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APPENDIX – A

SELECTION OF SEISMIC RETROFITTING CATEGORY

APPENDIX – B

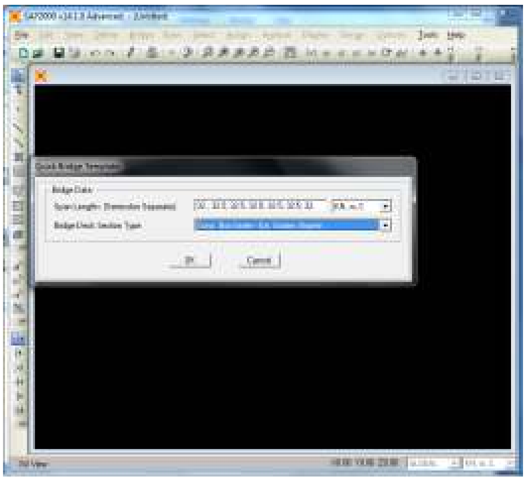
PREPARATION OF BRIDGE MODEL USING SAP 2000 VR. 14.1.0

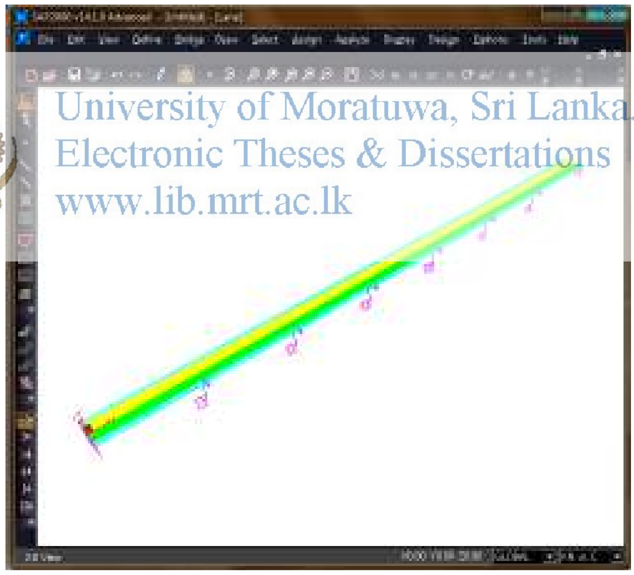
PREPARATION OF BRIDGE MODEL USING SAP 2000 Vr. 14.1.0

Some Important Steps of Building of the FEM

SAP 2000 version 14.1.0 was used to prepare the bridge model.

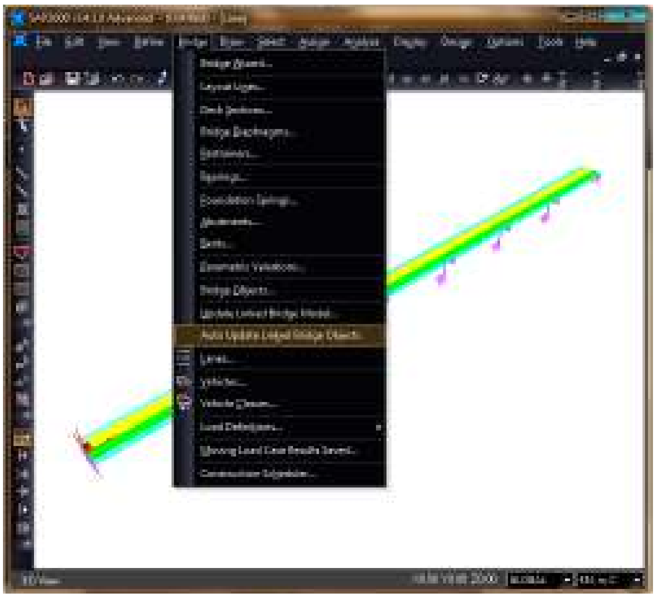
File ⟶ New Model ⟶ Quick Bridge



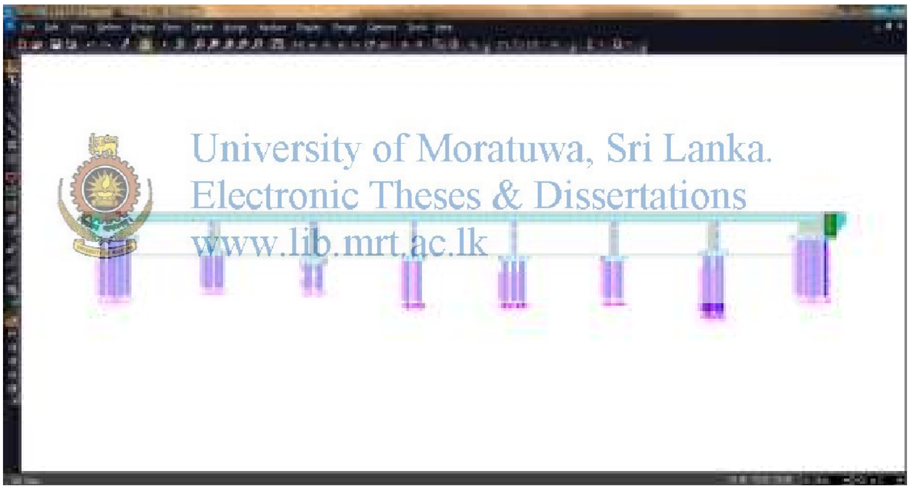


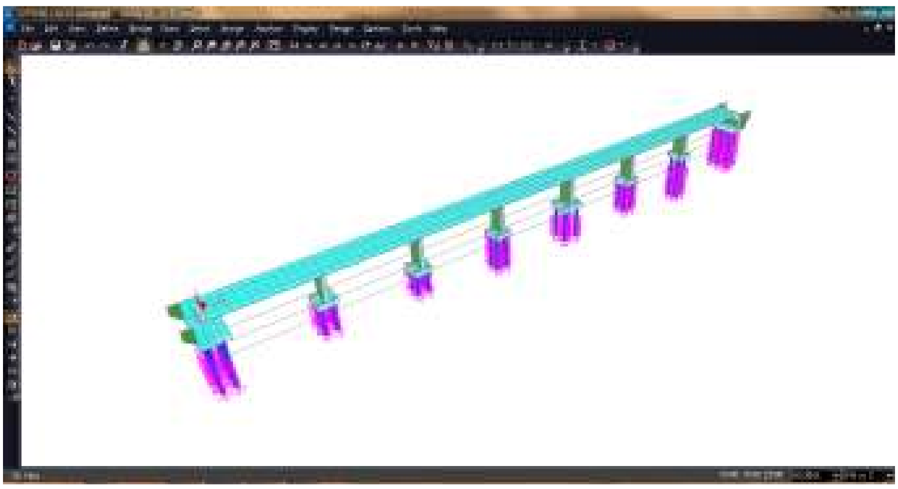
Once it is prepared the primary modal the geometry and the material properties can be changed as you wish using Bridge wizard. In the bridge modeler wizard, it can be defined and modified all the material properties, section properties and also it can be assigned the same.

In this case study, only the superstructure was defined using the bridge wizard and substructure was defined and connected to the superstructure manually using area elements (for pile caps, abutments, piers and wing walls), frame elements (for abutment cap, pier cap and piles) and link elements (for bearings). Also make sure to offline the "Auto update linked bridge objects" in the bridge menu of the SAP 2000.

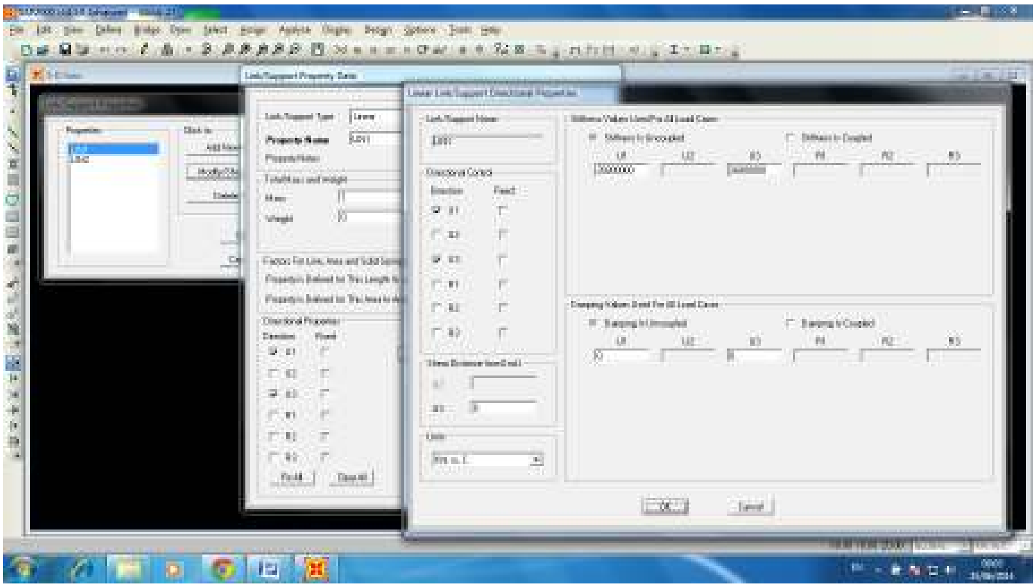


After completing model building, it was as follows.

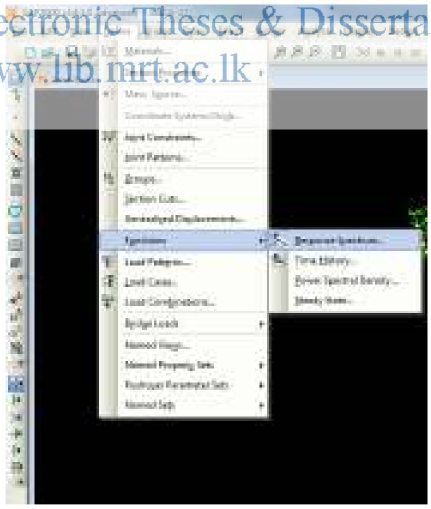


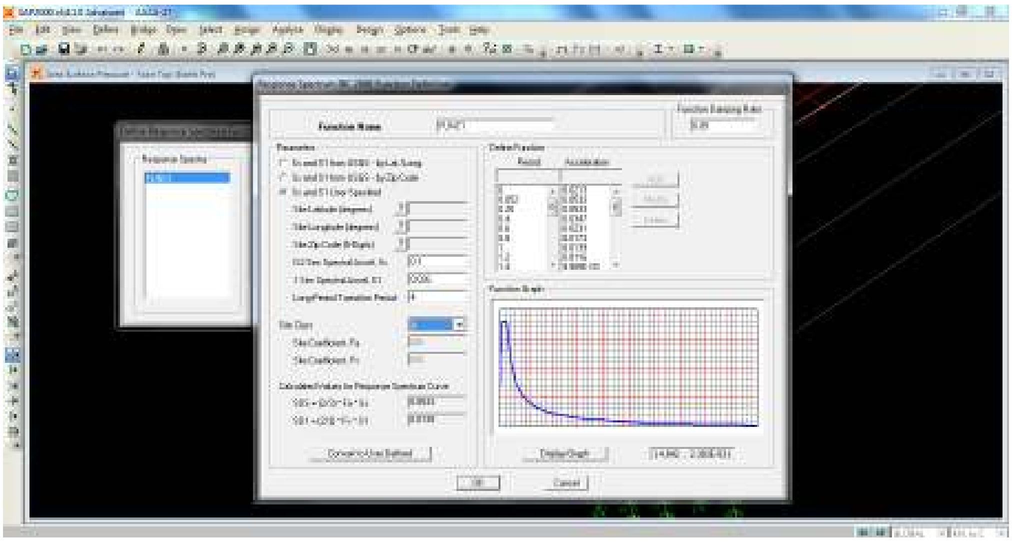


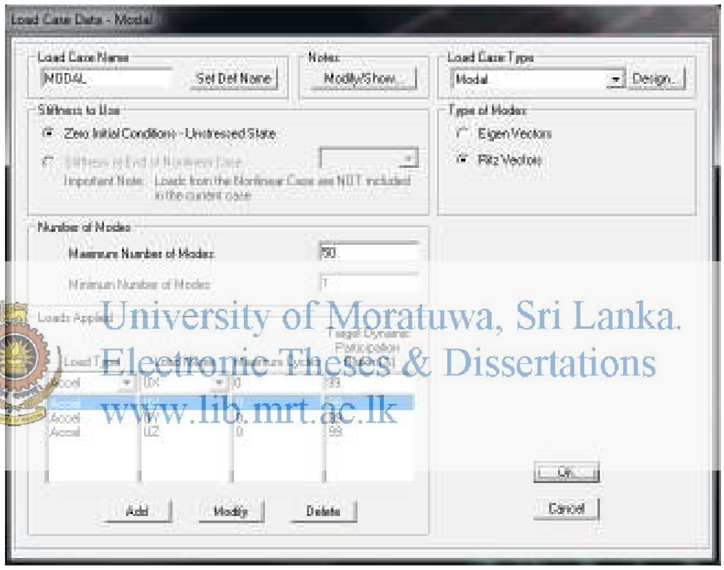
When it defines the link object properties to define the bearings, two objects were defined to get the fixed and free connections.



Soil properties were assigned to the model using springs. The values of the springs were taken using the N values (1500N). The N values were extracted from the as built drawings. The drawing was annexed.







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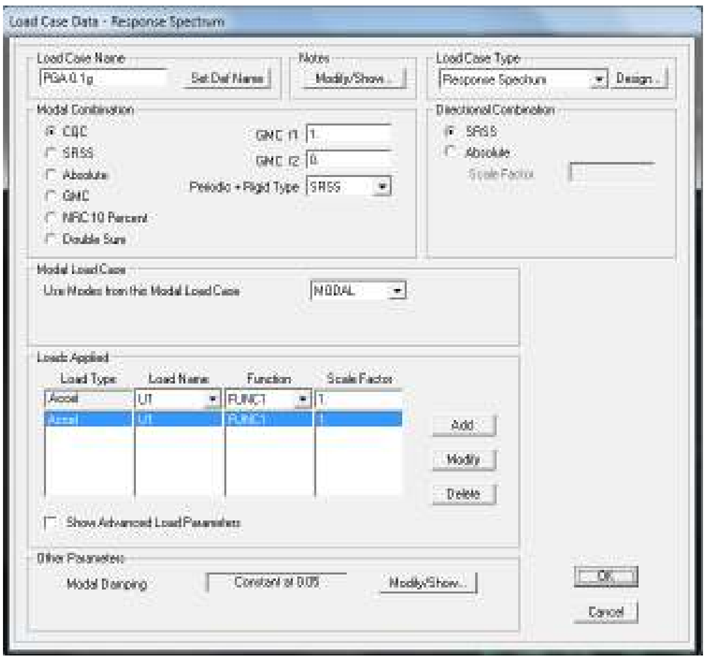
Load Case Name
MODAL
Set Def Name
Notes
Modify/Show...
Load Case Type
Modal
Design...
Stiffness to Use
Zero Initial Conditions - Unstressed State
Stiffness at End of Nonlinear Case
Important Note: Loads from the Nonlinear Case are NOT included in the current case
Type of Modes
Eigen Vectors
Ritz Vectors
Number of Modes
Maximum Number of Modes
50
Minimum Number of Modes
1
Loads Applied
Accel
UX
UZ
99
OK
Cancel
Add
Modify
Delete



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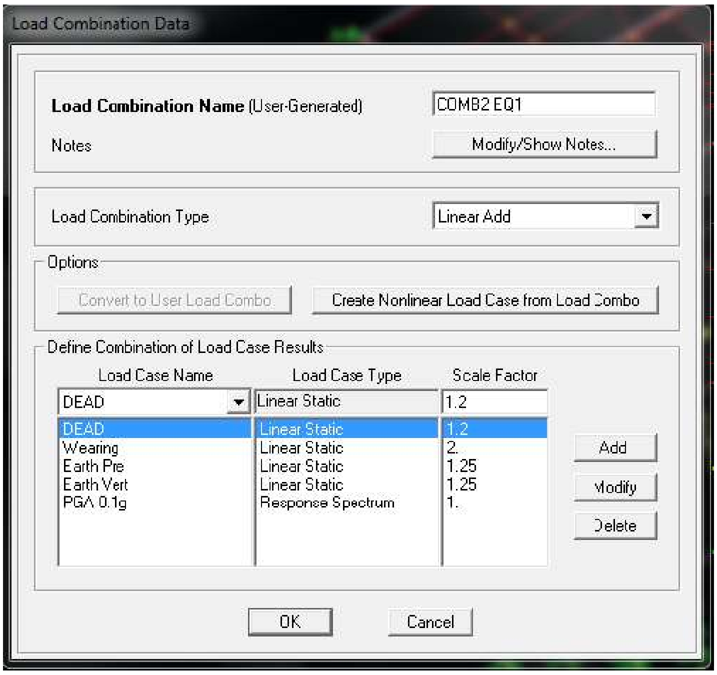
Load Case Name
PGA 0.1g
Set Def Name
Notes
Modify/Show...
Load Case Type
Response Spectrum
Design...
Modal Combination
CQC
SRSS
Absolute
GMC
NRC 10 Percent
Double Sum
GMC f1
1.
GMC f2
0.
Periodic + Rigid Type
SRSS
Directional Combination
SRSS
Absolute
Scale Factor
Modal Load Case
Use Modes from this Modal Load Case
MODAL
Loads Applied
Load Type
Load Name
Function
Scale Factor
Accel
U1
FUNC1
1.
Accel
U1
FUNC1
1.
Add
Modify
Delete
Show Advanced Load Parameters
Other Parameters
Modal Damping
Constant at 0.05
Modify/Show...
OK
Cancel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COMB2 EQ1
Notes
Modify/Show Notes...
Load Combination Type
Linear Add
Options
Convert to User Load Combo
Create Nonlinear Load Case from Load Combo
Define Combination of Load Case Results
Load Case Name
Load Case Type
Scale Factor
DEAD
Linear Static
1.2
DEAD
Linear Static
1.2
Wearing
Linear Static
2.
Earth Pre
Linear Static
1.25
Earth Vert
Linear Static
1.25
PGA 0.1g
Response Spectrum
1.
Add
Modify
Delete
OK
Cancel

APPENDIX – C

RESULTS OBTAINED FROM BRIDGE MODEL DEVELOPED USING SAP 2000 VR.14.1.0

RESULTS OBTAINED FROM BRIDGE MODEL DEVELOPED USING SAP 2000 Vr. 14.1.0

Modal Analysis

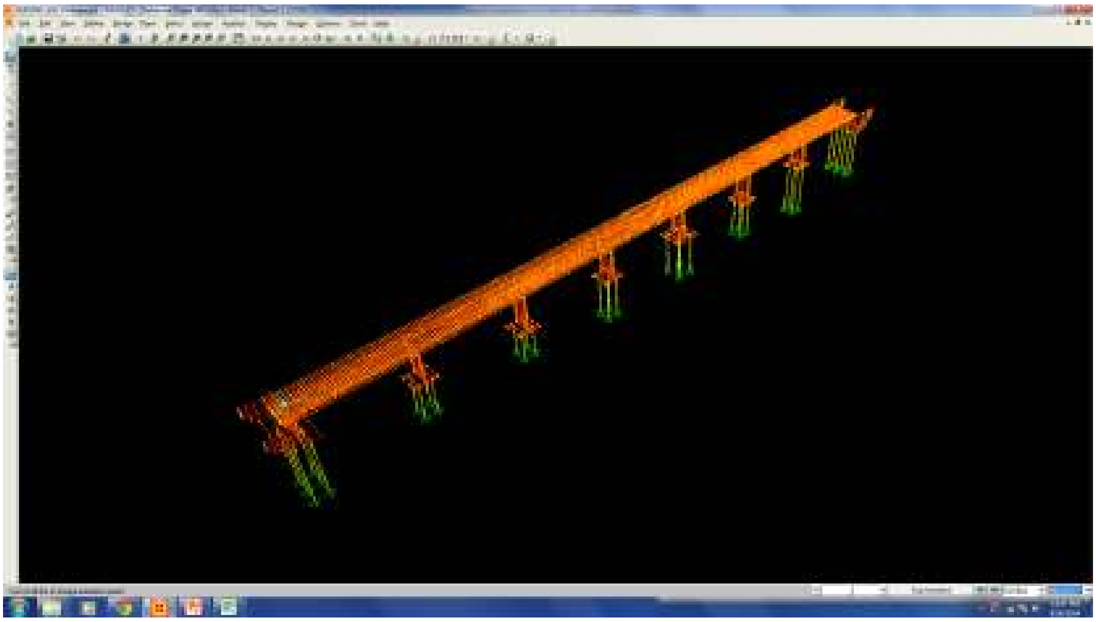


Fig Aiii-1; Mode No.1 – translation mode

Fig Aiii-2; Mode No.8 – Bending mode

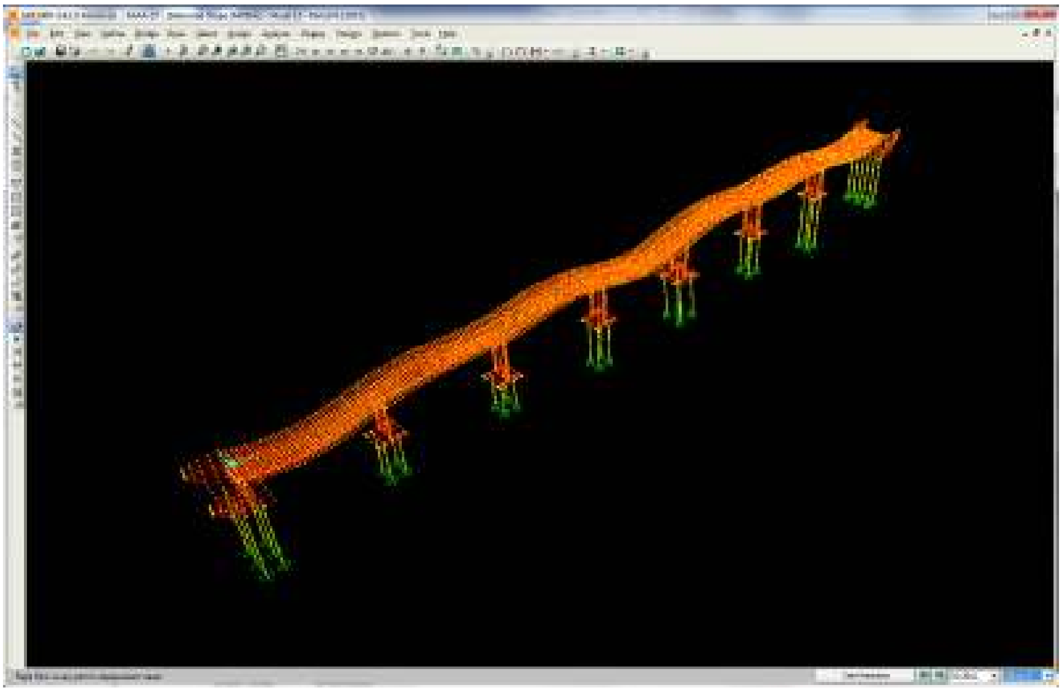


Fig Aiii-3; Mode No.12 – Bending mode

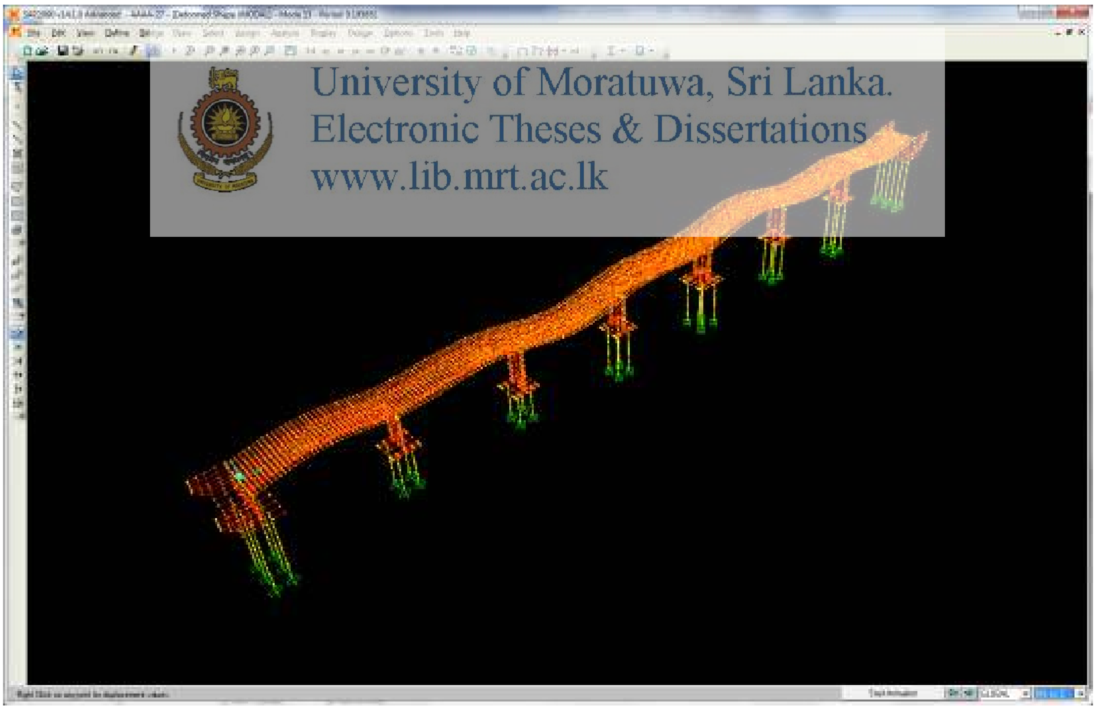


Fig Aiii-4; Mode No.13 – Bending mode

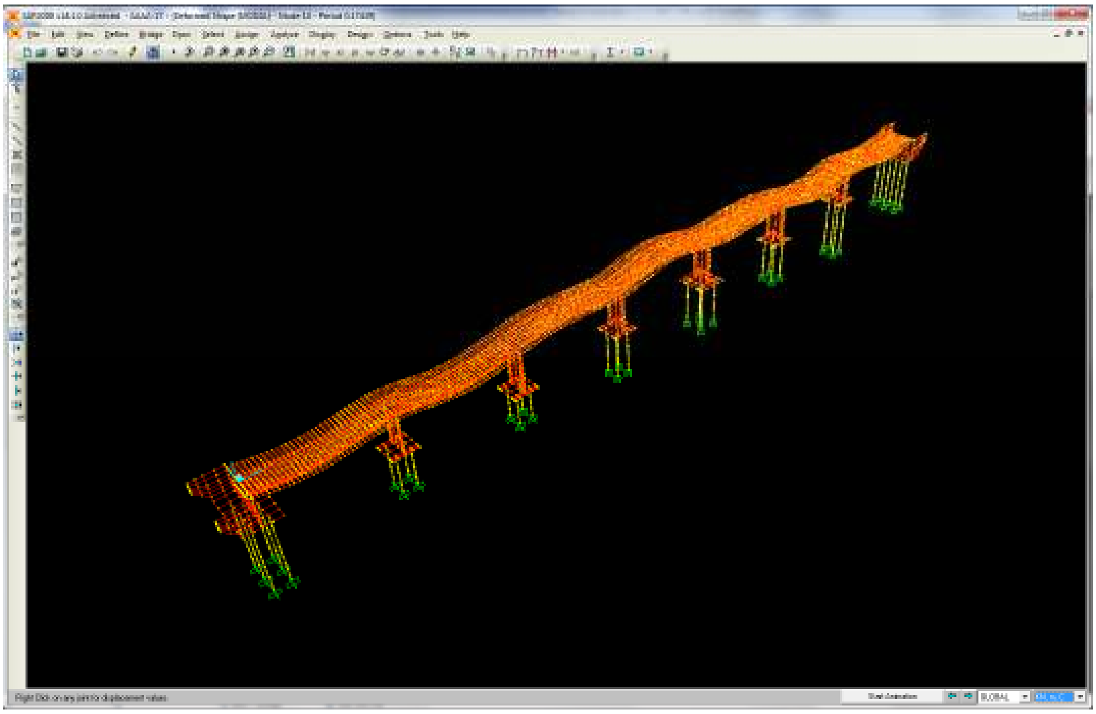


Fig Aiii-5; Mode No.14 – Bending mode

Fig Aiii-6; Mode No.41 – Bending mode

Results (Superstructure)

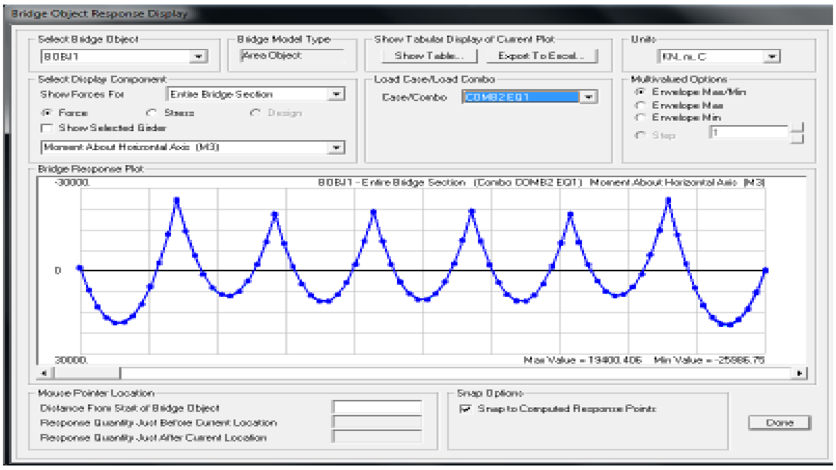


Fig Aiii-7; Bending moment envelope (Com2 EQ1)

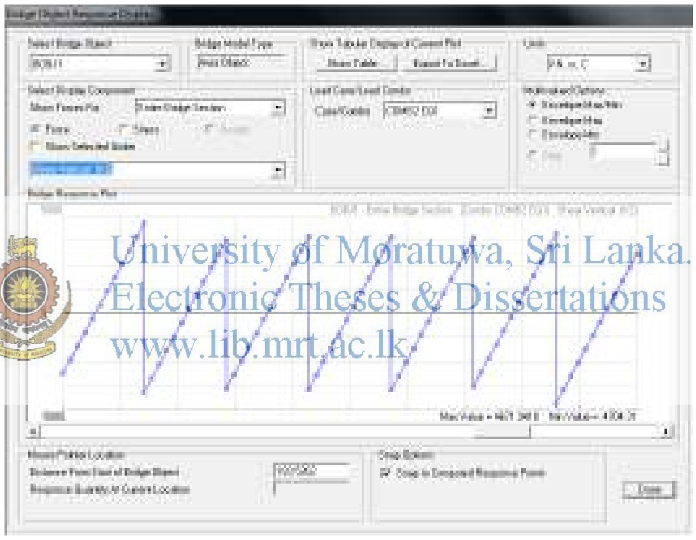


Fig Aiii-8; Shear force envelope (Com2 EQ1)

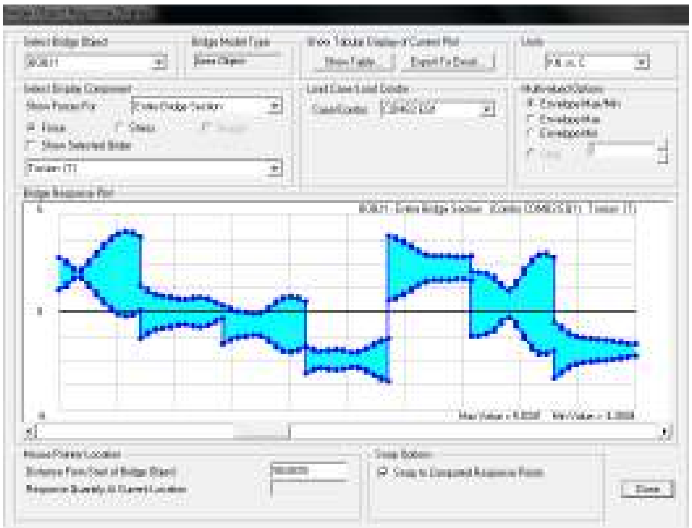


Fig Aiii-9; Torsion envelope (Com2 EQ1)

Results (Substructure)

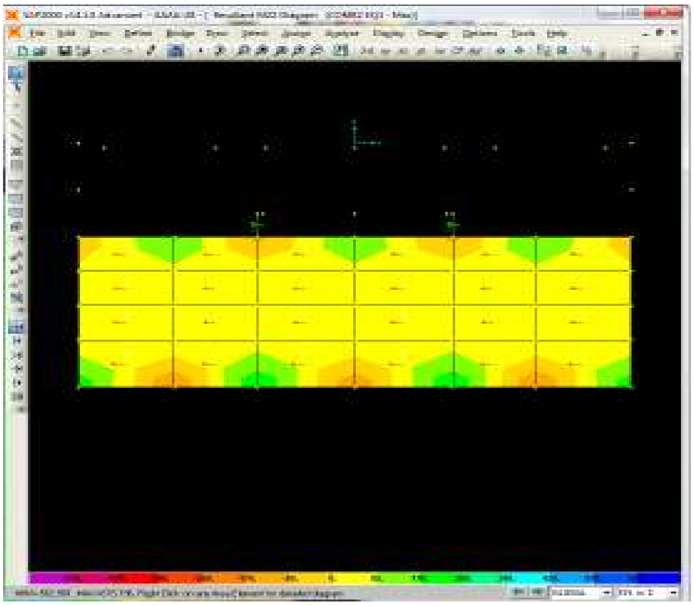


Fig Aiii-10; Bending moment distribution - Abutment A1 (Com2 EQ1)

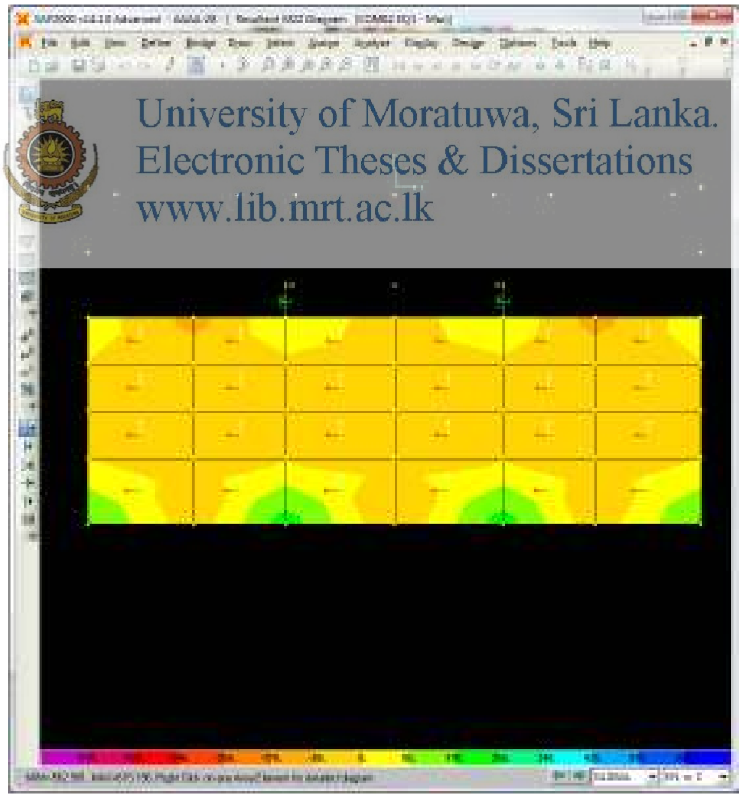


Fig Aiii-11; Bending moment distribution - Abutment A2 (Com2 EQ1)

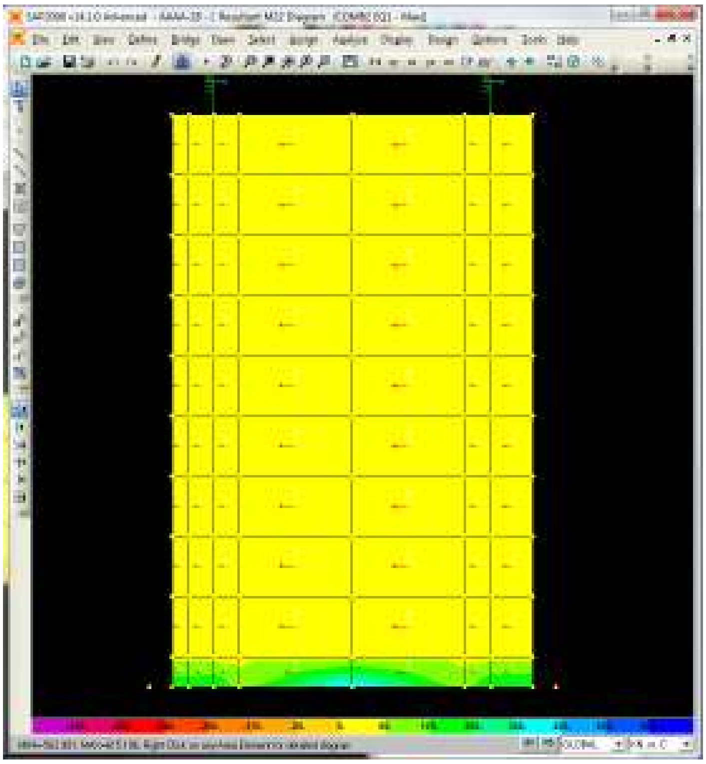


Fig Aiii-12; Bending moment distribution – Pier P1 (Com2 EQ1)

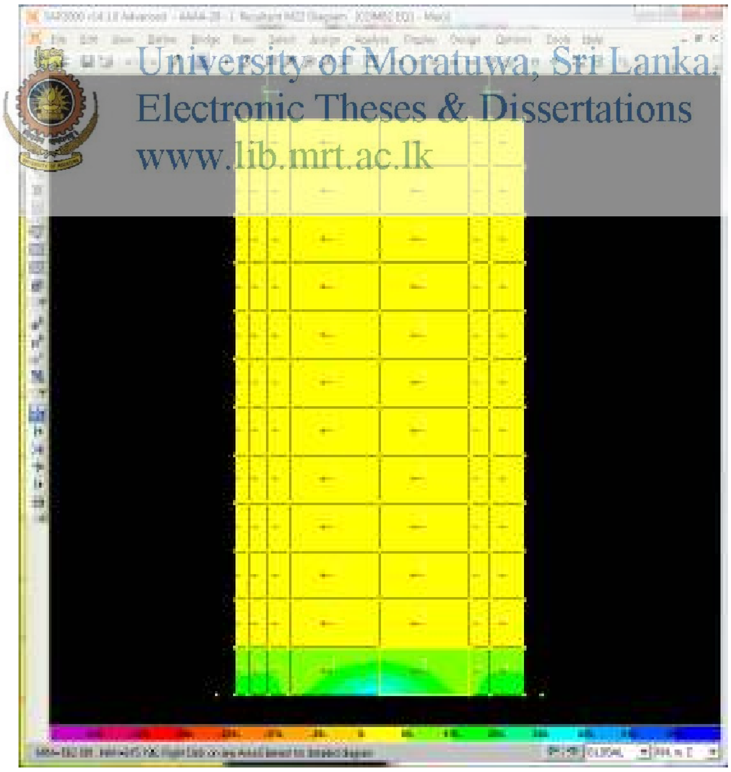


Fig Aiii-13; Bending moment distribution – Pier P2 (Com2 EQ1)

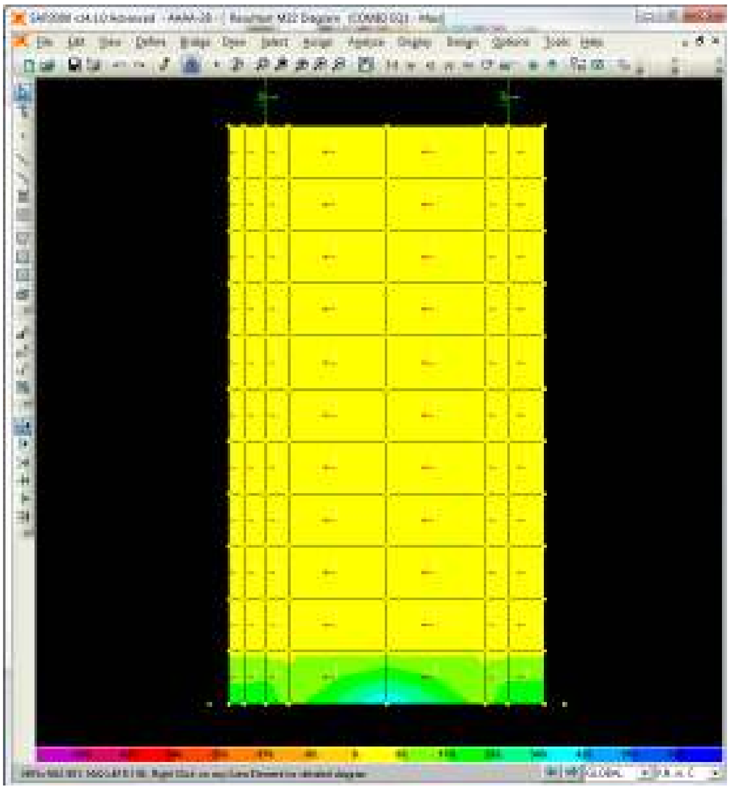


Fig Aiii-14; Bending moment distribution – Pier P3 (Com2 EQ1)

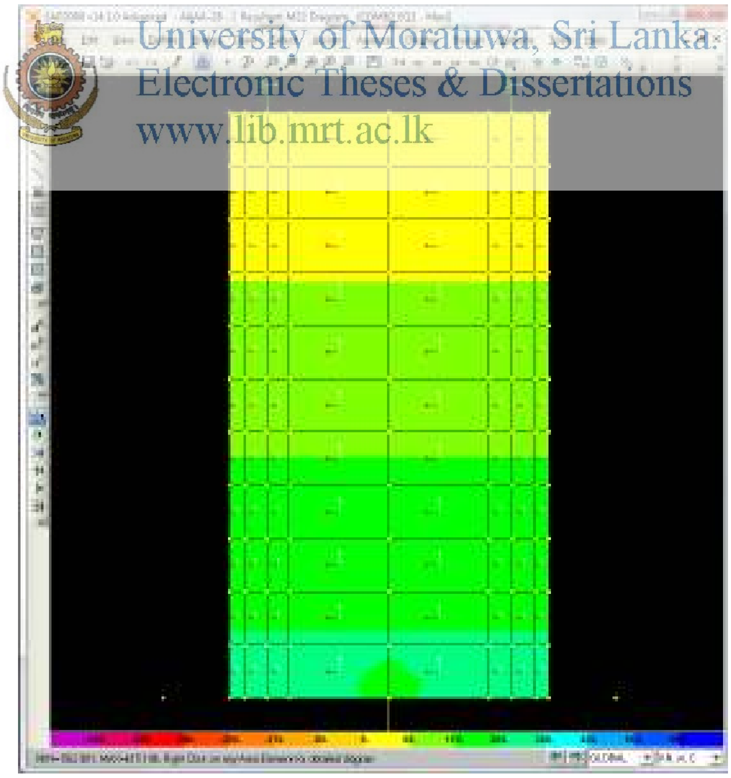


Fig Aiii-14; Bending moment distribution – Pier P4 (Com2 EQ1)

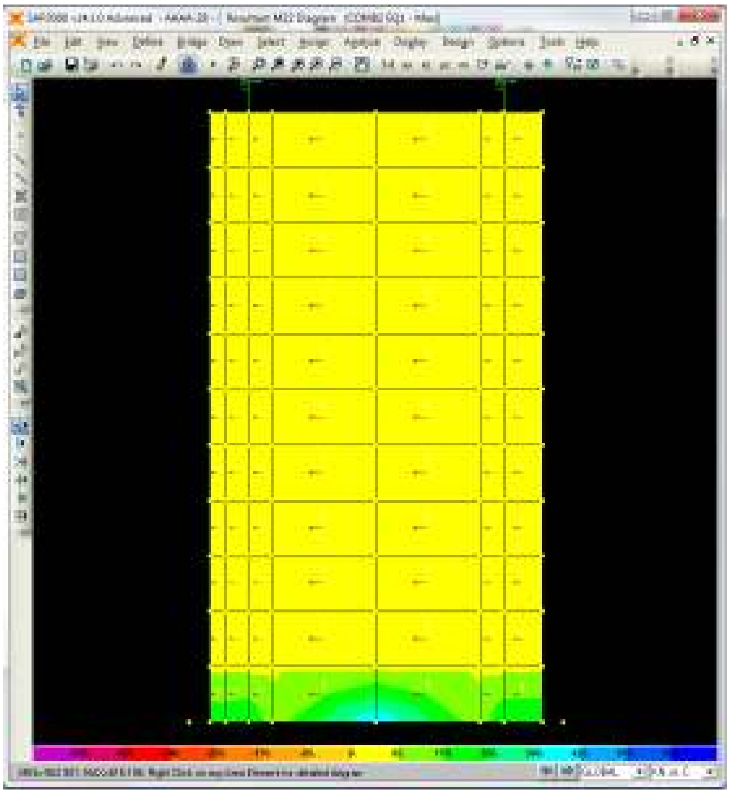


Fig Aiii-15; Bending moment distribution – Pier P5 (Com2 EQ1)

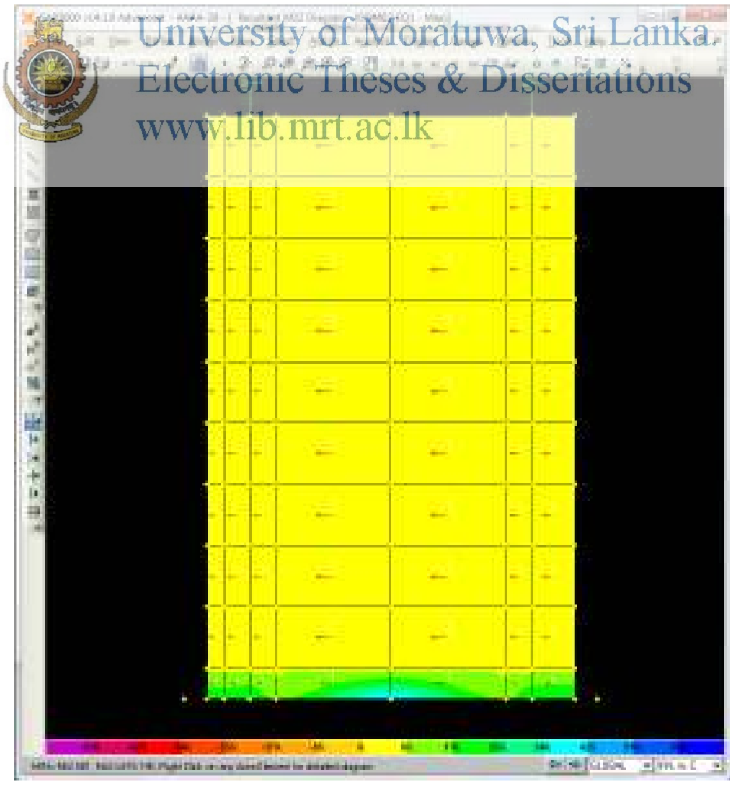


Fig Aiii-16; Bending moment distribution – Pier P6 (Com2 EQ1)

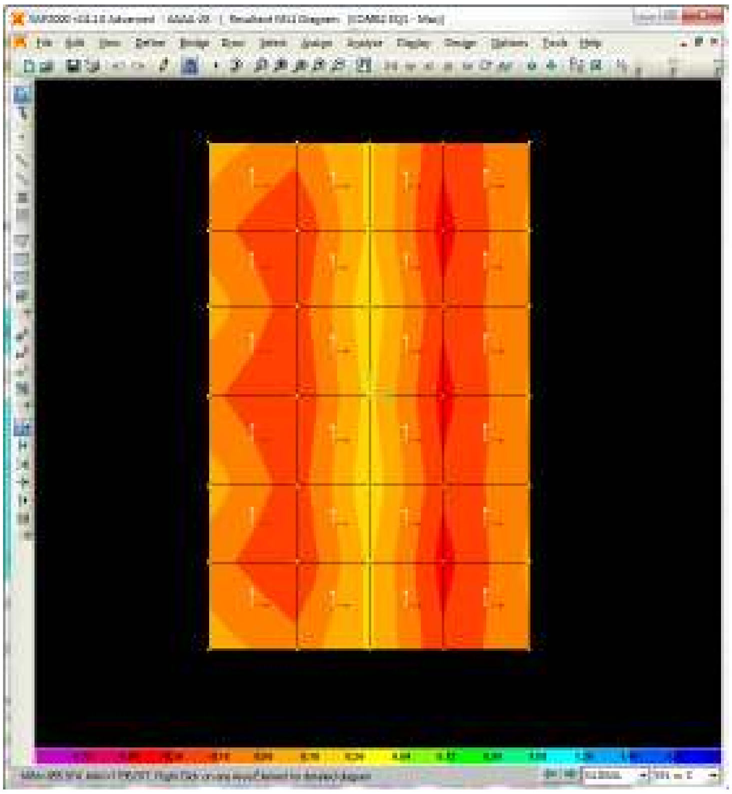


Fig Aiii-17; Bending moment distribution – Pile cap A1 (Com2 EQ1)

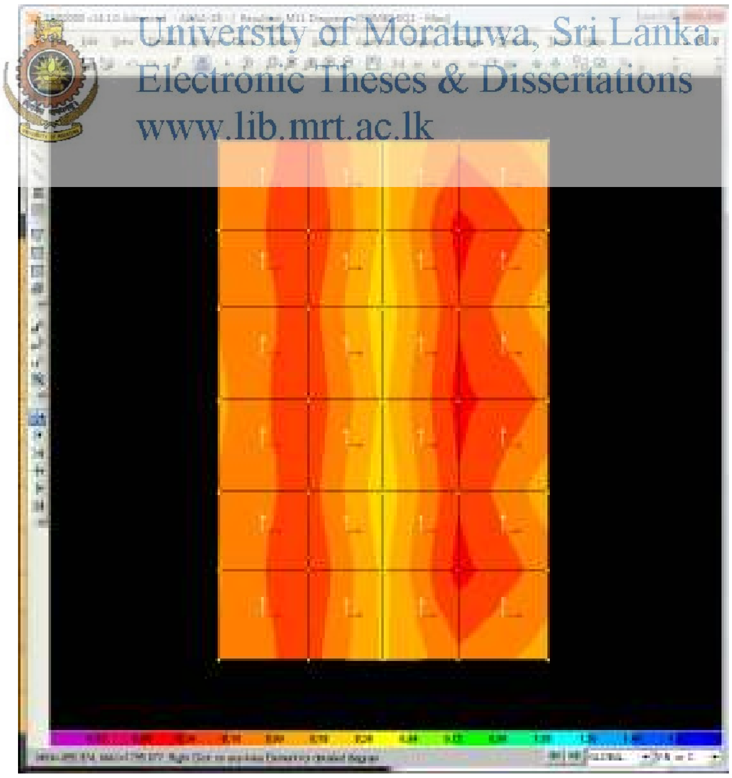


Fig Aiii-18; Bending moment distribution – Pile cap A2 (Com2 EQ1)

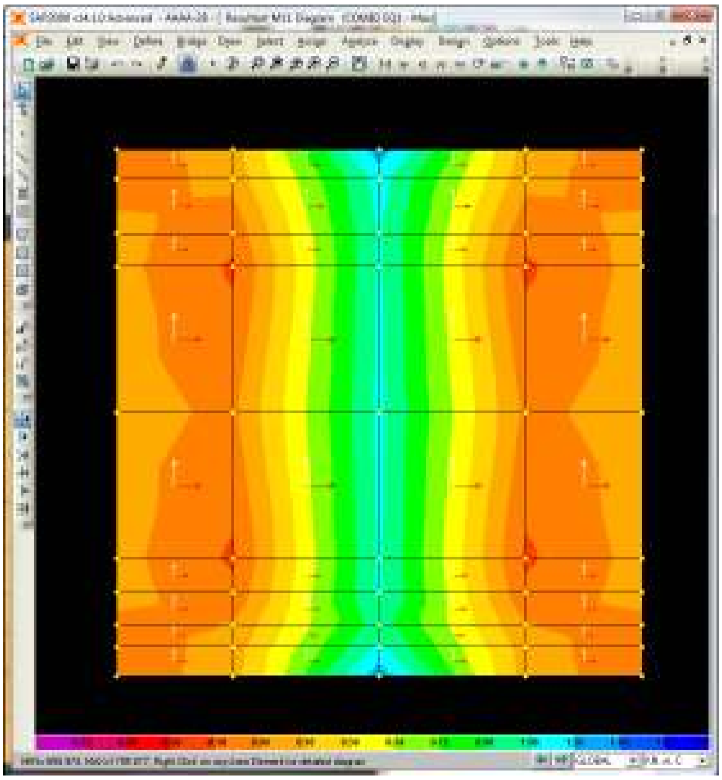


Fig Aiii-19; Bending moment distribution – Pile cap P1 (Com2 EQ1)

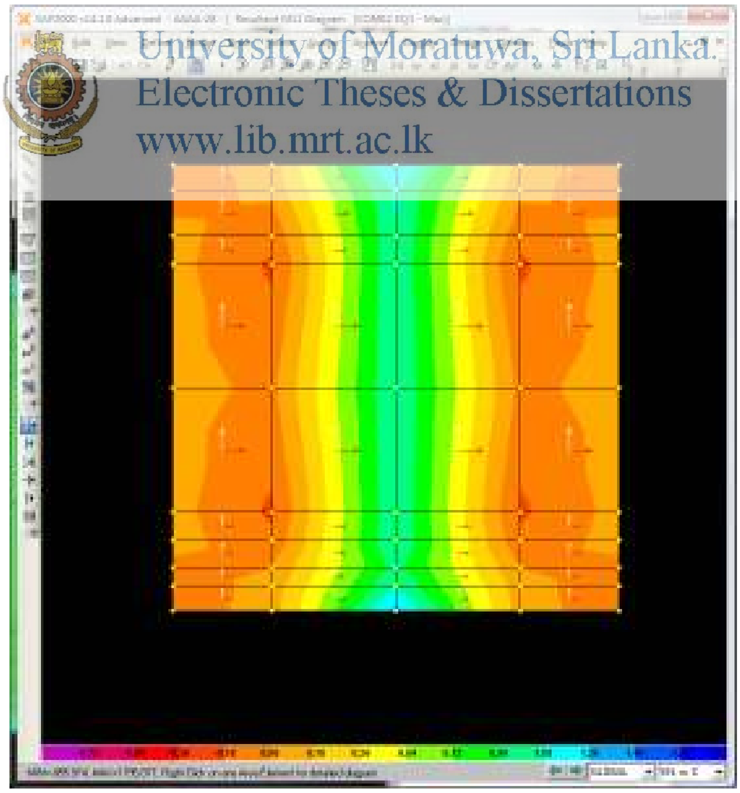


Fig Aiii-20; Bending moment distribution – Pile cap P2 (Com2 EQ1)

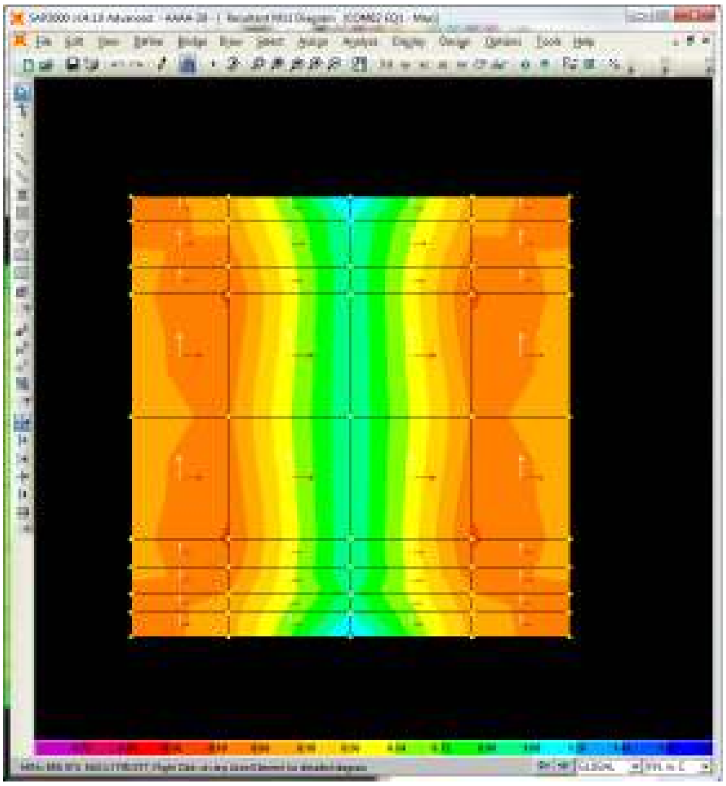


Fig Aiii-21; Bending moment distribution – Pile cap P3 (Com2 EQ1)

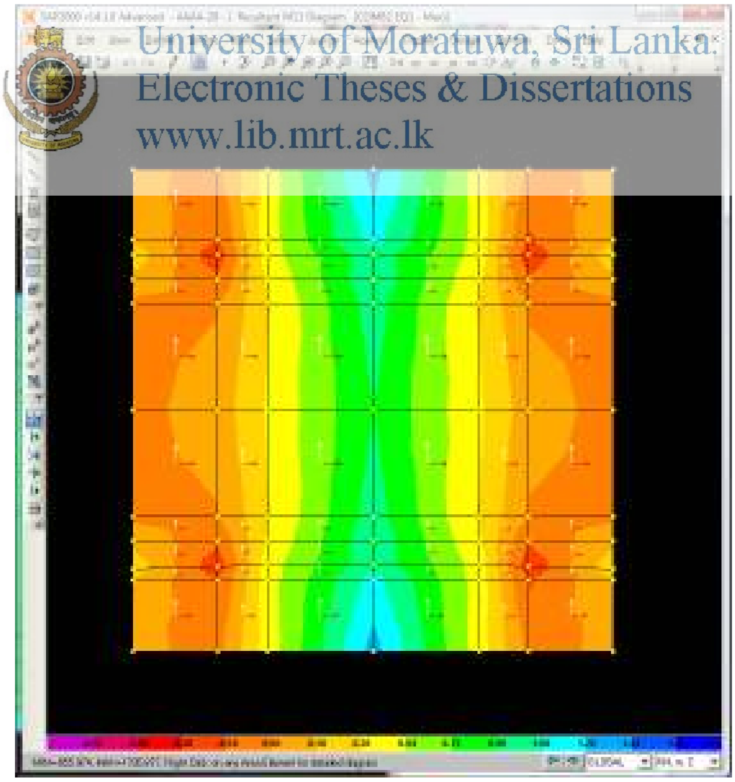


Fig Aiii-22; Bending moment distribution – Pile cap P4 (Com2 EQ1)

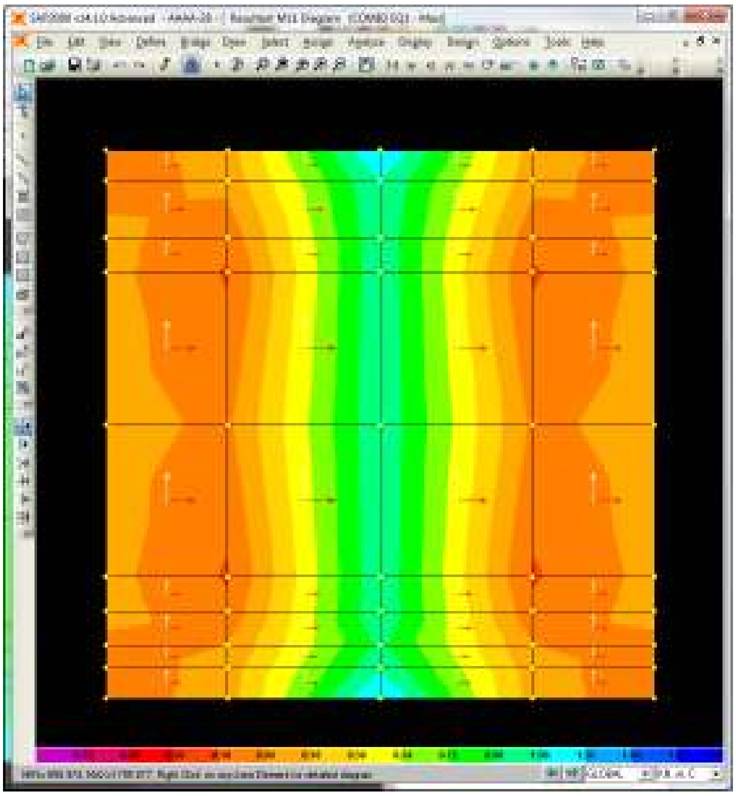


Fig Aiii-23; Bending moment distribution – Pile cap P5 (Com2 EQ1)

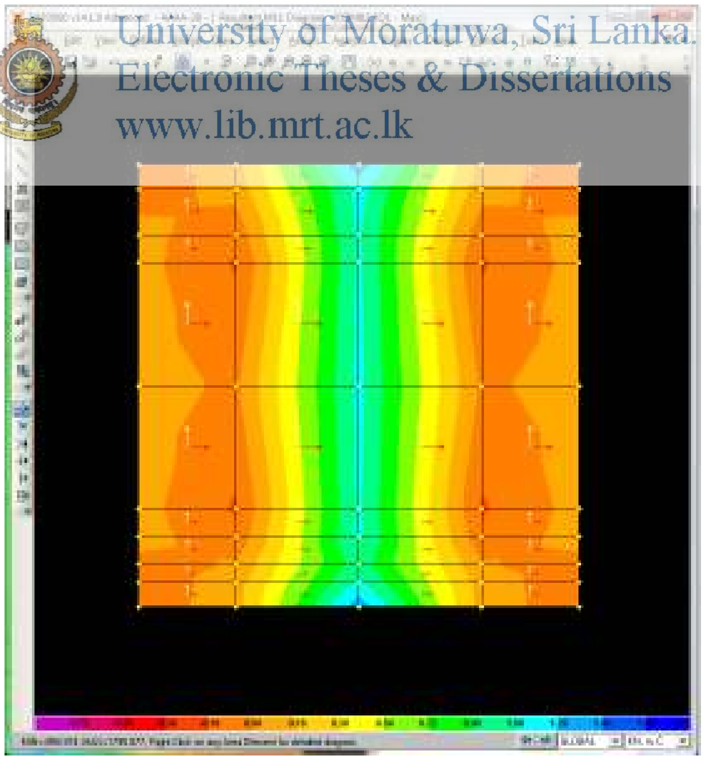


Fig Aiii-24; Bending moment distribution – Pile cap P6 (Com2 EQ1)

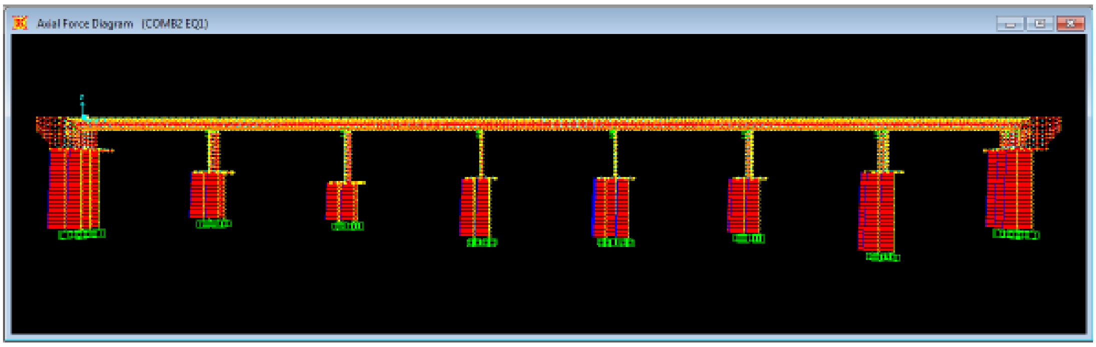


Fig Aiii-25; Axial force distribution – Piles (Com2 EQ1)

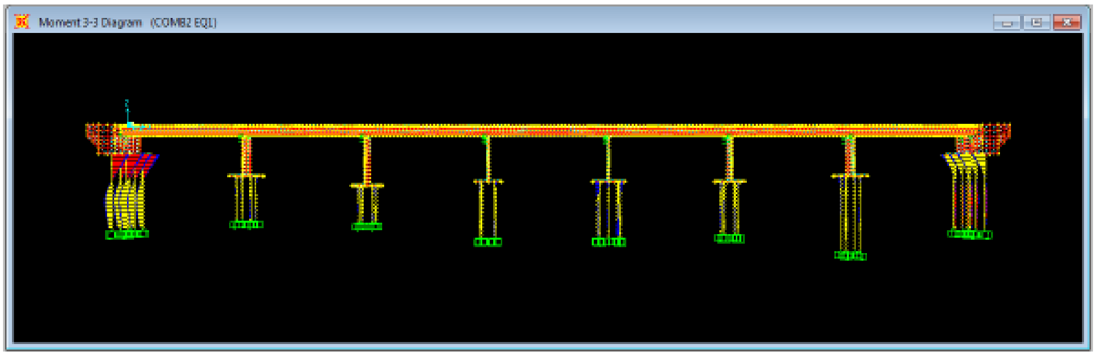


Fig Aiii-26; Bending moment distribution – Piles (Com2 EQ1)

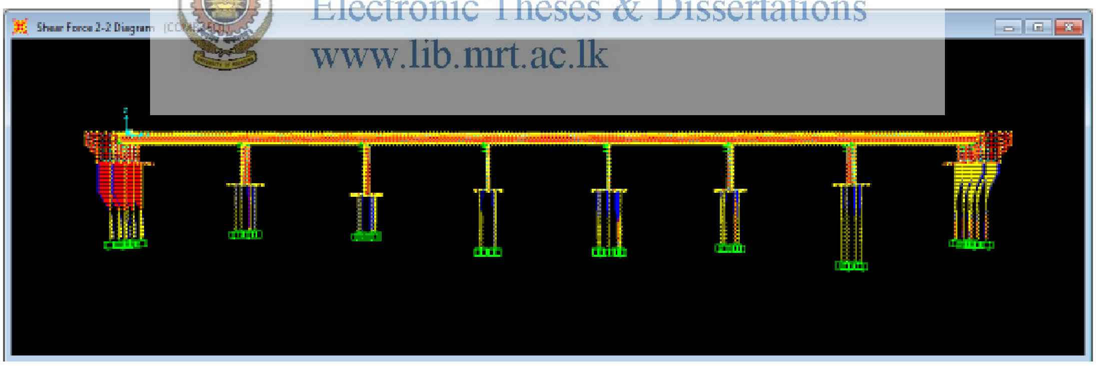


Fig Aiii-27; Shear force distribution – Piles (Com2 EQ1)

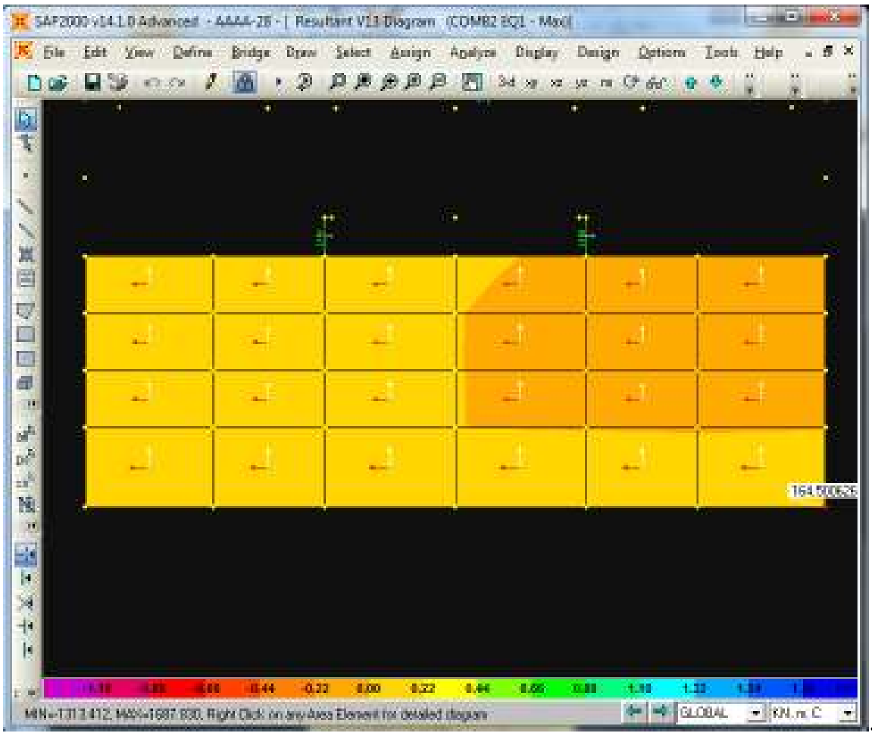


Fig Aiii-28; Shear force distribution – Abutment A1 (Com2 EQ1)

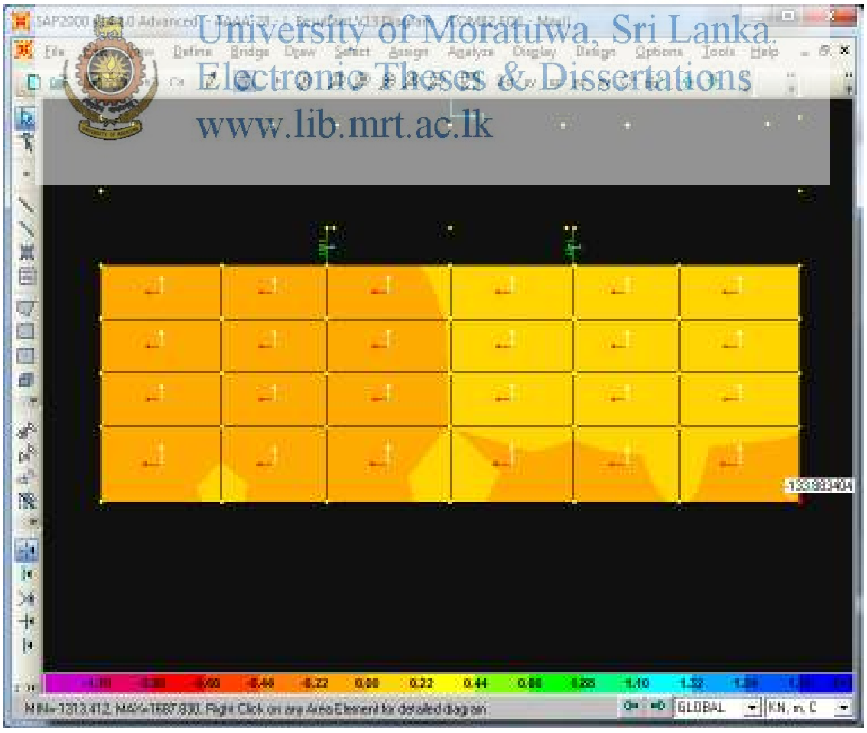


Fig Aiii-29; Shear force distribution – Abutment A2 (Com2 EQ1)

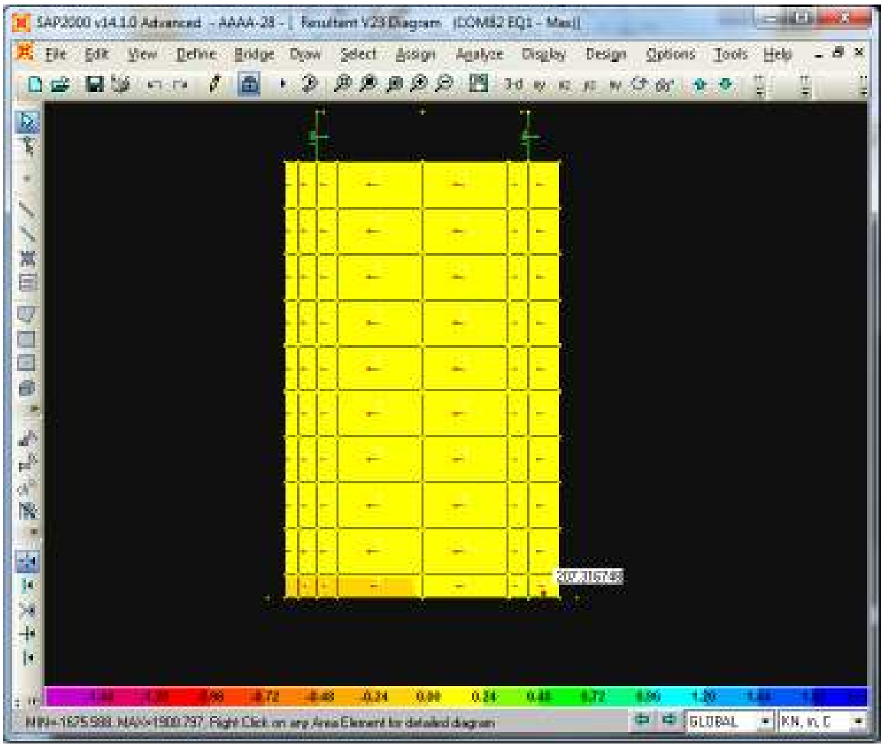


Fig Aiii-30; Shear force distribution – Pier P1 (Com2 EQ1)

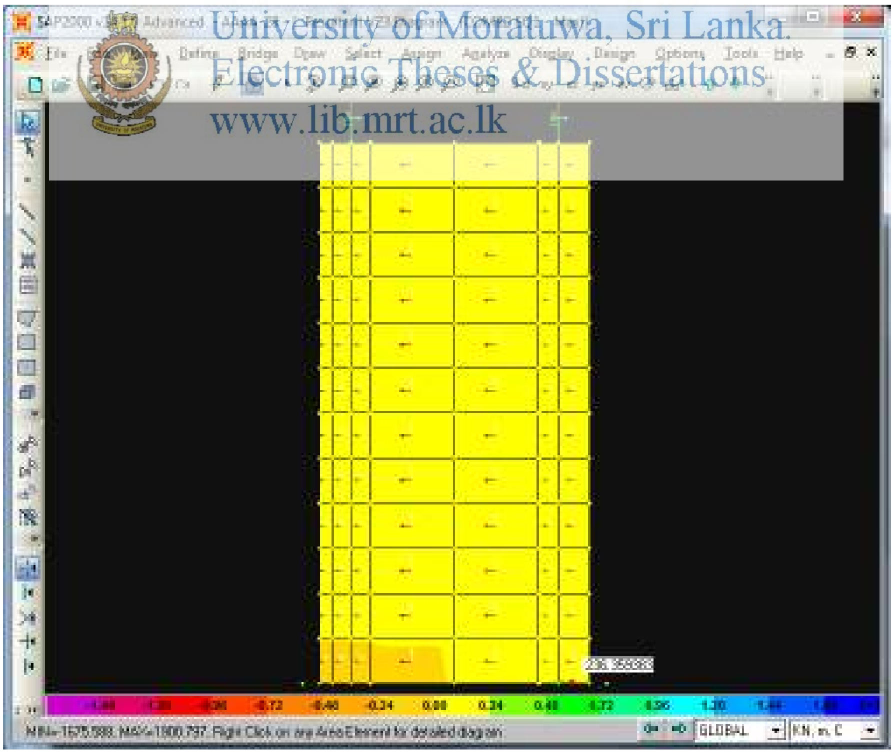


Fig Aiii-31; Shear force distribution – PierP2 (Com2 EQ1)

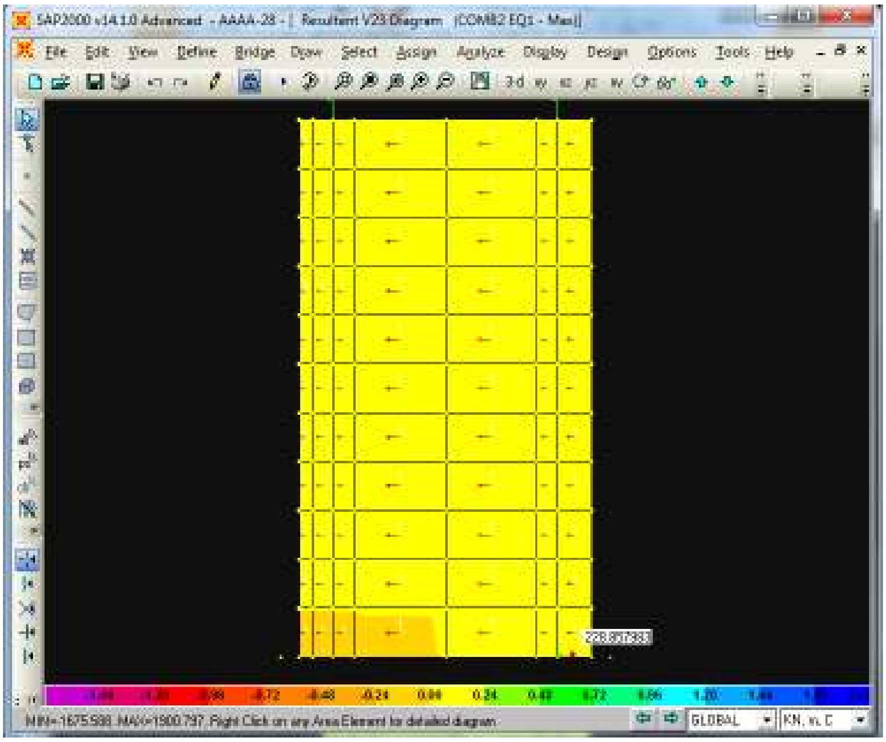


Fig Aiii-32; Shear force distribution – Pier P3 (Com2 EQ1)

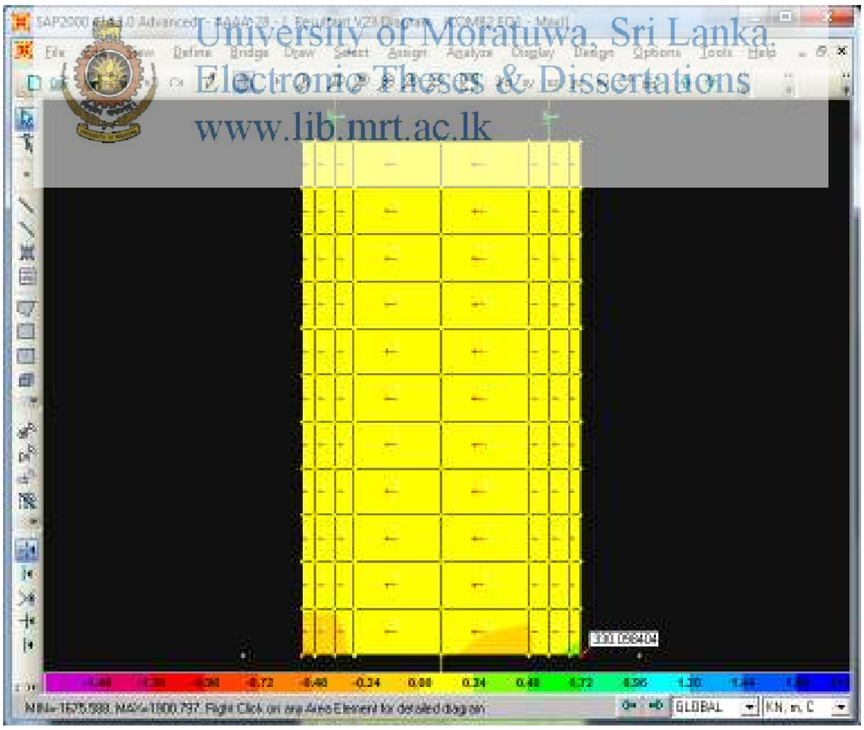


Fig Aiii-33; Shear force distribution – Pier P4 (Com2 EQ1)

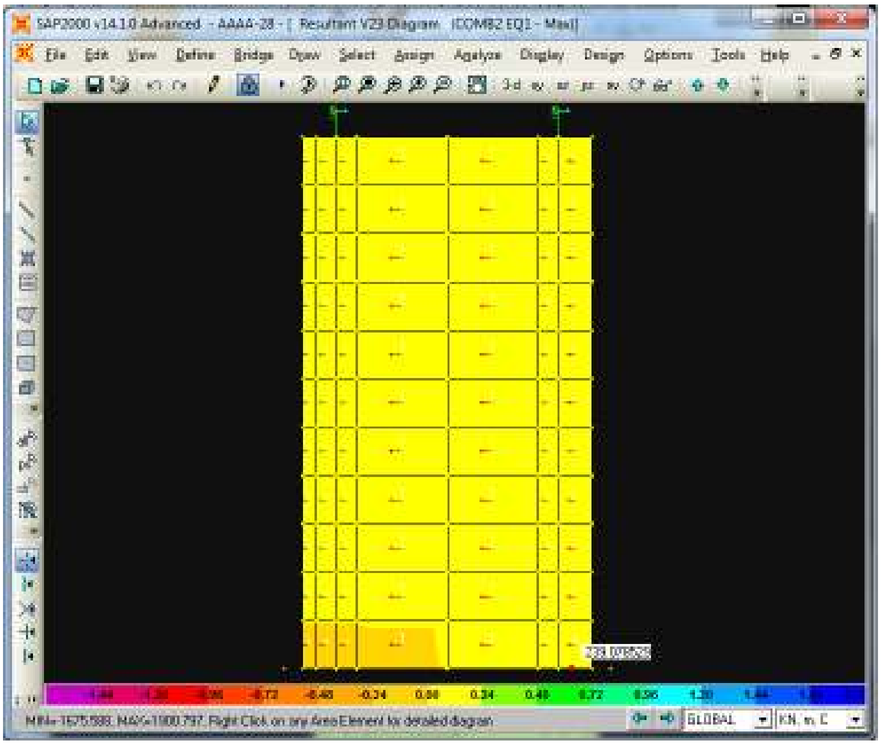


Fig Aiii-34; Shear force distribution – Pier P5 (Com2 EQ1)

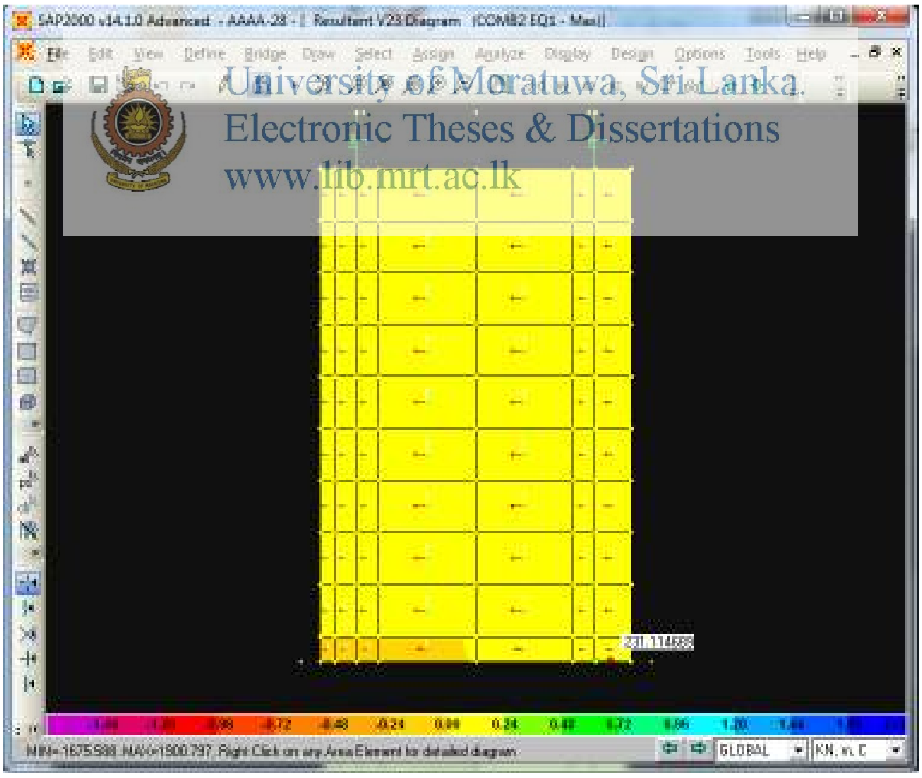


Fig Aiii-35; Shear force distribution – Pier P6 (Com2 EQ1)

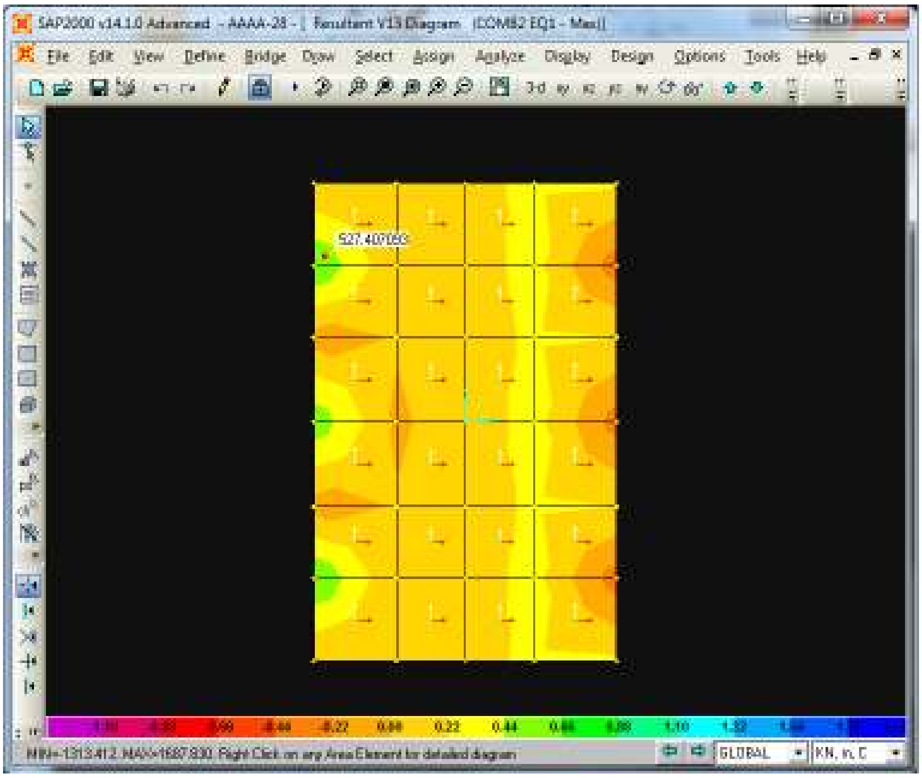


Fig Aiii-36; Shear force distribution – Pile cap A1 (Com2 EQ1)

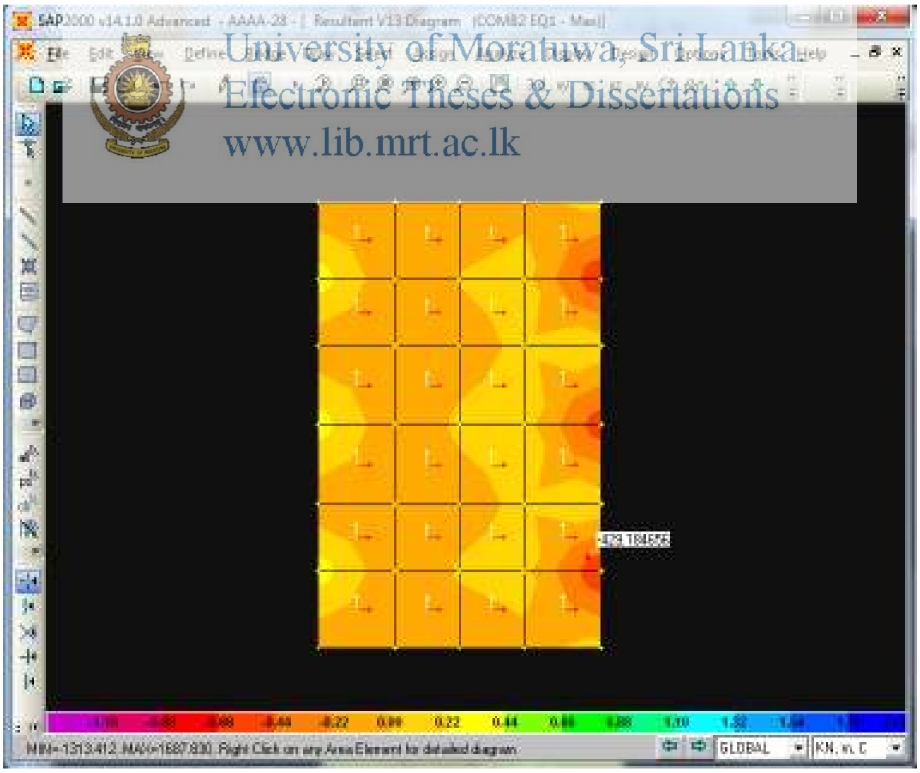


Fig Aiii-37; Shear force distribution – Pile cap A2 (Com2 EQ1)

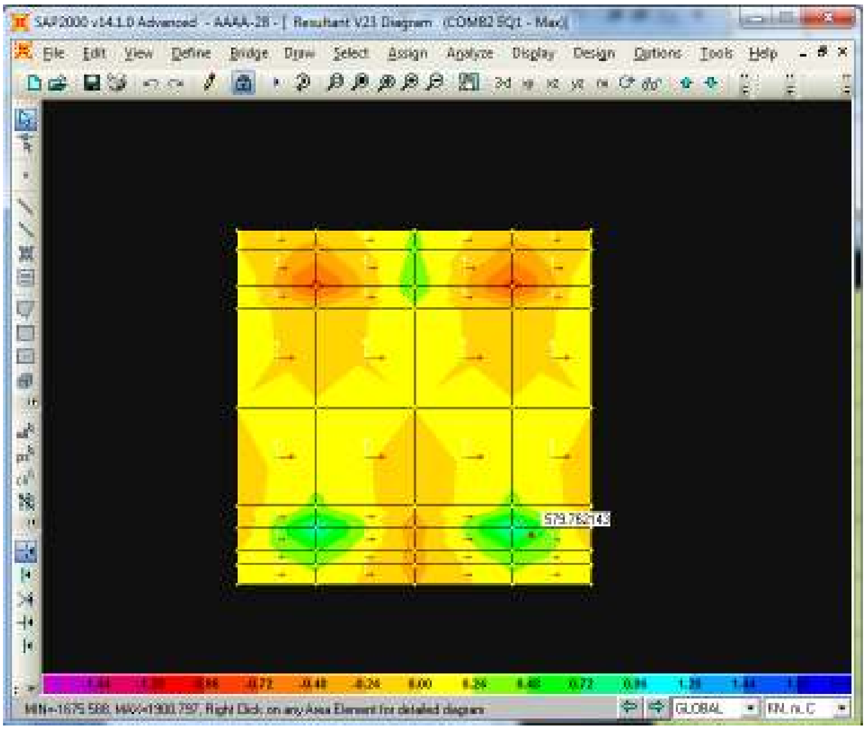


Fig Aiii-38; Shear force distribution – Pile cap P1 (Com2 EQ1)

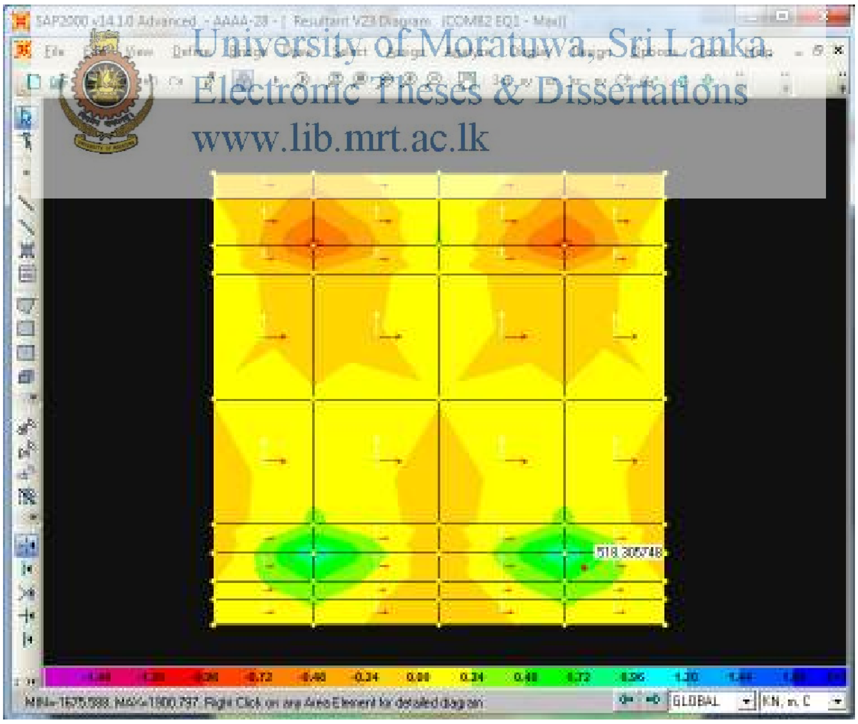


Fig Aiii-39; Shear force distribution – Pile cap P2 (Com2 EQ1)

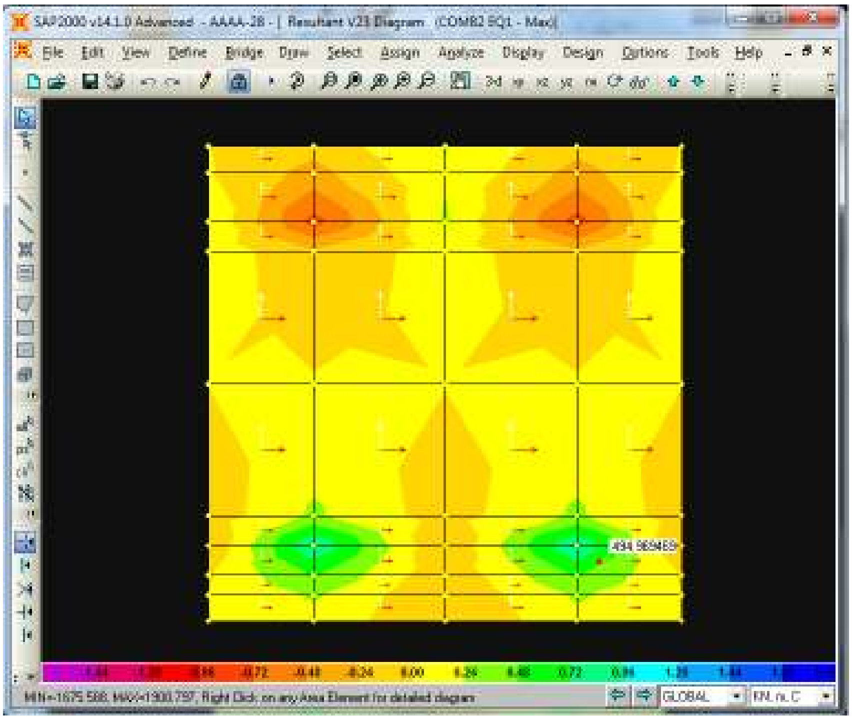


Fig Aiii-40; Shear force distribution – Pile cap P3 (Com2 EQ1)

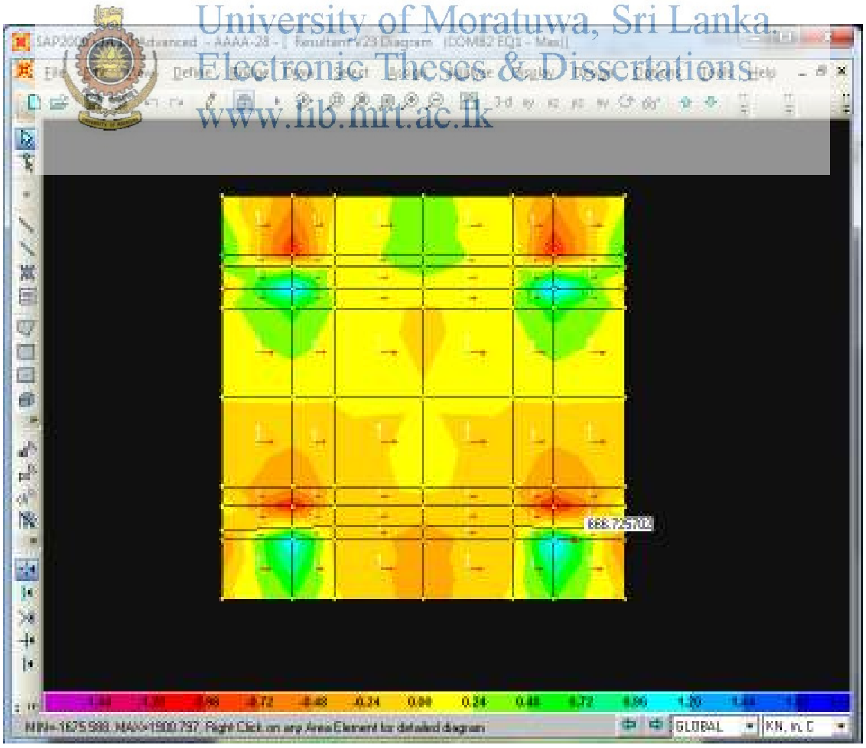


Fig Aiii-41; Shear force distribution – Pile cap P4 (Com2 EQ1)

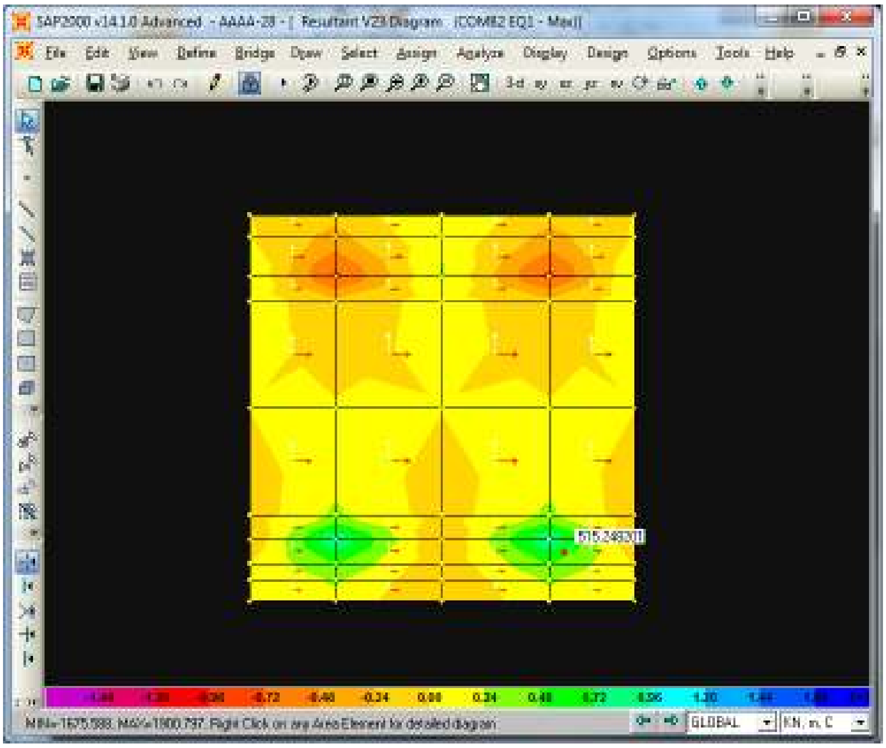


Fig Aiii-42; Shear force distribution – Pile cap P5 (Com2 EQ1)

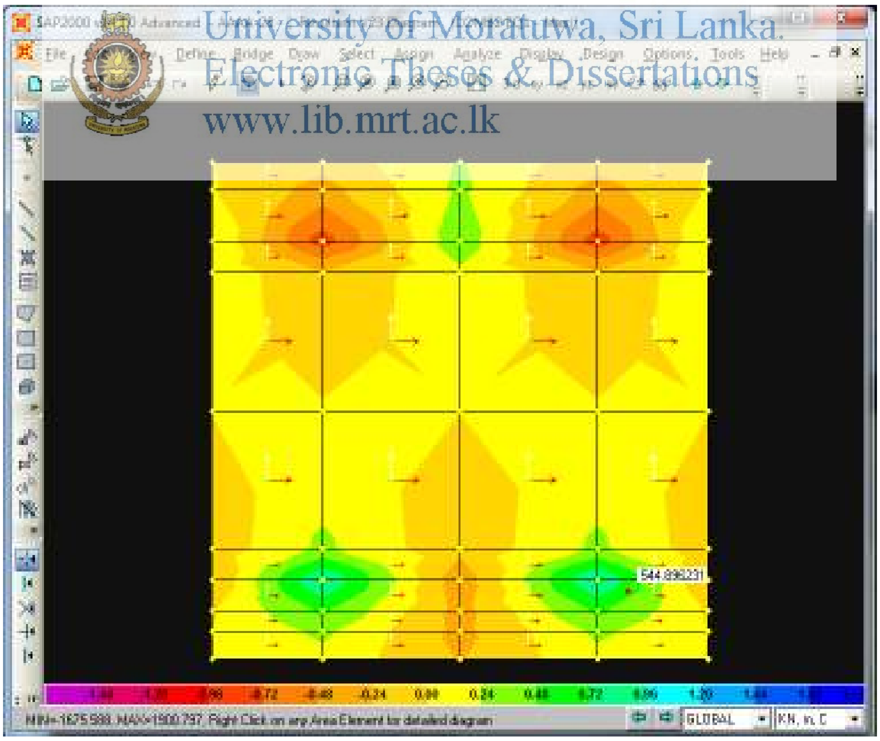


Fig Aiii-43; Shear force distribution – Pile cap P6 (Com2 EQ1)

APPENDIX – D

CAPACITY CALCULATIONS OF THE ELEMENTS

Check for Flexure for Australian Standards

for $k_u \leq 0.4$, design strength in bending = ΦM_{uo}

$$M_{uo} = 1.2\left\{z\left(f_{cf'} + \frac{P}{A_g}\right) + Pe\right\}$$

Where,

M_{uo}	Ultimate strength in bending without axial forces
Z	Section modulus of the uncracked section
$f_{cf'}$	Characteristic flexural strength of the concrete
P	Prestressing force
A_g	Gross cross sectional area of the member
e	Eccentricity of the prestressing force
k_u	Neutral axis parameter

From 1st principles

$$k_u = \frac{0.003 A_s E_s}{0.85 f_c^{'} b d \gamma} \times (1 - k_u)$$

Where $\gamma = \left[0.85 - 0.007\left(f_c^{'} - 28\right)\right]$

Therefore $k_u = \dfrac{\left|\sqrt{(\alpha^2 + 4\alpha)}\right| - \alpha}{2}$

	Stems							
	P_1	P_2	P_3	P_4	P_5	P_6	A_1	A_2
width of the section (mm)	1000	1000	1000	1000	1000	1000	1000	1000
Depth of the section (mm)	1500	1500	1500	1500	1500	1500	2150	2150
Cover to r/f (mm)	110	110	110	110	110	110	100	100
Diameter of main r/f (mm)	32	32	32	32	32	32	25	25
Spacing of the main r/f (mm)	125	125	125	125	125	125	250	250
A_s Provided (mm^2)	6433.982	6433.98	6433.98	6433.98	6433.982	6433.98	1963.50	1963.50
$f_c^{'}$ (N/mm^2)	30	30	30	30	30	30	30	30
$f_{cf}^{'}$ (N/mm^2)	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29
f_y (N/mm^2)	340	340	340	340	340	340	340	340

E_s (kN/mm^2)	200	200	200	200	200	200	200	200
d (mm)	1374	1374	1374	1374	1374	1374	2037.5	2037.5
γ	0.836	0.836	0.836	0.836	0.836	0.836	0.836	0.836
α	0.13	0.13	0.13	0.13	0.13	0.13	0.03	0.03
k_u	0.30	0.30	0.30	0.30	0.30	0.30	0.15	0.15
	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
I	1.25E+11	1.3E+11	1.3E+11	1.3E+11	1.25E+11	1.3E+11	1.8E+11	1.79E+11
d_{NA}	500	500	500	500	500	500	500	500
Z	2.5E+08	2.5E+08	2.5E+08	2.5E+08	2.5E+08	2.5E+08	3.6E+08	3.58E+08
P	0	0	0	0	0	0	0	0
e	0	0	0	0	0	0	0	0
A_g	1500000	1500000	1500000	1500000	1500000	1500000	2150000	2150000
M_{uo}	985.9006	985.901	985.901	985.901	985.9006	985.901	1413.12	1413.124
ϕ	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
ϕM_{uo}	788.7205	788.72	788.72	788.72	788.7205	788.72	1130.5	1130.499
$M_{applied}$	424.00	423.00	418.00	320.00	410.00	428.00	246.00	214.00
	Safe	Safe	Safe	Safe	Safe	Safe	Safe	Safe

Pile Caps

	P_1	P_2	P_3	P_4	P_5	P_6	A_1	A_2
width of the section (mm)	1000	1000	1000	1000	1000	1000	1000	1000
Depth of the section (mm)	2000	2000	2000	2000	2000	2000	2000	2000
Cover to r/f (mm)	100	100	100	100	100	100	100	100
Diameter of main r/f (mm)	29	29	29	32	29	29	25	25
Spacing of the main r/f (mm)	125	125	125	125	125	125	250	250
A_s Provided (mm^2)	5284.16	5284.16	5284.16	6433.98	5284.16	5284.16	1963.50	1963.50
f_c' (N/mm^2)	30	30	30	30	30	30	30	30
f_{cf}' (N/mm^2)	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29
f_y (N/mm^2)	340	340	340	340	340	340	340	340
E_s (kN/mm^2)	200	200	200	200	200	200	200	200
d (mm)	1885.5	1885.5	1885.5	1884	1885.5	1885.5	1887.5	1887.5
γ	0.836	0.836	0.836	0.836	0.836	0.836	0.836	0.836
α	0.08	0.08	0.08	0.10	0.08	0.08	0.03	0.03
k_u	0.24	0.24	0.24	0.27	0.24	0.24	0.16	0.16
	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
I	1.67E+11	1.7E+11	1.7E+11	1.7E+11	1.67E+11	1.7E+11	1.7E+11	1.67E+11
d_{NA}	500	500	500	500	500	500	500	500
Z	3.33E+08	3.33E+08	3.33E+08	3.33E+08	3.33E+08	3.33E+08	3.33E+08	3.33E+08
P	0	0	0	0	0	0	0	0
e	0	0	0	0	0	0	0	0
A_g	2000000	2000000	2000000	2000000	2000000	2000000	2000000	2000000
M_{uo}	1314.534	1314.53	1314.53	1314.53	1314.534	1314.53	1314.53	1314.534
ϕ	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
ϕM_{uo}	1051.627	1051.627	1051.627	1051.627	1051.627	1051.627	1051.627	1051.627
$M_{applied}$	1021.00	972.00	963.00	1025.00	944.00	998.00	427.00	429.00
	Safe	Safe	Safe	Safe	Safe	Safe	Safe	Safe

Check for Shear for Australian Standards

Design shear strength = ϕV_u

$V_u = V_{uc} + V_{us}$

Where,

V_{uc} Shear strength excluding shear r/f

V_{us} Shear strength contributed by shear r/f

$$V_{uc} = \beta_1 \beta_2 \beta_3 b_v d_0 \left[\frac{A_{st} f'_c}{b_v d_0} \right]^{\frac{1}{3}}$$

Where,

$$\beta_1 = 1.1 \left[1.6 - \frac{d_0}{1000} \right] \geq 1.1$$

$$\beta_2 = 1.0$$

or

$$1 - \left[\frac{N^*}{3.5 A_g} \right] \geq 0$$ for members subjected to axial tension

$$1 + \left[\frac{N^*}{14 A_g} \right] \geq 0$$ for members subjected to axial compression

$\beta_3 =$ 1.0 or

$2d_0/a_v$ but not greater than 2

$$V_{us} = \frac{A_{sv} f_{sy.f} d_o}{s} Cot\theta_v$$

In abutments & Piers it was not used shear reinforcements. Therefore V_{us} will be zero

	Stems							
	P_1	P_2	P_3	P_4	P_5	P_6	A_1	A_2
Applied Shear Force V (kN)	207	236	229	330	239	231	164	133
d_0 (mm)	1,374	1,374	1,374	1,374	1,374	1,374	2,038	2,038
β_1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
A_g (mm^2)	1,500,000	1,500,000	1,500,000	1,500,000	1,500,000	1,500,000	2,150,000	2,150,000
N^*								
β_2	1	1	1	1	1	1	1	1
β_3	2	2	2	2	2	2	2	2
b_v (mm)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
f'_c(N/mm^2)	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
A_{st} (mm^2)	6,434	6,434	6,434	6,434	6,434	6,434	1,963	1,963
V_{uc} (kN)	1,571	1,571	1,571	1,571	1,571	1,571	1,376	1,376

V_{us} (kN)	-	-	-	-	-	-	-	-
V_u (kN)	1,571	1,571	1,571	1,571	1,571	1,571	1,376	1,376
ϕ	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
ϕV_u(kN)	1,100	1,100	1,100	1,100	1,100	1,100	963	963
	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy

	Pile caps							
	P_1	P_2	P_3	P_4	P_5	P_6	A_1	A_2
Applied Shear Force V (kN)	580	518	495	667	515	545	527	429
d_0 (mm)	1,886	1,886	1,886	1,884	1,886	1,886	1,888	1,888
β_1	1	1	1	1	1	1	1	1
A_g (mm^2)	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
N^*								
β_2	1	1	1	1	1	1	1	1
β_3	2	2	2	2	2	2	2	2
b_v (mm)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
f'_c(N/mm^2)	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
A_{st} (mm^2)	5,284	5,284	5,284	6,434	5,284	5,284	1,963	1,963
V_{uc} (kN)	1,652	1,652	1,652	1,763	1,652	1,652	1,189	1,189
V_{us} (kN)	-	-	-	-	-	-	-	-
V_u (kN)	1,652	1,652	1,652	1,763	1,652	1,652	1,189	1,189
ϕ	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
ϕV_u(kN)	1,156	1,156	1,156	1,234	1,156	1,156	832	832
	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy

Check for Flexure for British Standards

Ultimate Bending Capacity

$$M_u = 0.87 f_y A_s Z$$

Where,

$$Z = \left(1 - \frac{1.1 f_y A_s}{f_{cu} bd}\right) d$$

or

Z = 0.95d

Z will be selected the minimum of above

$$K = \frac{M_u}{f_{cu} bd^2}$$

Where,

M_u	Ultimate resistance moment
f_y	Yield strength of reinforcement
A_s	Area of tension reinforcement
Z	liver arm
f_{cu}	characteristic strength of concrete
b	width of the section
d	Effective depth to tension reinforcement

	Pier shaft						Abutment	
	P_1	P_2	P_3	P_4	P_5	P_6	A_1	A_2
Ultimate Bending Moment (kNm/m)	424.00	423.00	418.00	320.00	410.00	428.00	246.00	214.00
Width of the section (mm)	1000	1000	1000	1000	1000	1000	1000	1000
Depth of the section (mm)	1500	1500	1500	1500	1500	1500	2150	2150
Diameter of main r/f (mm)	32	32	32	32	32	32	25	25
cover to r/f (mm)	110	110	110	110	110	110	100	100
Strength of concrete (fcu) (N/mm^2)	30	30	30	30	30	30	30	30
Strength of main r/f (fy) (N/mm2)	340	340	340	340	340	340	340	340
Effective depth -d (mm)	1374	1374	1374	1374	1374	1374	2037.5	2037.5
$K = \frac{M_u}{f_{cu} b d^2}$	0.007	0.007	0.007	0.006	0.007	0.008	0.002	0.002
	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required
Z-method I	1360.87	1360.90	1361.06	1364.11	1361.31	1360.74	2032.40	2033.06
0.95d	1305.30	1305.30	1305.30	1305.30	1305.30	1305.30	1935.63	1935.63
Z	1305.30	1305.30	1305.30	1305.30	1305.30	1305.30	1935.63	1935.63
mm^2	1098.14	1095.55						
Main r/f **T**	**32**	**32**	**32**	**32**	**32**	**32**	**25**	**25**
spacing @	**125**	**125**	**125**	**125**	**125**	**125**	**250**	**250**
A_s provided	**6434**	**6434**	**6434**	**6434**	**6434**	**6434**	**1963**	**1963**
Moment Capasity	**2484.21**	**2484.21**	**2484.21**	**2484.21**	**2484.21**	**2484.21**	**1124.21**	**1124.21**
Applied Moment	**424.00**	**423.00**	**418.00**	**320.00**	**410.00**	**428.00**	**246.00**	**214.00**
	OK	OK	OK	OK	OK	OK	OK	OK

Pile cap

	P_1	P_2	P_3	P_4	P_5	P_6	A_1	A_2
Ultimate Bending Moment (kNm/m)	1021.00	972.00	963.00	1025.00	944.00	998.00	427.00	429.00
Width of the section (mm)	1000	1000	1000	1000	1000	1000	1000	1000
Depth of the section (mm)	2000	2000	2000	2000	2000	2000	2000	2000
Diameter of main r/f (mm)	29	29	29	32	29	29	25	25
cover to r/f (mm)	100	100	100	100	100	100	100	100
Strength of concrete (fcu) (N/mm^2)	30	30	30	30	30	30	30	30
Strength of main r/f (fy) (N/mm2)	340	340	340	340	340	340	340	340
Effective depth -d (mm)	1885.5	1885.5	1885.5	1884	1885.5	1885.5	1887.5	1887.5
$K = \frac{M_u}{f_{cu} b d^2}$	0.010	0.009	0.009	0.010	0.009	0.009	0.004	0.004
	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required	No compression r/f required
Z-method I	1862.39	1863.52	1863.72	1860.78	1864.16	1862.92	1877.92	1877.87
0.95d	1791.23	1791.23	1791.23	1789.80	1791.23	1791.23	1793.13	1793.13
Z	1791.23	1791.23	1791.23	1789.80	1791.23	1791.23	1793.13	1793.13
mm^2	1926.98	1834.50						
Main r/f **T**	**29**	**29**	**29**	**32**	**29**	**29**	**25**	**25**
spacing @	**125**	**125**	**125**	**125**	**125**	**125**	**250**	**250**
A_s provided	**5284**	**5284**	**5284**	**6434**	**5284**	**5284**	**1963**	**1963**
Moment Capasity	**2799.78**	**2799.78**	**2799.78**	**3406.30**	**2799.78**	**2799.78**	**1041.45**	**1041.45**
Applied Moment	**1021.00**	**972.00**	**963.00**	**1025.00**	**944.00**	**998.00**	**427.00**	**429.00**
	OK	OK	OK	OK	OK	OK	OK	OK

Check for shear for British Standards

	Pier shaft						Abutment	
	P_1	P_2	P_3	P_4	P_5	P_6	A_1	A_2
Shear force - V (kN)	207.32	236.35	228.85	330.10	239.07	231.11	164.00	133.00
Shear stress - $v=V/bd$ (N/mm^2)	0.15	0.17	0.17	0.24	0.17	0.17	0.08	0.07
Shear capasity of concrete = $0.75(f_{cu})^{0.5}$ (N/mm^2)	4.11	4.11	4.11	4.11	4.11	4.11	4.11	4.11
	satisfy	satisfy	satisfy	satisfy	satisfy	satisfy	satisfy	satisfy
$v_c = \frac{0.27}{\gamma_m}\left[\frac{100A_s}{bd}\right]^{1/3} f_{cu}^{1/3}$	0.52	0.52	0.52	0.52	0.52	0.52	0.31	0.31
$\xi_s = (500/d)^{1/4}$	0.78	0.78	0.78	0.78	0.78	0.78	0.70	0.70
Shear capacity $=\xi_s v_c (N/mm^2)$	0.40	0.40	0.40	0.40	0.40	0.40	0.22	0.22
	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy	Satisfy

	Pile cap							
	P_1	P_2	P_3	P_4	P_5	P_6	A_1	A_2
Shear force - V (kN)	579.76	518.31	494.97	666.73	515.25	544.90	527.41	429.18
Shear stress - $v=V/bd$ (N/mm^2)	0.31	0.27	0.26	0.35	0.27	0.29	0.28	0.23
Shear capasity of concrete = $0.75(f_{cu})^{0.5}$ (N/mm^2)	4.11	4.11	4.11	4.11	4.11	4.11	4.11	4.11
	satisfy	satisfy	satisfy	satisfy	satisfy	satisfy	satisfy	satisfy
$v_c = \frac{0.27}{\gamma_m}\left[\frac{100A_s}{bd}\right]^{1/3} f_{cu}^{1/3}$	0.44	0.44	0.44	0.47	0.44	0.44	0.32	0.32
$\xi_s = (500/d)^{1/4}$	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Shear capacity $=\xi_s v_c (N/mm^2)$	0.32	0.32	0.32	0.34	0.32	0.32	0.23	0.23
	Satisfy	Satisfy	Satisfy	need shear r/f	Satisfy	Satisfy	need shear r/f	need shear r/f

calculations	Output

	Pier P_1,P_2,P_3,P_5,P_6	Abutment A_1,A_2
Bearing Length L(mm)	1000	560
Bearing width W (mm)	710	560
Bearing thickness H (mm)	104	122
Total elastomer thickness H_r(mm)	96	112
Thickness of one elastomer layer Hri (mm)	16	16
Thickness of one steel layer H_s (mm)	1	1
Gross plan area A (mm^2)	710000	313600
Elastomer Second moment of inertia I (mm^4)	64502257.5	80207727
Shape factor S		
Shear Modulus (G) (N/mm^2)	0.9	0.9
Bulk modulus E_c (N/mm^2)	604.22	357.52

Calculation stiffness to input the FEM

	Formula	Pier	Abutment	Unit
Lateral Stiffness K_H	$K_H = \frac{GA}{H_r}$	6656.25	2520	kN/m
Vertical Stiffness K_v	$K_v = \frac{E_c A}{H}$	26812262.5	7007392	kN/m
Rotational Stiffness K_θ	$K_\theta = \frac{EI}{H_r}$	405.97	256.03	kN/m

Design check for bearing pads

Check for maximum shear strain

$$\varepsilon_{sc} + \varepsilon_{sR} + \varepsilon_{sh} \langle \frac{2.6}{\sqrt{G}}$$

ε_{sc} shear strain at edge of bonded surface due to loads normal to bearing surface $= 6S\varepsilon_c$

ε_{sr} shear strain at edge of bonded surface due to relative rotation of bearing surface to bearing surface

ε_{sh} shear strain at edge of bonded surface due to force tangential to the surface or movement of the structure or both

$$\varepsilon_c = \frac{N}{3A_{eff}G(1+2S^2)}$$

Where,

$$A_{eff} = A_b\left[1 - \frac{\delta_a}{a} - \frac{\delta_b}{b}\right]$$

N - Compressive load on a bearing at serviceability limit state

δ_a- maximum shear displacement tangential to the bearing surface in the direction of dimension "a" due to movement of the structure and tangential forces

a - plan dimension of the edge of the bonded surface of rectangular bearings parallel to the span of the bridge

δ_b- maximum shear displacement tangential to the bearing surface in the direction of dimension "b" due to movement of the structure and tangential forces

b - plan dimension of the edge of the bonded surface of rectangular bearings transverse to the span of the bridge

$$S = \frac{A_b}{Pt_e}$$

A_b - bonded surface area

P - Surface perimeter

t_e - effective thickness of the individual elastomer layer in compression(due to vertical load or rotation)

$$\varepsilon_{sr} = \frac{\alpha_a a^2 + \alpha_b b^2}{2t_i t}$$

α_a - angle of rotation parallel to the span of the bridge

α_b - angle of rotation transverse to the span of the bridge

$$\varepsilon_{sh} = \frac{\delta_s}{t}$$

δ_s- maximum resultant vector shear displacement tanngential to the bearing surface in the direction of "a" and "b"

Check for compressive stress

Mean compressive stress (N/A_b) < 15Mpa

Check for rotational limitation

$$d_c \geq \frac{\alpha_a a + \alpha_b b}{3}$$

where,

$$d_c = \sum \left(t_n \varepsilon_c \right)$$

t_n - layer thickness of elastomer

$\varepsilon_c = \dfrac{N}{EA_b}$ compressive strain of a layer

$$E = E_h + \left[\frac{C_1 G S^2}{1 + \left(\dfrac{C_1 G S^2}{0.75 B} \right)} \right]$$

$$E_h = 4G \left[1 + \left(\frac{q}{1 + q^2} \right)^2 \right]$$

$$C_1 = 4 + q(6 - 3.3q)$$

q = a/b or b/a whichever is the lesser

check for stability

$$N \leq \frac{2 b_e G S A_{eff}}{3t}$$

where,

b_e - lesser of a and b

	Pier P_1,P_2,P_3,P_5,P_6	Abutment A_1,A_2
Size of the bearing	710 X 1000	560 X 560
thickness of the bearing (mm)	104	122
Inner layer thickness (mm)	16	16
No of inner layers	4	5
Steel layer thickness (mm)	1	1
Outer layer thickness (mm)	16	16
Hardness (IRHD)	60	60
Shear Modulus (G) (N/mm^2)	0.9	0.9
Bulk Modulus (B) (N/mm^2)	2000	2000
N (kN)	3,619	1,579
A_b (mm^2)	710,000	313,600
P (mm)	3420	2240
t_e (mm)	16	16
S	12.975	8.750
a (mm)	1000	560
δ_a (mm)	4.2	13.3
b (mm)	710	560
δ_b(mm)	0	0
δ_s(mm)	4.200	13.300
A_{eff} (mm^2)	707018	306152
ε_c	0.0056	0.0124
ε_{sc}	0.437	0.651
α_a (rad)	0.0025	0.0025
α_b (rad)	0	0
ε_{sr}	0.7512	0.2008
ε_{sh}	0.0404	0.1090

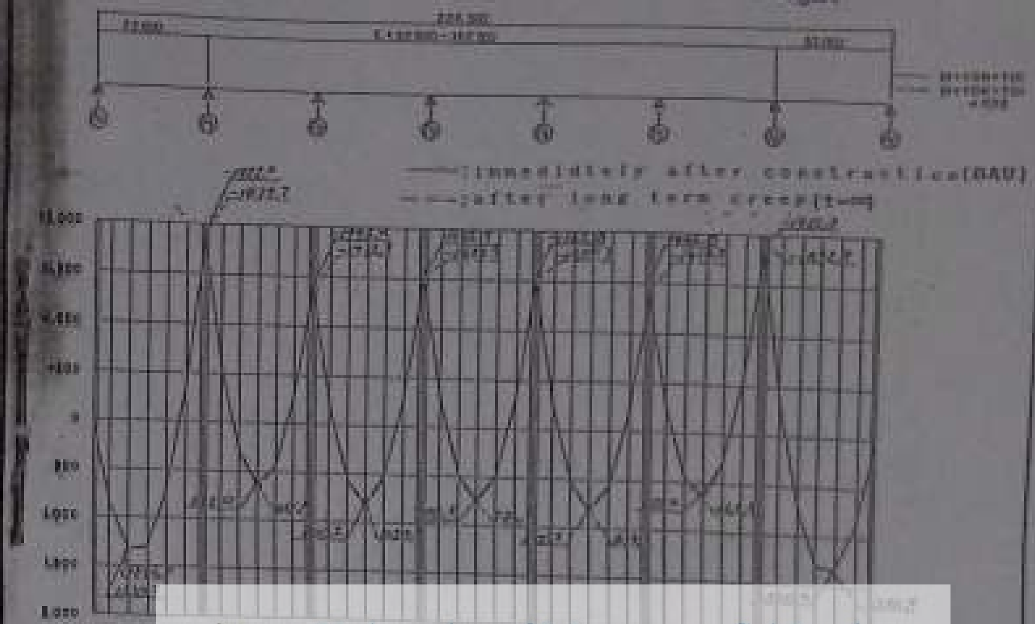
$\varepsilon_{sc}+\varepsilon_{sr}+\varepsilon_{sh}$	1.2286	0.9605
2.6/G	2.9	2.9
	shear strain OK	**shear strain OK**
N/A_b (Mpa)	5.097	5.035
	Compressive stress within the limit	**Compressiv e stress within the limit**
q	0.710	1.000
C_1	6.596	6.700
E_h (N/mm^2)	4.402	4.500
E (N/mm^2)	604.22	357.52
ε_c	0.008	0.014
$(\alpha_a a+\alpha_b b)/3$	0.833	0.467
d_c	0.810	1.577
	Rotational limitations fail	**Rotational limitations OK**
$\frac{2b_e GSA_{eff}}{3t}$	56365.10	11066.64
	Stability OK	**Stability OK**

APPENDIX – E

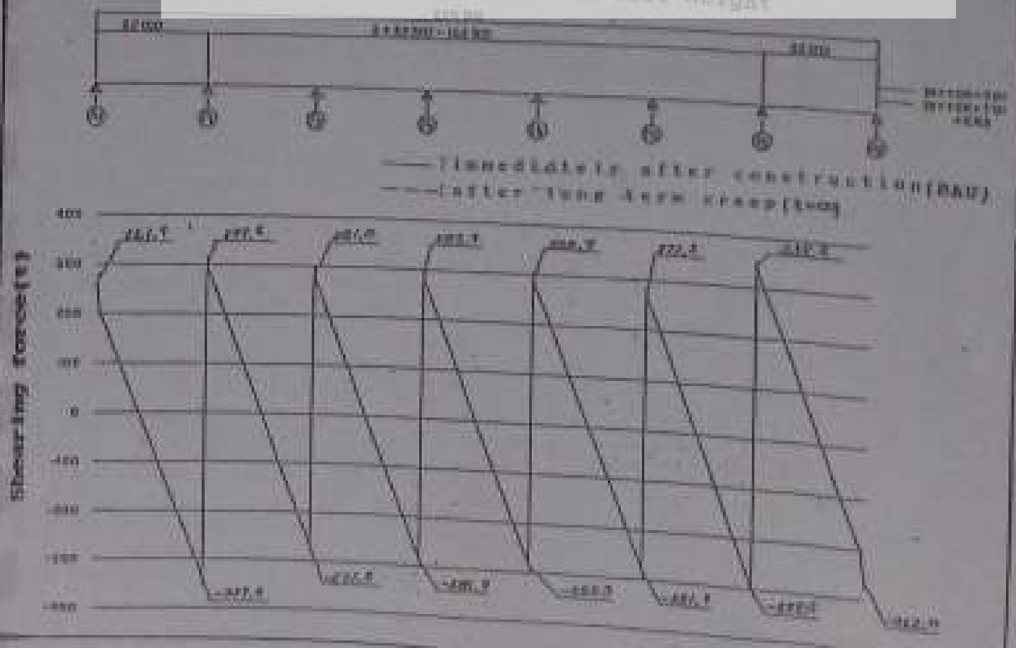
EXTRACTIONS OF ORIGINAL DESIGN REPORT

5) Calculation of Sectional Forces

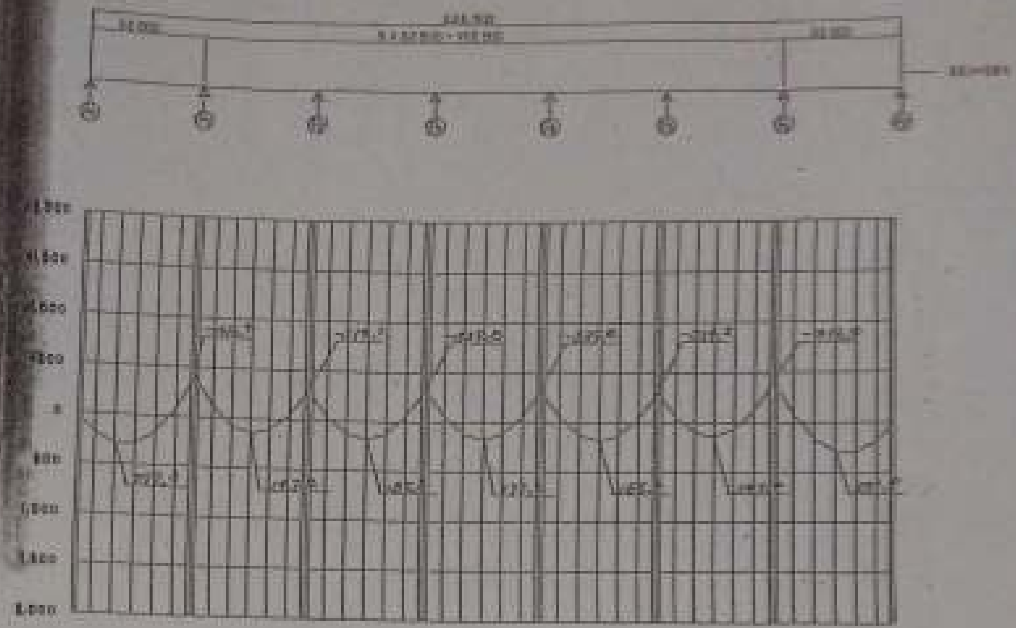
Bending moment diagram due to self weight



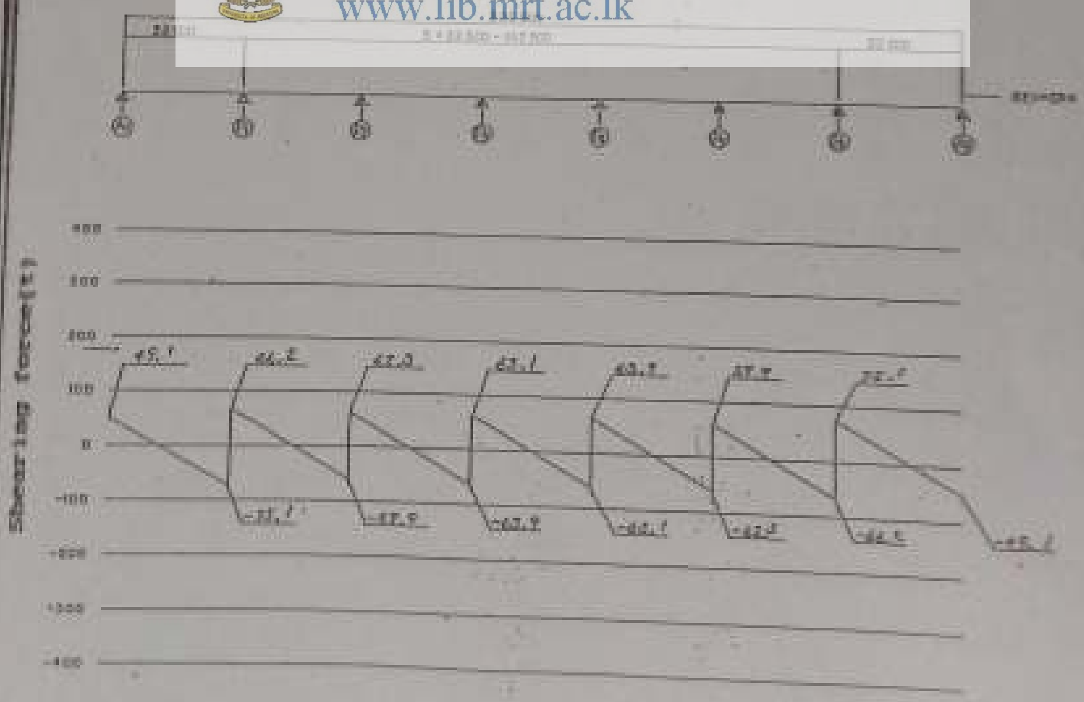
Shearing force diagram due to self weight



Bending moment diagram dut to superimposed dead load



Shearing force diagram dut to superimposed dead load



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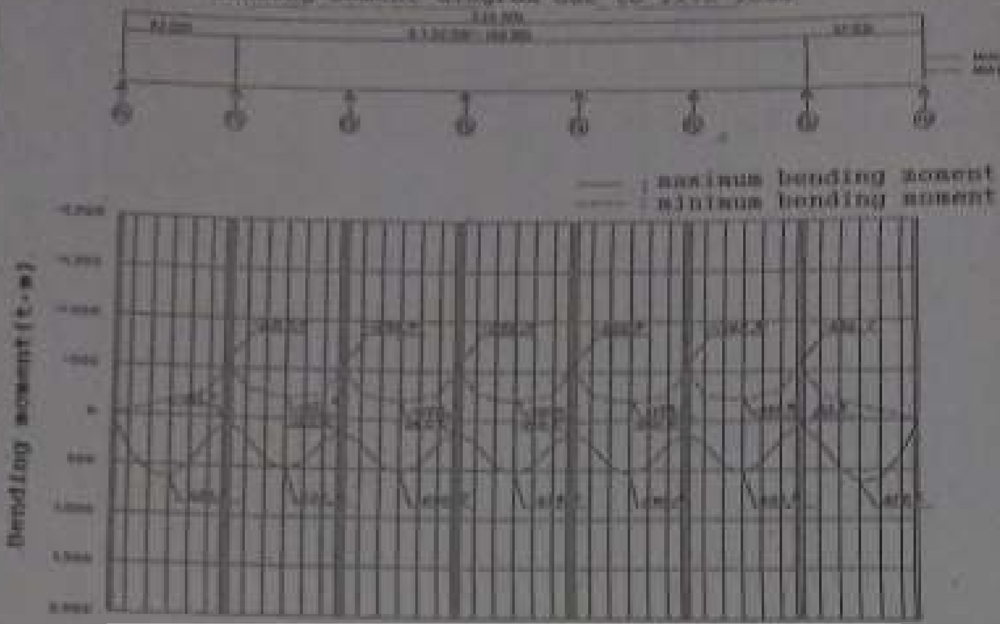
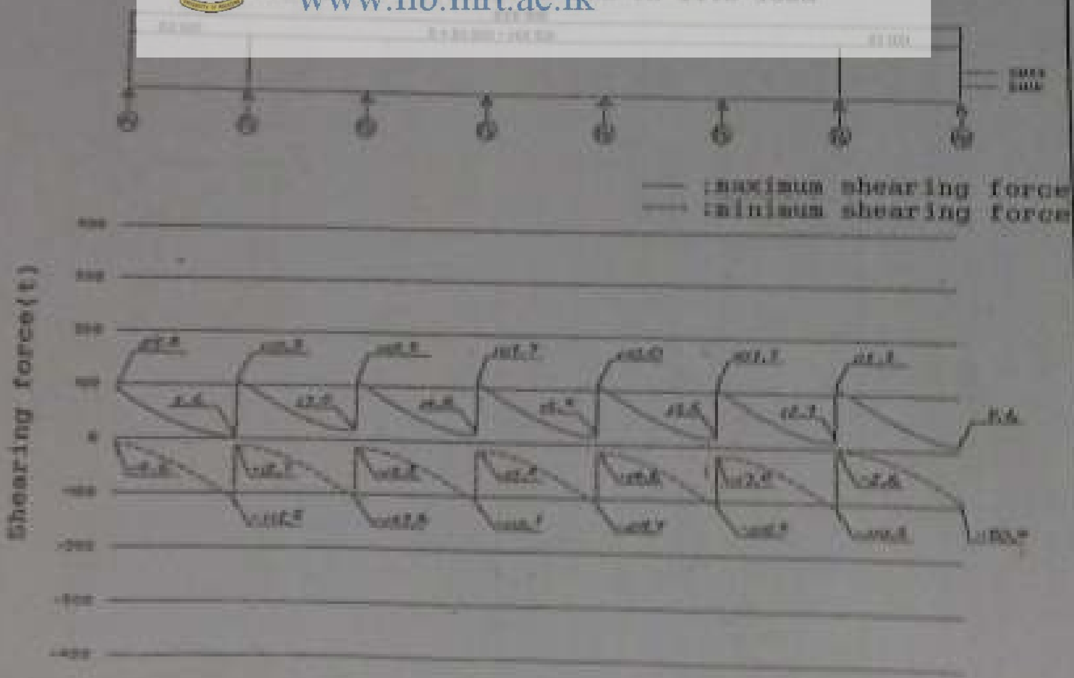
Bending moment diagram due to live load



Shearing force diagram due to live load



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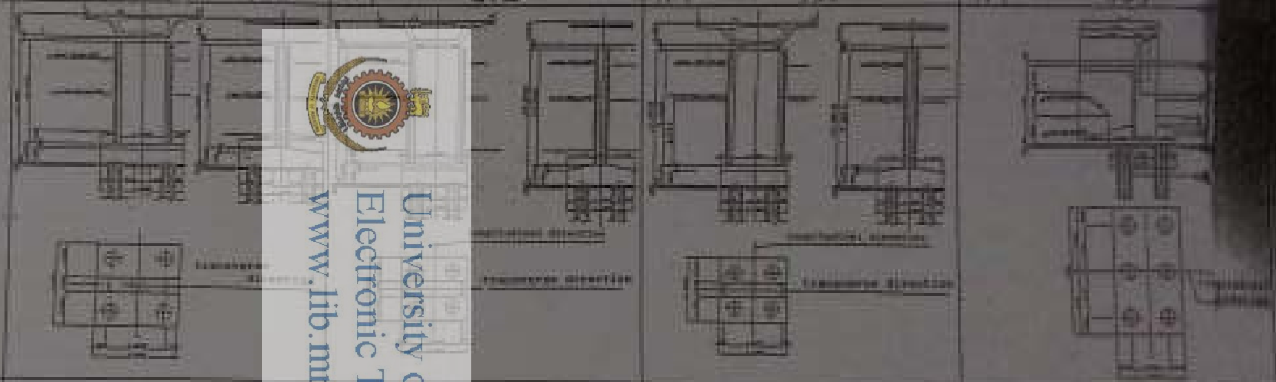
Name			P1		P2 (P5,P6)	P3 (P7)	A1 (A2)
Reaction from Super-structure	Dead load	H / N	N 780		N 770	N 783	N 347
	Live load	H / N	H 70	N 183	N 172	N 175	N 90
	total	H / N	H 70	N 963	N 892	N 961	N 437
Dimensions							
Check of Main column	arrangement of reinforcement		[illegible]		[illegible]	[illegible]	[illegible]
	load case		①	④	①	①	①
	sectional force & stress intensity		N 1275, σc 49; M 3356, σs 677; S 20, τ 0.8	N 773, [illegible]; M 3356, [illegible]; S 20, [illegible]	σc 13; σs (whole section compressive); τ 0	N 1155, σc 35; M 455, σs 114; S 405, τ 0	N —, σc 9; M 28, σs 189; S 13, τ 0.6
Check of Pile Caps	arrangement of reinforcement		[illegible]		[illegible]	[illegible]	[illegible]
	load case		③				
	sectional force & stress intensity		N 0, σc 40; M 621, σs 1693; S 302, τ 4.9	N —; M —; S —	σc 27; σs 1204; τ 5.6	N 0, σc 26; M 100.2, σs 1150; S 92.1, τ 5.4	N 0, σc 11; M 29.7, σs 850; S 67.8, τ 3.9
pile reaction (t)			361	318	355	374	331
Allowable Stress Intensity	bending compressive σca		80	—	80	80	80
	bending tensile σsa		1400	—	1600	1600	1600
	shearing τa		3.9	—	3.9	3.9	3.9
	vertical bearing of pile		375	263	375	375	375
Remarks			arrangement of pile cap's stirrups D16 ctc 500		arrangement of pile cap's stirrups D16 ctc 600	arrangement of pile cap's stirrups D16 ctc 600	

GENERAL NOTES

The following notes shall be taken into account as applicable when reading the drawings.

They are summarized here for ease of reference even if in their majority contained in the Specification.

1. All levels and dimensions as shown on the drawings are in meters and millimeters respectively, except where described.

2. Concrete for structural members

Design compressive strength and Young's modulus for structural members shall be as follows:

Table 1 Design Compressive Strength and Young's Modulus of Concrete

Structural Member	Design Compressive Strength	Young's Modulus
Main girder	350 kg/cm²	3.35 x 10⁵ kg/cm²
Piers, Abutments Piles, [illegible]	240 kg/cm²	2.9 x 10⁵ kg/cm²

3. Reinforcing bars

1) Reinforcing bars shall conform to SD35 according to JAPAN INDUSTRIAL STANDARD (JIS) G3112-1986 and shall have the minimum yield strength of 35 kg/mm².

2) Bending, cutting, hook and anchoring shall comply with Specifications for Highway Bridges (1972, Japan Road Association, hereinafter referred to as Japanese Bridge Specifications).

3) Spacing, splicing and development of reinforcing bars shall comply with Specifications for Highway Bridges.

4) Lap length shall be satisfied as follows.

Tension reinforcement .... la and 20D
Compression reinforcement ..... 0.8 la and 20D

where, D is nominal diameter (mm) of reinforcing bars.
la is splicing length calculated from bond stress intensity of bar and concrete in accordance with Japanese Bridge Specifications.

5) Maximum length of reinforcing bars shall not exceed 12 m in general.

6) Cross sectional area, unit weight, etc. shall comply with JIS G3112-1985.

7) Minimum concrete cover for reinforcing bars shall be satisfied as following values:

Box girder outer and inner perimeter ... 35 mm
Bored piles .... 150 mm
Piers and abutments .... 100 mm

8) Symbol for reinforcing bars used in the drawings are [illegible]:

GIRDER
S : Re[illegible] upper slab
W : Reinforce[illegible] in web
T : Reinforcement in bottom slab
C : Curb
E : [illegible]

PIER, PILE
[illegible] : Pi[illegible]
F : [illegible]
F : Pi[illegible]

ABUTMENT
A : [illegible]
F : Pile [illegible]
W : Wi[illegible]
C : Ap[illegible] slab

4. Prestressing

1) Low relaxation [illegible] strand (SWPR-7B, diameter 12.7 mm) as specified in JAPAN INDUSTRIAL STANDARD (JIS G3536-1971) shall be used for longitudinal prestressing.

2) Prestressing [illegible], diameter 32 mm, as specified in [illegible]-1971) shall be used for longitudinal, transverse and vertical prestressing.

3) Table 2 Design [illegible] of Prestressing Tendons

	Cable	Bar
Notation	SWPR-7B	SBPR-95/120
Area (mm²)	1184.52	804.25
Weight (kg/m)	9.288	6.310
Ultimate tensile strength (kg/mm²)	190	120
0.2% proof stress (kg/mm²)	160	95

4) Initial tensioning stress is as follows:

SWPR-7B = 144.0 kg/mm²
SBPR-95/120 = 85.5 kg/mm²

Internal diameter of sheaths of strip metal shall be specified as follows:

	Cable	Bar
General part	90	38
Sheath joint	75	42
Coupler	—	50

5) Symbol of cables and bars on the drawings are defined as follows:

- 1 to 7 are cables which are arranged in the main girder.
- 61 to 68 are bars which are arranged in the upper slab.
- 101 to 110, 201 and 202 are bars which are arranged in the bottom slab.
- A1 to A247 and B1 to B247 are bars for vertical prestressing.
- 1001 to 1434 are bars for transversal prestressing.

5. Miscellaneous facilities

1) Miscellaneous facilities of the bridge (bearing, expansion joint, drainage, railing, etc.) shall comply with the relevant articles of JIS.

2) All symbols and abbreviations on these drawings are in accordance with definition of [illegible] where described on each drawings.

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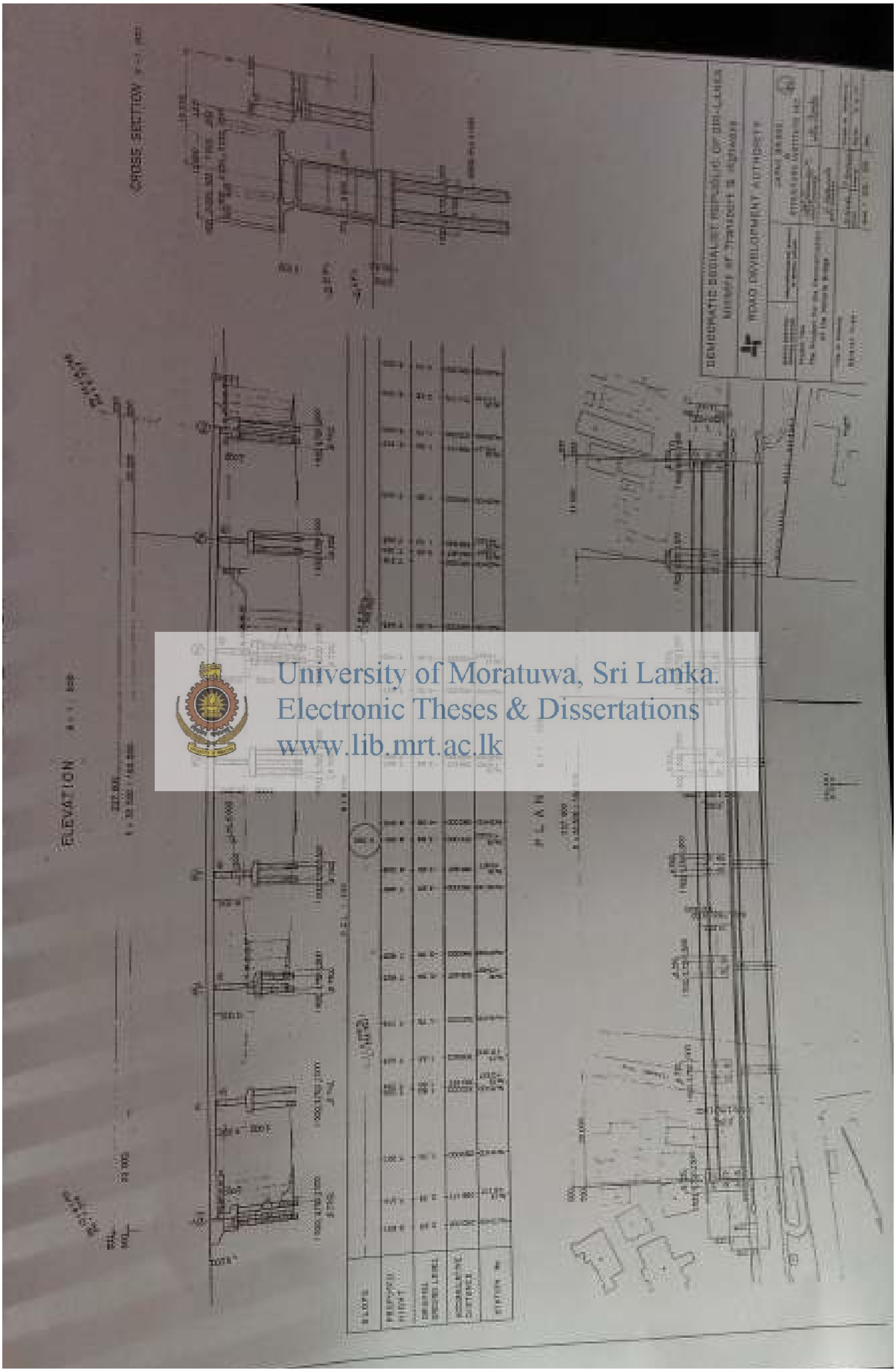
Ministry of Transport & Highways

ROAD DEVELOPMENT AUTHORITY

JAPAN BRIDGE & STRUCTURE INSTITUTE INC.

Project title
The Proposed Repair and Reconstruction of the Victoria Bridge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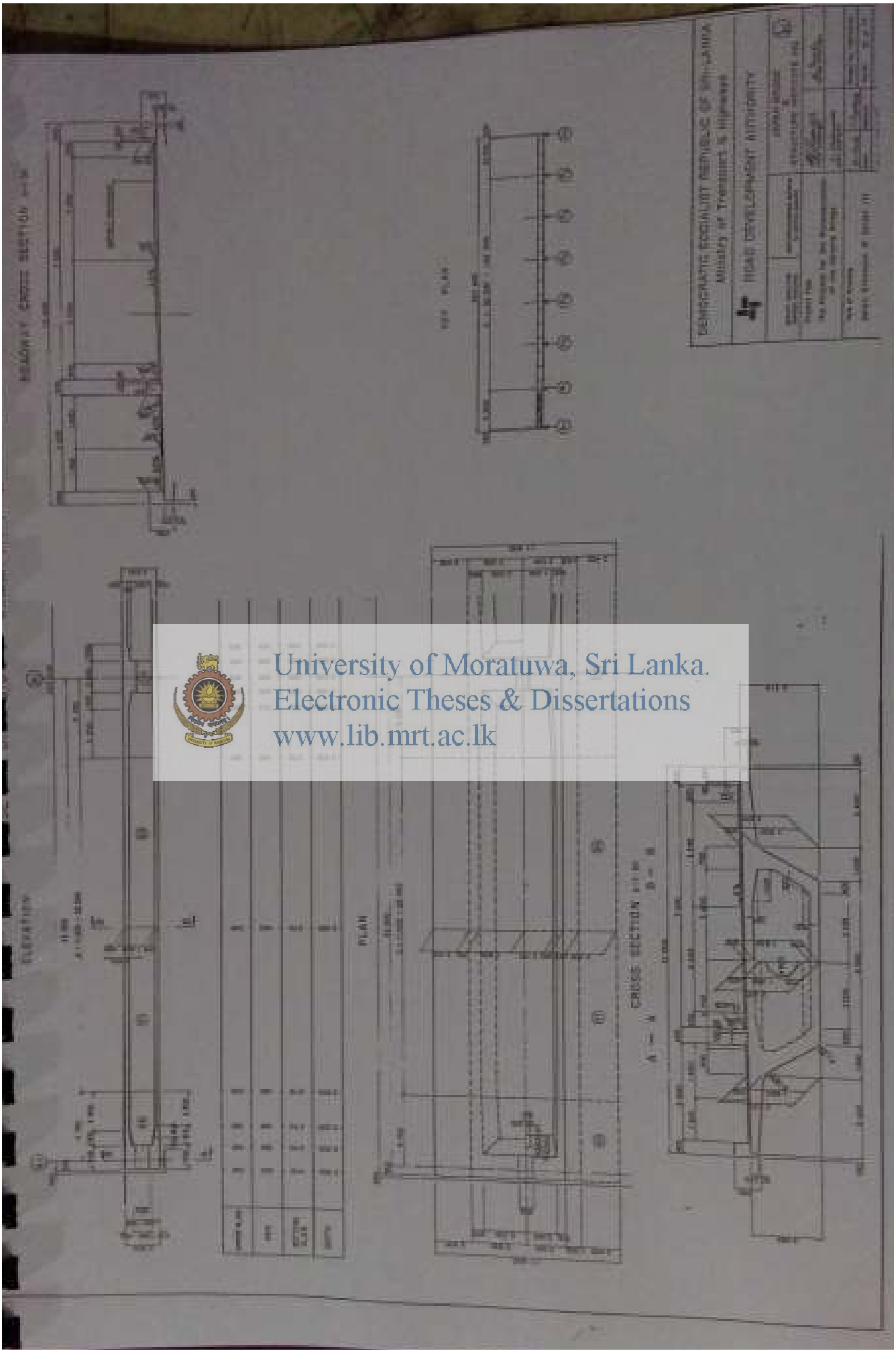
PLAN
CROSS SECTION
DEMOCRATIC SOCIALIST REPUBLIC OF SRI LANKA
ROAD DEVELOPMENT AUTHORITY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Ministry of Transport & Highways
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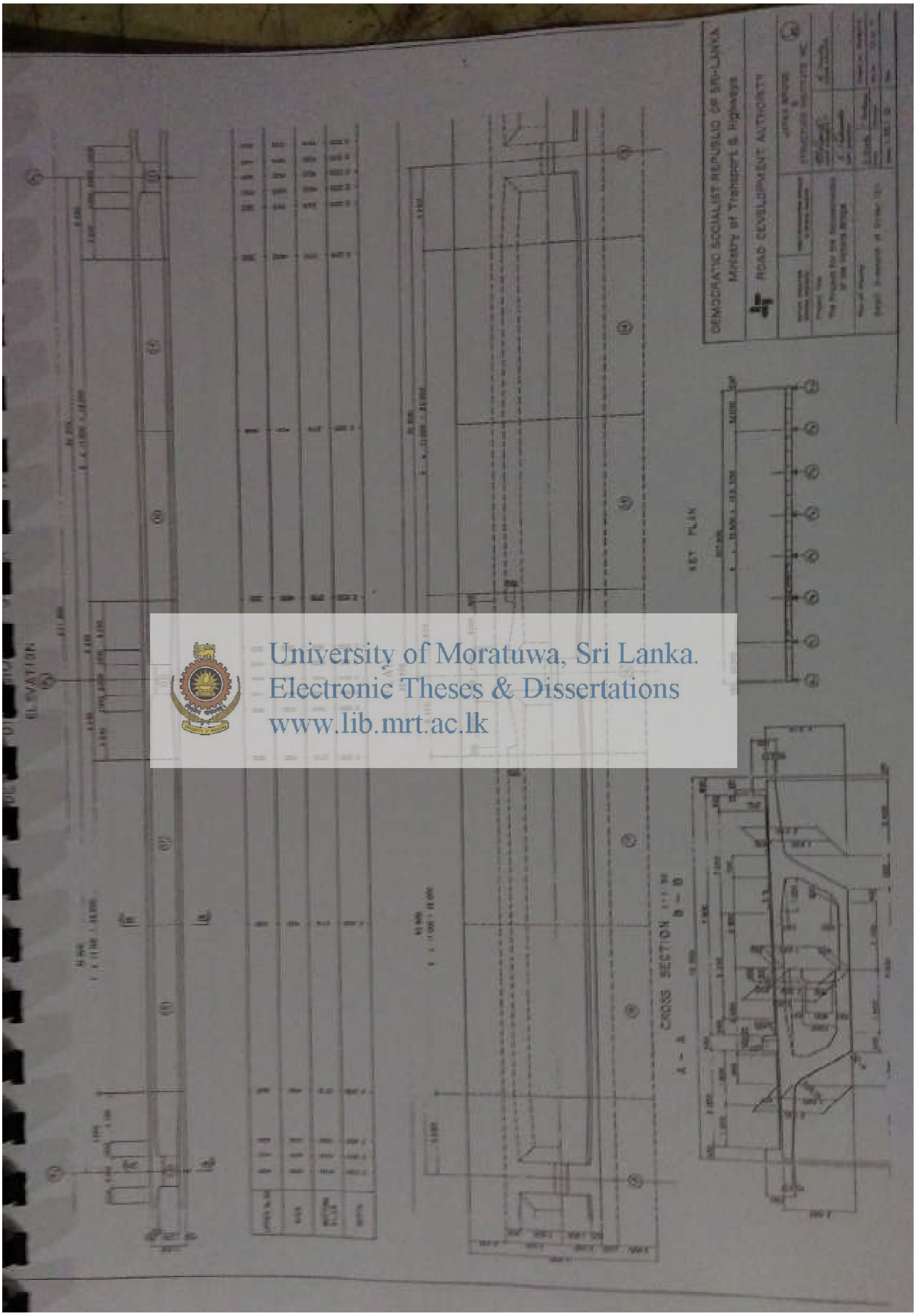
ROADWAY CROSS SECTION
ELEVATION
PLAN
CROSS SECTION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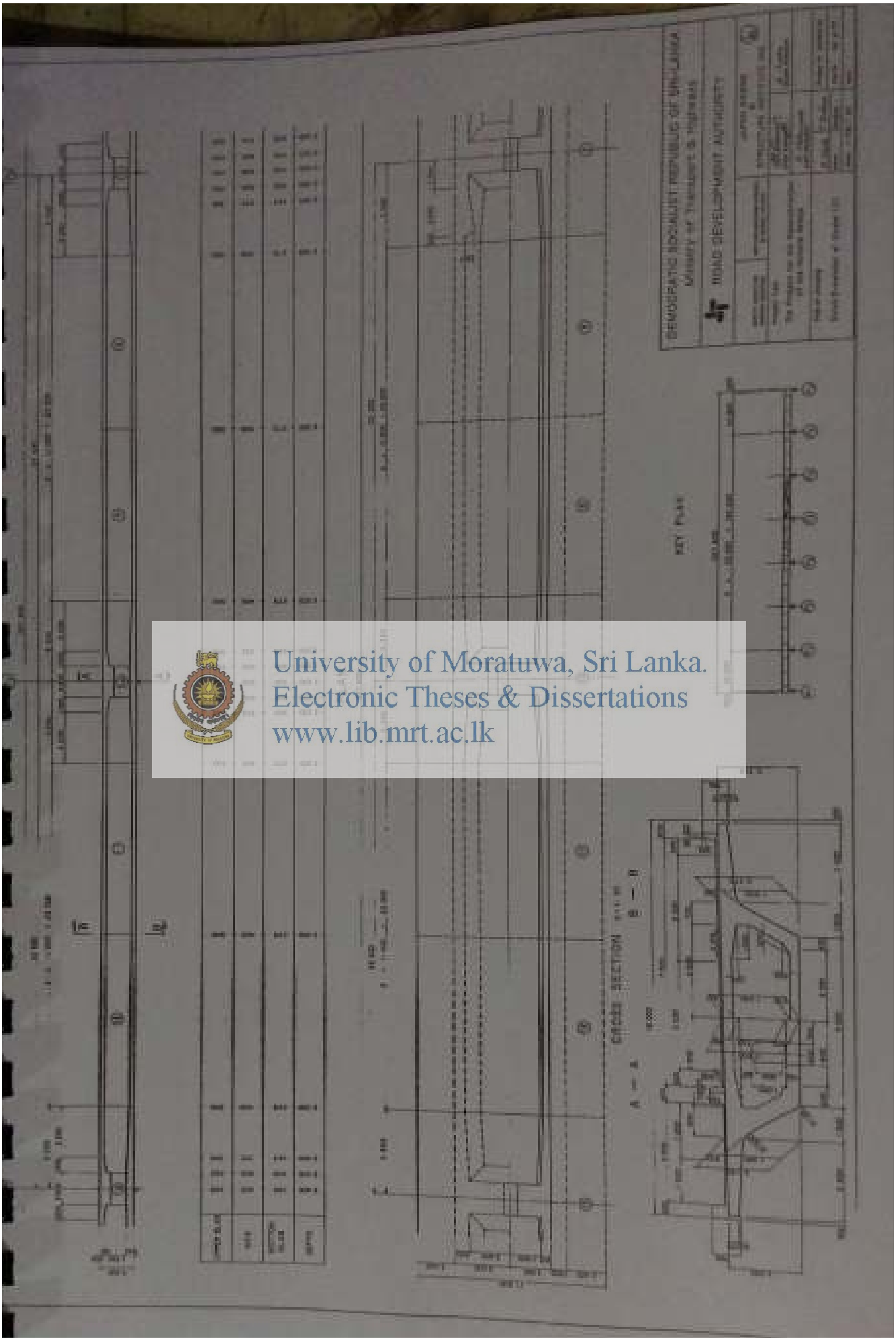
Ministry of Transport & Highways
ROAD DEVELOPMENT AUTHORITY
ELEVATION
CROSS SECTION
KEY PLAN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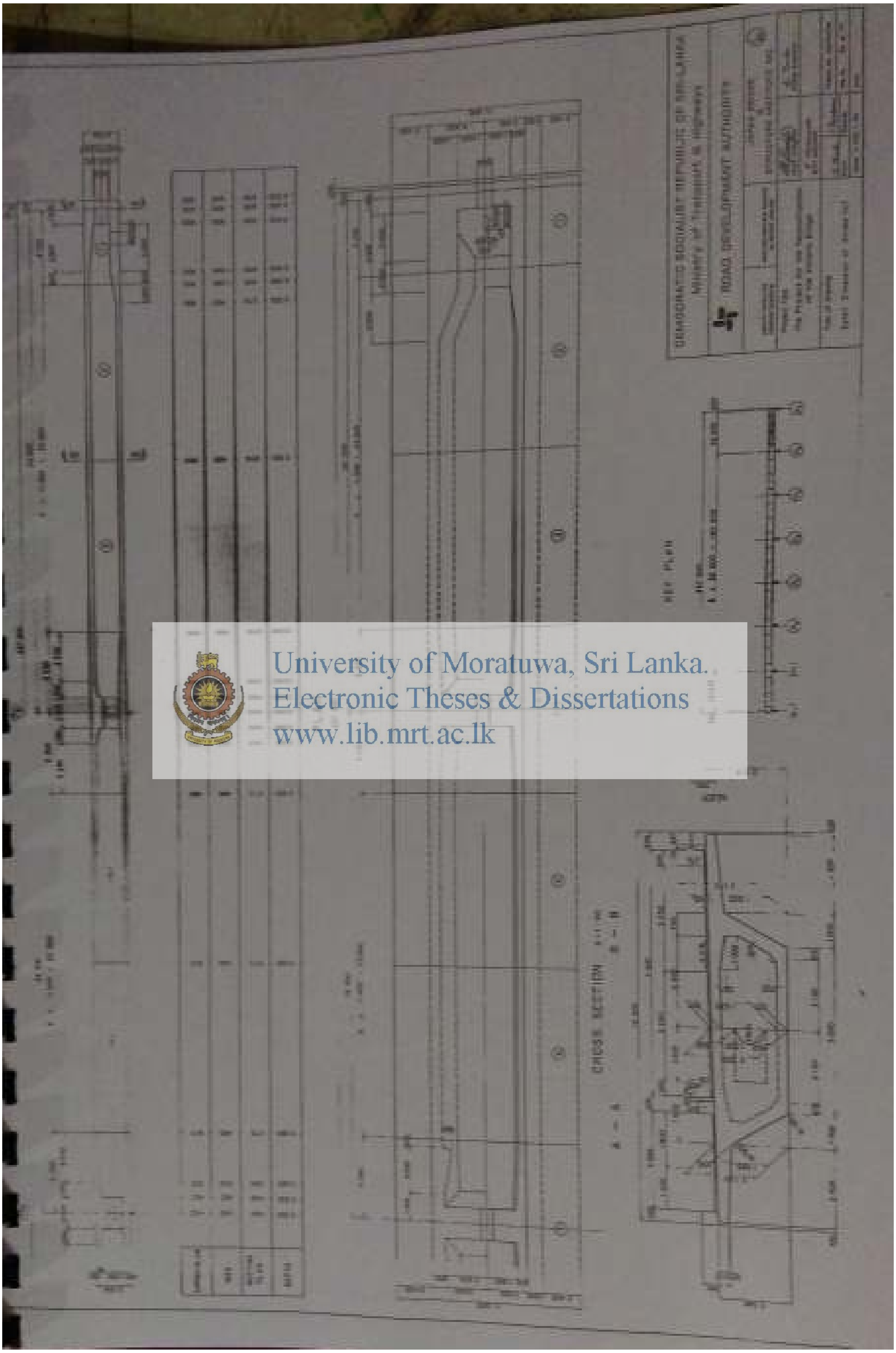
KEY PLAN
CROSS SECTION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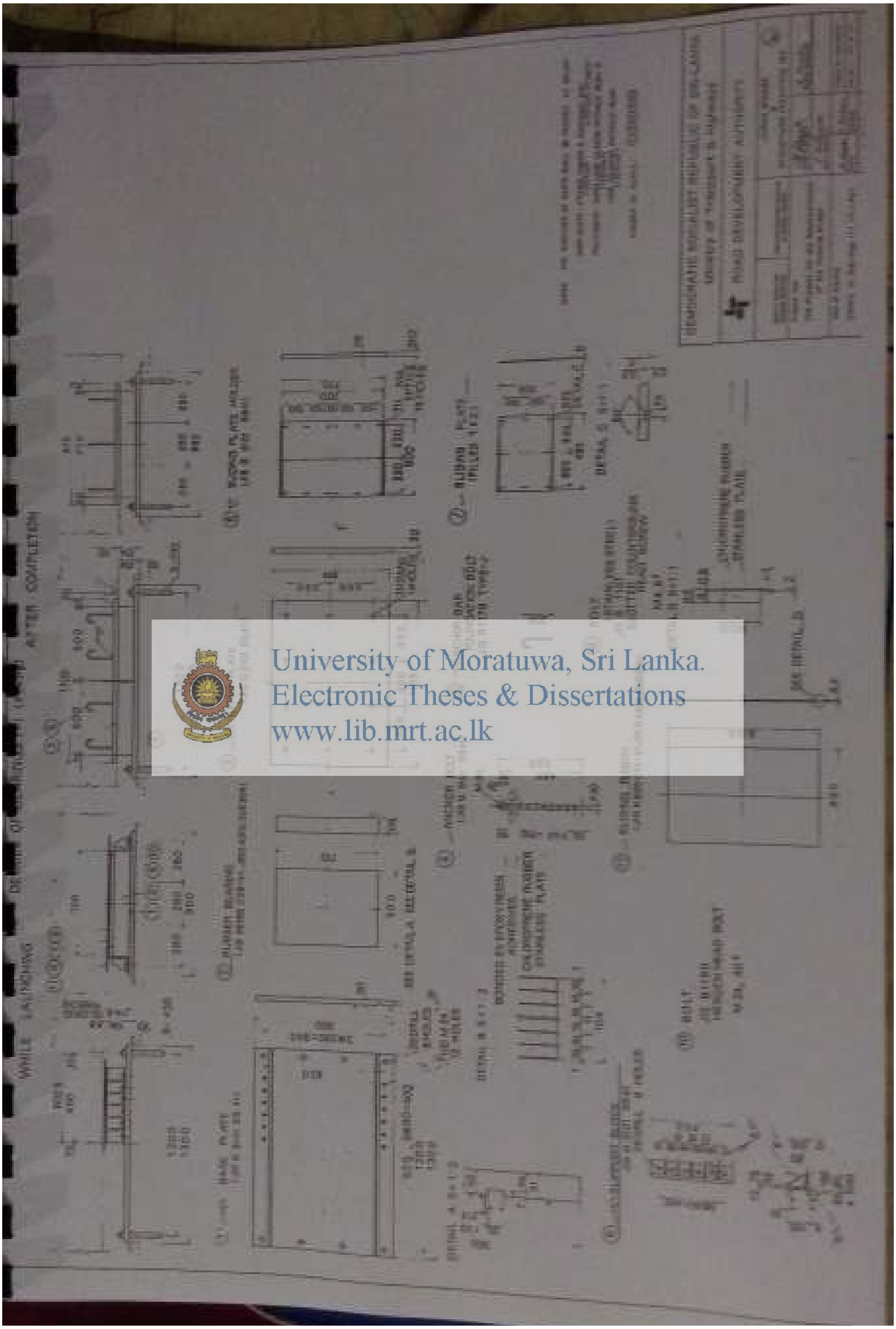

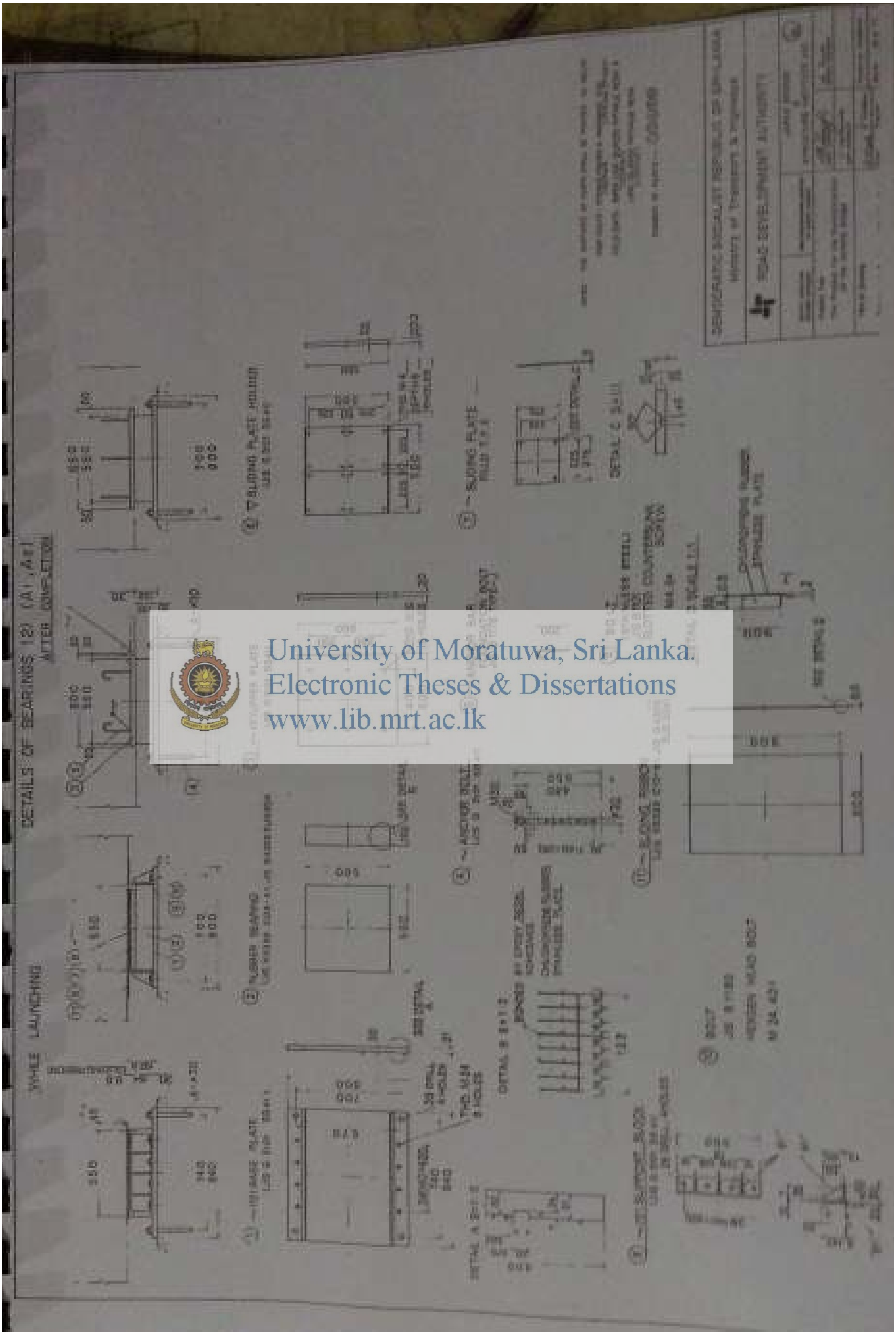
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DETAILS OF BEARINGS (2) (A1 ,A2)
AFTER COMPLETION
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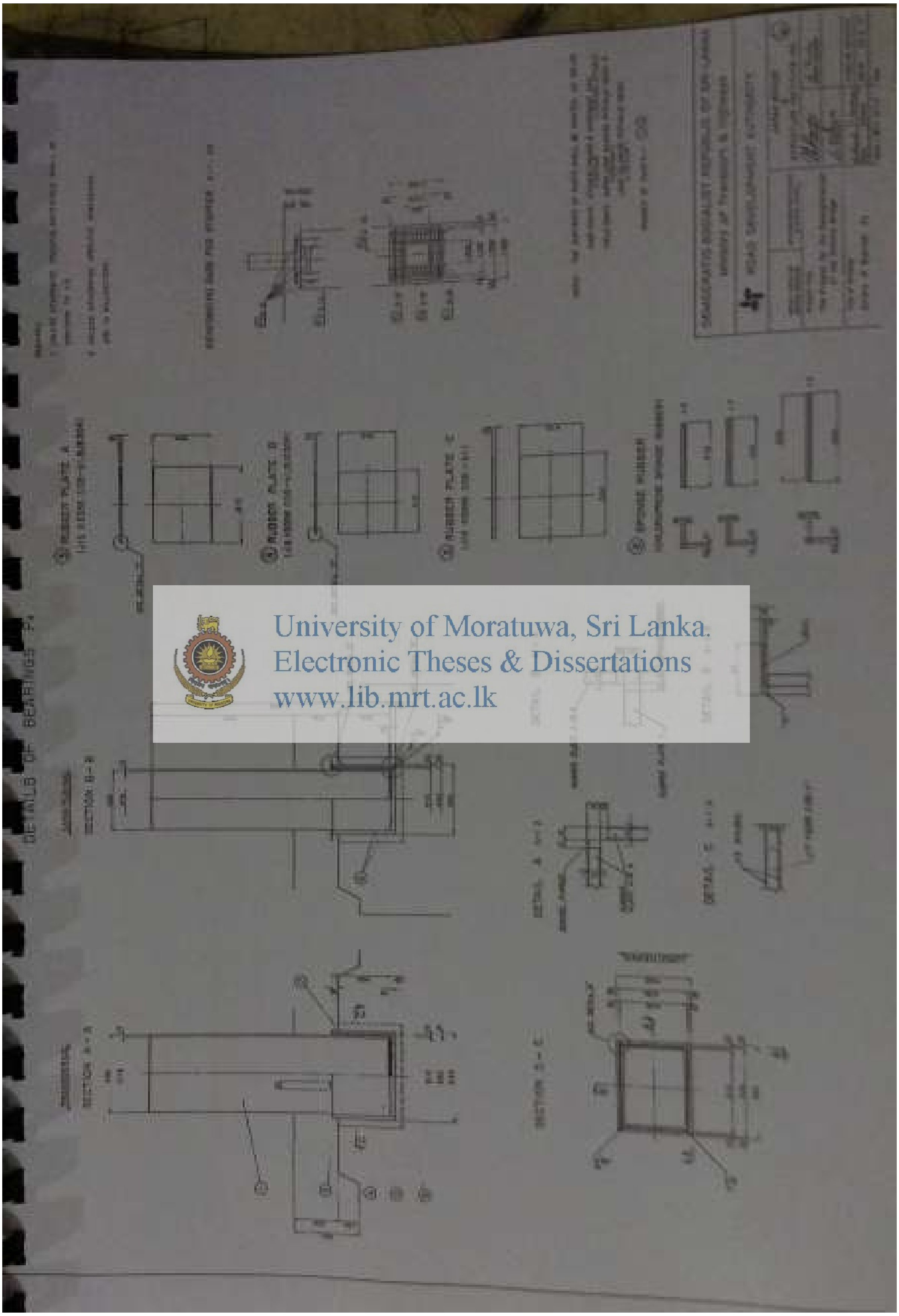
ROAD DEVELOPMENT AUTHORITY


DETAILS OF BEARINGS


DETAIL DIMENSION OF ABUTMENTS
KEY PLAN
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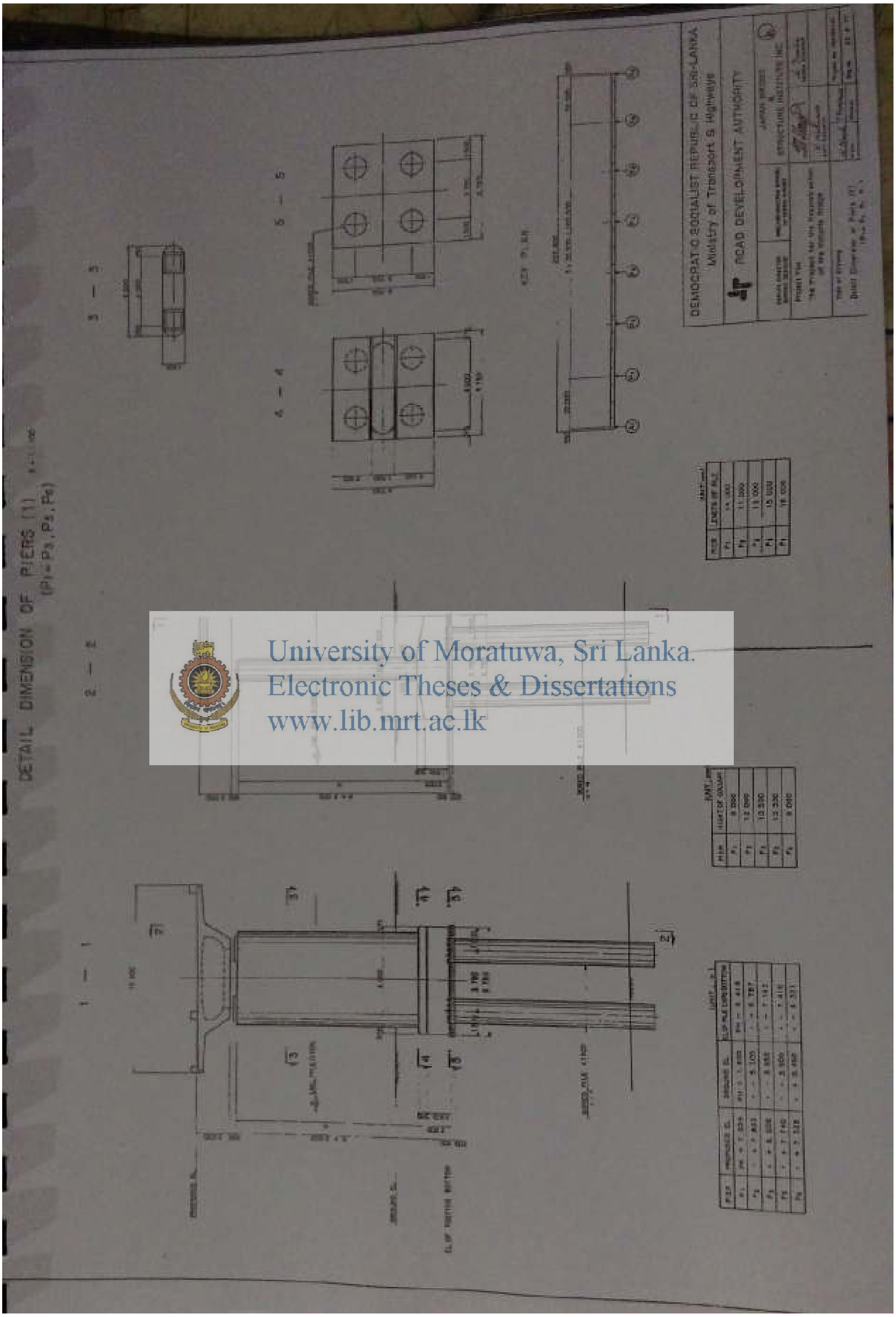
ROAD DEVELOPMENT AUTHORITY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(P1~P3, P5, P6)
1 — 1
2 — 2
3 — 3
4 — 4
5 — 5
KEY PLAN
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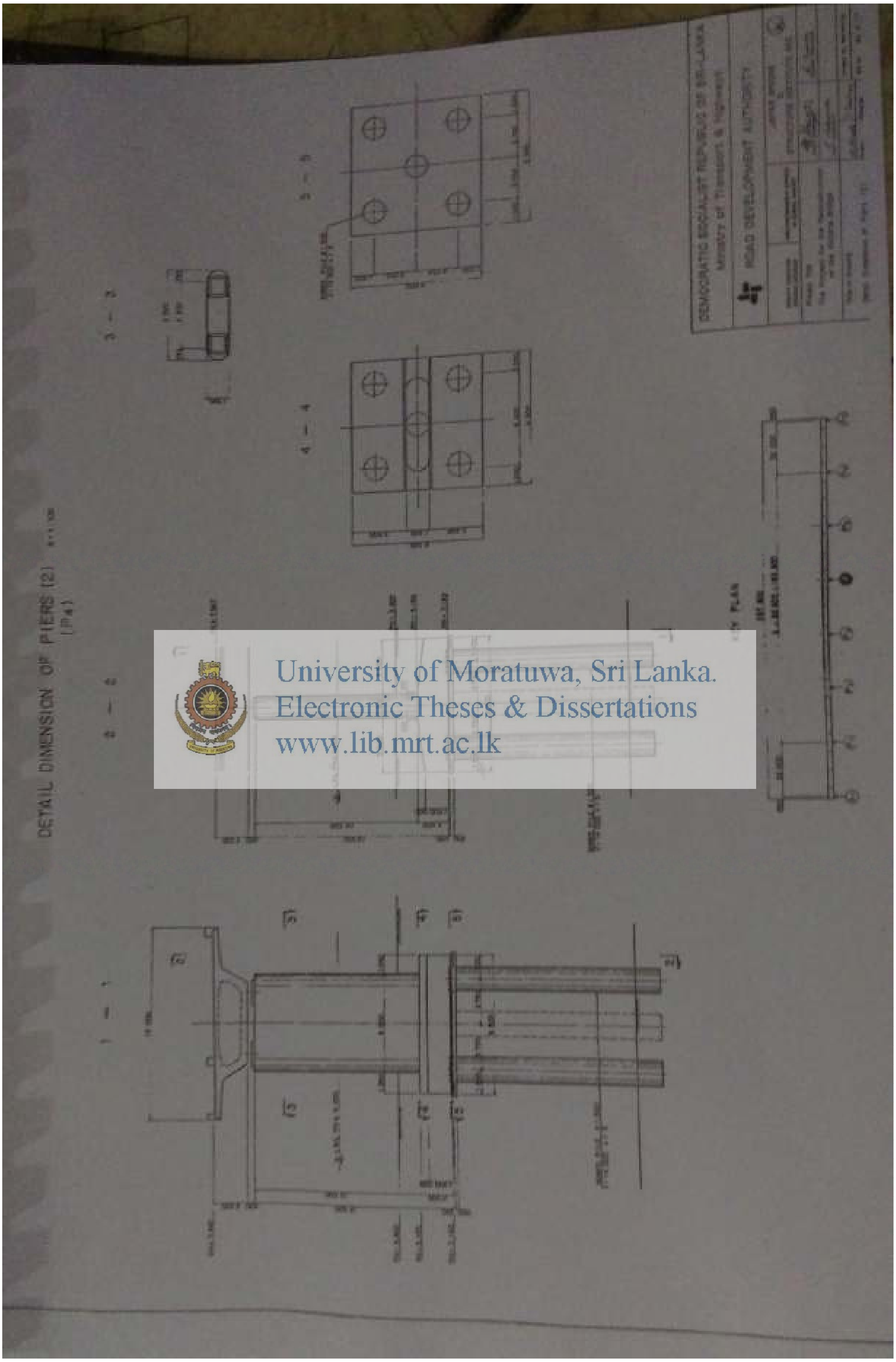
DETAIL DIMENSION OF PIERS (2)
(P4)
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2 — 2
3 — 3
4 — 4
5 — 5
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ROAD DEVELOPMENT AUTHORITY