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APPENDIX A - USAGE OF OAPI FOR THE STUDY

OAPI facility given in SAP2000 allows 3rd party software to create models, run analysis and extract analysis results by using specific set of commands given in SAP2000

In this project Microsoft Excel (EXCEL) together with Visual Basic (VB) use as 3rd party software

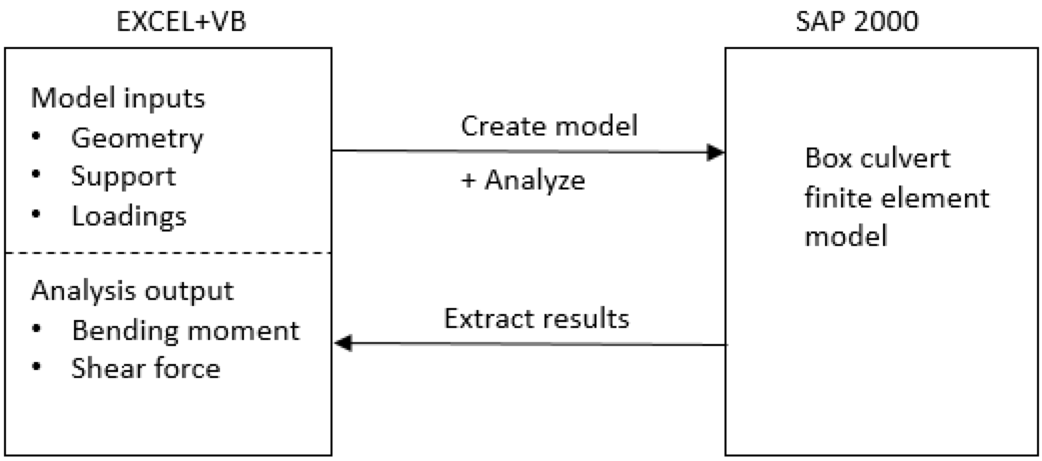


Figure A.1: Usage of OAPI

All the VB codes required to modelling analysis and extracting the results are given in CSi OAPI Documentation which is available in SAP2000 installed folder

APPENDIX B - ANALYSIS DETAILS

2D Model

2D model develop only for the cases which is traction force not apply (H'>L_L), to explain the modelling procedure use following example

W =3.0m

H =3.0m

H' =6.0m

t =0.3m

Soil unit weight (γ_s) = 18 kN/m^3

Road construction material unit weight (γ_r) = 23 kN/m^3

1.1 Model geometry details

Center to center width of culvert = internal width of culvert + slab thickness

= 3.0 +0.3

=3.3m

Center to center height of culvert = internal height of culvert + slab thickness

= 3.0 +0.3

=3.3m

1.2 Box culvert geometry modelling

Draw 3.3m height and 3.3m width box using frame element as shown in figure

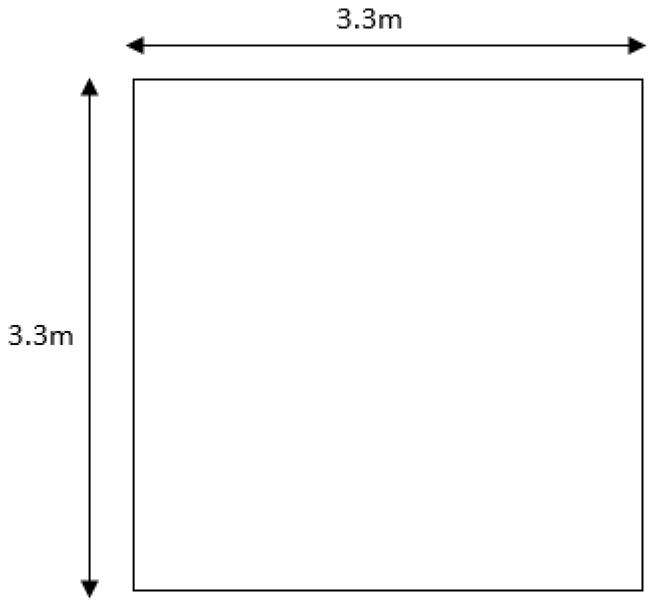


Figure B.1: Centerline model of box culvert

Frame mesh at main results interesting location as shown in figure 18 and figure 19 and further meshed as maximum element size is not more than 150mm

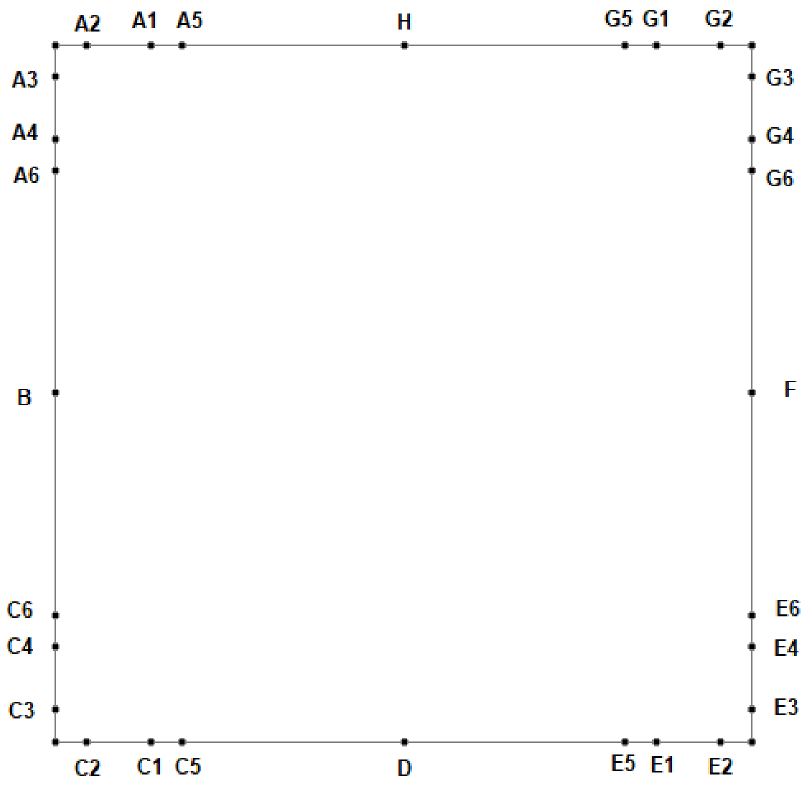


Figure B.2: FEM Mesh of box culvert

1.3 Define material property

For concrete G30

Strength	=	30 N/mm^2
Elastic module	=	28 kN/mm^2
Poisson's ration	=	0.2
Coefficient of thermal expansion	=	12x10^{-6}

1.4 Define section property

Stiff section inside the wall	=2t	=0.60m (height) x 1.0m (width)
Chamfer	=1.5t	=0.45m (height) x 1.0m (width)
Normal section	=t	=0.30m (height) x 1.0m (width)

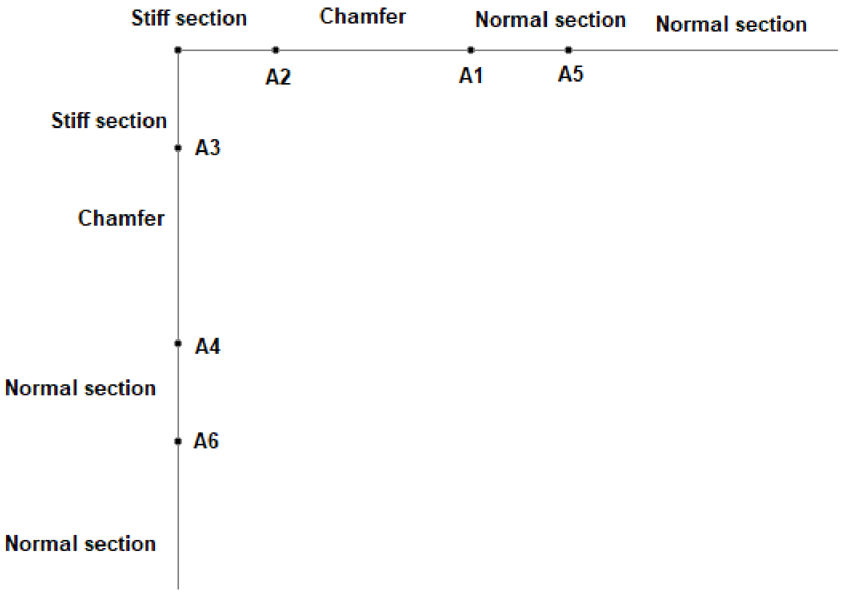


Figure B.3: Section property assignment

1.5 Support conditions

For bottom slab assign line spring

Soil subgrade module	=	40 x F.O.S x Allowable bearing capacity
	=	40 x 2.5 x 100
	=	10000 kN/m^2/m
Line spring	=	10000 x 1
	=	10000 kN/m/m

1.6 Assign loads

Modelling step 6

Dead load –Self weight automatically generated by the software

Soil horizontal (k=1)

Soil load on top edge of wall = (H’+t/2-0.2) x γ_s+ 0.2 x γ_r

= (6+0.15-0.2) x 18+ 0.2 x 23

= 111.7 kN/m^2

Soil load on bottom edge of wall = (H'+H+1.5t-0.2) x γ_s+ 0.2 x γ_r

= (6+3+0.45-0.2) x 18+ 0.2 x 23

= 171.1 kN/m^2

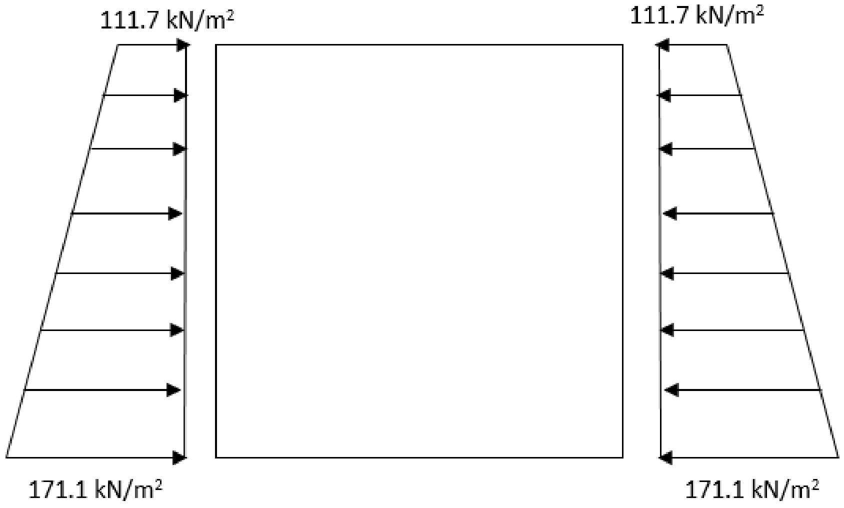


Figure B.4: Horizontal soil load on culvert

HA Surcharge (k=1) = 10 kN/m^2

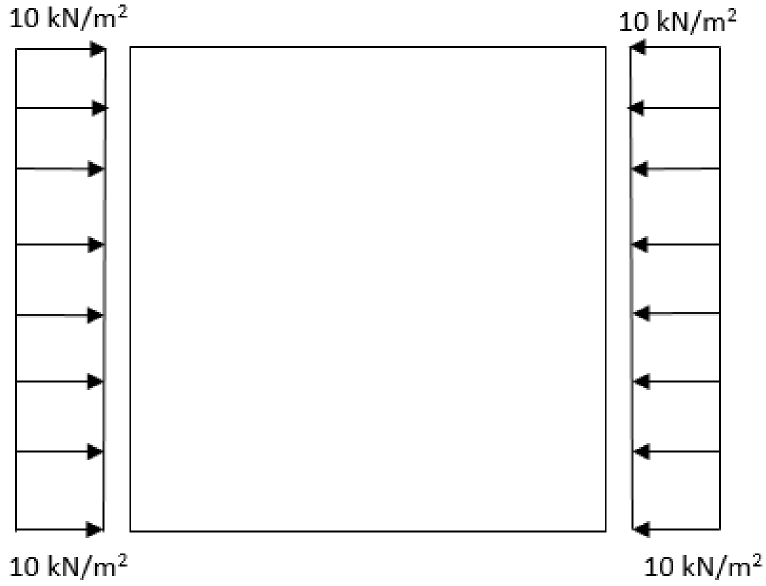


Figure B.5: Horizontal HA surcharge load on culvert

HB Surcharge (k=1) = 12 kN/m^2

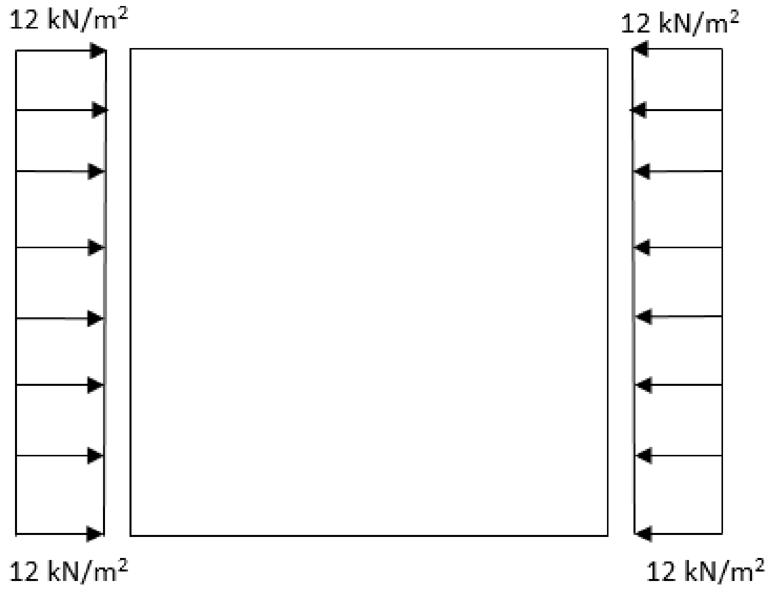


Figure B.6: Horizontal HB surcharge load on culvert

HB vertical load

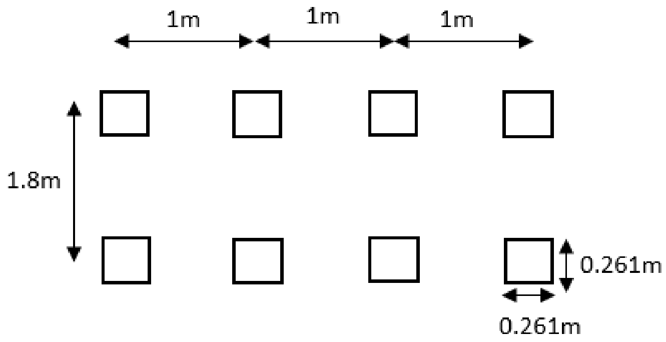


Figure B.7: Wheel arrangement of HB vehicle that load transfer on to culvert

Dispersion of wheel load through the fill is vertical 2 to horizontal 1, since fill height is 6m dispersion area of all wheel overlap therefore can consider as one unit

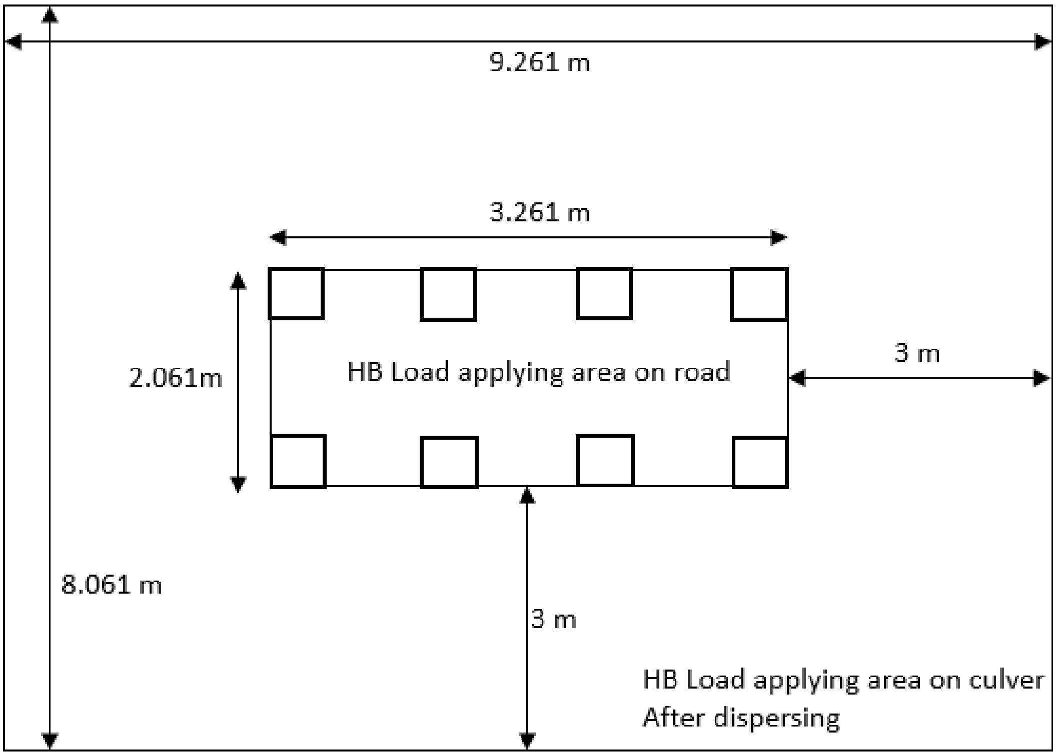


Figure B.8: Effective area of HB wheel on culvert top slab level

HB load by 8 wheels =75 x 8

=600 kN

HB Vertical load as a pressure =600 / (8.061 x 9.261)

$=8.03kN/m^2$

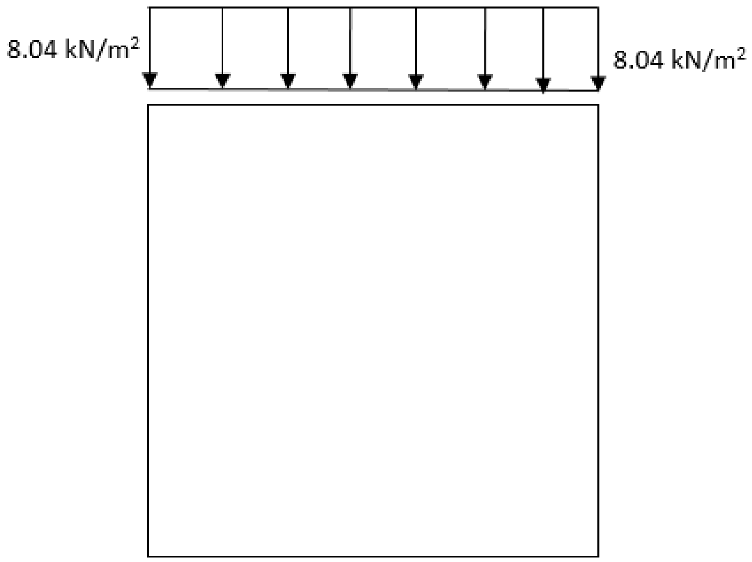


Figure B.9: HB vertical load on culvert

HA vertical load

Since fill height is greater than 0.6m HA load replaced by HB load value

Therefore

HA Vertical load as a pressure $=8.03kN/m^2$

SID load due to road construction material

SID load on top slab = 0.2 x γ_r = 0.2 x 23 = 4.6 kN/m^2

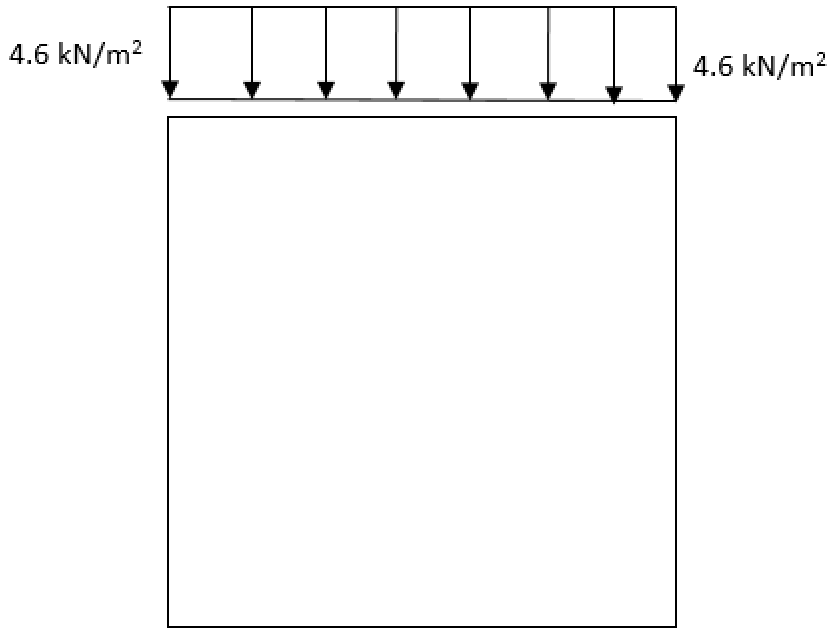


Figure B.10: SID road load on culvert

SID load due to soil fill

SID load on top slab = (H'-0.2) x γ_r = 5.8 x 18 = 104.4 kN/m^2

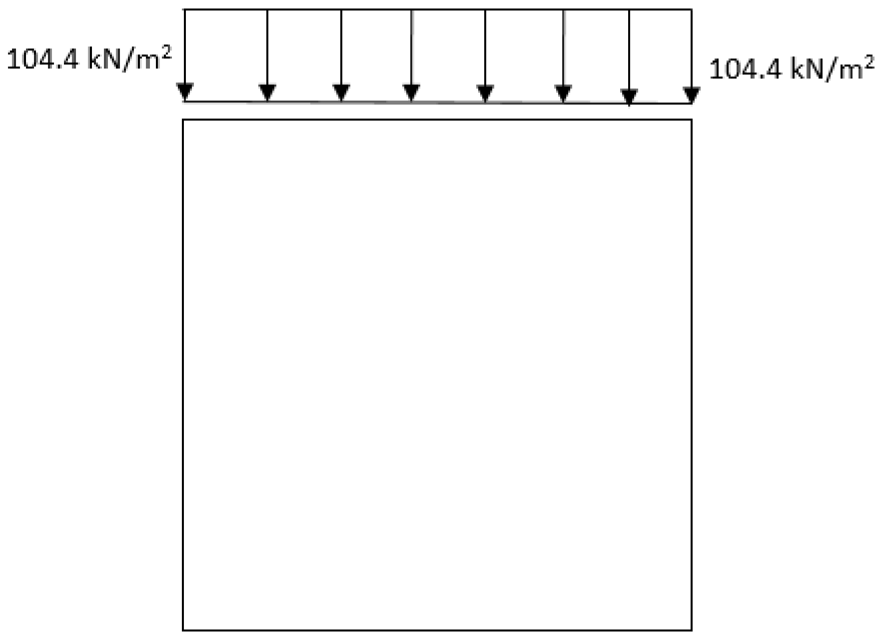
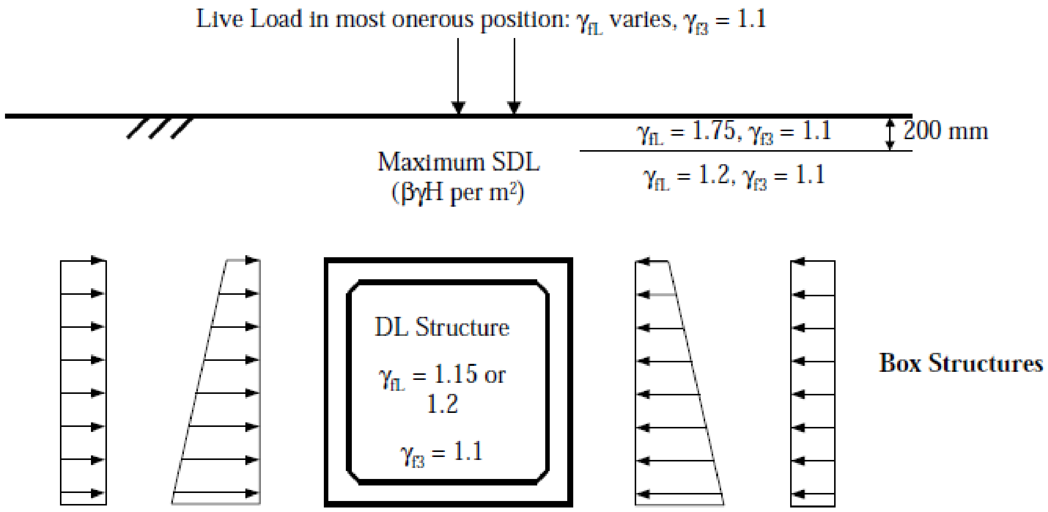


Figure B.11: SID soil load on culvert

1.7 Define Load combinations

Combination A1



LLSC	Earth		Earth	LLSC
K = 0.6 γ_{fL} = 1.5 γ_{f3} = 1.1	K = 0.6 γ_{fL} = 1.5 γ_{f3} = 1.1	Default values	K = 0.6 γ_{fL} = 1.5 γ_{f3} = 1.1	K = 0.6 γ_{fL} = 1.5 γ_{f3} = 1.1
K = K_o γ_{fL} = 1.5 γ_{f3} = 1.1	K = K_o γ_{fL} = 1.2 γ_{f3} = 1.1	BS 8002 coefficients	K = K_o γ_{fL} = 1.2 γ_{f3} = 1.1	K = K_o γ_{fL} = 1.5 γ_{f3} = 1.1

Figure B.12: Combination A1

Combination A1 HA ULS

Name	factors notations	factors values	final load factor
DEAD	γ_{fl} x γ_{f3}	1.15 x 1.1	1.265
SID top 200	γ_{fl} x γ_{f3} x β	1.75 x 1.1 x 1.15	2.214
SID Soil	γ_{fl} x γ_{f3} x β	1.20 x 1.1 x 1.15	1.518
Soil horizontal	γ_{fl} x γ_{f3} x K_o	1.50 x 1.1 x 0.60	0.990
HA surcharge	γ_{fl} x γ_{f3} x K_o	1.50 x 1.1 x 0.60	0.990
HB surcharge			
HA Vertical	γ_{fl} x γ_{f3}	1.50 x 1.1	1.650
HB Vertical			

Combination A1 HA SLS

Name	factors notations	factors values	final load factor
DEAD	Υfl	1.00	1.00
SID top 200	$\Upsilon fl \times \beta$	1.20 x 1.15	1.38
SID Soil	$\Upsilon fl \times \beta$	1.00 x 1.15	1.15
Soil horizontal	$\Upsilon fl \times Ko$	1.00 x 0.60	0.60
HA surcharge	$\Upsilon fl \times Ko$	1.00 x 0.60	0.60
HB surcharge			
HA Vertical	Υ_{fl}	1.20	1.20
HB Vertical			

Combination A1 HB ULS

Name	factors notations	factors values	final load factor
DEAD	$\Upsilon_{fl} \times \Upsilon_{f3}$	1.15 x 1.1	1.265
SID top 200	$\Upsilon_{fl} \times \Upsilon_{f3} \times \beta$	1.75 x 1.1 x 1.15	2.214
SID Soil	$\Upsilon_{fl} \times \Upsilon_{f3} \times \beta$	1.20 x 1.1 x 1.15	1.518
Soil horizontal	$\Upsilon_{fl} \times \Upsilon_{f3} \times K_o$	1.50 x 1.1 x 0.60	0.990
HA surcharge			
HB surcharge	$\Upsilon_{fl} \times \Upsilon_{f3} \times K_o$	1.50 x 1.1 x 0.60	0.990
HA Vertical			
HB Vertical	$\Upsilon_{fl} \times \Upsilon_{f3}$	1.30 x 1.1	1.430

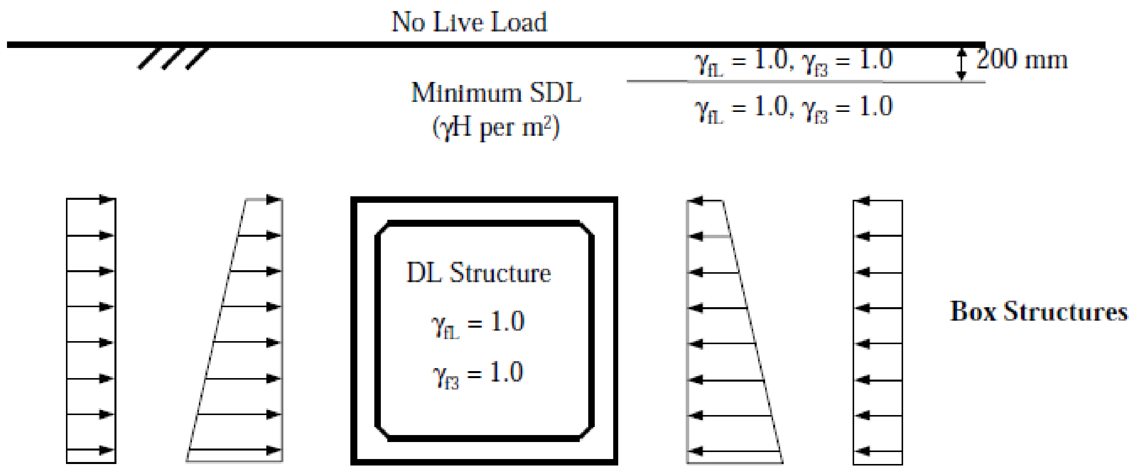
Combination A1 HB SLS

Name	factors notations	factors values	final load factor
DEAD	Υfl	1.00	1.00
SID top 200	$\Upsilon fl \times \beta$	1.20 x 1.15	1.38
SID Soil	$\Upsilon fl \times \beta$	1.00 x 1.15	1.15
Soil horizontal	$\Upsilon fl \times Ko$	1.00 x 0.60	0.6
HA surcharge			
HB surcharge	$\Upsilon fl \times Ko$	1.00 x 0.60	0.6
HA Vertical			
HB Vertical	Υ_{fl}	1.10	1.10

Combination A1 SLS Permanent

Name	factors notations	factors values	final load factor
DEAD	Ɣfl	1.00	1.00
SID top 200	Ɣfl x β	1.20 x 1.15	1.38
SID Soil	Ɣfl x β	1.00 x 1.15	1.15
Soil horizontal	Ɣfl x Ko	1.00 x 0.60	0.60
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical			

Combination A2



LLSC	Earth		Earth	LLSC
$K = 0.6$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	$K = 0.6$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	Default values	$K = 0.6$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	$K = 0.6$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$
$K = K_o$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	$K = K_o$ $\gamma_{fL} = 1.2$ $\gamma_{f3} = 1.1$	BS 8002 coefficients	$K = K_o$ $\gamma_{fL} = 1.2$ $\gamma_{f3} = 1.1$	$K = K_o$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$

Figure B.13: Combination A2

Combination A2 HB ULS

Name	factors notations	factors values	final load factor
DEAD	Υ_{fl} x Υ_{f3}	1.00 x 1.00	1.265
SID top 200	Υ_{fl} x Υ_{f3} x β	1.00 x 1.00 x 1.00	2.214
SID Soil	Υ_{fl} x Υ_{f3} x β	1.00 x 1.00 x 1.00	1.518
Soil horizontal	Υ_{fl} x Υ_{f3} x K_o	1.50 x 1.1 x 0.60	0.990
HA surcharge			
HB surcharge	Υ_{fl} x Υ_{f3} x K_o	1.50 x 1.1 x 0.60	0.990
HA Vertical			
HB Vertical			

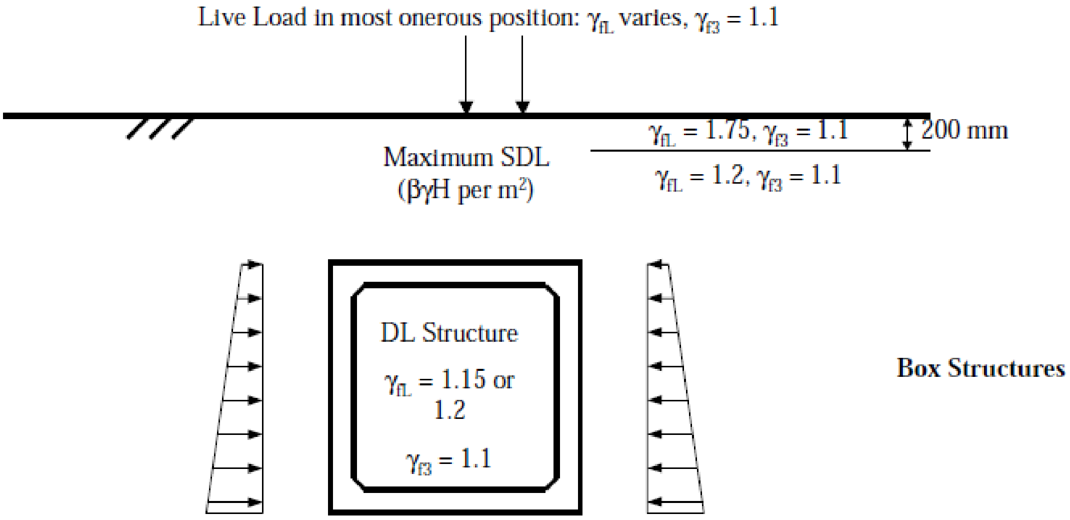
Combination A2 HB SLS

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00 x 1.00	1.265
SID top 200	ϒfl x β	1.00 x 1.00 x 1.00	2.214
SID Soil	ϒfl x β	1.00 x 1.00 x 1.00	1.518
Soil horizontal	ϒfl x Ko	1.00 x 0.60	0.6
HA surcharge			
HB surcharge	ϒfl x Ko	1.00 x 0.60	0.6
HA Vertical			
HB Vertical			

Combination A2 SLS Permanent

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00 x 1.00	1.265
SID top 200	ϒfl x β	1.00 x 1.00 x 1.00	2.214
SID Soil	ϒfl x β	1.00 x 1.00 x 1.00	1.518
Soil horizontal	ϒfl x Ko	1.00 x 0.60	0.6
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical			

Combination A3



Earth		Earth
K = 0.2 γ_{fL} = 1.0 γ_{f3} = 1.0	Default values	K = 0.2 γ_{fL} = 1.0 γ_{f3} = 1.0
K = 0.2 γ_{fL} = 1.0 γ_{f3} = 1.0	BS 8002 coefficients	K = 0.2 γ_{fL} = 1.0 γ_{f3} = 1.0

Figure B.14: Combination A3

Combination A3 HA ULS

Name	factors notations	factors values	final load factor
DEAD	γ_{fl} x γ_{f3}	1.15 x 1.1	1.265
SID top 200	γ_{fl} x γ_{f3} x β	1.75 x 1.10 x 1.15	2.214
SID Soil	γ_{fl} x γ_{f3} x β	1.20 x 1.10 x 1.15	1.518
Soil horizontal	γ_{fl} x γ_{f3} x K_o	1.00 x 1.00 x 0.20	0.200
HA surcharge			
HB surcharge			
HA Vertical	γ_{fl} x γ_{f3}	1.50 x 1.1	1.650
HB Vertical			

Combination A3 HA SLS

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00	1.00
SID top 200	ϒfl x β	1.20 x 1.15	1.38
SID Soil	ϒfl x β	1.00 x 1.15	1.15
Soil horizontal	ϒfl x Ko	1.00 x 0.20	0.20
HA surcharge			
HB surcharge			
HA Vertical	$ϒ_{fl}$	1.20	1.20
HB Vertical			

Combination A3 HB ULS

Name	factors notations	factors values	final load factor
DEAD	$ϒ_{fl}$ x $ϒ_{f3}$	1.15 x 1.1	1.265
SID top 200	$ϒ_{fl}$ x $ϒ_{f3}$ x β	1.75 x 1.1 x 1.15	2.214
SID Soil	$ϒ_{fl}$ x $ϒ_{f3}$ x β	1.20 x 1.1 x 1.15	1.518
Soil horizontal	$ϒ_{fl}$ x $ϒ_{f3}$ x K_o	1.00 x 1.00 x 0.20	0.200
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical	$ϒ_{fl}$ x $ϒ_{f3}$	1.30 x 1.1	1.430

Combination A3 HB SLS

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00	1.00
SID top 200	ϒfl x β	1.20 x 1.15	1.38
SID Soil	ϒfl x β	1.00 x 1.15	1.15
Soil horizontal	ϒfl x Ko	1.00 x 0.20	0.20
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical	$ϒ_{fl}$	1.10	1.10

Combination A3 SLS Permanent

Name	factors notations	factors values	final load factor
DEAD	Yfl	1.00	1.00
SID top 200	Yfl x β	1.20 x 1.15	1.38
SID Soil	Yfl x β	1.00 x 1.15	1.15
Soil horizontal	Yfl x Ko	1.00 x 0.20	0.20
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical			

Create envelope for ULS, SLS and SLS permanent load combinations

Appendix C -(1.5X1.5)

																		outter T			inner T																				
		A1	A5	A1	A1	A4	A6	A4	A4	C4	C6	C4	C4	C1	C5	C1	C1	B	B	B	B	B	B	H	H	H	D	D	D	A2	A2	A2	A3	A3	A3	C3	C3	C3	C2	C2	C2
fill height	thickness	ULS BM	ULS SF	SLS BM	SLS P BM	ULS BM	ULS SF	SLS BM	SLS P BM	ULS BM	ULS SF	SLS BM	SLS P BM	ULS BM	ULS SF	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM
0.5	200	32	153	22	1	50	27	35	2	50	33	35	4	38	120	26	1	38	26	3	15	10	0	56	41	4	49	34	5	58	41	3	63	44	3	64	45	6	59	40	5
0.5	**250**	26	136	18	0	49	25	35	3	49	31	34	5	34	117	23	0	38	26	4	13	8	0	58	42	4	50	35	7	57	40	3	65	46	4	67	46	7	59	40	6
0.5	300	21	129	15	0	48	23	34	3	48	32	34	6	31	117	20	0	37	26	5	10	6	0	61	44	5	54	36	8	56	40	2	66	47	4	70	49	8	61	41	6
0.5	350	17	128	11	0	48	20	33	4	47	30	33	7	26	112	16	0	38	28	6	8	4	1	63	45	6	56	38	10	55	39	2	68	48	4	72	50	10	60	41	7
0.5	**400**	13	125	8	0	47	17	33	5	46	29	33	8	21	109	11	0	40	29	7	5	2	2	65	47	7	60	41	11	53	38	2	69	49	5	75	52	11	61	41	7
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1	**200**	20	72	14	1	28	22	19	4	27	18	18	5	21	66	12	1	20	13	4	8	4	0	25	18	6	26	17	7	38	26	4	37	25	5	36	24	8	33	21	7
1	250	15	64	10	0	28	17	19	4	27	18	18	6	20	68	11	0	19	13	5	8	3	0	26	19	7	28	18	9	33	23	4	38	26	5	38	25	9	36	23	7
1	300	12	63	7	0	28	15	18	5	27	17	18	7	18	68	9	0	19	13	6	6	2	0	28	20	7	29	19	10	33	23	4	40	27	6	41	28	10	37	23	8
1	**350**	10	62	5	0	27	12	18	6	27	15	19	8	15	68	6	0	20	14	7	5	1	0	29	21	8	32	21	12	33	23	3	42	29	6	44	30	12	38	24	8
2	150	7	36	4	3	14	21	10	6	16	22	12	7	8	39	4	3	14	10	6	8	2	1	22	16	9	23	17	10	16	10	7	19	13	8	21	15	10	18	12	9
2	**200**	6	32	2	1	16	18	11	6	18	20	13	8	7	37	3	2	16	11	7	7	2	0	24	17	10	26	19	11	15	10	7	20	14	9	23	17	11	18	12	9
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4	**250**	7	39	1	0	21	27	15	13	24	29	17	15	7	41	1	0	20	14	12	9	0	0	31	22	19	34	24	21	23	15	13	28	20	17	32	23	20	26	17	15
4	300	5	33	0	0	23	22	16	14	26	25	19	16	5	36	0	0	22	15	13	9	0	0	33	24	20	37	27	23	22	14	12	29	21	18	34	25	22	26	17	16
4	350	3	26	0	0	24	17	17	15	28	21	20	18	2	30	0	0	24	17	15	9	0	0	35	25	22	40	29	26	21	13	12	30	22	19	36	27	24	26	17	15
4	**400**	1	20	0	0	26	12	19	16	30	17	22	19	0	23	0	0	27	19	16	9	0	0	38	27	23	44	32	28	21	12	11	31	22	19	38	29	25	26	17	15
6	200	12	59	4	3	26	43	19	18	28	44	20	19	12	58	4	3	22	15	14	12	1	0	37	27	25	40	29	27	31	20	19	36	26	24	38	28	26	34	22	21
6	**250**	9	51	0	0	27	36	20	19	30	39	22	21	9	52	0	0	25	17	16	12	0	0	40	29	27	43	31	29	31	20	18	37	27	25	41	30	28	34	23	21
6	300	6	43	0	0	29	30	21	20	32	33	23	22	6	45	0	0	28	19	18	11	0	0	42	31	29	46	34	32	30	19	18	38	28	26	43	32	30	34	23	21
6	350	4	34	0	0	31	23	22	21	35	28	25	24	2	37	0	0	31	22	20	11	0	0	45	33	31	50	37	35	29	18	17	39	29	27	45	34	32	34	22	20
6	**400**	1	26	0	0	33	16	24	22	37	22	27	25	0	28	0	0	34	24	22	11	0	0	48	35	33	55	40	38	28	17	16	40	30	28	47	35	34	33	21	20
8	200	15	75	5	4	32	54	24	23	34	55	25	24	15	72	5	4	28	19	19	15	0	0	47	34	33	50	36	35	40	26	25	45	32	31	48	35	33	42	28	27
8	**250**	11	64	0	0	34	46	25	24	37	48	27	26	11	64	0	0	31	22	21	14	0	0	50	36	35	53	39	38	39	26	24	47	34	32	51	37	36	43	28	27
8	300	7	54	0	0	37	38	26	26	40	41	29	28	7	55	0	0	35	24	24	14	0	0	53	38	37	57	42	40	39	25	23	48	35	34	53	39	38	43	28	26
8	350	4	43	0	0	39	29	28	27	42	34	31	30	2	45	0	0	38	27	26	14	0	0	56	41	40	62	45	44	38	24	22	49	36	35	55	41	40	42	27	26
8	**400**	0	32	0	0	41	21	30	29	45	26	32	32	0	34	0	0	41	29	28	14	0	0	60	43	42	67	49	48	36	22	21	50	37	36	57	43	42	41	26	24
10	200	17	109	6	4	48	65	35	35	49	66	37	36	18	103	6	5	42	30	29	17	0	0	70	51	50	72	53	52	52	35	33	64	46	45	66	48	47	54	36	35
10	**250**	13	94	0	0	51	55	37	37	53	58	39	39	13	90	0	0	47	33	33	17	0	0	73	54	53	77	56	55	51	34	32	66	48	47	69	51	50	54	36	34
10	300	9	78	0	0	54	46	39	39	57	49	42	41	8	76	0	0	51	36	36	16	0	0	77	56	56	82	60	59	50	32	31	68	50	49	73	54	53	53	35	34
10	350	4	62	0	0	57	36	41	41	61	40	44	44	2	62	0	0	56	39	39	16	0	0	82	60	59	87	64	63	48	30	29	70	52	51	76	56	55	52	34	32
10	**400**	0	46	0	0	61	26	44	43	64	31	46	46	0	47	0	0	60	42	42	16	0	0	87	63	63	94	69	68	45	28	27	72	53	52	78	59	58	49	31	30
12	200	20	150	6	5	66	76	49	49	68	77	50	50	21	140	6	5	60	42	42	20	0	0	97	71	71	100	73	73	66	44	43	85	62	61	87	63	62	68	46	44
12	**250**	15	129	0	0	71	65	52	52	73	67	54	53	15	122	0	0	66	47	47	19	0	0	102	75	74	105	78	77	64	43	41	89	65	64	92	67	67	67	45	43
12	300	10	108	0	0	75	54	55	55	78	57	57	57	9	103	0	0	72	51	51	19	0	0	107	79	78	112	82	82	62	40	39	92	68	67	96	71	70	65	43	41
12	350	5	86	0	0	80	42	58	58	83	46	60	60	3	83	0	0	77	55	55	18	0	0	113	83	83	119	88	87	59	38	36	95	70	69	100	75	74	62	40	39
12	**400**	0	64	0	0	84	31	61	61	87	35	64	63	0	63	0	0	83	59	59	19	0	0	119	88	87	127	94	94	55	34	33	98	73	72	104	78	77	58	37	36

Appenndix C(2.0X2.0)

		A1	A5	A1	A1	A4	A6	A4	A4	C4	C6	C4	C4	C1	C5	C1	C1	B (outter T)	B	B	B (inner T)	B	B	H	H	H	D	D	D	A2	A2	A2	A3	A3	A3	C3	C3	C3	C2	C2	C2
fill height	thickness	ULS BM	ULS SF	SLS BM	SLS P BM	ULS BM	ULS SF	SLS BM	SLS P BM	ULS BM	ULS SF	SLS BM	SLS P BM	ULS BM	ULS SF	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM	ULS BM	SLS BM	SLS P BM
0.5	200	51	191	35	3	68	38	47	4	74	48	51	7	60	133	39	4	58	40	5	29	19	2	75	54	6	68	45	9	79	55	6	83	58	6	92	63	10	86	57	10
0.5	250	44	178	31	2	67	35	46	4	73	46	50	8	54	134	35	3	57	40	7	27	17	1	79	57	7	69	47	10	78	54	6	85	59	6	95	65	12	87	58	11
0.5	300	39	180	27	1	66	33	45	5	72	46	50	10	51	138	33	2	57	40	8	24	15	1	84	60	8	73	49	12	78	54	5	87	60	7	99	68	14	90	60	12
0.5	350	33	155	23	0	65	29	44	6	71	45	50	11	46	138	28	0	56	40	10	21	13	0	82	59	9	75	51	15	75	52	5	87	61	7	102	70	16	90	60	13
0.5	400	28	152	18	0	63	26	43	7	70	45	49	13	41	140	24	0	56	40	11	19	10	0	83	60	11	78	53	17	74	52	5	88	61	8	106	73	19	92	61	14
1	200	31	89	21	3	43	33	28	6	43	34	28	9	36	84	21	5	34	22	7	16	8	2	38	27	9	38	25	12	50	34	8	53	36	9	54	35	13	52	32	12
1	250	27	88	18	2	43	31	28	7	44	34	29	11	35	90	19	4	34	23	9	16	7	1	40	29	10	42	28	14	50	34	8	55	37	10	60	39	15	56	35	13
1	300	24	87	15	1	42	28	27	7	45	32	30	12	32	92	17	2	35	23	10	14	6	0	42	30	12	45	31	16	50	34	8	57	39	10	64	41	17	58	36	14
1	350	20	84	12	0	42	25	27	8	45	31	30	14	29	92	13	0	35	24	12	13	5	0	44	32	13	46	33	18	50	34	8	59	40	11	67	44	20	59	36	15
1	400	17	84	9	0	42	22	27	9	46	30	31	16	25	93	10	0	36	25	14	11	3	0	47	34	15	50	36	21	49	33	7	61	41	11	72	47	22	61	37	16
2	200	13	63	7	5	28	37	19	11	31	40	22	14	15	72	8	7	27	19	12	15	4	2	40	29	16	43	31	19	29	19	13	35	24	15	40	28	19	34	23	17
2	250	12	60	5	3	30	34	20	11	33	38	24	15	14	73	6	5	30	22	13	14	4	1	42	30	17	46	34	21	29	19	13	38	25	16	45	31	22	35	24	18
2	300	10	58	3	1	31	31	21	12	36	36	26	17	12	73	4	2	33	24	15	14	2	0	45	32	19	50	36	23	28	18	13	41	26	17	50	34	24	37	25	19
2	350	9	55	1	0	32	28	23	13	39	34	28	19	10	73	1	0	37	26	17	13	1	0	47	34	20	54	39	26	27	18	13	43	28	17	54	36	26	39	25	20
2	400	7	51	0	0	34	24	24	14	42	32	31	21	7	72	0	0	40	29	19	13	0	0	50	37	22	59	43	29	27	17	12	46	29	18	59	39	29	40	26	21
4	200	20	86	10	8	33	62	24	20	36	66	27	23	22	86	12	10	28	19	16	19	4	1	49	35	30	52	38	32	42	28	24	47	33	28	51	36	32	47	31	28
4	250	17	80	7	5	34	57	25	21	39	62	29	25	19	83	8	6	31	21	18	19	3	0	51	37	31	56	40	35	42	28	24	48	34	29	55	39	34	48	32	29
4	300	15	74	4	2	36	52	26	22	42	58	31	27	16	79	4	2	34	24	20	18	1	0	54	39	33	60	43	38	42	27	23	50	35	30	58	42	37	50	33	30
4	350	12	68	0	0	39	47	28	24	46	54	33	29	13	75	0	0	38	26	22	17	0	0	57	41	35	64	47	41	41	26	23	51	37	31	62	45	40	51	34	30
4	400	9	61	0	0	41	42	30	25	49	50	36	31	9	71	0	0	41	29	25	17	0	0	60	43	37	69	50	44	41	26	22	53	38	33	65	48	43	51	34	30
6	200	26	113	14	12	43	83	32	30	46	88	34	32	28	110	15	13	36	24	23	24	3	1	64	46	43	67	49	46	56	38	35	62	44	41	66	47	44	61	41	38
6	250	23	105	9	7	45	77	33	31	50	82	37	35	24	105	10	8	40	27	25	23	2	0	67	48	45	71	52	49	56	37	34	64	45	42	70	51	47	63	42	39
6	300	19	97	4	2	48	70	35	32	53	76	39	37	20	100	5	3	44	30	28	22	0	0	70	51	47	76	55	52	56	37	34	66	47	44	74	54	51	64	43	40
6	350	15	89	0	0	50	64	36	34	57	70	42	39	16	94	0	0	48	33	31	22	0	0	73	53	50	81	59	55	56	36	33	68	49	45	78	57	54	65	43	40
6	400	11	80	0	0	53	57	38	36	61	65	44	42	11	87	0	0	52	36	34	21	0	0	77	56	52	86	63	59	55	35	32	69	50	47	81	60	57	65	43	40
8	200	33	143	17	15	54	105	41	39	57	109	43	41	35	137	18	16	45	30	30	29	3	0	81	59	57	83	61	59	71	48	45	79	56	53	83	59	57	76	51	48
8	250	28	133	11	9	57	97	42	41	62	102	46	44	30	130	12	10	49	34	33	28	1	0	84	61	59	88	64	62	72	47	45	81	58	55	87	63	60	78	52	49
8	300	23	122	5	3	60	88	44	42	66	94	48	47	24	123	5	3	54	37	36	27	0	0	88	64	62	93	68	66	71	47	44	83	60	57	91	66	64	79	52	50
8	350	18	112	0	0	63	80	46	44	70	87	51	50	19	115	0	0	59	41	40	26	0	0	92	66	64	99	72	70	71	46	43	85	61	59	95	70	67	80	53	50
8	400	13	101	0	0	66	71	48	46	74	79	54	53	13	106	0	0	64	44	43	25	0	0	96	70	68	105	77	75	70	44	42	87	63	61	99	73	71	80	52	50
10	250	34	193	13	11	84	116	62	61	88	121	65	64	35	184	14	12	74	52	51	32	0	0	123	90	89	128	94	92	94	63	60	113	81	79	118	86	84	99	67	64
10	300	28	178	5	3	88	107	65	64	94	112	69	68	29	172	6	4	80	56	56	31	0	0	128	94	93	134	98	97	93	61	59	116	84	82	124	90	88	100	67	64
10	350	22	162	0	0	92	97	68	67	99	103	73	72	22	159	0	0	87	61	61	30	0	0	133	98	96	141	104	102	91	60	57	119	87	85	129	95	93	100	66	64
10	400	16	146	0	0	97	86	71	70	105	94	77	76	14	146	0	0	93	66	65	29	0	0	139	102	101	149	109	108	89	58	55	122	90	88	134	99	97	99	65	63
10	450	10	130	0	0	102	76	74	73	110	85	80	79	7	132	0	0	99	70	70	29	0	0	146	107	105	157	116	114	87	55	52	125	92	90	139	104	102	98	64	61
12	300	32	244	6	4	122	125	90	90	128	130	95	94	33	232	6	4	113	80	80	35	0	0	178	131	130	184	135	135	116	78	75	155	113	112	163	119	118	123	83	81
12	350	25	222	0	0	128	113	95	94	135	119	100	99	25	214	0	0	121	86	86	34	0	0	185	136	135	192	142	141	114	75	73	160	117	116	170	125	123	122	82	79
12	400	18	200	0	0	135	101	99	98	142	108	104	104	16	195	0	0	129	93	92	34	0	0	192	142	141	202	149	148	110	72	69	165	121	120	176	131	129	120	79	77
12	450	11	178	0	0	141	89	103	103	149	97	109	109	8	176	0	0	137	99	98	33	0	0	201	148	147	212	157	156	106	68	66	169	125	123	182	136	134	117	76	74
12	500	4	155	0	0	148	77	107	107	156	86	114	113	0	155	0	0	145	104	104	33	0	0	209	154	153	224	166	165	102	64	62	173	128	127	188	141	140	113	73	70

Appendx C (3.0X3.0)

		A1	A5	A1	A1	A4	A6	A4	A4	C4	C6	C4	C4	C1	C5	C1	C1	B (outer T)	B (outer T)	B (outer T)	B (inner T)	B (inner T)	B (inner T)	H	H	H	D	D	D	A2	A2	A2	A3	A3	A3	C3	C3	C3	C2	C2	C2
fill height	**thickness**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**
0.5	250	84	233	57	9	111	63	74	10	124	78	82	17	100	162	60	15	108	72	18	49	29	8	127	91	14	106	70	20	126	86	15	133	90	16	153	100	26	144	91	26
0.5	**300**	78	229	53	7	111	60	74	10	125	78	83	20	97	165	57	13	109	73	20	48	27	7	134	96	15	112	75	24	126	86	15	135	91	16	160	105	30	149	94	29
0.5	350	70	226	47	6	109	56	72	11	125	76	84	23	90	168	52	12	110	74	21	46	25	5	133	96	18	116	79	28	124	84	15	137	93	17	166	110	34	152	96	32
0.5	400	63	206	42	4	109	53	72	12	127	76	85	26	85	172	48	9	111	76	23	44	23	4	135	97	20	121	84	32	122	83	15	139	94	18	173	115	38	156	98	34
0.5	**450**	57	203	37	2	108	50	71	13	128	75	87	29	79	174	42	6	113	77	27	41	20	2	141	102	22	126	89	37	121	82	15	142	95	18	180	119	43	159	99	37
1	200	80	138	52	13	85	71	54	15	88	74	54	19	75	126	41	18	75	47	24	35	16	10	76	54	19	74	53	24	104	69	21	100	66	22	106	65	29	103	61	29
1	**250**	59	133	38	11	82	63	52	15	87	72	54	22	71	127	37	17	75	47	25	34	14	8	77	55	21	81	58	28	92	61	21	100	65	23	110	67	33	104	61	32
1	300	53	131	34	9	81	61	51	15	89	71	56	25	68	132	34	15	77	49	26	34	13	7	81	58	23	87	63	32	93	61	21	102	67	23	116	72	37	108	63	35
1	350	49	128	30	7	81	58	51	16	91	69	58	28	65	136	30	13	79	51	28	33	11	5	84	60	25	93	68	36	92	60	21	105	68	24	123	77	41	112	65	37
1	**400**	44	126	26	5	81	55	50	17	93	68	60	32	62	140	27	10	81	53	29	32	10	4	88	63	28	100	72	40	92	60	21	107	70	25	130	82	45	116	67	40
2	200	39	120	24	19	69	76	42	26	72	87	45	29	47	126	28	24	61	41	36	41	16	10	85	61	34	87	63	38	70	47	33	81	53	35	88	60	42	79	53	41
2	**250**	35	117	20	16	70	74	42	25	75	85	48	32	43	132	25	22	65	45	37	40	14	8	89	64	36	95	69	42	70	47	33	84	55	36	96	65	47	84	56	44
2	300	33	115	17	13	70	71	43	25	78	83	53	35	40	135	23	19	68	49	39	39	12	6	92	66	38	102	74	47	70	46	33	88	57	38	103	70	51	88	59	46
2	350	31	112	14	10	71	68	45	27	82	81	57	39	38	138	20	15	74	54	40	38	11	5	97	70	41	109	80	51	70	46	33	91	59	39	111	75	55	91	61	49
2	**400**	29	109	11	6	72	65	47	28	85	79	62	42	35	140	16	11	80	58	41	37	9	3	101	73	44	117	85	56	69	45	33	94	61	40	119	81	60	95	64	51
4	250	52	158	30	26	72	120	54	45	80	135	60	52	59	159	35	31	58	39	32	51	14	8	108	78	66	115	83	71	98	66	57	107	74	64	118	83	73	111	75	67
4	**300**	48	153	25	21	75	115	55	47	86	131	64	56	55	160	30	26	64	43	36	49	11	5	113	81	69	123	89	77	99	65	57	109	77	66	125	89	79	115	78	69
4	350	45	147	19	15	78	110	57	48	92	126	68	60	51	159	25	20	70	47	40	48	9	3	117	84	72	130	95	82	99	65	57	112	79	68	131	94	84	119	80	72
4	400	41	142	14	10	81	105	59	50	99	122	73	64	46	158	19	14	76	52	44	47	6	0	122	88	75	138	100	88	99	65	56	114	81	70	138	100	89	123	82	74
4	**450**	36	136	9	4	85	100	62	52	105	118	77	68	41	156	12	7	82	56	48	45	4	0	127	92	78	146	107	93	99	64	56	117	83	72	145	106	95	126	84	76
6	250	69	208	40	36	95	159	71	66	101	174	76	72	75	203	44	40	75	50	47	62	13	7	142	103	96	147	107	100	131	88	81	141	99	92	151	107	100	143	96	90
6	**300**	63	200	32	28	98	153	73	68	109	168	81	76	70	202	37	33	82	55	52	60	10	4	146	106	99	156	114	107	132	87	81	144	101	94	159	113	106	147	99	93
6	350	58	193	25	21	102	146	75	70	116	162	86	81	64	200	30	26	89	60	57	58	7	1	151	110	103	164	120	113	132	87	80	147	104	97	166	119	112	151	102	95
6	400	52	185	17	13	106	139	77	72	123	156	91	86	57	197	22	17	96	66	62	57	4	0	157	114	106	173	126	119	132	86	80	150	107	99	173	126	118	155	104	97
6	**450**	46	177	10	5	110	132	80	75	130	150	96	90	50	193	13	8	103	71	67	55	1	0	163	118	110	182	133	125	132	85	79	153	109	102	181	132	125	158	106	99
8	300	78	253	40	36	124	190	92	89	134	205	100	97	85	249	45	41	102	69	68	70	9	3	184	134	130	193	141	137	166	110	104	181	128	123	196	140	134	181	122	116
8	**350**	71	243	30	26	128	182	95	92	142	197	105	102	77	244	35	31	110	75	73	69	6	0	190	138	134	202	148	143	166	110	104	185	131	126	204	146	141	185	124	118
8	400	63	232	21	16	133	173	98	95	150	190	111	108	69	239	25	20	118	81	79	67	2	0	196	142	138	212	155	150	166	109	103	188	134	129	212	153	148	189	126	120
8	450	56	222	11	6	138	165	101	98	157	182	116	113	60	233	14	9	126	87	85	65	0	0	202	147	143	221	162	158	165	108	102	192	137	132	220	160	155	192	128	122
8	**500**	48	211	1	0	143	156	104	101	165	174	121	118	50	227	2	0	135	94	91	63	0	0	209	152	148	232	170	165	165	106	100	195	140	135	228	167	161	194	129	123
10	350	84	351	36	31	187	217	139	137	200	233	149	147	90	340	40	36	164	114	114	79	4	0	277	203	200	289	212	210	216	145	139	255	183	179	273	197	193	234	158	153
10	**400**	75	336	24	19	194	207	143	141	210	223	156	154	80	331	28	23	175	122	121	77	0	0	285	209	206	301	221	218	215	143	137	261	188	183	283	206	201	237	159	154
10	450	65	320	12	7	201	197	148	146	220	214	163	161	69	321	15	10	185	130	129	75	0	0	294	215	212	312	230	227	213	141	135	266	192	188	293	214	210	239	160	155
10	500	56	304	0	0	208	186	153	151	230	205	169	167	58	310	1	0	196	138	137	73	0	0	303	222	219	325	239	236	211	138	133	271	197	193	303	223	218	240	160	155
10	**550**	46	288	0	0	215	175	158	156	240	195	176	174	46	298	0	0	207	146	145	71	0	0	312	229	226	338	249	246	209	135	129	276	201	197	313	231	227	241	160	154
12	400	86	461	27	23	268	241	199	198	283	257	211	209	91	442	31	26	244	173	173	87	0	0	395	291	289	409	302	301	270	181	176	347	251	248	368	268	265	291	197	192
12	**450**	75	439	13	9	278	229	206	204	296	246	220	218	79	427	16	11	258	184	183	84	0	0	405	298	297	424	313	311	267	178	173	355	258	254	380	279	275	291	196	191
12	500	64	417	0	0	288	217	212	211	309	235	228	227	66	410	0	0	272	194	194	82	0	0	417	307	305	439	324	323	263	174	169	362	264	261	393	289	286	291	195	190
12	550	52	394	0	0	298	204	219	218	321	224	237	236	52	393	0	0	286	204	204	80	0	0	429	316	314	455	336	334	259	169	164	370	270	267	405	299	296	289	193	188
12	**600**	41	372	0	0	308	191	226	225	333	212	246	244	38	375	0	0	299	214	214	79	0	0	442	325	323	472	349	347	253	164	159	377	277	273	417	310	306	287	191	185

Reference	Calculation	Output

APPENDIX D CALCULATION OF REINFORCEMENT REQUIRMENT

This section explain the procedure followed in the calculation of reinforcement for each requirment

Top slab bottom reinforcement calculation is presented

D-1 BENDING REINFORCEMENT REQUIREMENT

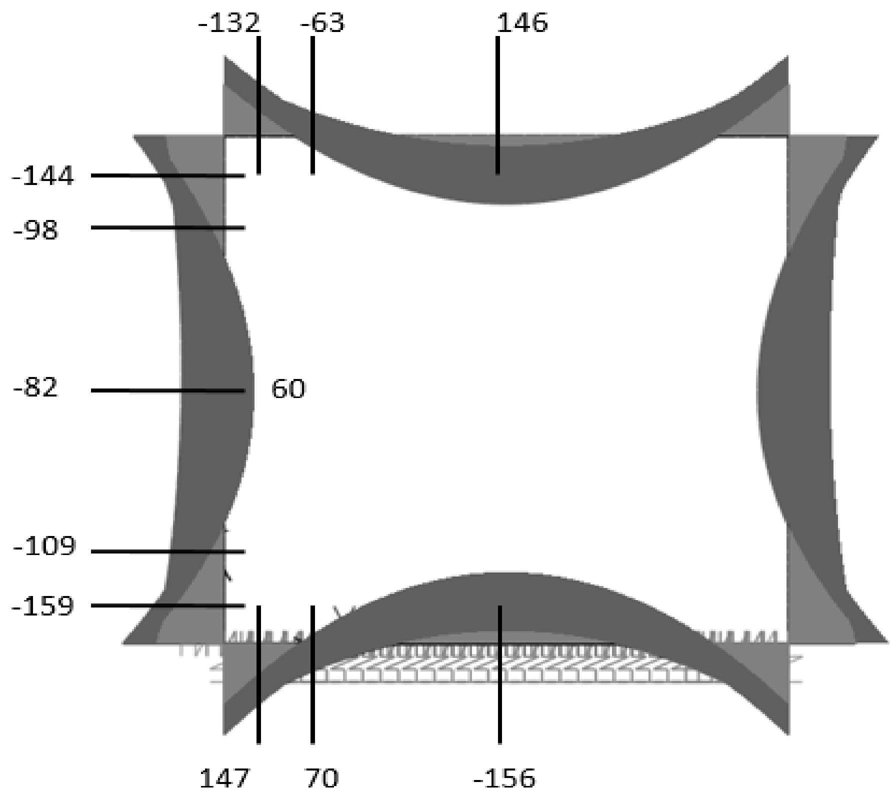


Figure D.1:ULS bending moment (kNm/m) diagram

Reference	Calculation			Output
	Characteristic strength of concrete, f_{cu}	= 30	N/mm^2	
	Characteristic strength of reinforcement, f_y	= 460	N/mm^2	
	Thickness of top slab, h	= 300	mm	
	ULS Bending moment from analysis	= 146	kNm/m	
RDA Bridge Design Manual:1997	Cover	= 50	mm	Cover = 50 mm
	Assume diametre of main reinforcement	= 20	mm	
	Effective depth, d = 300-50-20/2	= 240.0	mm	d = 240.0 mm

BS 5400 Part 4: 1990 5.3.2.3

$M = (0.87f_y)A_sz$ equation 1

$z = (1 - 1.1f_yA_s/ f_{cu}bd)\ d$ equation 5 from these two equations

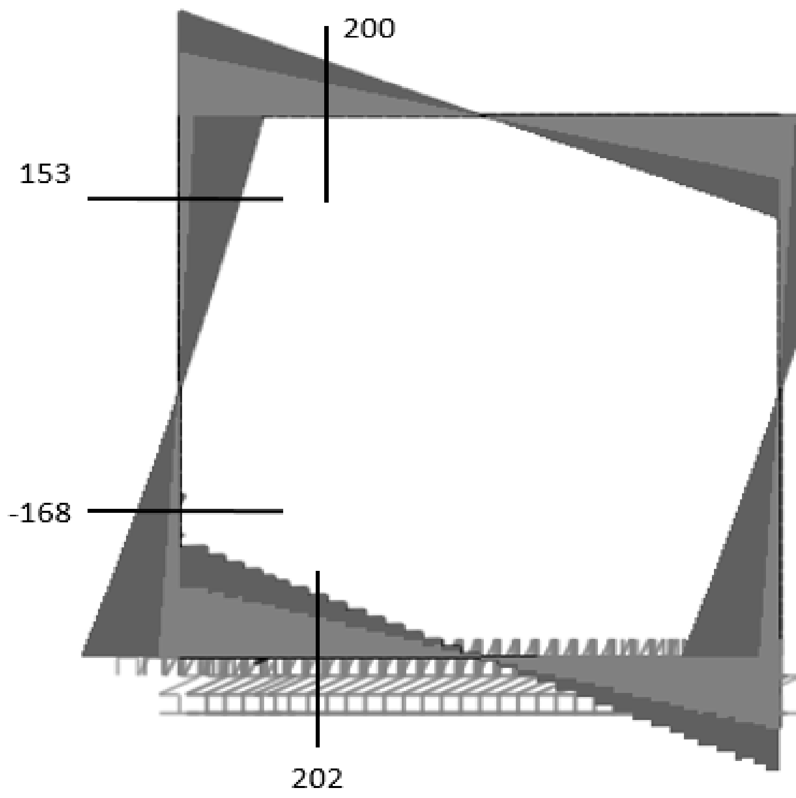
$z = 0.5d\ [1+ (1-5M/f_{cu}bd^2)^{1/2}]$

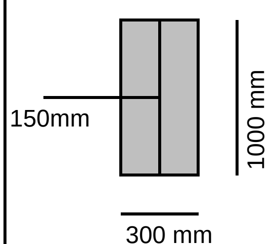
$z = 0.5d\ [1+ (1-5x146x10^6/30x1000x240^2)^{1/2}]$

$= 0.880\ d < 0.950\ d$

$Z = 0.880\ d$

$= 0.95x240 = 211.2$ mm

Reference	Calculation	Output
	Main reinforcement	
equation 1	A_s = $M / 0.87f_yz$	
	= $146\times10^6 / 0.87\times460\times211.2$ = 1727 mm^2/m	$A_{s\,req}$ = 1727 mm^2/m
	D-2 MINIMUM REINFORCEMENT REQUIREMENT	
BS 5400 Part 4: 1990 5.8.4.1	$100A_s / b_ad$ = 0.15	
	A_s = 0.15 X 240 X 1000 / 100	
	= 360 mm^2/m	
	D-3 SHEAR REINFORCEMENT REQUIREMENT	
	to find the reinforcement requirment for shear , assume a amount for reinforcement and calculate shear capacity	
	then change the assumed amount of reinforcement until shear capacity reach actual shear strength of the section	
		
	Figure D.2:ULS Shear force (kN/m) diagram	
	Characteristic strength of concrete, f_{cu} = 30 N/mm^2	
	Characteristic strength of reinforcement, f_y = 460 N/mm^2	
BS 5400 Part 4:1990 Table 13	Thickness of approch slab, h = 300 mm	
RDA Bridge Design Manual:1997	Cover = 50 mm	Cover = 50 mm

Reference	Calculation	Output
	Shear force from analysis = 200 kN/m	V = 200 kN/m
	Effective depth, d = 240.0 mm	
BS 5400	Design shear stress, V = V / bd	
Part 4: 1990	= $(200\text{x}10^3)/(1000\text{x}240)$	
5.3.3.1	= 0.83 N/mm^2	v =
equation 8	$0.75X(f_{cu})^{1/2}$ = $0.75x(30)^{1/2}$ = 4.108 N/mm^2	0.833 N/mm^2
	Design shear stress, v = 0.83 < $0.75x(f_{cu})^{1/2}$ or 4.75 N/mm^2	
	Hence O.K	
	Assume longitudanal tension reinforcement	
	$A_{s\ pro}$ = 2637 mm^2/m	
BS 5400	Allow. shear resistance ,$x_s v_c$ = $(0.27/g_m)(100A_s/b_w d)^{1/3}\ (f_{cu})^{1/3}\ x_s$	
Part 4: 1990		
5.3.3.2	Where, depth ratio, ξ_s = $(500/d)^{1/4}$	
	= $(500/240)^{1/4}$	
	= 1.20 or 0.7 (greater value)	
	$\xi_s v_c$ = $(0.27/1.25)x(100x2637/1000x240)^{1/3}x(30)^{1/3}x1.20$	
	= 0.83 N/mm^2	$\xi_s v_c$
	= actual shear stress	= 0.83 N/mm^2
B/D 28/87	**D-4 SHRINKAGE AND TEMPERATURE REINFORCEMENT REQUIREMENT**	
Incorporating		
Amendment		
No.1 1989	f_{cu} = 30 N/mm^2	
	f_y = 460 N/mm^2	
	Ac = 1000 x 150	
	= 150000 mm^2	
5.1	f_{ct} = 0.12 (f_{cu})$^{0.7}$ = 0.12 (30) $^{0.7}$	
	= 1.30 N/mm^2	
5.3	As = (f_{ct} ÷ f_y) x Ac = $\frac{1.30}{460}$ x 150000	
	As = 423 mm^2	
5.3	As = $\frac{f_{ct} \times A_c \times \phi}{f_b \times 2w}$ [R(ε_{sh} + εt_h) - 0.5 ε_{ult})]	
BS 5400		
Part 4: 1990		
Table 1	w = 0.25 mm	
B/D 28/87	ε_{ult} = 200 x 10^{-6}	
Incorporating	f_{ct} ÷ f_b = 0.67	
Amendment	ε_{sh} = 0.5 x ε_{ult} = 100 x 10^{-6}	
No.1 1989	ϕ = 20 mm	
Table 2	R = 0.5	
Table 1	T_1 = 35	
5.9	T_2 = 12	
5.7	α = 12 x 10^{-6}	

Reference	Calculation	Output

$\varepsilon_{th} = 0.8 \quad \alpha \quad (T1 + T2)$

$= 0.8 \quad x \quad 12 \times 10^{-6} \quad (\quad 35 \quad + \quad 12 \quad)$

$= 451.2 \quad \times 10^{-6}$

As = 706 mm^2

Maximum r/f required = 706 mm^2

D-5 FLEXURAL CRACK WIDTH REINFORCEMENT REQUIREMENT

to find the reinforcement requirment for crack width , assume a amount for reinforcement and calculate crack width

then change the assumed amount of reinforcement until crack width reach to design crack width (0.25mm)

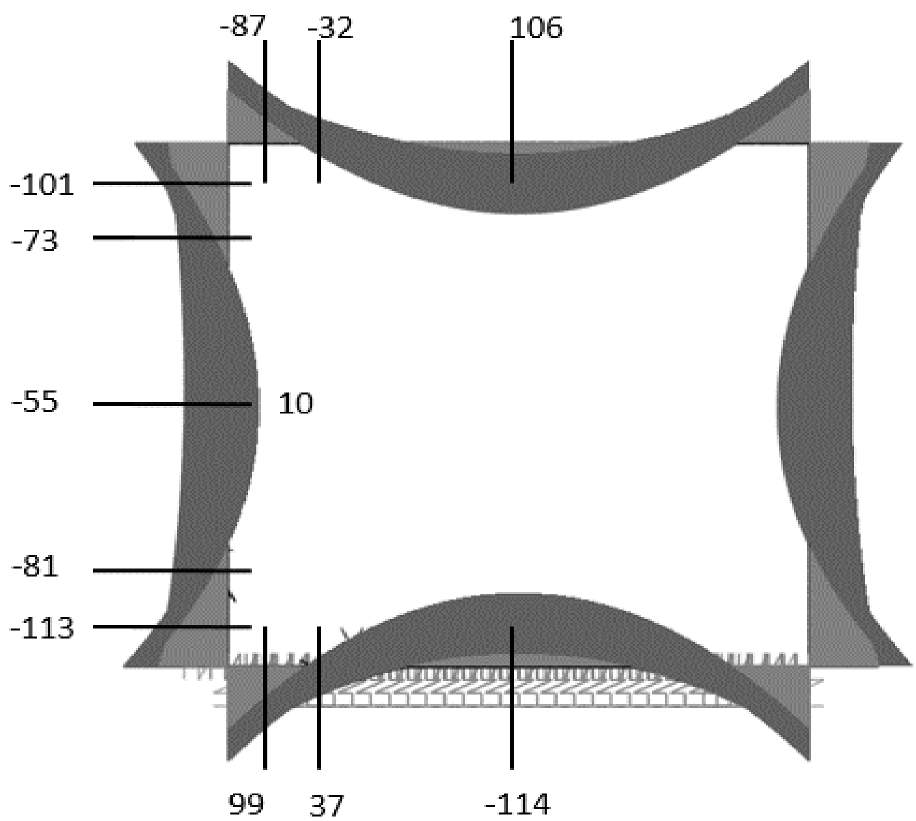


Figure D.3:SLS bending moment (kNm/m) diagram

Reference	Calculation	Output

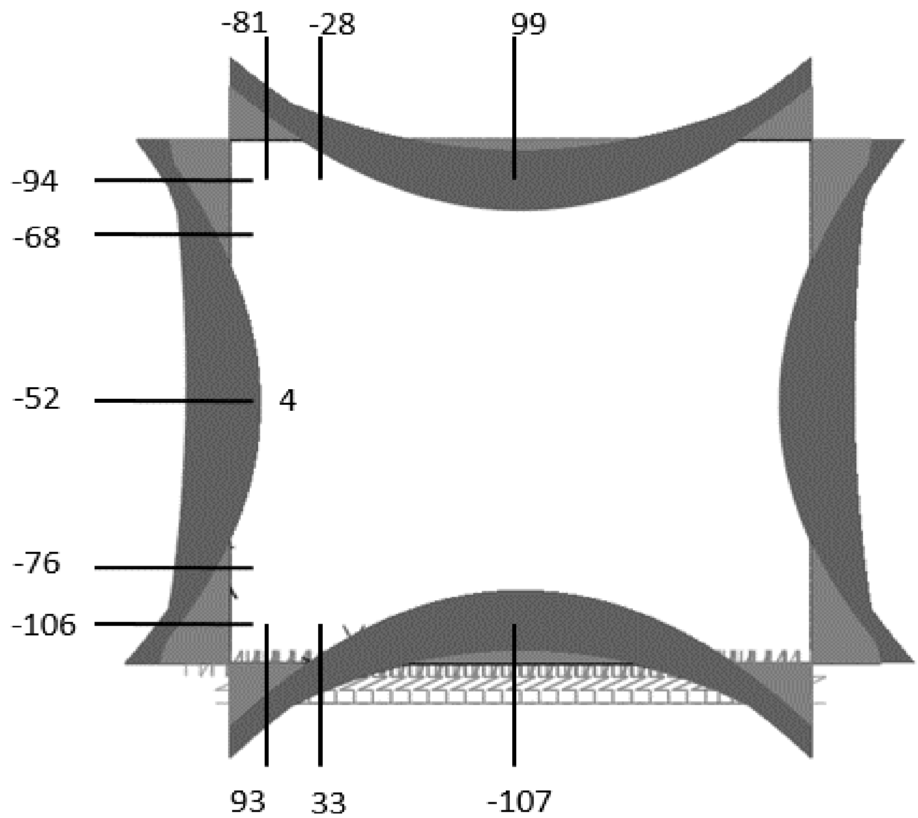


Figure D.4:SLS permanent bending moment (kNm/m) diagram

Bending moment at SLS	M	=	106	kNm
Bending moment due to permanent loads	M_g	=	99	kNm
Bending moment due to live loads	M_q	=	7	kNm
Elastic modulus of concrete (long term)	E_c	=	14	kN/mm^2
Elastic modulus of reinforcement	E_S	=	200	kN/mm^2
Moduli ratio	$\alpha_e = E_S/E_c$	=	14.29	

BS 5400 Part 4 5.8.8.2 eq 24

Design crack width $= \dfrac{3a_{cr}\epsilon_m}{1+2(a_{cr}\text{-}c_{nom})/(h\text{-}d_c)}$

d_c = depth to neutral axis
d = effective depth
h = overall depth
ϵ_c = strain of concrete at compression face
ϵ_s = strain at reinforcement
ϵ_1 = strain of concrete at tensile surface

Above figure shows the strain variation of the section under SLS loading

d_c can be calculated considering the force equilibrium of the section and strain compatibility.

$d_c/d \quad = \alpha_e\rho\,[(1+2/\alpha_e\rho)^{1/2}-1]$ Where $\rho = A_s/(bd)$

Depth of the wing wall section, h	=	300	mm
Breadth considered, b	=	1000	mm
Main r/f size	=	20	mm

Reference	Calculation	Output
	Assume amount of reinforcement ,As = 2013 mm^2/m	
	Cover to r/f = 50 mm	
	Effective depth, d = 240 mm	
	$\rho = A_s/(bd)$ = 0.0084	
	$\alpha_e\rho$ = 0.1198	
	d_c/d , from above equation = 0.384	
	d_c = 92 mm	
	Then the lever arm, $Z = d - d_c/3$ = 209.3 mm	
	Check for stress levels	
	Bending moment at Serviceability limit state (M_s) = 106 kNm/m	
	$s_c = 2M_s/bzd_c$	
BS 5400 Part 4 Table 2	$s_c = 10.99\ N/mm^2 < s_a = 15\ N/mm^2$	
	Hence ok	
	$s_{se} = M_s/zA_s$	
	$= 251.6\ N/mm^2 < s_s = 345\ N/mm^2$	
	Hence ok	
	$\varepsilon_m = \varepsilon_1 - \Delta\varepsilon$	
	$\Delta\varepsilon = \dfrac{[(3.8).b_t.h.(a'-d_c)]}{\varepsilon_s.A_s.(h-d_c)} \times [(1-M_q/M_g).10^{-9}]$	
BS 5400 5.8.8.2 eq : 25	$\varepsilon_1 = \dfrac{(h-dc)}{(d-dc)} \times \dfrac{s_{se}}{E_s}$	
	$= \dfrac{300 - 92}{240 - 92} \times \dfrac{252}{200 \times 10^3}$	
	$\varepsilon_1 = 1.769 \times 10^{-3}$	
	$\varepsilon_s = \dfrac{s_{se}}{E_s}$	
	$= 1.258 \times 10^{-3}$	
	$\Delta\ \varepsilon_s = 0.418 \times 10^{-3}$	
	$\varepsilon_m = \varepsilon_1 - \Delta\varepsilon$	
	$= 1.350 \times 10^{-3}$	
	$a_{cr} = (d'^2 + a'^2)^{1/2} - \varphi/2$	
	a' = Centre to centre distance of nearest tension r/f	
	d' d' = h - d	
	ϕ = diametre of tension r/f	

Reference	Calculation	Output

2.a' = Spacing of reinforcement

= 150 mm

a_1 = 75 mm

d' = 60 mm

a_{cr} = 86.05 mm

BS 5400 5.8.8.2 eq : 24

$$\text{Design crack width} = \frac{3a_{cr}€_m}{1+2(a_{cr}-c_{nom})/(h-d_c)}$$

= 0.25 mm

D-6 SUMMARY OF REINFORCEMENT REQUIREMENT

Criteria	Amount of RF required (mm^2/m)
Bending	1727
Minimum	360
Shear	2637
Thermal and Shrinkage	706
Crack width	2013
Final amount of RF required	2637