists.

b) Ventilation

Since the tunnel length is less than 305m, mechanical emergency ventilation system will not be required (in accordance with NFPA 130). Reference to the tunnel cross section at different locations, it is considered that with the proposed tunnel width and height, the space between the trams and the tunnel soffit should be able to serve as smoke reservoirs and maintain a tenable environment for evacuation during a fire incident.

C) Means of Escape / Means of Access

The acceptance of the proposed fire safety design is based on demonstrating that the occupants can safely evacuate to an ultimate place of safety when a fire occurs. The approach is to use a time line analysis, which demonstrates that the time period required by the occupants to evacuate is less than the time available due to the development of a fire. The safety of the design during evacuation can be demonstrated by carrying out an ASET-RSET calculation. Available Safe Egress Time (ASET) represents the time available during which occupants may evacuate in tenable conditions, while Required Safe Egress Time (RSET) represents the time required in order for all occupants to evacuate to a place of relative safety. The ASET should always be greater than the RSET to assure safe evacuation.

Spreadsheet analyses and/or Computational evacuation analyses will be carried out to determine the evacuation time of the occupants to the tunnel portals, which will be based on the occupant load and the discharge capacity of the tram doors and the tunnel portals.

Computational Fluid Dynamics (CFD) analyses will be carried out to simulate the smoke stratification and ensures that the design will achieve an ASET sufficiently greater than the RSET.

Access for fire-fighting to the tunnels will be from the two portals.

d) Tunnel Fire Services Installations

Fire-fighting equipment such as portable fire extinguishers and fire hydrants will be provided in accordance with criteria specified by the authority.

Fire/smoke detection and alarm system will be provided along the tunnels in order to initiate the evacuation as soon as a fire starts. Communication systems will also be provided for effective communication between the tunnel occupants and control centre.

Emergency lighting will be provided along the tunnel. Directional exit signs will be provided in order to inform the tunnel occupants to escape in the direct to the nearest portals.

e) Fire Safety Management Plan

Emergency procedures and training plan will be developed and reviewed by tram operator, emergency services and all relevant stakeholders periodically.

Emergency procedures should outline a set of predetermined procedures for all parties to follow in the event of a fire or an emergency. Training of tram staff/operator and emergency services personnel will be required in order for them to be familiar with emergency procedures and to maintain a state of emergency preparedness.