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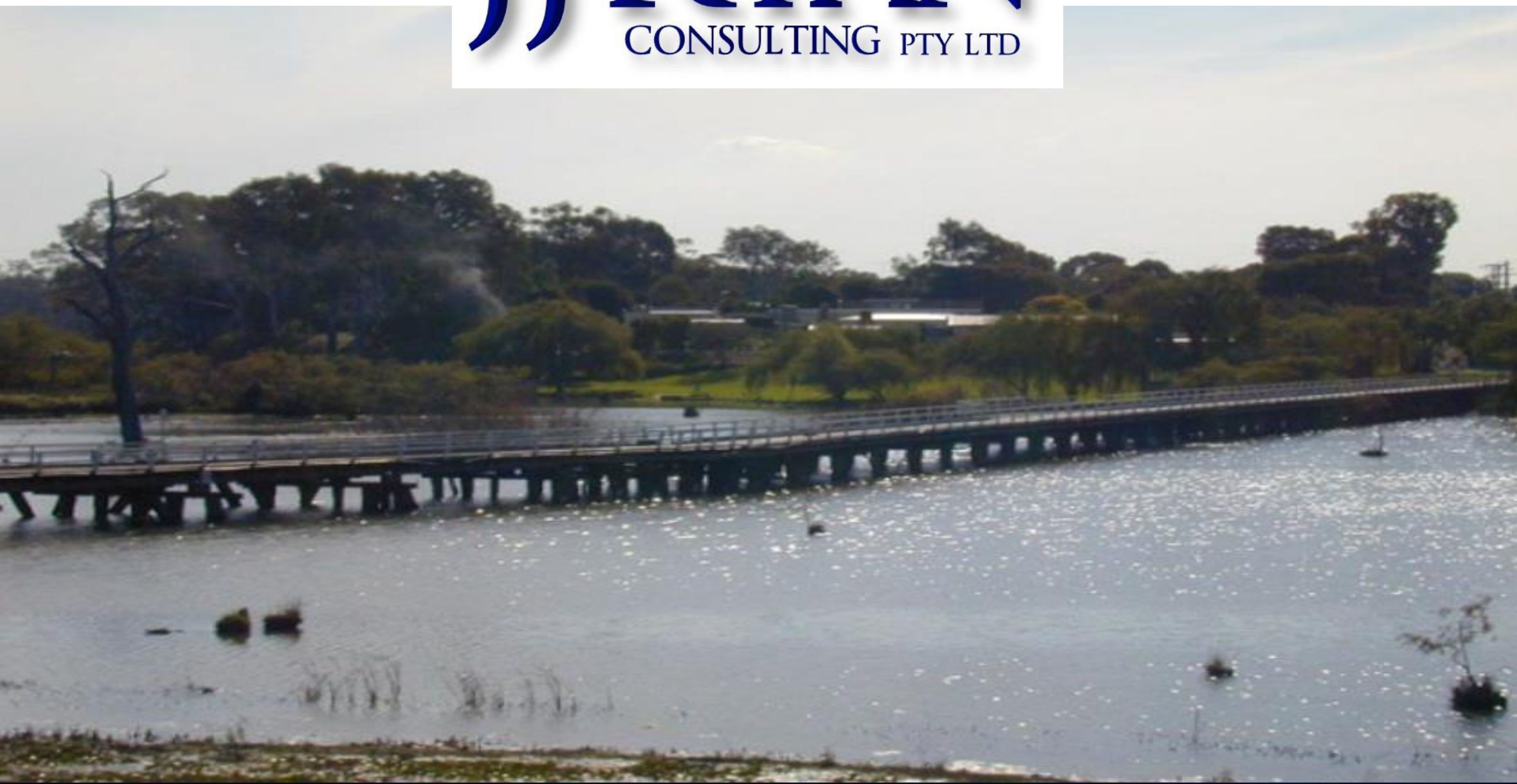

Structural Assessment Report

Kirwans Bridge

Strathbogie Shire Council

May 2023

Prepared by JJ Ryan Consulting Pty Ltd for Strathbogie Shire Council

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A	MJ-MO	15/05/2023	MKO	16/05/2023	For Review
B	MJ-MO	29/05/2023	CJ	30/05/2023	For Review

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Executive Summary

JJ Ryan Consulting (JJR) was engaged by the Strathbogie Shire Council (SSC) to undertake option investigations for the rehabilitation, replacement or other hybrid remediation of the historical Kirwans Bridge, Nagambie. This report presents site inspections of Kirwans Bridge and structural assessment of the existing condition.

The result of the structural assessment report is as follows:

Currently, 3 tonne weight limit is imposed on the bridge. To investigate the capability of the structural elements, the piles located adjacent to the bridge and have undergone more than 90% strength reduction were removed from the model. T44 and 3 tonne live loading were considered for ULS and SLS Limit State. However, some steel girders, headstocks, cross beams, and piles specified in Table 8 fail to satisfy the 3 tonne live loading assessment. Therefore, 1.5 tonne live loading was applied to the model, and the Load Rating Factor (RF) of all structural elements was more than unity, which means it's safe to apply this loading to the structure.

<u>Recommendation:</u>

As the bridge capacity has been diminished to a serviceable level, motor vehicles cannot be allowed until further investigations have been undertaken.

Contents

Tables

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1 Introduction

1.1 Project Background

JJ Ryan Consulting (JJR) was engaged by the Strathbogie Shire Council (SSC) to undertake a site inspection, condition assessment report, and feasibility report for investigation, assessment, and detailed design of Kirwans Bridge.

Figure 1 shows the location of the bridge. The coordinates are as follows:

Lat. -36.745869

Lon. 145.139649

Figure 1: Location of the project

1.2 Structural Background

Kirwans Bridge is historically, scientifically, socially, and aesthetically significant at the State level which was constructed in 1890. This Bridge is uniquely angled and has exceptionally long timber deck with occasional passing bays.

Together with Barwon Heads Bridge, they are equally the longest timber road bridge in Victoria. Kirwans Bridge retains its original 48 spans measuring 5 metres, with its original 7 main river channel spans of 10 metres, giving a deck length of approximately 308 metres. Original timber stringers were replaced in 1957 by steel joists. Its original tall timber trestle piers are largely immersed under Lake Nagambie and its aging timber deck has been narrowed for one-way traffic, with only the passing bays extending the full 6.3 metres width of the original deck. Remnants of its original squared beams and strutted corbels – one of only two remaining examples in Victoria – are still visible beside the bridge.

The superstructure is supported by timber Headstocks which are attached to the driven timber piles. The length of the timber piles is approximately from 3.1m to 13.5m above natural surface of Goulburn River. The piles are unbraced.

Kirwans Bridge has been taken under construction twice for rehabilitation work. It appears to be at the end of its service life, and a 3t load limit is currently posted.

The structural elements of the bridge are as follows:

Steel Girders

There are two steel girders per span, which is extended out to four girders per span at the overtaking bays.
The steel girders are No. 14” x 5.5” RSJ’s for the short spans and 20” x 6.5” RSJ’s for the long spans. Based on the visual inspection, the existing paint coating has failed, and corrosion has started to occur.

Timber Corbels

There are large timber blocks (185x600 mm) supporting most girders.

Timber Crossbeams

The timber crossbeams are located at approximately 550 mm spacing, and the dimensions are 200x150 millimetres.

Timber Planks

The bridge deck includes 18 longitudinal timber planks, and the dimensions of them are 180x60 millimetres. They were covered with asphalt, which is now severely damaged. The overall thickness of the deck is 70 millimetres. The details of the timber deck and handrail are shown in Figure 2.

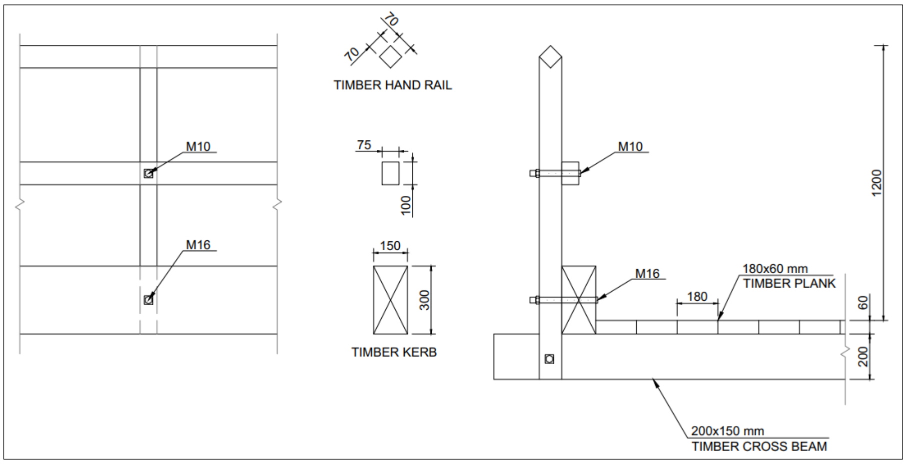

Figure 2: Details of Timber Deck and Handrail

Steel Bracing

Cross bracing at the ends of some girders is provided by angle sections.

Timber Headstock

The dimensions of the Headstocks are 275x145 millimetres, and the steel girder are bolted to them. The details are depicted in Figure 3.

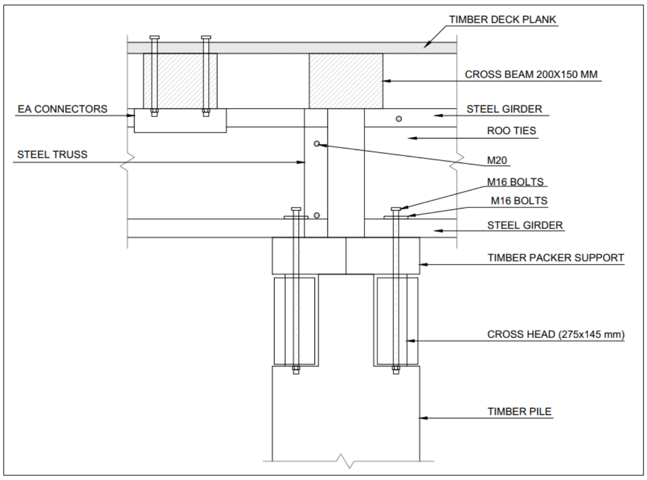

Figure 3: Headstock Connection Detail

Timber Piles

The timber piles have been largely refurbished as part of previous work. A range of different techniques were employed to rehabilitate them, including splicing new timbers using concrete collars, banding, and jackets with cementitious infill. Some of the jackets have split, including those which had strengthened with bands.

The plan and elevation views of the bridge along with the typical pier cut-section are shown in Figure 4-Figure 8.

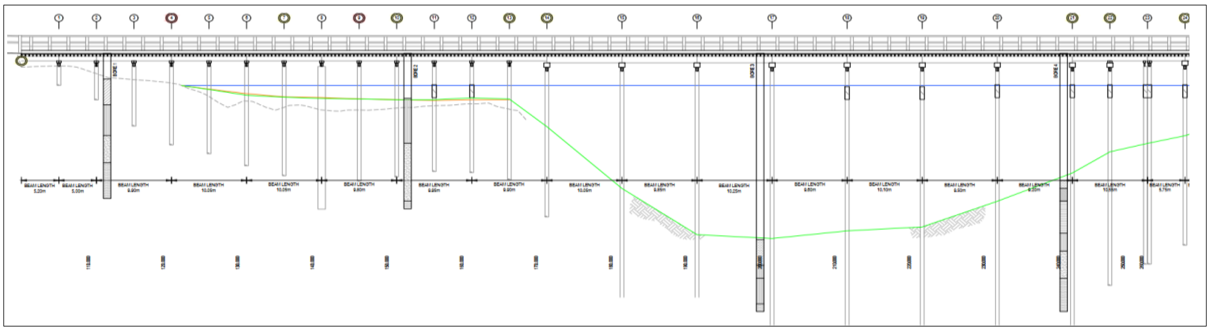

Figure 4: Bridge Longitudinal Section 1 (Source: Ref [1])

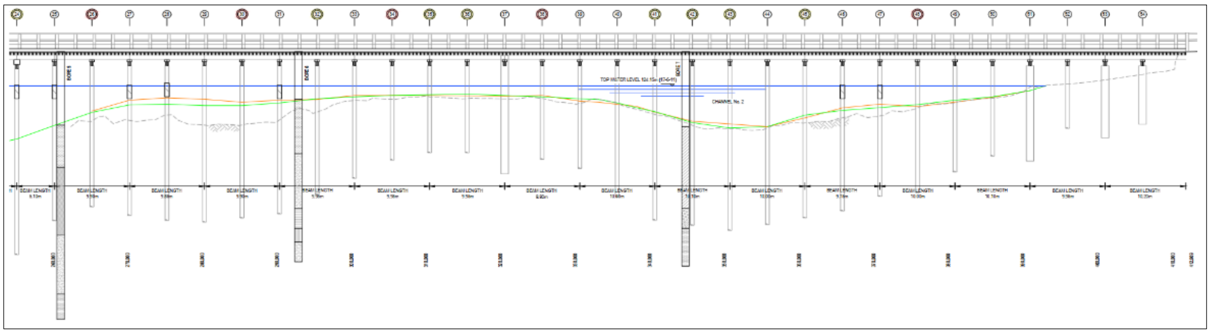

Figure 5: Bridge Longitudinal Section 2 (Source: Ref [1])

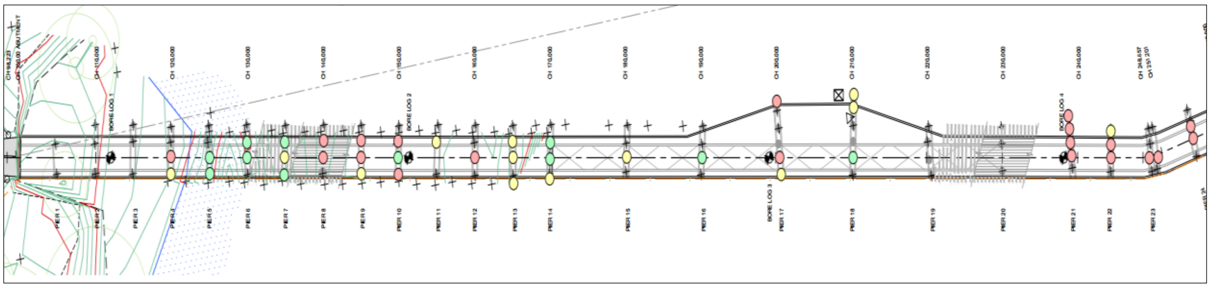

Figure 6: Bridge Plan Enlargement 1 (Source: Ref [1])

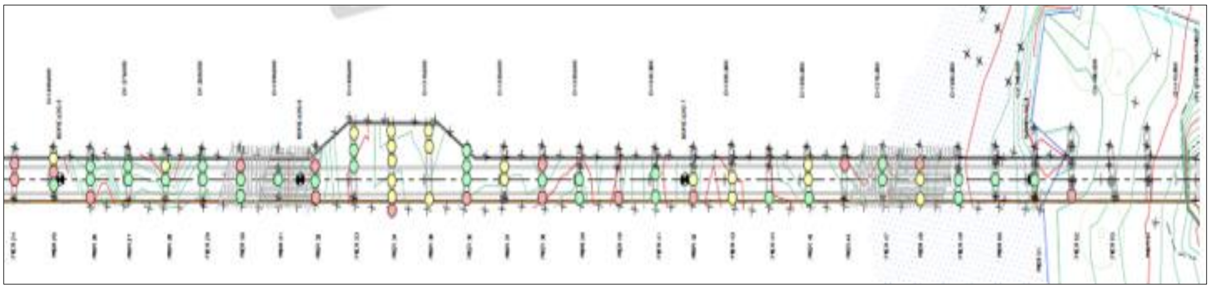

Figure 7: Bridge Plan Enlargement 2 (Source: Ref [1])

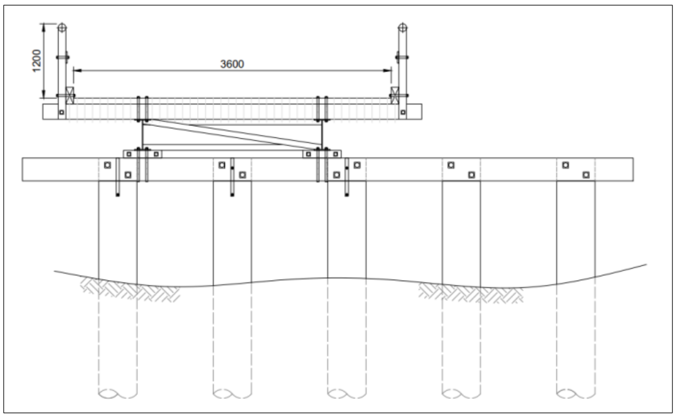

Figure 8: Pier Cut Section

1.3 Scope of Works

In this report, JJR's scope of work includes the following items:

- Site inspections of the current condition of the bridge.
- Condition assessment report.

1.4 Standards

This calculation report is prepared in accordance with the following standards:

1- AS1170 – Structural Design Actions
2- AS5100.2 – Bridge Design Loads
3- AS5100.6 – Steel and Composite Construction
4- AS5100.7 – Bridge Assessment
5- AS5100.9 – Timber

2 Site Inspection

Strathbogie Shire Council (SSC) engaged JJ Ryan Consulting (JJR) to conduct a visual inspection of the structural members. This inspection has been done in two days by the JJR's team for the superstructure and substructure of the bridge.

2.1 Bridge Parts

Superstructure

In Figure 9, the elements of the bridge superstructure are shown. See

Table 3 for a clear breakdown of the components.

Figure 9: Bridge Superstructure

Substructure

In Figure 10, the elements of the bridge substructure are shown. See

Table 3 for a clear breakdown of the components.

Figure 10: Bridge Substructure

2.2 Defects

The visual inspection reveals significant defects requiring attention.

Table 1 shows some defects in superstructure:

- Minor Surface abrasion on asphalt
- Worn asphalt with gaps, and missing bolts on timber planks.
- Timber planks have major splitting and decay.
- Major cracks on the surface of the timber kerbs and missing bolts
- Timber splitting on surface of the handrails with algae growth and rusted bolts.
- Major cracks and splitting on the timber cross beams.
- Surface rust on the steel girders and bracings.

Table 2 shows some defects in substructure:

- Minor splitting and discoloration of the timber corbels.
- Major shrinkage gaps, rot, splitting, decay, discoloration, and rusted bolts on the timber headstocks.
- Underwater inspection has not yet been done when this report was preparing, but there are major splitting, star and ring shake defects in the timber piles.
- Concrete pile jackets have minor discoloration.
- Major cracks on concrete pile jackets.

Table 1: Defects on the Superstructure Structural Elements

Superstructure Defects	
Worn asphalt with gaps, major cracks on the surface of the timber kerbs, and missing bolts	
	
Major cracks and splitting on the timber cross beams	
	

Table 1: Defects on the Superstructure Structural Elements (Continued)

Superstructure Defects	
Surface rust on the steel girders and bracings	
	

Table 2: Defects on the Substructure Structural Elements

Substructure Defects	
Major shrinkage gaps, rot, splitting, decay, discoloration, and rusted bolts on the timber headstocks	
	
Major splitting in timber piles, star and ring shake defects	
	

Table 2: Defects on the Substructure Structural Elements (Continued)

Substructure Defects	
Major cracks on concrete pile jackets	
	

3 Structural Modelling

3.1 Structural Modelling

To accurately calculate stresses and deflections in the members, a 3D structural model is created using SAP2000. Appropriate loads calculated in the following parts are applied to the model.

The Figure 11 depicts the 3D structural model of the Bridge.

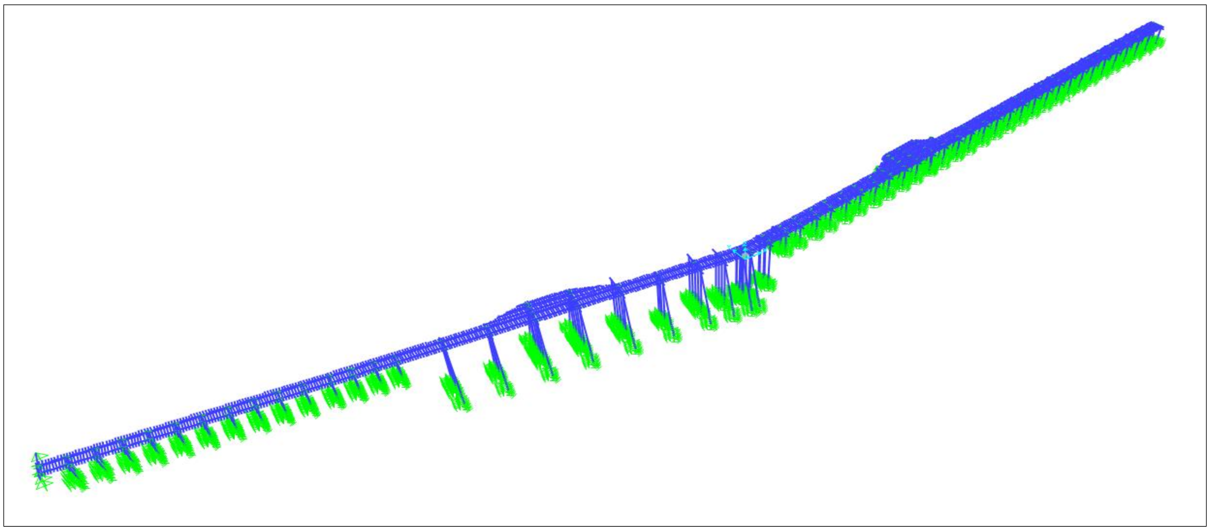

Figure 11: Bridge 3D Structural Model

3.2 Superstructure and Substructure Components

The components of the bridge are summarised in

Table 3 as follows:

Table 3: Bridge Components Summary

No. (Each)	Component		Thk/H/D *(mm)*	L/W/D *(mm)*	Remark
	Element	Material			
1721	Cross Beam	Timber	200x150	4450	Rectangular Beam
73	Cross Beam	Timber	200x150	7540	Rectangular Beam
2	Girder	Steel	356x140	10200	RSJ
12	Girder	Steel	356x140	9950	RSJ
6	Girder	Steel	356x140	10100	RSJ
6	Girder	Steel	356x140	10000	RSJ
2	Girder	Steel	356x140	9750	RSJ
10	Girder	Steel	356x140	9900	RSJ
2	Girder	Steel	356x140	10050	RSJ
2	Girder	Steel	356x140	9850	RSJ
2	Girder	Steel	356x140	5100	RSJ
2	Girder	Steel	356x140	5750	RSJ
2	Girder	Steel	356x140	10550	RSJ
2	Girder	Steel	508x165	9200	RSJ
2	Girder	Steel	508x165	9500	RSJ
4	Girder	Steel	508x165	9600	RSJ
2	Girder	Steel	508x165	10250	RSJ
2	Girder	Steel	508x165	9850	RSJ
2	Girder	Steel	508x165	10100	RSJ
2	Girder	Steel	508x165	10050	RSJ
2	Girder	Steel	356x140	9800	RSJ
2	Girder	Steel	356x140	5000	RSJ
2	Girder	Steel	356x140	5200	RSJ
14	Headstock (P1, P2, P3, P4, P5)	Timber	290x150	7400	Rectangular Beam
2	Headstock (P1, P2, P3, P4, P5)	Timber	290x150	7750	Rectangular Beam
4	Headstock (P3, P4, P5)	Timber	290x150	4750	Rectangular Beam
1	Headstock (P3, P4, P5, P6)	Timber	290x150	4400	Rectangular Beam
1	Headstock (P3, P4, P5)	Timber	290x150	4400	Rectangular Beam
1	Headstock (P1, P2, P3, P4, P5, P5A)	Timber	290x150	8000	Rectangular Beam
1	Headstock (P3, P4, P5, P5A)	Timber	290x150	4,600	Rectangular Beam
1	Headstock (P1A, P1, P2, P3, P4, P5, P5A)	Timber	290x150	9100	Rectangular Beam
1	Headstock (P1A, P1, P2, P3, P4, P5, P5A)	Timber	290x150	7900	Rectangular Beam
1	Headstock (P2, P3, P4, P5, P5A)	Timber	290x150	6100	Rectangular Beam
1	Headstock (P3, P4C, P5, P5A)	Timber	290x150	4900	Rectangular Beam
1	Headstock (P1, P2, P3, P4, P5, P5A)	Timber	290x150	7100	Rectangular Beam
1	Headstock (P1, P2, P3, P4, P5, P5A)	Timber	290x150	7200	Rectangular Beam
1	Headstock (P2A&B, P3A&B, P4A, P5A&B, P6B)	Timber	290x150	5850	Rectangular Beam
1	Headstock (P4, P5, P6, P7, P8)	Timber	290x150	5200	Rectangular Beam
1	Headstock (P2, P3, P4, P5, P6, P7, P8, P9)	Timber	290x150	8100	Rectangular Beam
1	Headstock (P3, P4, P5)	Timber	290x150	4900	Rectangular Beam

Table 3: Bridge Components Summary (Continued)

No. (Each)	Component		Thk/H/D *(mm)*	L/W/D *(mm)*	Remark
	Element	Material			
2	Headstock (P3, P4, P5)	Timber	290x150	4550	Rectangular Beam
2	Headstock (P3, P4, P5)	Timber	290x150	4700	Rectangular Beam
1	Headstock (P3, P4, P5)	Timber	290x150	4150	Rectangular Beam
3	Headstock (P1, P2, P3, P4, P5)	Timber	290x150	8150	Rectangular Beam
1	Headstock (P1, P2, P3, P4, P5, P6)	Timber	290x150	7400	Rectangular Beam
1	Headstock (P1, P2, P3, P4, P5)	Timber	290x150	7600	Rectangular Beam
2	Headstock (P1, P2, P3, P4, P5)	Timber	290x150	6900	Rectangular Beam
1	Headstock (P1, P2, P3, P4, P5)	Timber	290x150	7100	Rectangular Beam
1	Headstock (P1, P2, P3, P4, P5)	Timber	290x150	8250	Rectangular Beam
1	Headstock (P3, P4, P5)	Timber	290x150	4950	Rectangular Beam
1	Headstock (P1, P2, P3, P4, P5)	Timber	290x150	8700	Rectangular Beam
2	Headstock (P3, P4, P5)	Timber	290x150	4000	Rectangular Beam
1	Headstock (P1, P2, P3, P4, P5)	Timber	290x150	8000	Rectangular Beam
1	Headstock (P3, P4, P5)	Timber	290x150	4800	Rectangular Beam
3	Pile	Timber	240-250	6600	Circular Pile
3	Pile	Timber	310-325	6600	Circular Pile
19	Pile	Timber	330-350	6600	Circular Pile
4	Pile	Timber	330-350	17000	Circular Pile
51	Pile	Timber	355-400	6600	Circular Pile
23	Pile	Timber	355-400	17000	Circular Pile
38	Pile	Timber	405-445	6600	Circular Pile
18	Pile	Timber	405-445	17000	Circular Pile
11	Pile	Timber	450-500	6600	Circular Pile
6	Pile	Timber	450-500	17000	Circular Pile
1	Pile	Timber	510	8000	Circular Pile
10	Pile	Timber	1050	12900	Circular Pile

3.3 Assumptions

The following information were assumed when analysing the model.

- The timber unit weight is assumed to be 11 kN/m^3.
- The steel unit weight is assumed to be 78.5 kN/m^3.
- The grade of timber elements is assumed to be F17.
- The grade of steel girder is assumed to be G250.
- Deterioration percentage values are assumed based on the (Source: Ref [1]) and visual inspection done by JJR.
- The period of recovering the coating of the steel girders is assumed to be 15 years.
- The piles that are beside the bridge and are not under the deck have been removed from the model and calculations.
- The piles that have undergone more than 90% strength reduction due to the damages were removed from the model and calculations.

3.4 Corrosion Rate

Corrosion rate for steel girders is calculated as follows:

Category	=	C3		AS 2312- Table 2.1
Corrosion Rate	=	25.00	μm/y	
LR life	=	66	*years*	
Coating	=	15	*years*	AS 2312- Table 6.3
Effective LR life	=	51	*years*	
Corrosion	=	2550.00	μm	
Corrosion	=	2.55	mm	

3.5 Loading

3.5.1 Dead Loads

The dead load includes the self-weight of structural model which is automatically considered by SAP2000 and the load of kerbs, and barriers which is applied to the model.

Kerb= 0.49 *kN/m*

Handrail = 0.4 *kN*/m

3.5.2 Super Imposed Dead Load (SDL)

It includes wearing surface which has been calculated and applied to the model as superimposed dead load.

Timber Plank = 0.83 *kPa*

3.5.3 Live Loads

- **T44 Truck**

The axle weight and spacing of T44 is shown in Figure 12.

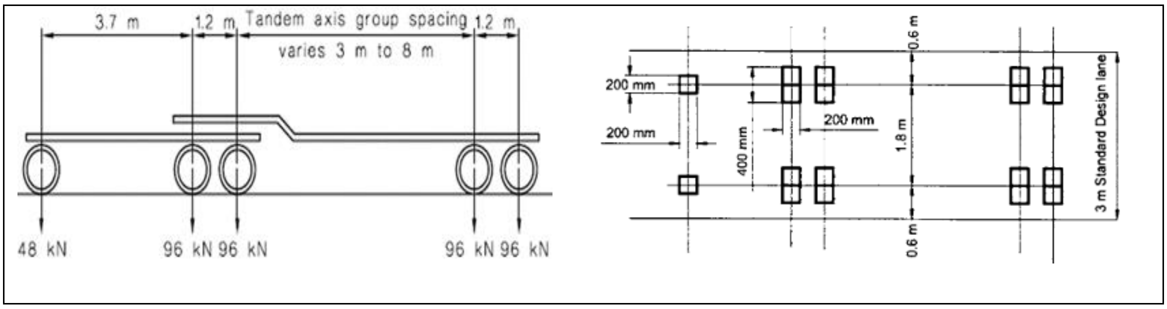

Figure 12: T44 Live Loading

3.5.4 Wind Loads

Wind Speed

Design working life:	100 years	
ARI:	1/2000	*AS 5100.2 17.2.2*
Wind region:	A5	
TC	2.5	

Regional Wind Speed

V_{2000}	=	48	*m/s*	ULS
V_{20}	=	37	*m/s*	SLS

Site Wind Speed

V_{sit}	=	$V_R M_c M_d M_Z M_S M_t$		*AS 1170.2 2.2*
M_c	=	1.0		*AS 1170.2 Table 3.3*
M_d	=	1.0		*AS 1170.2 Table 3.2*
M_Z	=	1.0	(Terrain category 1)	*AS 1170.2 Table 4.1*
M_S	=	1.0		*AS 1170.2 Table 4.2*
M_t	=	M_h		*AS 1170.2 4.4*
M_t	=	1.0		

Design Wind Speed

V_{des}-ULS	=	48.00	*m/s*	>	V_{min} =	30	*m/s*
V_{des}-SLS	=	37.00	*m/s*				

Transverse Wind Load

The windward solid area for transverse direction is listed in Table 4.

Table 4: Windward Solid Area

Member	Dimensions (mm^2)	Solid Area (m^2)
Girder	308x0.508	156.46
Plank	308x0.075	23.10
Handrail + Kerb	308x0.6	184.80
Cross Beam	0.2x0.15	16.80
Headstock	0.275x0.145	2.15
Pile	0.46x3	74.52
	Sum	**457.84**

The amount of wind load in transverse direction on the bridge is calculated as follows:

A_t	=	457.84	m^2	Total Area
C_d	=	1.3		*AS5100.2 Figure 17.3.3*
$W_{t\ (ULS)}$	=	$0.0006V_u^2A_tC_d$		
$W_{t\ (ULS)}$	=	822.79	*KN*	
$W_{t\ (SLS)}$	=	$0.0006V_s^2A_tC_d$		
$W_{t\ (SLS)}$	=	488.89	*KN*	

Longitudinal Wind Load

A_t	=	3.23	m^2
C_d	=	1.3	
$W_{t\ (ULS)}$	=	$0.0006V_u^2A_tC_d$	
$W_{t\ (ULS)}$	=	5.81	*KN*
$W_{t\ (SLS)}$	=	$0.0006V_s^2A_tC_d$	
$W_{t\ (SLS)}$	=	3.45	*KN*

Vertical Wind Load

A_p	=	1373.68	m^2
C_L	=	0.75	
$W_{t\,(ULS)}$	=	$0.0006V_u^2A_pC_L$	
$W_{t\,(ULS)}$	=	1424.23	KN
$W_{t\,(SLS)}$	=	$0.0006V_s^2A_pC_L$	
$W_{t\,(SLS)}$	=	846.26	KN

3.5.5 Earthquake Loads

BRIDGE DESIGN CATEGORY		BEDC-2		AS5100.2 15.4.1&15.4.3
ANNUAL PROBABILITY - P		1/500		AS5100 Table 15.6
K_p	=	1.00		AS1170.4 Table 3.1
Z	=	0.09		AS1170.4 Figure 3.2(F)
K_pZ	=	0.09		
$(K_pZ)_{min}$	=	0.08		AS1170.4 Table 3.3
$C_h(T_f)$	=	0.45		AS1170.4 Table 6.4
$C(T_f)=K_pZ\,C_h(T_f)$	=	0.04		AS5100.2 15.9.2
μ	=	1.00		
$C_d(T_f)=C(T_f)/\mu$	=	0.04		AS5100.2 15.9.2
$W_t=W_{Dead}+W_{SDL}$	=	8618.31	KN	AS1170.4 6.2.2
$F_F=C_d(T_f)xW_t$	=	349.0	KN	AS5100.2 15.10.1

3.5.6 Braking Force

For single standard design lane:

F_{BS}	=	$0.45W_{BS}$	200 KN < F_{BS} < 720 KN
F_{BS}	=	200	KN

4 Analysis and Controls

4.1 Load Factors

A summary of load factors used for the assessment of the structure, DLA and ALF are listed in Table 5 as below:

Table 5: Permanent and Live Load Factors, DLA, and ALF Values

Factor	Material / Vehicle	Value		Reference
	Adjacent Lane Factor	ULS	SLS	
γ_g	Timber Dead Load	1.4	1.0	AS 5100.7 Table 12.2 (A) and Table 12.1 AS 5100.2 Table 6.2 (SLS)
γ_g	Steel Dead Load	1.1	1.0	
γ_{gs}	Superimposed Dead Load	2.0	1.0	
γ_Q	Live Load	2.0	1.0	AS 5100.7 12.2
DLA	Dynamic Load Allowance	0.4	0.4	AS 5100.7 11.3.6
ALF	One Lane	1.0	1.0	AS 5100.2 7.6

4.1.1 Calculating Load Rating Factor

Load Rating Factor (RF) for each structural element in each failure mode is calculated using the relevant element capacity and action effect according to the following formula (refer AS 5100.7 14.1):

$$RF = \frac{\text{Factored Capacity - Factored Effects of all Actions except Traffic}}{\text{Factored Effect of Traffic Action}}$$

$$RF = \frac{\phi R_u - (\gamma_g S_g + \gamma_{gs} S_{gs} + S_p + S_s + S_t)}{\gamma_Q\,(1+\alpha)\,S_Q}$$

R_u:	Capacity	S_s:	Shrinkage & creep load effec	γ_g:	Dead load LF
S_g:	Dead load effect	S_t:	Temperature load effect	γ_{gs}:	SDL LF
S_{gs}:	SDL effect	S_Q:	Traffic load effect	γ_Q:	Traffic LF
S_p:	Prestressing load effect				

4.2 Load Rating of Elements

4.2.1 Action Effects

The maximum action effects of timber planks, girders, headstocks, and piles is indicated in the Table 6 as below.

Table 6: Summary of the Action Effects

Element	Action Effect (Unit)	Dead Load	Super-Imposed Dead Load	BARRIER	T44	3 tones	1.5 tones
Steel Girder 356x140mm-Short Spans	Bending Moment(*kN.m*)	10.55	7.77	3.14	173.00	27.18	11.81
	Shear (*kN*)	7.38	5.46	2.20	136.52	17.54	7.51
Steel Girder 356x140mm-Long Spans	Bending Moment(*kN.m*)	44.27	27.15	8.30	607.40	21.39	9.32
	Shear (*kN*)	15.44	10.20	6.44	205.78	22.63	9.82
Steel Girder 508x165mm	Bending Moment(*kN.m*)	38.60	26.85	14.85	610.00	82.66	35.40
	Shear (*kN*)	16.80	11.73	7.17	250.75	28.63	12.25
Timber Cross Beams 200x150mm (L 4450)	Bending Moment(*kN.m*)	1.51	1.06	0.94	32.22	5.00	2.18
	Shear (*kN*)	1.27	0.99	0.56	122.24	19.76	8.60
Timber Cross Beams 200x150mm (L 7540)	Bending Moment(*kN.m*)	0.91	0.67	0.72	60.02	12.24	2.55
	Shear (*kN*)	3.69	2.77	0.89	116.85	18.75	6.91
Headstock(3Pile-L)	Bending Moment(*kN.m*)	5.39	3.40	1.38	45.81	4.35	1.76
	Shear (*kN*)	20.30	12.34	4.99	189.86	16.25	6.57
Headstock(3Pile-S)	Bending Moment(*kN.m*)	4.22	3.25	1.09	47.22	6.70	2.92
	Shear (*kN*)	12.83	9.00	4.54	175.70	17.03	7.19
Headstock(4Pile-L)	Bending Moment(*kN.m*)	5.84	2.74	1.11	40.20	4.30	1.82
	Shear (*kN*)	15.54	9.80	3.97	192.73	18.24	7.55
Headstock(5Pile-L)	Bending Moment(*kN.m*)	2.60	2.15	0.87	40.00	4.32	1.82
	Shear (*kN*)	9.25	6.76	2.74	134.39	13.87	5.82

Table 6: Summary of the Action Effects (Continued)

Element	Action Effect (Unit)	Dead Load	Super-Imposed Dead Load	BARRIER	T44	3 tones	1.5 tones
Headstock(5Pile-S)	Bending Moment(*kN.m*)	2.76	2.35	2.10	40.62	4.12	1.71
	Shear (*kN*)	12.79	9.70	10.26	191.74	20.20	8.54
Headstock(6Pile-L)	Bending Moment(*kN.m*)	6.26	3.62	2.58	48.24	4.58	1.89
	Shear (*kN*)	26.00	15.17	9.71	205.25	18.40	7.49
Pile(S)-(240-250)mm	Bending Moment(*kN.m*)	0.27	0.30	0.12	5.80	0.41	0.23
	Shear (*kN*)	0.11	0.11	0.05	2.18	0.21	0.08
	Axial-Compression(*kN*)	16.63	7.50	3.04	151.52	15.00	6.26
Pile(S)-(310-325)mm	Bending Moment(*kN.m*)	0.72	0.67	0.27	13.07	1.18	0.49
	Shear (*kN*)	0.13	0.24	0.10	4.57	0.42	0.17
	Axial-Compression(*kN*)	20.64	7.93	3.20	156.80	15.50	6.53
Pile(S)-(330-350)mm	Bending Moment(*kN.m*)	2.87	1.05	0.47	16.34	2.58	0.89
	Shear (*kN*)	1.02	0.41	0.16	5.80	0.86	0.30
	Axial-Compression(*kN*)	26.62	9.72	7.16	162.27	18.89	7.11
Pile(L)-(330-350)mm	Bending Moment(*kN.m*)	7.50	1.06	0.42	7.00	0.60	0.56
	Shear (*kN*)	3.65	0.48	0.34	1.50	0.51	0.26
	Axial-Compression(*kN*)	49.83	7.45	5.27	51.51	7.35	3.11
Pile(S)-(355-400)mm	Bending Moment(*kN.m*)	2.70	1.77	0.80	21.70	2.85	1.89
	Shear (*kN*)	0.87	0.58	0.27	7.30	0.94	0.62
	Axial-Compression(*kN*)	30.55	9.60	8.09	172.72	20.19	7.99
Pile(L)-(355-400)mm	Bending Moment(*kN.m*)	8.10	1.30	0.35	13.70	2.26	0.71
	Shear (*kN*)	4.52	0.15	0.01	3.34	0.58	0.56
	Axial-Compression(*kN*)	60.00	12.57	4.94	302.70	22.07	3.11
Pile(S)-(405-445)mm	Bending Moment(*kN.m*)	4.05	1.40	1.54	25.06	3.72	0.90
	Shear (*kN*)	4.55	2.14	1.75	33.70	5.83	2.48
	Axial-Compression(*kN*)	29.01	8.54	6.27	185.95	18.84	7.01
Pile(L)-(405-445)mm	Bending Moment(*kN.m*)	8.74	4.74	0.76	20.68	3.25	1.31
	Shear (*kN*)	5.64	1.34	0.13	3.80	0.52	0.26
	Axial-Compression(*kN*)	73.12	16.50	7.98	332.03	23.63	7.10
Pile(S)-(450-500)mm	Bending Moment(*kN.m*)	7.97	4.75	0.79	27.81	2.70	4.80
	Shear (*kN*)	0.80	1.35	0.26	8.50	0.77	1.40
	Axial-Compression(*kN*)	65.07	12.55	4.17	179.63	16.56	10.22

Table 6: Summary of the Action Effects (Continued)

Element	Action Effect (Unit)	Dead Load	Super-Imposed Dead Load	BARRIER	T44	3 tones	1.5 tones
Pile(L)-(450-500) mm	Bending Moment(*kN.m*)	10.97	1.37	1.09	14.20	1.83	0.77
	Shear (*kN*)	6.77	0.37	0.27	4.16	0.54	0.08
	Axial-Compression(*kN*)	81.77	12.00	5.47	177.48	13.56	5.48
Pile(L)-(510) mm	Bending Moment(*kN.m*)	3.74	2.17	0.87	28.79	3.32	2.26
	Shear (*kN*)	1.00	0.50	0.20	4.80	0.65	0.41
	Axial-Compression(*kN*)	55.24	8.20	3.31	143.36	11.85	6.80
Pile(S)-(1050) mm	Bending Moment(*kN.m*)	2.49	2.46	0.99	35.27	3.27	1.37
	Shear (*kN*)	0.58	0.57	0.23	8.33	0.77	0.32
	Axial-Compression(*kN*)	57.75	8.62	3.48	144.70	15.61	6.61

Summary of the component capacities are indicated in Table 7 as below. Refer to the Attachment A and B for details.

Table 7: Summary of Element Capacities

Element	Failure Mode (Unit)	Ultimate Capacity (R_u)	Remark on Ultimate Capacity	Capacity Factor (ϕ)	Capacity Factor Reference	(ϕR_U)
Steel Girder 356x140mm-Short Spans	Bending Moment(*kN.m*)	200.16	See Attachment A	0.90	AS 5100.6 Table 3.2	180.15
	Shear (*kN*)	300.63		0.90		270.57
Steel Girder 356x140mm-Long Spans	Bending Moment(*kN.m*)	190.04		0.90		171.04
	Shear (*kN*)	300.63		0.90		270.57
Steel Girder 508x165mm	Bending Moment(*kN.m*)	467.36		0.90		420.62
	Shear (*kN*)	627.96		0.90		565.17
Timber Cross Beams 200x150mm (L 4450)	Bending Moment(*kN.m*)	23.22		0.75	AS 5100.9 Table 3.2	17.41
	Shear (*kN*)	53.07		0.75		39.80
Timber Cross Beams 200x150mm (L 7540)	Bending Moment(*kN.m*)	23.22		0.75		17.41
	Shear (*kN*)	53.07		0.75		39.80
Headstock(3Pile-L)	Bending Moment(*kN.m*)	56.58	See Attachment B	0.75	AS 5100.9 Table 3.2	42.43
	Shear (*kN*)	70.54		0.75		52.91
Headstock(3Pile-S)	Bending Moment(*kN.m*)	56.58		0.75		42.43
	Shear (*kN*)	70.54		0.75		52.91
Headstock(4Pile-L)	Bending Moment(*kN.m*)	56.58		0.75		42.43
	Shear (*kN*)	70.54		0.75		52.91

Table 7: Summary of Element Capacities (Continued)

Element	Failure Mode (Unit)	Ultimate Capacity (Ru)	Remark on Ultimate Capacity	Capacity Factor (ϕ)	Capacity Factor Reference	(ϕRU)
Headstock(5Pile-L)	Bending Moment(*kN.m*)	56.58	See Attachment B	0.75	AS 5100.9 Table 3.2	42.43
	Shear (*kN*)	70.54		0.75		52.91
Headstock(5Pile-S)	Bending Moment(*kN.m*)	56.58		0.75		42.43
	Shear (*kN*)	70.54		0.75		52.91
Headstock(6Pile-L)	Bending Moment(*kN.m*)	56.58		0.75		42.43
	Shear (*kN*)	70.54		0.75		52.91
Pile(S)-(240-250)mm	Bending Moment(*kN.m*)	37.25		0.75		27.94
	Shear (*kN*)	69.50		0.75		52.12
	Axial-Compression(*kN*)	544.70		0.75		408.53
Pile(S)-(310-325)mm	Bending Moment(*kN.m*)	52.78		0.75		39.58
	Shear (*kN*)	76.59		0.75		57.44
	Axial-Compression(*kN*)	828.57		0.75		621.42
Pile(S)-(330-350)mm	Bending Moment(*kN.m*)	66.37		0.75		49.77
	Shear (*kN*)	89.23		0.75		66.92
	Axial-Compression(*kN*)	1264.10		0.75		948.07
Pile(L)-(330-350)mm	Bending Moment(*kN.m*)	126.96		0.75		95.22
	Shear (*kN*)	173.25		0.75		129.94
	Axial-Compression(*kN*)	384.36		0.75		288.27
Pile(S)-(355-400)mm	Bending Moment(*kN.m*)	44.52		0.75		33.39
	Shear (*kN*)	54.27		0.75		40.71
	Axial-Compression(*kN*)	647.04		0.75		485.28
Pile(L)-(355-400)mm	Bending Moment(*kN.m*)	44.52		0.75		33.39
	Shear (*kN*)	54.27		0.75		40.71
	Axial-Compression(*kN*)	647.04		0.75		485.28
Pile(S)-(405-445)mm	Bending Moment(*kN.m*)	125.10		0.75		93.82
	Shear (*kN*)	136.16		0.75		102.12
	Axial-Compression(*kN*)	1759.38		0.75		1319.54
Pile(L)-(405-445)mm	Bending Moment(*kN.m*)	180.68		0.75		135.51
	Shear (*kN*)	189.88		0.75		142.41
	Axial-Compression(*kN*)	249.42		0.75		187.07

Table 7: Summary of Element Capacities (Continued)

Element	Failure Mode (Unit)	Ultimate Capacity (Ru)	Remark on Ultimate Capacity	Capacity Factor (ϕ)	Capacity Factor Reference	(ϕRU)
Pile(S)-(450-500)mm	Bending Moment(*kN.m*)	164.35	See Attachment B	0.75	AS 5100.9 Table 3.2	123.26
	Shear (*kN*)	163.33		0.75		122.50
	Axial-Compression(*kN*)	2228.75		0.75		1671.56
Pile(L)-(450-500)mm	Bending Moment(*kN.m*)	180.79		0.75		135.59
	Shear (*kN*)	179.66		0.75		134.75
	Axial-Compression(*kN*)	263.91		0.75		197.93
Pile(L)-(510)mm	Bending Moment(*kN.m*)	111.99		0.75		83.99
	Shear (*kN*)	100.38		0.75		75.29
	Axial-Compression(*kN*)	181.25		0.75		135.94
Pile(S)-(1050)mm	Bending Moment(*kN.m*)	3127.45		0.75		2345.59
	Shear (*kN*)	1361.61		0.75		1021.21
	Axial-Compression(*kN*)	19289.51		0.75		14467.14

4.2.2 Calculating Load Rating Factor

Load rating factor of the timber planks, girders, headstocks, and piles is indicated in the Table 8.

Table 8: Element's RF

Element	Failure Mode (Unit)	T44	3 tones	1.5 tones	Status (T44)	Status (3t)	Status (1.5t)
Steel Girder 356x140mm-Short Spans	Bending Moment(*kN.m*)	0.31	1.97	4.52	NOT OK	OK	OK
	Shear (*kN*)	0.65	5.07	11.85	NOT OK	OK	OK
Steel Girder 356x140mm-Long Spans	Bending Moment(*kN.m*)	0.04	0.98	2.26	NOT OK	NOT OK	OK
	Shear (*kN*)	0.39	3.57	8.22	NOT OK	OK	OK
Steel Girder 508x165mm	Bending Moment(*kN.m*)	0.18	1.33	3.11	NOT OK	OK	OK
	Shear (*kN*)	0.73	6.43	15.03	NOT OK	OK	OK
Timber Cross Beams 200x150mm (L 4450)	Bending Moment(*kN.m*)	0.13	0.85	1.94	NOT OK	NOT OK	OK
	Shear (*kN*)	0.10	0.64	1.46	NOT OK	NOT OK	OK
Timber Cross Beams 200x150mm (L 7540)	Bending Moment(*kN.m*)	0.08	0.40	1.93	NOT OK	NOT OK	OK
	Shear (*kN*)	0.09	0.53	1.44	NOT OK	NOT OK	OK
Headstock(3Pile-L)	Bending Moment(*kN.m*)	0.20	5.63	13.96	NOT OK	OK	OK
	Shear (*kN*)	N/A	1.00	2.48	NOT OK	NOT OK	OK
Headstock(3Pile-S)	Bending Moment(*kN.m*)	0.22	3.78	8.68	NOT OK	OK	OK
	Shear (*kN*)	0.02	1.33	3.16	NOT OK	NOT OK	OK
Headstock(4Pile-L)	Bending Moment(*kN.m*)	0.24	5.79	13.71	NOT OK	OK	OK
	Shear (*kN*)	0.01	1.15	2.78	NOT OK	NOT OK	OK

Table 8: Element's RF (Continued)

Element	Failure Mode (Unit)	T44	3 tones	1.5 tones	Status (T44)	Status (3t)	Status (1.5t)
Headstock(5Pile-L)	Bending Moment(*kN.m*)	0.30	6.26	14.90	NOT OK	OK	OK
	Shear (*kN*)	0.06	1.94	4.63	NOT OK	OK	OK
Headstock(5Pile-S)	Bending Moment(*kN.m*)	0.27	6.36	15.32	NOT OK	OK	OK
	Shear (*kN*)	0.00	0.96	2.27	NOT OK	NOT OK	OK
Headstock(6Pile-L)	Bending Moment(*kN.m*)	0.17	5.09	12.35	NOT OK	OK	OK
	Shear (*kN*)	N/A	0.49	1.22	NOT OK	NOT OK	OK
Pile(S)-(240-250)mm	Bending Moment(*kN.m*)	1.65	23.44	41.96	OK	OK	OK
	Shear (*kN*)	8.47	87.97	219.73	OK	OK	OK
	Axial-Compression(*kN*)	0.86	8.85	20.90	NOT OK	OK	OK
Pile(S)-(310-325)mm	Bending Moment(*kN.m*)	1.01	11.24	26.75	NOT OK	OK	OK
	Shear (*kN*)	4.43	48.22	116.26	OK	OK	OK
	Axial-Compression(*kN*)	1.30	13.35	31.28	NOT OK	OK	OK
Pile(S)-(330-350)mm	Bending Moment(*kN.m*)	0.99	6.09	17.29	NOT OK	OK	OK
	Shear (*kN*)	4.03	26.91	75.97	OK	OK	OK
	Axial-Compression(*kN*)	1.95	16.85	44.25	OK	OK	OK
Pile(L)-(330-350)mm	Bending Moment(*kN.m*)	4.29	48.82	52.77	OK	OK	OK
	Shear (*kN*)	29.79	86.41	170.81	OK	OK	OK
	Axial-Compression(*kN*)	1.49	9.53	22.55	OK	OK	OK
Pile(S)-(355-400)mm	Bending Moment(*kN.m*)	0.45	3.13	4.71	NOT OK	OK	OK
	Shear (*kN*)	1.89	14.42	21.82	OK	OK	OK
	Axial-Compression(*kN*)	0.86	7.29	18.42	NOT OK	OK	OK
Pile(L)-(355-400)mm	Bending Moment(*kN.m*)	0.52	3.00	9.48	NOT OK	OK	OK
	Shear (*kN*)	3.72	20.97	21.92	OK	OK	OK
	Axial-Compression(*kN*)	0.43	5.97	42.43	NOT OK	OK	OK
Pile(S)-(405-445)mm	Bending Moment(*kN.m*)	1.24	7.99	33.01	OK	OK	OK
	Shear (*kN*)	1.00	5.45	12.83	NOT OK	OK	OK
	Axial-Compression(*kN*)	2.40	23.75	63.83	OK	OK	OK
Pile(L)-(405-445)mm	Bending Moment(*kN.m*)	2.04	12.39	30.78	OK	OK	OK
	Shear (*kN*)	12.73	90.42	178.10	OK	OK	OK
	Axial-Compression(*kN*)	0.05	0.61	2.04	NOT OK	OK	OK
Pile(S)-(450-500)mm	Bending Moment(*kN.m*)	1.47	13.43	7.55	OK	OK	OK
	Shear (*kN*)	5.02	54.88	30.29	OK	OK	OK
	Axial-Compression(*kN*)	3.09	33.42	54.16	OK	OK	OK

Table 8: Element's RF (Continued)

Element	Failure Mode (Unit)	T44	3 tones	1.5 tones	Status (T44)	Status (3t)	Status (1.5t)
Pile(L)-(450-500)mm	Bending Moment(*kN.m*)	2.98	22.63	54.14	OK	OK	OK
	Shear (*kN*)	10.90	82.11	547.41	OK	OK	OK
	Axial-Compression(*kN*)	0.09	1.36	3.38	OK	OK	OK
Pile(L)-(510)mm	Bending Moment(*kN.m*)	0.92	7.87	11.57	NOT OK	OK	OK
	Shear (*kN*)	5.47	39.89	62.64	OK	OK	OK
	Axial-Compression(*kN*)	0.01	1.13	1.97	NOT OK	OK	OK
Pile(S)-(1050)mm	Bending Moment(*kN.m*)	23.65	255.11	611.15	OK	OK	OK
	Shear (*kN*)	43.69	472.60	1123.17	OK	OK	OK
	Axial-Compression(*kN*)	35.45	328.64	775.87	OK	OK	OK

Note:
N/A indicates the negative load rating factor.

4.3 Deflection Control

The assessment of the maximum deflection of the girders in serviceability limit state for the vehicle (1.5 tonne) is summarised in Table 9, and it is shown in Figure 13.

Table 9: Girder Deflection Control

Component	Length *(mm)*	Δall = Length/600 *(mm)*	Max. ΔLive *(mm)*	Status
Span 18	10000	16.67	8.79	OK

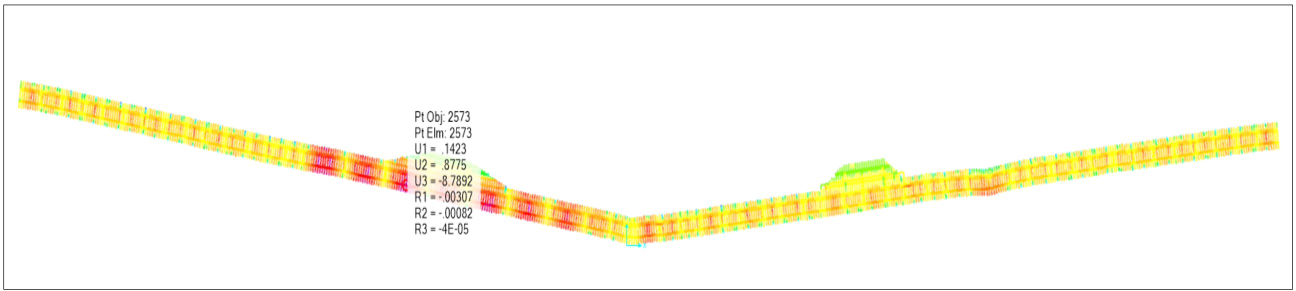

Figure 13: Bridge Deck Deflection

5 Discussion

5.1 Condition Assessment Report

The following steps were taken to assess the structure:

- Visual inspection and provided information by Strathbogie Shire Council were used to generate a three-dimensional model of the bridge in SAP2000.
- Using AS5100.2, AS5100.6, and AS5100.9, the mechanical properties and appropriate loading were applied to the structural elements.
- ULS and SLS load combinations were generated.
- Appropriate live loading, including T44, 3 tonne, and 1.5 tonne are considered to investigate the structural capacity of the bridge.
- Using AS5100.7, structural assessment for the bridge components under mentioned live loadings were investigated.

The result of the structural assessment detailed in the attachments is as follows:

Currently, 3 tonne weight limit is imposed on the bridge. To investigate the capability of the structural elements, the piles located adjacent to the bridge and have undergone more than 90% strength reduction were removed from the model. T44 and 3 tonne live loading were considered for ULS and SLS Limit State. However, some steel girders, headstocks, cross beams, and piles specified in Table 8 fail to satisfy the 3 tonne live loading assessment. Therefore, 1.5 tonne live loading was applied to the model, and the Load Rating Factor (RF) of all structural elements was more than unity, which means it's safe to apply this loading to the structure.

6 Conclusion

JJ Ryan Consulting (JJR) was engaged by the Strathbogie Shire Council to undertake option investigations for the rehabilitation, replacement or other hybrid remediation of the historical Kirwans Bridge, Nagambie. This report presents site inspections of Kirwans Bridge and structural assessment of the existing condition.

Site inspection was carried out in two days by JJR's team to investigate the structural defects of the bridge elements. The results of this inspection are as follows:

- Minor Surface abrasion on asphalt
- Worn asphalt with gaps, and missing bolts on timber planks.
- Timber planks have major splitting and decay.
- Major cracks on the surface of the timber kerbs and missing bolts
- Timber splitting on surface of the handrails with algae growth and rusted bolts.
- Major cracks and splitting on the timber cross beams.
- Surface rust on the steel girders and bracings.
- Minor splitting and discoloration of the timber corbels.
- Major shrinkage gaps, rot, splitting, decay, discoloration, and rusted bolts on the timber headstocks.
- Underwater inspection has not yet been done when this report was preparing, but there are major splitting, star and ring shake defects in the timber piles.
- Concrete pile jackets have minor discoloration.
- Major cracks on concrete pile jackets.

The result of the structural assessment report is as follows:

Currently, 3 tonne weight limit is imposed on the bridge. To investigate the capability of the structural elements, the piles located adjacent to the bridge and have undergone more than 90% strength reduction were removed from the model. T44 and 3 tonne live loading were considered for ULS and SLS Limit State. However, some steel girders, headstocks, cross beams, and piles specified in Table 8 fail to satisfy the 3 tonne live loading assessment. Therefore, 1.5 tonne live loading was applied to the model, and the Load Rating Factor (RF) of all structural elements was more than unity, which means it's safe to apply this loading to the structure.

<u>Recommendation:</u>

As the bridge capacity has been diminished to a serviceable level, motor vehicles cannot be allowed until further investigations have been undertaken.

ATTACHMENT A: CAPACITY CALCULATION OF THE SUPERSTRUCTURE

A1- Capacity Calculation of Timber Cross Beam- Rectangular 200x150mm - (L 4450):

b	=	200	*mm*
d	=	150	*mm*
A	=	30000	*mm²*
Z	=	750000	*mm³*

F17 Grade *AS 5100.8 Table D4*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
E	=	14000	*MPa*

A1-1-Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	4450	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	5.00	$S_b \le 10$	
K_{12}	=	1.00		
M_d	=	$K_1\ K_4\ K_6\ K_{11}\ K_{12}\ f'_b\ Z$		*AS 5100.9 6.3.1*
M_d	=	25.80	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	17.41	*KN.m*	10% capacity loss
M*	=	9.91	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

A1-2-Shear Force:

V_d	=	$K_1\ K_4\ K_6\ f'_s\ A_s$		*AS 5100.9 6.3.6*
V_d	=	58.97	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	39.80	*KN*	10% capacity loss
V*	=	21.75	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

A2- Capacity Calculation of Timber Cross Beam- Rectangular 200x150mm - (L 7540):

Notes:

- The grade of timber is assumed to be F17 and F22.

b	=	200	*mm*
d	=	150	*mm*
A	=	30000	*mm^2*
Z	=	750000	*mm^3*

F17 Grade *AS 5100.8 Table D4*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
E	=	14000	*MPa*

A2-1-Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	7540	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	6.51	*$S_b \leq 10$*	
K_{12}	=	1.00		
M_d	=	$K_1 K_4 K_6 K_{11} K_{12} f'_b Z$		*AS 5100.9 6.3.1*
M_d	=	25.80	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	17.41	*KN.m*	10% capacity loss
M*	=	8.73	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

A2-2-Shear Force:

V_d	=	$K_1 K_4 K_6 f'_s A_s$		*AS 5100.9 6.3.6*
V_d	=	58.97	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	39.80	*KN*	10% capacity loss
V*	=	25.77	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

A3- Capacity Calculation of Steel Girder 355x140mm- Short Spans:

Table A1- Steel Girder Specifications

Type	D (mm)	B (mm)	t_w (mm)	t_f (mm)	I_{x-x} (mm^4)	I_{y-y} (mm^4)
I-Section	356.0	140.0	6.1	13.5	128,622,070	6,157,328

A3-1- Bending Moment

λ_{ep} (web)	=	82		
λ_{ep} (flange)	=	9		*AS 5100.6 Table 5.1.2*
λ_{e1} (web)	=	54.04		*AS 5100.6 5.1.2*
λ_{e2} (flange)	=	5.20		
λ_e	≤	λ_{ep}	→ Compact section	
Z_e	=	Min(S,1.5Z)		*AS 5100.6 5.1.3*
Z_e	=	8.10E+05	*mm^3*	
Ms	=	$f_y Z_e$		*AS 5100.6 5.2.1*
Ms	=	202.48	*KN.m*	
L	=	5000	*mm*	
r_y	=	55.02	*mm*	
β_m	=	-1		
L/r_y	≥	$(80+50\beta_m)(250/f_y)^{0.5}$		*AS 5100.6 5.3.2.4*
L/r_y	=	90.88		
$0+50\beta_m)(250/f_y)^{0.5}$	=	30.00		
L/r_y	≥	30.00	→ Without full lateral restraint	
I_y	=	6.16E-06	*m^4*	
J	=	1.35E-04	*m^4*	
d_f	=	0.34	*m*	
$I_w=I_y d_f^2/4$	=	1.81E-07	*m^6*	
k_t	=	1.00		*AS 5100.6 Table 5.6.5(A)*
k_l	=	1.40		*AS 5100.6 Table 5.6.5(B)*
k_r	=	0.70		*AS 5100.6 Table 5.6.5(C)*
L	=	5.00	*m*	
$L_e=k_t*k_l*k_r*L$	=	4.90	*m*	*AS 5100.6 5.6.5*
M_o	=	2337.87	*KN.m*	
M_s / M_o	=	0.09		
α_s	=	0.99		
α_m	=	1		
$M_b=\alpha_s\alpha_m M_s$	=	200.16	*KN.m*	*AS 5100.6 5.6.1.1*
ϕ	=	0.90		*AS 5100.6 Table 3.2*
ϕM_b	=	180.15	*KN.m*	
M*	=	54.21	*KN.m*	*SAP2000*
M*	≤	ϕMb	OK	

A3-2- Shear Force:

t_w	=	6.09	*mm*	
d_1	=	329.1	*mm*	
$(d_1/180)(f_y/250)^{0.5}$	=	1.83	*mm*	*AS 5100.6 5.9.1*
t_w	≥	$(d1/180)(fy/250)^{0.5}$	OK	
d_p / t_w	=	54.04		
$82 /(f_y /250)^{0.5}$	=	82.00		
d_p / t_w	≤	82.00	→ Vu=Vw	*AS 5100.6 5.10.2*
V_w	=	$0.6fyA_w$		*AS 5100.6 5.10.4*
V_w	=	300.63	*KN*	
ϕ	=	0.90		*AS 5100.6 Table 3.2*
ϕV_u	=	270.57	*KN*	
V*	=	36.47	*KN*	*SAP2000*
V*	≤	ϕV_u	OK	

A3-3- Shear and Bending Interaction Method:

M^*	=	54.21	*KN.m*	
M_s	=	202.48	*KN.m*	
$0.75\phi M_s$	=	136.67	*KN.m*	
M^*	≤	$0.75\phi Ms$		
V_{vm}	=	$V_v[2.2-(1.6M^*/\phi M_s)]$		*AS 5100.6 5.11.3(2)*
V_{vm}	=	300.63	*KN*	
ϕ	=	0.90		*AS 5100.6 Table 3.2*
ϕV_{vm}	=	270.57	*KN*	
V^*	=	36.47	*KN*	*SAP2000*
V^*	≤	ϕV_{vm}	OK	

A4- Capacity Calculation of Steel Girder 355x140mm - Long Spans (Negative Moment):

Table A2- Steel Girder Specifications

Type	D (mm)	B (mm)	t_w (mm)	t_f (mm)	I_{x-x} (mm^4)	I_{y-y} (mm^4)
I-Section	355.0	140.0	6.1	13.5	128,622,070	6.16E+06

A4-1- Bending Moment:

λ_{ep} (web)	=	82		
λ_{ep} (flange)	=	9		*AS 5100.6 Table 5.1.2*
λ_{e1} (web)	=	54.04		*AS 5100.6 5.1.2*
λ_{e2} (flange)	=	5.20		
λ_e	≤	λ_{ep}	→ Compact section	
Z_e	=	Min(S,1.5Z)		*AS 5100.6 5.1.3*
Z_e	=	8.10E+05	*mm^3*	
Ms	=	$f_y Z_e$		*AS 5100.6 5.2.1*
Ms	=	202.48	*KN.m*	
L	=	10200	*mm*	
r_y	=	55.02	*mm*	
β_m	=	-1		
L/r_y	≥	$(80+50\beta_m)(250/f_y)^{0.5}$		*AS 5100.6 5.3.2.4*
L/r_y	=	185.40		
$(80+50\beta_m)(250/f_y)^{0.5}$	=	30.00		
L/r_y	≥	30.00	→ Without full lateral restraint	
I_y	=	6.16E-06	*m^4*	
J	=	1.35E-04	*m^4*	
d_f	=	0.34	*m*	
$I_w=I_y d_f^2/4$	=	1.81E-07	*m^6*	
k_t	=	1.00		*AS 5100.6 Table 5.6.5(A)*
k_l	=	1.40		*AS 5100.6 Table 5.6.5(B)*
k_r	=	0.70		*AS 5100.6 Table 5.6.5(C)*
L	=	10.20	*m*	
$L_e=k_t*k_l*k_r*L$	=	10.00	*m*	*AS 5100.6 5.6.5*
M_o	=	1145.42	*KN.m*	
M_s / M_o	=	0.18		
α_s	=	0.94		
α_m	=	1		
$M_b=\alpha_s\alpha_m M_s$	=	190.04	*KN.m*	*AS 5100.6 5.6.1.1*
ϕ	=	0.90		*AS 5100.6 Table 3.2*
ϕM_b	=	171.04	*KN.m*	
M^*	=	130.76	*KN.m*	*SAP2000*
M^*	≤	ϕM_b	OK	

A5-2- Shear Force:

t_w	=	6.09	*mm*	
d_1	=	329.1	*mm*	
$(d_1/180)(f_y/250)^{0.5}$	=	1.83	*mm*	*AS 5100.6 5.9.1*
t_w	≥	$(d1/180)(fy/250)^{0.5}$	OK	
d_p / t_w	=	54.04		
$82 / (f_y/250)^{0.5}$	=	82.00		
d_p / t_w	≤	82.00	→ Vu=Vw	*AS 5100.6 5.10.2*
V_w	=	$0.6fyA_w$		*AS 5100.6 5.10.4*
V_w	=	300.63	*KN*	
ϕ	=	0.90		*AS 5100.6 Table 3.2*
ϕV_u	=	270.57	*KN*	
V*	=	64.11	*KN*	*SAP2000*
V*	≤	ϕV_u	OK	

A5-3- Shear and Bending Interaction Method:

M*	=	130.76	*KN.m*	
M_s	=	202.48	*KN.m*	
$0.75\phi M_s$	=	136.67	*KN.m*	
M*	≤	$0.75\phi M_s$		
V_{vm}	=	$V_v[2.2-(1.6M^*/\phi M_s)]$		*AS 5100.6 5.11.3(2)*
V_{vm}	=	300.63	*KN*	
ϕ	=	0.90		*AS 5100.6 Table 3.2*
ϕV_{vm}	=	270.57	*KN*	
V*	=	64.11	*KN*	*SAP2000*
V*	≤	ϕV_{vm}	OK	

A5- Capacity Calculation of Steel Girder 508x165mm:

Table A2- Steel Girder Specifications

Type	D (mm)	B (mm)	t_w (mm)	t_f (mm)	I_{x-x} (mm^4)	I_{y-y} (mm^4)
I-Section	508.0	165.0	8.9	18.3	439,351,747	13,712,020

A5-1- Bending Moment:

λ_{ep} (web)	=	82		
λ_{ep} (flange)	=	9		*AS 5100.6 Table 5.1.2*
λ_{e1} (web)	=	53.09		*AS 5100.6 5.1.2*
λ_{e2} (flange)	=	4.51		
λ_e	≤	λ_{ep}	→ Compact section	
Z_e	=	Min(S,1.5Z)		*AS 5100.6 5.1.3*
Z_e	=	1.97E+06	*mm^3*	
M_s	=	f_yZ_e		*AS 5100.6 5.2.1*
M_s	=	492.59	*KN.m*	
L	=	10250	*mm*	
r_y	=	42.13	*mm*	
β_m	=	-1		
L/r_y	≥	$(80+50\beta m)(250/fy)^{0.5}$		*AS 5100.6 5.3.2.4*
L/r_y	=	243.27		
$(80+50\beta_m)(250/f_y)^{0.5}$	=	30.00		
L/r_y	≥	30.00	→ Without full lateral restraint	

$(80+50\beta_m)(250/f_y)^{0.5}$	=	30.00		
L/r_y	≥	30.00	→ Without full lateral restraint	
I_y	=	1.37E-05	m^4	
J	=	4.53E-04	m^4	
d_f	=	0.49	*m*	
$I_w=I_y d_f^2/4$	=	8.22E-07	m^6	
k_t	=	1.00		*AS 5100.6 Table 5.6.5(A)*
k_l	=	1.40		*AS 5100.6 Table 5.6.5(B)*
k_r	=	0.70		*AS 5100.6 Table 5.6.5(C)*
L	=	10.25	*m*	
$L_e=k_t{*}k_l{*}k_r{*}L$	=	10.05	*m*	*AS 5100.6 5.6.5*
M_o	=	3118.79	*KN.m*	
M_s / M_o	=	0.16		
α_s	=	0.95		
α_m	=	1.00		
$M_b=\alpha_s\alpha_m M_s$	=	467.36	*KN.m*	*AS 5100.6 5.6.1.1*
ϕ	=	0.90		*AS 5100.6 Table 3.2*
ϕM_b	=	420.62	*KN.m*	
M*	=	183.29	*KN.m*	*SAP2000*
M*	≤	ϕM_b	OK	

A5-1- Shear Force:

t_w	=	8.88	*mm*	
d_1	=	471.444	*mm*	
$(d_1/180)(f_y/250)^{0.5}$	=	2.62	*mm*	*AS 5100.6 5.9.1*
t_w	≥	$(d1/180)(fy/250)^{0.5}$	OK	
d_p / t_w	=	53.09		
$82/(f_y/250)^{0.5}$	=	82.00		
d_p / t_w	≤	82.00	→ Vu=Vw	*AS 5100.6 5.10.2*
V_w	=	$0.6fyA_w$		*AS 5100.6 5.10.4*
V_w	=	627.96	*KN*	
ϕ	=	0.90		*AS 5100.6 Table 3.2*
ϕV_u	=	565.17	*KN*	
V*	=	74.32	*KN*	*SAP2000*
V*	≤	ϕV_u	OK	

A5-3- Shear and Bending Interaction Method:

M*	=	183.29	*KN.m*	
M_s	=	492.59	*KN.m*	
$0.75\phi M_s$	=	332.50	*KN.m*	
M*	≤	$0.75\phi M_s$		
V_{vm}	=	627.96	*KN*	*AS 5100.6 5.11.3(2)*
ϕ	=	0.90		
ϕV_{vm}	=	565.17	*KN*	*AS 5100.6 Table 3.2*
V*	=	74.32	*KN*	
V*	≤	ϕV_{vm}	OK	*SAP2000*

ATTACHMENT B- CAPACITY CALCULATION OF THE SUBSTRUCTURE

B1- Capacity Calculation of Headstock (3Pile-L):

b	=	145	*mm*
d	=	275	*mm*
E_T	=	14000	*MPa*
A	=	39875	*mm²*
Z	=	1827604	*mm³*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
E	=	14000	*MPa*

B1-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	5750	*mm*	
S_b	=	$1.25\rho_b.d/b\,(L_{ay}/d)^{0.5}$		
S_b	=	10.62	$S_b \leq 10$	
K_{12}	=	1.00		
M_d	=	$K_1\,K_4\,K_6\,K_{11}\,K_{12}\,f'_b\,Z$		*AS 5100.9 6.3.1*
M_d	=	62.87	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	42.43	*KN.m*	10% capacity loss
$M^*=M/2$	=	9.89	*KN.m*	*SAP2000*
M^*	≤	ϕM_d	OK	

B1-2- Shear Force:

V_d	=	$K_1\,K_4\,K_6\,f'_s\,A_s$		*AS 5100.9 6.3.6*
V_d	=	78.38	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	52.91	*KN*	10% capacity loss
$V^*=V/2$	=	36.62	*KN*	*SAP2000*
V^*	≤	ϕV_d	OK	

B2- Capacity Calculation of Headstock (3Pile-S):

b	=	145	*mm*
d	=	275	*mm*
E_T	=	14000	*MPa*
A	=	39875	*mm^2*
Z	=	1827604	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
E	=	14000	*MPa*

B2-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	2200	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	6.57	*$S_b \leq 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\,K_4\,K_6\,K_{11}\,K_{12}\,f'_b\,Z$		*AS 5100.9 6.3.1*
M_d	=	62.87	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	42.43	*KN.m*	10% capacity loss
$M^*=M/2$	=	9.89	*KN.m*	*SAP2000*
M^*	≤	ϕM_d	OK	

B2-2- Shear Force:

V_d	=	$K_1\,K_4\,K_6\,f'_s\,A_s$		*AS 5100.9 6.3.6*
V_d	=	78.38	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	52.91	*KN*	10% capacity loss
$V^*=V/2$	=	28.34	*KN*	*SAP2000*
V^*	≤	ϕV_d	OK	

B3- Capacity Calculation of Headstock (4Pile-L):

b	=	145	*mm*
d	=	275	*mm*
E_T	=	14000	*MPa*
A	=	39875	*mm²*
Z	=	1827604	*mm³*

F17 Grade *AS 5100.9 Table A1*

f_b	=	42	*MPa*
f_s	=	3.6	*MPa*
E	=	14000	*MPa*

B3-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	2200	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	6.57	$S_b \le 10$	
K_{12}	=	1.00		
M_d	=	$K_1 K_4 K_6 K_{11} K_{12} f_b Z$		*AS 5100.9 6.3.1*
M_d	=	62.87	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	42.43	*KN.m*	10% capacity loss
M*=M/2	=	9.42	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B3-2- Shear Force:

V_d	=	$K_1 K_4 K_6 f_s A_s$		*AS 5100.9 6.3.6*
V_d	=	78.38	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	52.91	*KN*	10% capacity loss
V*=V/2	=	31.01	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B4- Capacity Calculation of Headstock (5Pile-L)

b	=	145	*mm*
d	=	275	*mm*
E_T	=	14000	*MPa*
A	=	39875	*mm^2*
Z	=	1827604	*mm^3*

F17 Grade — *AS 5100.9 Table A1*

f_b	=	42	*MPa*
f_s	=	3.6	*MPa*
E	=	14000	*MPa*

B4-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	2200	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	6.57	*$S_b \le 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\ K_4\ K_6\ K_{11}\ K_{12}\ f_b\ Z$		*AS 5100.9 6.3.1*
M_d	=	62.87	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	42.43	*KN.m*	10% capacity loss
M*=M/2	=	6.39	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B4-2- Shear Force:

V_d	=	$K_1\ K_4\ K_6\ f_s\ A_s$		*AS 5100.9 6.3.6*
V_d	=	78.38	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	52.91	*KN*	10% capacity loss
V*=V/2	=	20.98	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B5- Capacity Calculation of Headstock (5Pile-S):

b	=	145	*mm*
d	=	275	*mm*
E_T	=	14000	*MPa*
A	=	39875	*mm²*
Z	=	1827604	*mm³*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
E	=	14000	*MPa*

B5-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	2200	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	6.57	$S_b \leq 10$	
K_{12}	=	1.00		
M_d	=	$K_1\ K_4\ K_6\ K_{11}\ K_{12}\ f'_b\ Z$		*AS 5100.9 6.3.1*
M_d	=	62.87	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	42.43	*KN.m*	10% capacity loss
M*=M/2	=	7.46	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B5-2- Shear Force:

V_d	=	$K_1\ K_4\ K_6\ f'_s\ A_s$		*AS 5100.9 6.3.6*
V_d	=	78.38	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	52.91	*KN*	10% capacity loss
V*=V/2	=	34.37	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B6- Capacity Calculation of Headstock (6Pile-L):

b	=	145	*mm*
d	=	275	*mm*
E_T	=	14000	*MPa*
A	=	39875	*mm²*
Z	=	1827604	*mm³*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
E	=	14000	*MPa*

B6-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	2200	*mm*	
S_b	=	$1.25\rho_b.d/b\,(L_{ay}/d)^{0.5}$		
S_b	=	6.57	$S_b \leq 10$	
K_{12}	=	1.00		
M_d	=	$K_1\,K_4\,K_6\,K_{11}\,K_{12}\,f'_b\,Z$		*AS 5100.9 6.3.1*
M_d	=	62.87	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	42.43	*KN.m*	10% capacity loss
M*=M/2	=	11.70	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B6-2- Shear Force:

V_d	=	$K_1\,K_4\,K_6\,f'_s\,A_s$		*AS 5100.9 6.3.6*
V_d	=	78.38	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	52.91	*KN*	10% capacity loss
V*=V/2	=	27.52	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B7- Capacity Calculation of Pile(S)-(240-250) mm

Dimension (D)	=	245	*mm*
A	=	47144	*mm^2*
Z	=	1443770	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f_b	=	42	*MPa*
f_s	=	3.6	*MPa*
f_c	=	34	*MPa*
E	=	14000	*MPa*

B7-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	3100	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	4.36	*$S_b \le 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\ K_4\ K_6\ K_{11}\ K_{12}\ f_b\ Z$		*AS 5100.9 6.3.1*
M_d	=	49.66	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	27.94	*KN.m*	25% capacity loss
M*	=	6.90	*KN.m*	*SAP2000*
M*	<	ϕM_d	OK	

B7-2- Shear Force:

V_d	=	$K_1\ K_4\ K_6\ f_s\ A_s$		*AS 5100.9 6.3.6*
V_d	=	92.67	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	52.12	*KN*	25% capacity loss
V*	=	1.80	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B7-3- Axial Capacity-Compression:

Diameter (D)	=	245	*mm*	
I	=	176861880	*mm^4*	
A	=	47144	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.2		
k_{ey}	=	0.85		
L	=	3100	*mm*	
S_{cx}	=	$\rho_c\,(A\,(k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\,(A\,(k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	18.94	*$10 \le Scx \le 20$*	
$K_{10\text{-}x}$	=	0.55		*AS 5100.9 6.3.2.2*
S_{cy}	=	13.41	*$10 \le Scy \le 20$*	
$K_{10\text{-}y}$	=	0.83		
N_c	=	$K_1\,K_4\,K_6\,K_{10}\,f_c\,A_c$		*AS 5100.9 6.3.6*
N_c	=	726.27	*KN*	
ϕ	=	0.75		
ϕN_c	=	408.53	*KN*	25% capacity loss
N_c^*	=	55.05	*KN*	*SAP2000*
N_c^*	≤	ϕN_c	OK	

B7-4- Combined Actions in Bending and Compression:

N_c^*	=	55.05	*KN*	*SAP2000*
ϕN_c	=	408.53	*KN*	
M^*	=	6.90	*KN.m*	*SAP2000*
ϕM_d	=	27.94	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	=	0.20		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	=	0.38		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B8- Capacity Calculation of Pile(S)-(310-325) mm:

Dimension (D)	=	315	*mm*
A	=	77931	*mm^2*
Z	=	3068538	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f_b	=	42	*MPa*
f_s	=	3.6	*MPa*
f_c	=	34	*MPa*
E	=	14000	*MPa*

B8-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	3100	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	3.84	*$S_b \le 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\ K_4\ K_6\ K_{11}\ K_{12}\ f_b\ Z$		*AS 5100.9 6.3.1*
M_d	=	105.55	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	39.58	*KN.m*	50% capacity loss
M*	=	6.90	*KN.m*	
M*	≤	ϕM_d	OK	

B8-2- Shear Force

V_d	=	$K_1\ K_4\ K_6\ f_s\ A_s$		*AS 5100.9 6.3.6*
V_d	=	153.18	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	57.44	*KN*	50% capacity loss
V*	=	2.00	*KN*	
V*	≤	ϕV	OK	

B8-3- Axial Capacity-Compression

Diameter (D)	=	315	*mm*	
I	=	483294791	*mm⁴*	
A	=	77931	*mm²*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	3100	*mm*	
S_{cx}	=	$\rho_c\,(A\,(k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\,(A\,(k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	14.73	*10 ≤ Scx ≤ 20*	
$K_{10\text{-}x}$	=	0.76		*AS 5100.9 6.3.2.2*
S_{cy}	=	10.43	*10 ≤ Scy ≤ 20*	
$K_{10\text{-}y}$	=	0.98		
N_c	=	$K_1\,K_4\,K_6\,K_{10}\,f'_c\,A_c$		*AS 5100.9 6.3.6*
N_c	=	1657.13	*KN*	
ϕ	=	0.75		
ϕN_c	=	621.42	*KN*	50% capacity loss
N_c^*	=	62.30	*KN*	*SAP2000*
N_c^*	≤	ϕN_c	OK	

B8-4- Combined Actions in Bending and Compression

N_c^*	=	62.30	*KN*	*SAP2000*
ϕN_c	=	621.42	*KN*	
M^*	=	6.90	*KN.m*	*SAP2000*
ϕM_d	=	39.58	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	=	0.13		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	=	0.27		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B9- Capacity Calculation of Pile(S)-(330-350) mm

Dimension (D)	=	340	*mm*
A	=	90792	*mm^2*
Z	=	3858661	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f_b	=	42	*MPa*
f_s	=	3.6	*MPa*
f_c	=	34	*MPa*
E	=	14000	*MPa*

B9-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	2000	*mm*	
S_b	=	$1.25\rho_b.d/b\,(L_{ay}/d)^{0.5}$		
S_b	=	2.97	*$S_b \le 10$*	
K_{12}	=	1.00		
M_d	=	$K_1 K_4 K_6 K_{11} K_{12} f_b Z$		*AS 5100.9 6.3.1*
M_d	=	132.73	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	49.77	*KN.m*	50% capacity loss
M*	=	22.55	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B9-2- Shear Force:

V_d	=	$K_1 K_4 K_6 f_s A_s$		*AS 5100.9 6.3.6*
V_d	=	178.46	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	66.92	*KN*	50% capacity loss
V*	=	7.00	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B9-3- Axial Capacity- Compression

Diameter (D)	=	340	*mm*	
I	=	655972400	*mm^4*	
A	=	90792	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	2000	*mm*	
S_{cx}	=	$\rho_c\ (A\ (k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\ (A\ (k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	8.80	*Scx≤10*	
$K_{10\text{-}x}$	=	1.00		*AS 5100.9 6.3.2.2*
S_{cy}	=	6.24	*Scy≤10*	
$K_{10\text{-}y}$	=	1.00		
N_c	=	$K_1\ K_4\ K_6\ K_{10}\ f_c\ A_c$		*AS 5100.9 6.3.6*
N_c	=	2528.19	*KN*	
ϕ	=	0.75		
ϕN_c	=	948.07	*KN*	50% capacity loss
N_c*	=	80.96	*KN*	*SAP2000*
N_c*	≤	ϕN_c	OK	

B9-4- Combined Actions in Bending and Compression

N_c*	=	80.96	*KN*	*SAP2000*
ϕN_c	=	948.07	*KN*	
M*	=	22.55	*KN.m*	*SAP2000*
ϕM_d	=	49.77	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	=	0.29		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	=	0.54		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B10- Capacity Calculation of Pile(L)-(330-350) mm:

Dimension (D)	=	335	*mm*
A	=	88141	*mm^2*
Z	=	3690917	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
f'_c	=	34	*MPa*
E	=	14000	*MPa*

B10-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	8000	*mm*	
S_b	=	$1.25\rho_b.d/b\,(L_{ay}/d)^{0.5}$		
S_b	=	5.99	*$S_b \le 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\,K_4\,K_6\,K_{11}\,K_{12}\,f'_b\,Z$		*AS 5100.9 6.3.1*
M_d	=	126.96	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	95.22	*KN.m*	0% capacity loss
M*	=	26.02	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B10-2- Shear Force:

V_d	=	$K_1\,K_4\,K_6\,f'_s\,A_s$		*AS 5100.9 6.3.6*
V_d	=	173.25	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	129.94	*KN*	0% capacity loss
V*	=	10.66	*KN*	
V*	≤	ϕV_d	OK	

B10-3- Axial Capacity- Compression:

Diameter (D)	=	335	*mm*	
I	=	618228649	*mm^4*	
A	=	88141	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	8000	*mm*	
S_{cx}	=	$\rho_c\,(A\,(k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\,(A\,(k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	35.74	*Scx≥20*	
$K_{10\text{-}x}$	=	0.16		*AS 5100.9 6.3.2.2*
S_{cy}	=	25.31	*Scy≥20*	
$K_{10\text{-}y}$	=	0.31		
N_c	=	$K_1\,K_4\,K_6\,K_{10}\,f'_c\,A_c$		*AS 5100.9 6.3.6*
N_c	=	384.36	*KN*	
ϕ	=	0.75		
ϕN_c	=	288.27	*KN*	0% capacity loss
N_c^*	=	98.26	*KN*	*SAP2000*
N_c^*	≤	ϕN_c	OK	

B10-4- Combined Actions in Bending and Compression:

N_c^*	=	98.26	*KN*	*SAP2000*
ϕN_c	=	288.27	*KN*	
M^*	=	26.02	*KN.m*	*SAP2000*
ϕM_d	=	95.22	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	=	0.42		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	=	0.61		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B11- Capacity Calculation of Pile(S)-(355-400) mm:

Dimension (D)	=	375	*mm*
A	=	110447	*mm^2*
Z	=	5177185	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f_b	=	42	*MPa*
f_s	=	3.6	*MPa*
f_c	=	34	*MPa*
E	=	14000	*MPa*

B11-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	3300	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	3.63	*$S_b \le 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\, K_4\, K_6\, K_{11}\, K_{12}\, f_b\, Z$		*AS 5100.9 6.3.1*
M_d	=	178.08	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	33.39	*KN.m*	75% capacity loss
M*	=	18.52	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B11-2- Shear Force:

V_d	=	$K_1\, K_4\, K_6\, f_s\, A_s$		*AS 5100.9 6.3.6*
V_d	=	217.09	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	40.71	*KN*	75% capacity loss
V*	=	6.00	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B11-3- Axial Capacity- Compression:

Diameter (D)	=	375	*mm*	
I	=	970722217.33	*mm^4*	
A	=	110446.62	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	3300	*mm*	
S_{cx}	=	$\rho_c\,(A\,(k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\,(A\,(k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	13.17	*$10 \le Scx \le 20$*	
$K_{10\text{-}x}$	=	0.84		*AS 5100.9 6.3.2.2*
S_{cy}	=	9.33	*$Scy \le 10$*	
$K_{10\text{-}y}$	=	1.00		
N_c	=	$K_1\,K_4\,K_6\,K_{10}\,f'_c\,A_c$		*AS 5100.9 6.3.6*
N_c	=	2588.16	*KN*	
ϕ	=	0.75		
ϕN_c	=	485.28	*KN*	75% capacity loss
N_c*	=	89.27	*KN*	*SAP2000*
N_c*	≤	ϕN_c	OK	

B11-4- Combined Actions in Bending and Compression:

N_c*	=	89.27	*KN*	*SAP2000*
ϕN_c	=	485.28	*KN*	
M*	=	18.52	*KN.m*	*SAP2000*
ϕM_d	=	33.39	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	=	0.49		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	=	0.74		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B12- Capacity Calculation of Pile(L)-(355-400) mm:

Dimension (D)	=	375	*mm*
A	=	110447	*mm^2*
Z	=	5177185	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
f'_c	=	34	*MPa*
E	=	14000	*MPa*

B12-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	13500	*mm*	
S_b	=	$1.25\rho_b.d/b\,(L_{ay}/d)^{0.5}$		
S_b	=	7.35	*$S_b \le 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\,K_4\,K_6\,K_{11}\,K_{12}\,f'_b\,Z$		*AS 5100.9 6.3.1*
M_d	=	178.08	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	33.39	*KN.m*	75% capacity loss
M*	=	22.16	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B12-2- Shear Force:

V_d	=	$K_1\,K_4\,K_6\,f'_s\,A_s$		*AS 5100.9 6.3.6*
V_d	=	217.09	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	40.71	*KN*	75% capacity loss
V*	=	9.01	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B12-3- Axial Capacity-Compression:

Diameter (D)	=	375	*mm*	
I	=	970722217	*mm^4*	
A	=	110447	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	3300	*mm*	
S_{cx}	=	$\rho_c\,(A\,(k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\,(A\,(k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	13.17	*'0 ≤ Scx ≤ 20*	
$K_{10\text{-}x}$	=	0.84		*AS 5100.9 6.3.2.2*
S_{cy}	=	9.33	*Scy≤10*	
$K_{10\text{-}y}$	=	1.00		
N_c	=	$K_1\,K_4\,K_6\,K_{10}\,f'_c\,A_c$		*AS 5100.9 6.3.6*
N_c	=	2588.16	*KN*	
ϕ	=	0.75		
ϕN_c	=	485.28	*KN*	75% capacity loss
N_c^*	=	127.70	*KN*	*SAP2000*
N_c^*	≤	ϕN_c	OK	

B12-4- Combined Actions in Bending and Compression:

N_c^*	=	127.70	*KN*	*SAP2000*
ϕN_c	=	485.28	*KN*	
M*	=	22.16	*KN.m*	*SAP2000*
ϕM_d	=	33.39	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	=	0.70		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	=	0.93		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B13- Capacity Calculation of Pile(S)-(405-445) mm:

Dimension (D)	=	420	*mm*
A	=	138544	*mm^2*
Z	=	7273572	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
f'_c	=	34	*MPa*
E	=	14000	*MPa*

B13-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	3300	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	3.43	*$S_b \leq 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\ K_4\ K_6\ K_{11}\ K_{12}\ f'_b\ Z$		*AS 5100.9 6.3.1*
M_d	=	250.20	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	93.82	*KN.m*	50% capacity loss
M*	=	18.73	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B16-2- Shear Force:

V_d	=	$K_1\ K_4\ K_6\ f'_s\ A_s$		*AS 5100.9 6.3.6*
V_d	=	272.32	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	102.12	*KN*	50% capacity loss
V*	=	20.06	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B13-3- Axial Capacity- Compression:

Diameter (D)	=	420	*mm*	
I	=	1527450202	*mm^4*	
A	=	138544	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	3300	*mm*	
S_{cx}	=	$\rho_c\ (A\ (k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\ (A\ (k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	11.76	*'0 ≤ Scx ≤ 20*	
$K_{10\text{-}x}$	=	0.91		*AS 5100.9 6.3.2.2*
S_{cy}	=	8.33	*Scy≤10*	
$K_{10\text{-}y}$	=	1.00		
N_c	=	$K_1\ K_4\ K_6\ K_{10}\ f_c\ A_c$		*AS 5100.9 6.3.6*
N_c	=	3518.76	*KN*	
ϕ	=	0.75		
ϕN_c	=	1319.54	*KN*	50% capacity loss
N_c^*	=	80.49	*KN*	*SAP2000*
N_c^*	≤	ϕN_c	OK	

B13-4- Combined Actions in Bending and Compression:

N_c^*	=	80.49	*KN*	*SAP2000*
ϕN_c	=	1319.54	*KN*	
M*	=	18.73	*KN.m*	*SAP2000*
ϕM_d	=	93.82	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	=	0.10		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	=	0.26		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B14- Capacity Calculation of Pile(L)-(405-445) mm:

Dimension (D)	=	435	*mm*
A	=	148617	*mm^2*
Z	=	8081048	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f_b	=	42	*MPa*
f_s	=	3.6	*MPa*
f_c	=	34	*MPa*
E	=	14000	*MPa*

B14-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	13500	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	6.82	*$S_b \leq 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\ K_4\ K_6\ K_{11}\ K_{12}\ f_b\ Z$		*AS 5100.9 6.3.1*
M_d	=	277.97	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	135.51	*KN.m*	35% capacity loss
M*	=	37.10	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B14-2- Shear Force:

V_d	=	$K_1\ K_4\ K_6\ f_s\ A_s$		*AS 5100.9 6.3.6*
V_d	=	292.12	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	142.41	*KN*	35% capacity loss
V*	=	15.29	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B14-3- Axial Capacity- Compression:

Diameter (D)	=	435	*mm*	
I	=	1757627854	*mm^4*	
A	=	148617	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	13500	*mm*	
S_{cx}	=	$\rho_c\,(A\,(k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\,(A\,(k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	46.44	*Scx≥20*	
$K_{10\text{-}x}$	=	0.09		*AS 5100.9 6.3.2.2*
S_{cy}	=	32.90	*Scy≥20*	
$K_{10\text{-}y}$	=	0.18		
N	=	$K_1\,K_4\,K_6\,K_{10}\,f'_c\,A_c$		*AS 5100.9 6.3.6*
N	=	383.73	*KN*	
ϕ	=	0.75		
ϕN	=	187.07	*KN*	35% capacity loss
N_c*	=	160.73	*KN*	*SAP2000*
N_c*	≤	ϕN_c	OK	

B14-4- Combined Actions in Bending and Compression:

N_c*	=	160.73	*KN*	*SAP2000*
ϕN_c	=	187.07	*KN*	
M*	=	37.10	*KN.m*	*SAP2000*
ϕM_d	=	135.51	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	0.93		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.13		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B15- Capacity Calculation of Pile(S)-(450-500) mm:

Dimension (D)	=	460	*mm*
A	=	166190	*mm^2*
Z	=	9555939	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
f'_c	=	34	*MPa*
E	=	14000	*MPa*

B15-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	3300	*mm*	
S_b	=	$1.25\rho_b.d/b\,(L_{ay}/d)^{0.5}$		
S_b	=	3.28	$S_b \leq 10$	
K_{12}	=	1.00		
M_d	=	$K_1\,K_4\,K_6\,K_{11}\,K_{12}\,f_b\,Z$		*AS 5100.9 6.3.1*
M_d	=	328.71	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	123.26	*KN.m*	50% capacity loss
M*	=	37.66	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B15-2- Shear Force

V_d	=	$K_1\,K_4\,K_6\,f'_s\,A_s$		*AS 5100.9 6.3.6*
V_d	=	326.66	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	122.50	*KN*	50% capacity loss
V*	=	8.97	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B15-3- Axial Capacity- Compression

Diameter (D)	=	460	*mm*	
I	=	2197866074	*mm⁴*	
A	=	166190	*mm²*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	3300	*mm*	
S_{cx}	=	$\rho_c\ (A\ (k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\ (A\ (k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	10.74	*'0 ≤ Scx ≤ 20*	
$K_{10\text{-}x}$	=	0.96		*AS 5100.9 6.3.2.2*
S_{cy}	=	7.60	*Scy≤10*	
$K_{10\text{-}y}$	=	1.00		
N	=	$K_1\ K_4\ K_8\ K_{10}\ f_c\ A_c$		*AS 5100.9 6.3.6*
N	=	4457.50	*KN*	
ϕ	=	0.75		
ϕN	=	1671.56	*KN*	50% capacity loss
N_c^*	=	142.47	*KN*	*SAP2000*
N_c^*	≤	ϕN_c	OK	

B15-4- Combined Actions in Bending and Compression

N_c^*	=	142.47	*KN*	*SAP2000*
ϕN_c	=	1671.56	*KN*	
M^*	=	37.66	*KN.m*	*SAP2000*
ϕM_d	=	123.26	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	0.18		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	0.39		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B16- Capacity Calculation of Pile(L)-(450-500) mm:

Dimension (D)	=	460	*mm*
A	=	166190	*mm^2*
Z	=	9555939	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
f'_c	=	34	*MPa*
E	=	14000	*MPa*

B16-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	13500	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	6.64	*$S_b \le 10$*	
K_{12}	=	1.00		
M_d	=	$K_1\ K_4\ K_6\ K_{11}\ K_{12}\ f'_b\ Z$		*AS 5100.9 6.3.1*
M_d	=	328.71	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	135.59	*KN.m*	45% capacity loss
M*	=	32.85	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B16-2- Shear Force:

V_d	=	$K_1\ K_4\ K_6\ f'_s\ A_s$		*AS 5100.9 6.3.6*
V_d	=	326.66	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	134.75	*KN*	45% capacity loss
V*	=	14.76	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B16-3- Axial Capacity- Compression:

Diameter (D)	=	460	*mm*	
I	=	2197866074	*mm^4*	
A	=	166190	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	13500	*mm*	
S_{cx}	=	$\rho_c\,(A\,(k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\,(A\,(k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	43.92	*Scx≥20*	
$K_{10\text{-}x}$	=	0.10		*AS 5100.9 6.3.2.2*
S_{cy}	=	31.11	*Scy≥20*	
$K_{10\text{-}y}$	=	0.21		
N	=	$K_1\,K_4\,K_6\,K_{10}\,f'_c\,A_c$		*AS 5100.9 6.3.6*
N	=	479.84	*KN*	
ϕ	=	0.75		
ϕN	=	197.93	*KN*	45% capacity loss
N_c*	=	157.09	*KN*	*SAP2000*
N_c*	≤	ϕN_c	OK	

B16-4- Combined Actions in Bending and Compression

N_c*	=	157.09	*KN*	*SAP2000*
ϕN_c	=	197.93	*KN*	
M*	=	32.85	*KN.m*	*SAP2000*
ϕM_d	=	135.59	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	0.85		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.04		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B17- Capacity Calculation of Pile(L)-(510) mm:

Dimension (D)	=	510	*mm*
A	=	204282	*mm^2*
Z	=	13022981	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f'_b	=	42	*MPa*
f'_s	=	3.6	*MPa*
f'_c	=	34	*MPa*
E	=	14000	*MPa*

B17-1- Bending Moment:

K_1	=	1.00		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	13500	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	6.30	*$S_b \leq 10$*	
K_{12}	=	1.00		
M_d	=	$K_1 K_4 K_6 K_{11} K_{12} f'_b Z$		*AS 5100.9 6.3.1*
M_d	=	447.96	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	83.99	*KN.m*	75% capacity loss
M*	=	27.91	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B17-2- Shear Force:

V_d	=	$K_1 K_4 K_6 f'_s A_s$		*AS 5100.9 6.3.6*
V_d	=	401.54	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	75.29	*KN*	75% capacity loss
V*	=	7.51	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B17-3- Axial Capacity- Compression:

Diameter (D)	=	510	*mm*	
I	=	3320860275	*mm^4*	
A	=	204282	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	13500	*mm*	
S_{cx}	=	$\rho_c\,(A\,(k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\,(A\,(k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	39.61	*Scx≥20*	
$K_{10\text{-}x}$	=	0.13		*AS 5100.9 6.3.2.2*
S_{cy}	=	28.06	*Scy≥20*	
$K_{10\text{-}y}$	=	0.25		
N	=	$K_1\,K_4\,K_6\,K_{10}\,f'_c\,A_c$		*AS 5100.9 6.3.6*
N	=	725.02	*KN*	
ϕ	=	0.75		
ϕN	=	135.94	*KN*	75% capacity loss
N_c*	=	111.97	*KN*	*SAP2000*
N_c*	≤	ϕN_c	OK	

B17-4- Combined Actions in Bending and Compression:

N_c*	=	111.97	*KN*	*SAP2000*
ϕN_c	=	135.94	*KN*	
M*	=	27.91	*KN.m*	*SAP2000*
ϕM_d	=	83.99	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	0.93		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.16		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

B18- Capacity Calculation of Pile(S)-(1050) mm:

Dimension (D)	=	1050	*mm*
A	=	865901	*mm^2*
Z	=	113649569	*mm^3*

F17 Grade *AS 5100.9 Table A1*

f_b	=	42	*MPa*
f_s	=	3.6	*MPa*
f_c	=	34	*MPa*
E	=	14000	*MPa*

B18-1- Bending Moment:

K_1	=	0.97		*AS 5100.9 3.7*
K_4	=	0.91		
K_6	=	0.90		
K_{11}	=	1.00		
ρ_b	=	0.98		*AS 5100.9 Table A5*
L_{ay}	=	3300	*mm*	
S_b	=	$1.25\rho_b.d/b\ (L_{ay}/d)^{0.5}$		
S_b	=	2.17	*$S_b \leq 10$*	
K_{12}	=	1.00		
M_d	=	$K_1 K_4 K_6 K_{11} K_{12} f_b Z$		*AS 5100.9 6.3.1*
M_d	=	3792.04	*KN.m*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕM_d	=	2275.22	*KN.m*	20% capacity loss
M*	=	12.52	*KN.m*	*SAP2000*
M*	≤	ϕM_d	OK	

B18-2- Shear Force:

V_d	=	$K_1 K_4 K_6 f_s A_s$		*AS 5100.9 6.3.6*
V_d	=	1650.96	*KN*	
ϕ	=	0.75		*AS 5100.9 Table 3.2*
ϕV_d	=	990.57	*KN*	20% capacity loss
V*	=	2.92	*KN*	*SAP2000*
V*	≤	ϕV_d	OK	

B18-3- Axial Capacity- Compression:

Diameter (D)	=	1050	*mm*	
I	=	59666023522	*mm^4*	
A	=	865901	*mm^2*	
ρ_c	=	1.08		*AS 5100.9 Table A4*
k_{ex}	=	1.20		
k_{ey}	=	0.85		
L	=	3300	*mm*	
S_{cx}	=	$\rho_c\,(A\,(k_{ex}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cy}	=	$\rho_c\,(A\,(k_{ey}L)^2/12I)^{0.5}$		*AS 5100.9 6.3.2.3*
S_{cx}	=	4.70	*Scx≤10*	
$K_{10\text{-}x}$	=	1.00		*AS 5100.9 6.3.2.2*
S_{cy}	=	3.33	*Scy≤10*	
$K_{10\text{-}y}$	=	1.00		
N	=	$K_1\,K_4\,K_6\,K_{10}\,f_c\,A_c$		*AS 5100.9 6.3.6*
N	=	24111.89	*KN*	
ϕ	=	0.75		
ϕN	=	14467.14	*KN*	20% capacity loss
N_c*	=	116.19	*KN*	*SAP2000*
N_c*	≤	ϕN_c	OK	

B18-4- Combined Actions in Bending and Compression:

N_c*	=	116.19	*KN*	*SAP2000*
ϕN_c	=	14467.14	*KN*	
M*	=	18.82	*KN.m*	*SAP2000*
ϕM_d	=	2345.59	*KN.m*	
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	0.01		*AS 5100.9 6.3.3*
$(M^*/\phi M_d)^2+(N_c^*/\phi N_c)$	≤	1.00	OK	
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	0.02		*AS 5100.9 6.3.3*
$(M_x^*/\phi M_d)+(N_c^*/\phi N_c)$	≤	1.00	OK	

References

[1] **GMR. 2015.** *Kirwans Bridge Rehabilitation.* Strathbogie Shire Council : GMR Engineering Services, 2015.

[2] **Council, Strathbogie Shire. 2022.** *Investigation, Assessment and Detailed Design of Kirwans Bridge* : Strathbogie Shire Council, 2022.

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14th June 2023

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Dear Marlena,

RE: Underwater Inspection – Kirwans Timber Bridge

Please find below inspection report for the Kirwans timber bridge as requested. The inspection took place on Wednesday 24th May 2023 by our Commercial Dive Crew and the works were carried out as per the Australian Standard AS2299 for Occupational Diving.

It was identified many of the timber piles had been wrapped with a Denso strengthening system, including a fibreglass outer wrap and grout fill. Piles with this system could be recognized as filled with either epoxy grout or UW (underwater Cementous) grout. The piles with the epoxy grout fill were observed in fair condition, however those with UW grout were splitting and cracking, and, in some instances, the inner fibreglass mesh could be seen breaking apart within the grout. A diagram of this repair method has been attached to this report.

Several piles had also been strengthened with an outer concrete shell or repaired with a pile splice method. The pile splice method typically involves a new timber pile jacked above the old stump below riverbed and tied together using a steel pipe (can) encasement with a grout fill. A diagram of this repair method has been attached to this report.

Overall, our team determined most issues exist from the waterline and above into the underside of the bridge structure. Below water pile and waler components are in fair to good condition throughout the structure. There are some exceptions to this, particularly regarding piles at the abutment, which appear no longer load bearing, looking very degraded and the immediate supports appear to be absorbing most of the weight.

Additional items below were also observed throughout inspection of the structure.

- Several of the raker piles are missing locking blocks which are installed to provide lateral stability against slippage.
- Old steel SHS staging work was observed throughout the structure. This is not serving any structural function, however they have been left in place.
- Some of the corbels on the underside of the steel beams also appear to have been crushed & failed.
- Many deck beams and some crossheads in the under structure were also observed rotten/collapse. Everything was inspected up to the road deck, road deck timbers and any components above the timber beams were not inspected by our team.
- Steel stringers appear in good condition. Orange red tinge assumes lead paint on steel.

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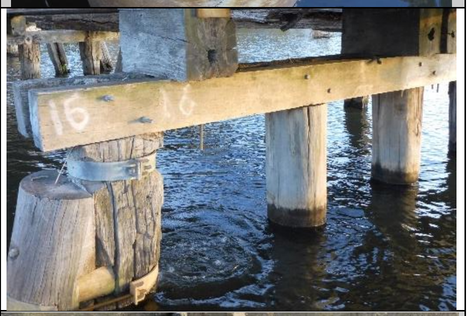
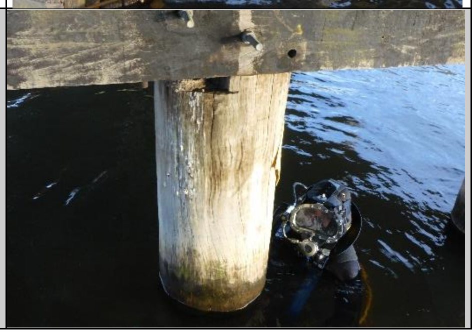
Nominated Piles for Inspection

Pile locations for top to bottom assessment. Pile locations provided by JJ Ryan Consulting.

Pile No.	Pile Length Top of crosshead to riverbed	Pile type/description	
4.2	2.1 meters	Denso fiberglass wrap & grout system. Wrap is ripped and beginning to fail. Pile diameter 510mm.	
5.1	2.10 meters	Fist size hole in pile head. Diameter at riverbed 415mm. Diameter at mid pile 435mm. Diameter at pile top 440mm	
13.3	3 meters	Denso fiberglass wrap & grout system. Wrap approximately 2m length. Diameter at riverbed 370mm. Wrap diameter 610mm	
16.1	11.6 meters	Timber pile in fair condition.	
17.3	12.8 meters	Pile splice with steel can. Top of steel can 2.7 meters. Seabed thumbs.	

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Pile No.	**Pile Length Top of crosshead to riverbed**	**Pile type/description**	
18.2	12.6 meters	Mid pile 360mm. Thumbs 3.9 to first waler/crosshead. 3x walers at mid water. Waler 2 meters off seabed.	
21.3	8.4 meters	Denso fiberglass wrap & grout system. Cracks/ corrosion. Seabed 430 mid 430	
22.2	6.3 meters	Concrete/small jacket 1.2m @surface min 340 330 1.3m of concrete	
24.2	5.2 meters	Double pile configuration. Riverbed diameter 360mm. Mid diameter 440mm. Top diameter 540mm.	
34.2	2.3 meters	Denso fiberglass wrap & grout system. 550 top seabed 340. 100 of exposed pile at seabed.	
37.3	2.3 meters	Denso fiberglass wrap & grout system. Wrap is ripped and beginning to fail. 100mm length of exposed pile at seabed. Diameter at riverbed 360mm. Diameter at pile top 440mm.	

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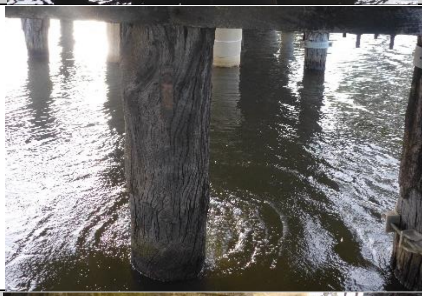
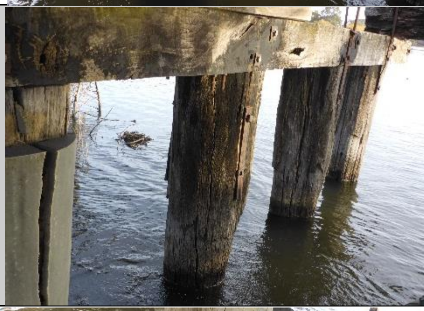
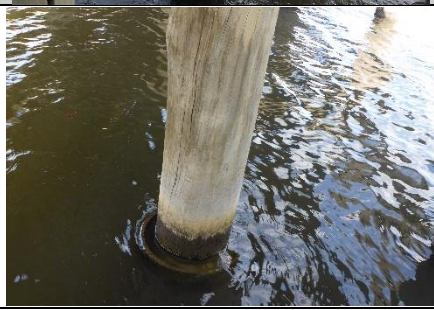
Pile No.	Pile Length Top of crosshead to riverbed	Pile type/description	
39.1	2.7 meters	Denso fiberglass wrap & grout system. Fist sized hole in pile identified. Wrap diameter 500mm. Riverbed diameter 390mm. 600mm of exposed pile at riverbed.	
43.3	4.85 meters	Top diameter 510mm. Mid pile diameter 420/385mm. Riverbed diameter 400mm.	
44.2	4.75 meters	Pile head hollow. Mid pile diameter 355mm. Riverbed diameter 355mm.	
46.1	3.5 meters	Pile splice with steel can. Top diameter 360mm. Bottom diameter 100mm. Bottom of splice can 1.2m off seabed. Mid pile diameter 360mm. Steel can 460mm. Diameter at riverbed 360mm.	

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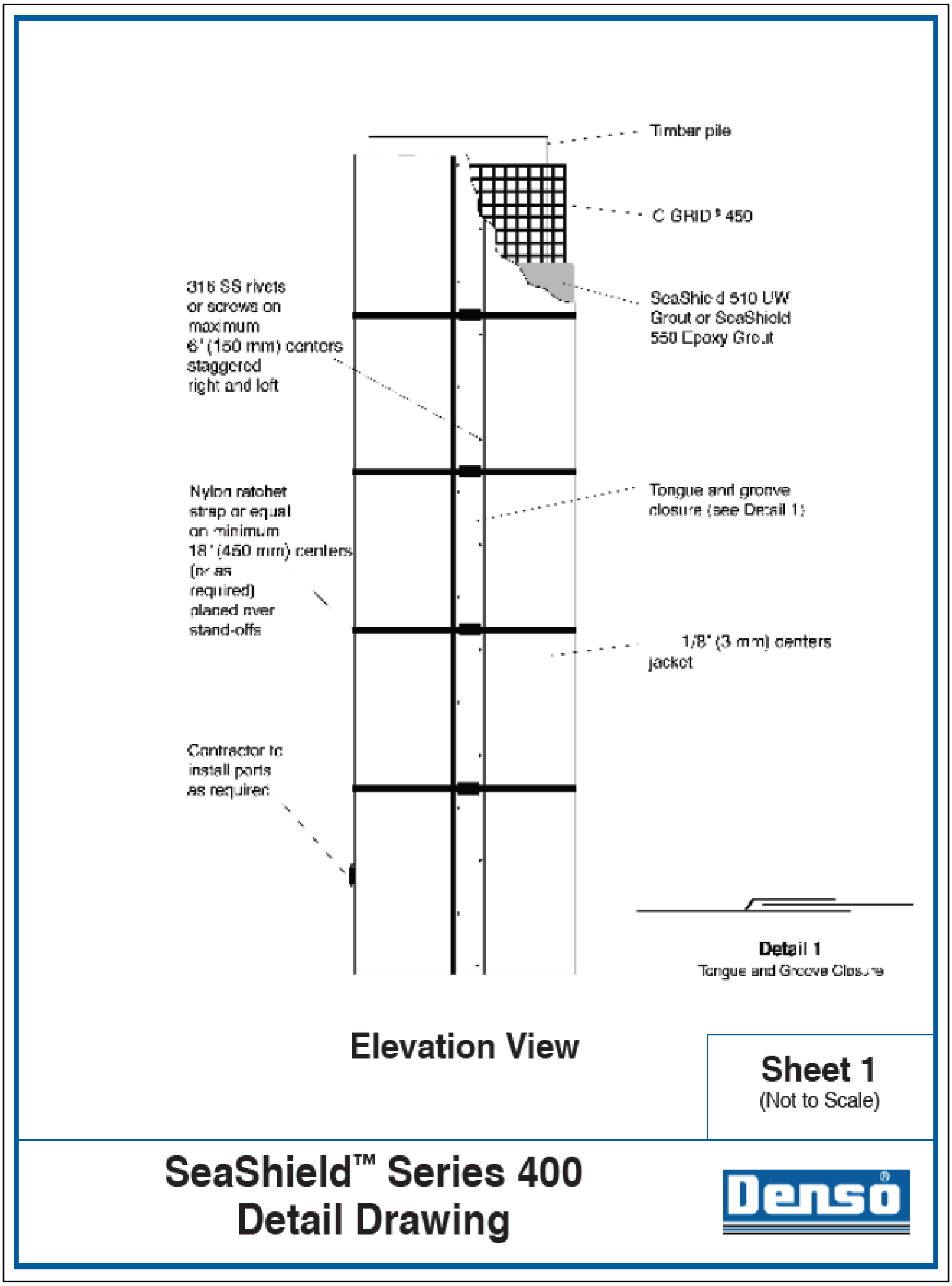

Denso Strengthening System – Fiberglass outer wrap & grout fill

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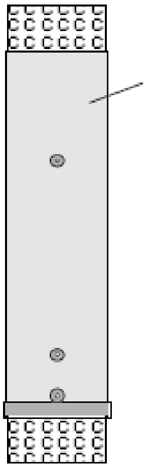
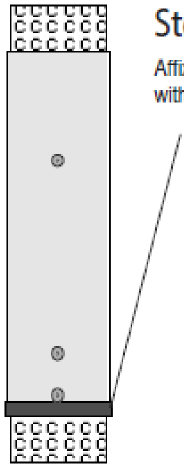


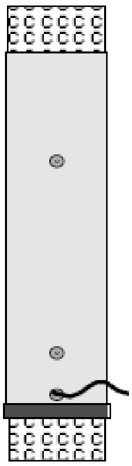
Step 1

Position SeaShield™ Fiber-Form Jacket around pile/ C-GRID® 450 and seal longitudinal seams.



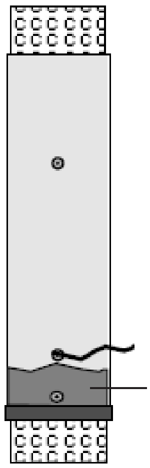
Step 2

Affix bottom seal gasket with select strapping.



Step 3

Connect grout hose to lower injection port and pump SeaShield™ 510 UW Grout or SeaShield™ 550 Epoxy Grout. Visually check for leaks. Plug upper port(s) and pump grout until it reaches top of jacket. (Upper ports are used only if pumping from lower ports becomes difficult.)



Step 4

(Alternate Pumping Method)

Contractor may choose to inject approximately 6" (150 mm) of SeaShield™ 510 UW Grout or SeaShield™ 550 Epoxy Grout and let cure before moving grout hose to next higher port and pumping remainder of grout. Pumping would then continue until grout reaches top of jacket.

Cured SeaShield™ 510 UW Grout or SeaShield™ 550 Epoxy Grout.

Sheet 2
(Not to Scale)

SeaShield™ Series 400 Grout Placement Sequence

Denso®

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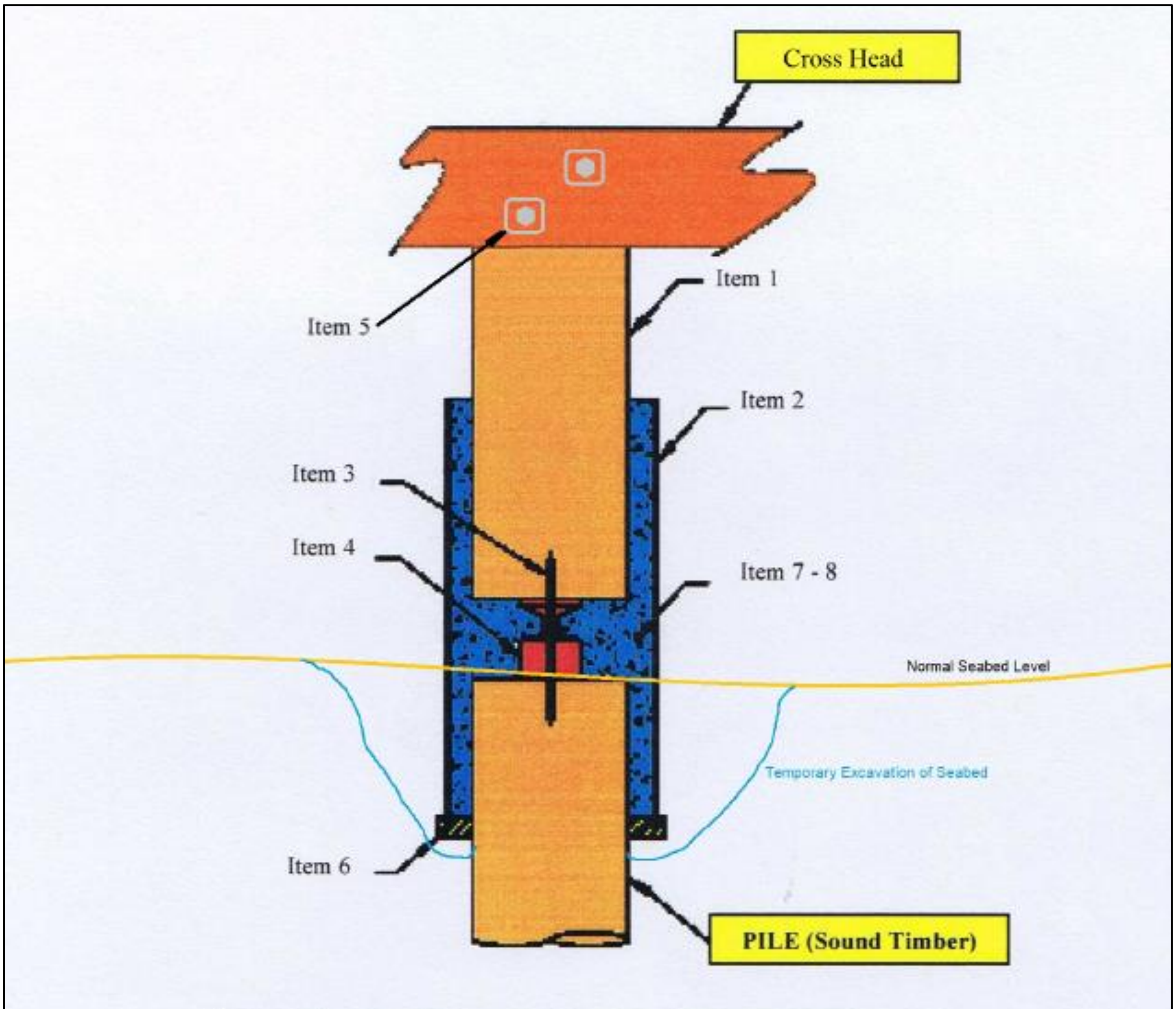

ITEM	DESCRIPTION	QTY
1	F22 TIMBER PILE	1
2	STEEL SLEEVE	1
3	LOCATION PIN	1
4	HYDRAULIC JACK	1
5	BOLTS,NUTS, WASHERS	2
6	FORM SEAL	1
7	EPOXY/GROUT	>80kg
8	ROUND RIVER GRAVEL	

Typical Pile Splice Diagram

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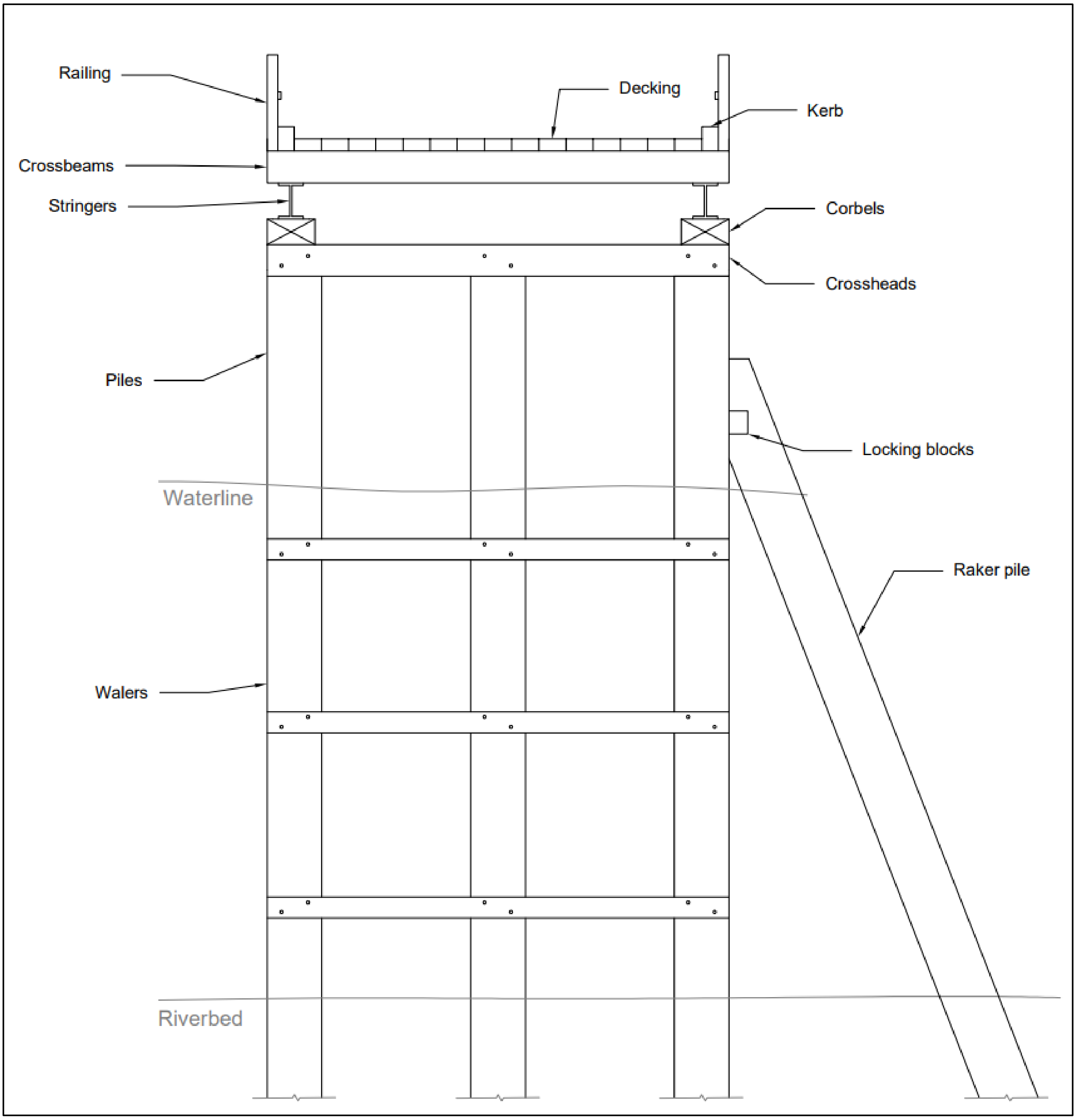

Kirwans Timber Bridge Typical Section View & Components

Drawing not to scale

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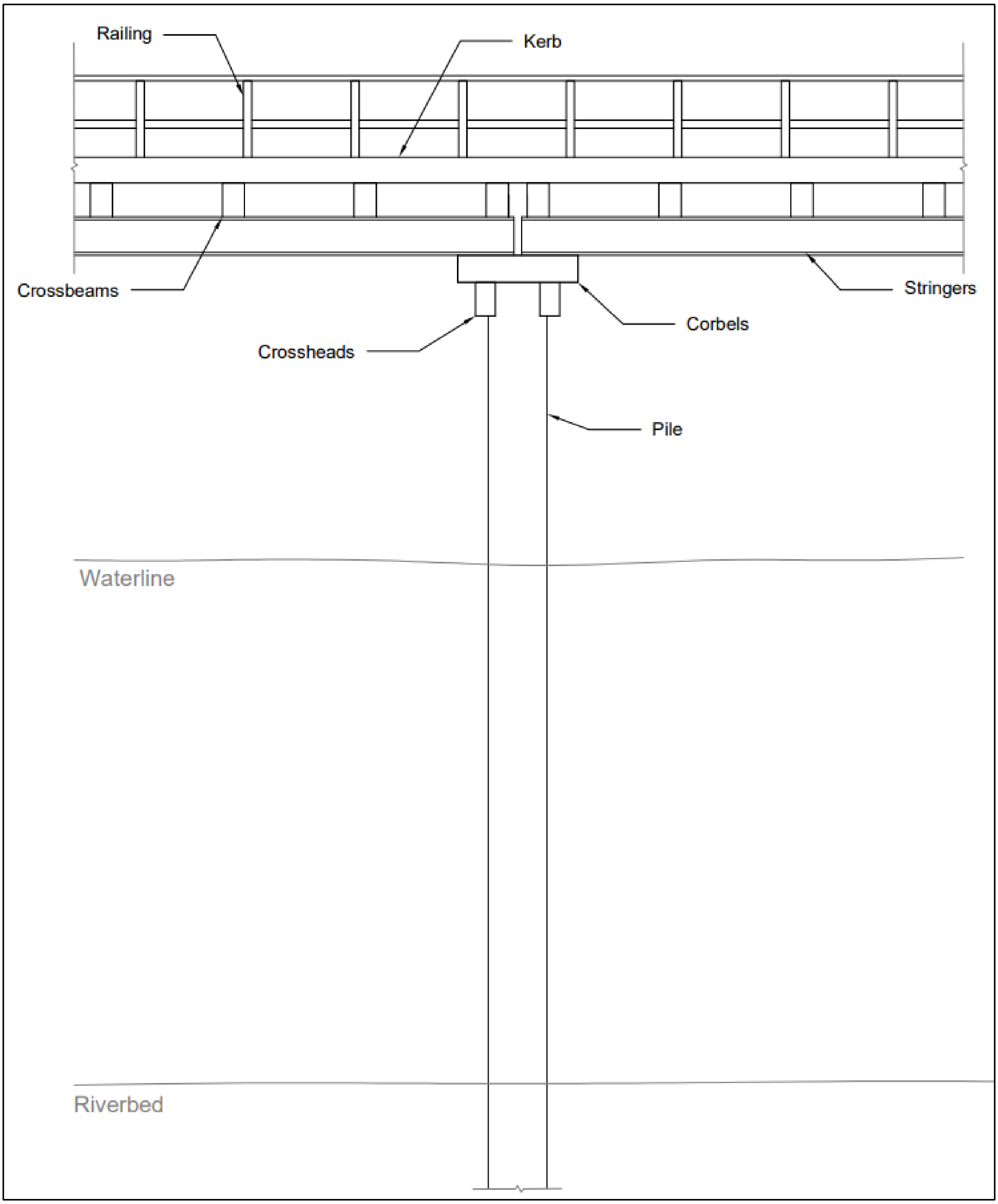

Kirwans Timber Bridge Typical Elevation View & Components

Drawing not to scale

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Conclusion

It should be noted that underwater visibility was very poor due to silt and the dive team could not capture any significant photos of the piles underwater. The dive team did swim down each nominated pile and felt along the circumference for any damage/obstructions, although no considerable damage was found.

The riverbed is approximately 600mm of soft mud/silt before switching to clay. However, this is from our visual/touch inspection only and does not consider any testing etc. The divers could not visually observe the riverbed condition around the base of the piles, however no scouring was identified around any of the piles. Additionally, the team did not observe any fungi/bacterial attack on the piles underwater, however there was a slime layer typical for in rivers. Again, the absence of bacterial attack was not confirmed through any testing.

As directed by JJ Ryan, 15 of the piles were inspected in water, most of which were in fair to good condition, including those repaired piles. As timber is a natural product, we cannot say with certainty the remainder of the timber piles will age, deteriorate, or rot at the same rate. As such we cannot guarantee that the remaining piles are all in the same condition underwater as those 15 inspected. We conclude that the pile condition is of most concern above water, this also extends to the crossheads, corbels and deck beams. It’s likely the rot at the pile heads was initiated by fresh water falling from above and penetrating the pile, which has accelerated the rotting process from inside out. This would be similar to the crossheads, corbels & crossbeams.

Please find accompanying survey document highlighting pile condition/locations. The images taken during this inspection will be provided in a Dropbox link together with this report. If you have any questions regarding the findings in this report, please don’t hesitate to contact me.

Regards,

Leon Comben
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