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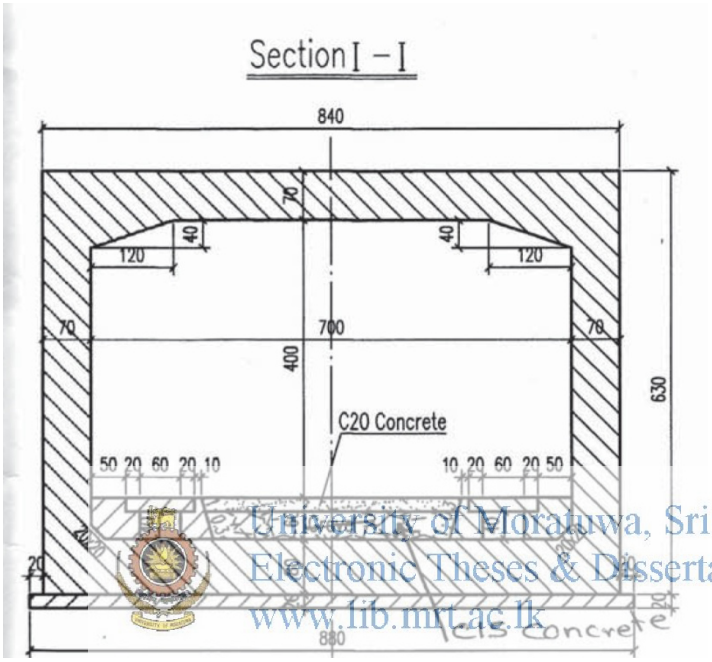
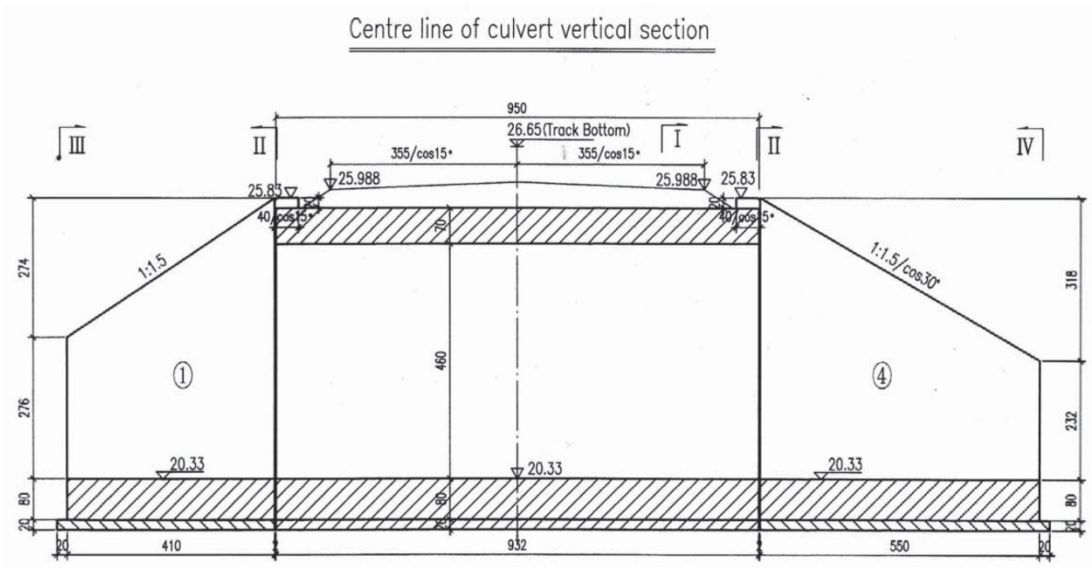
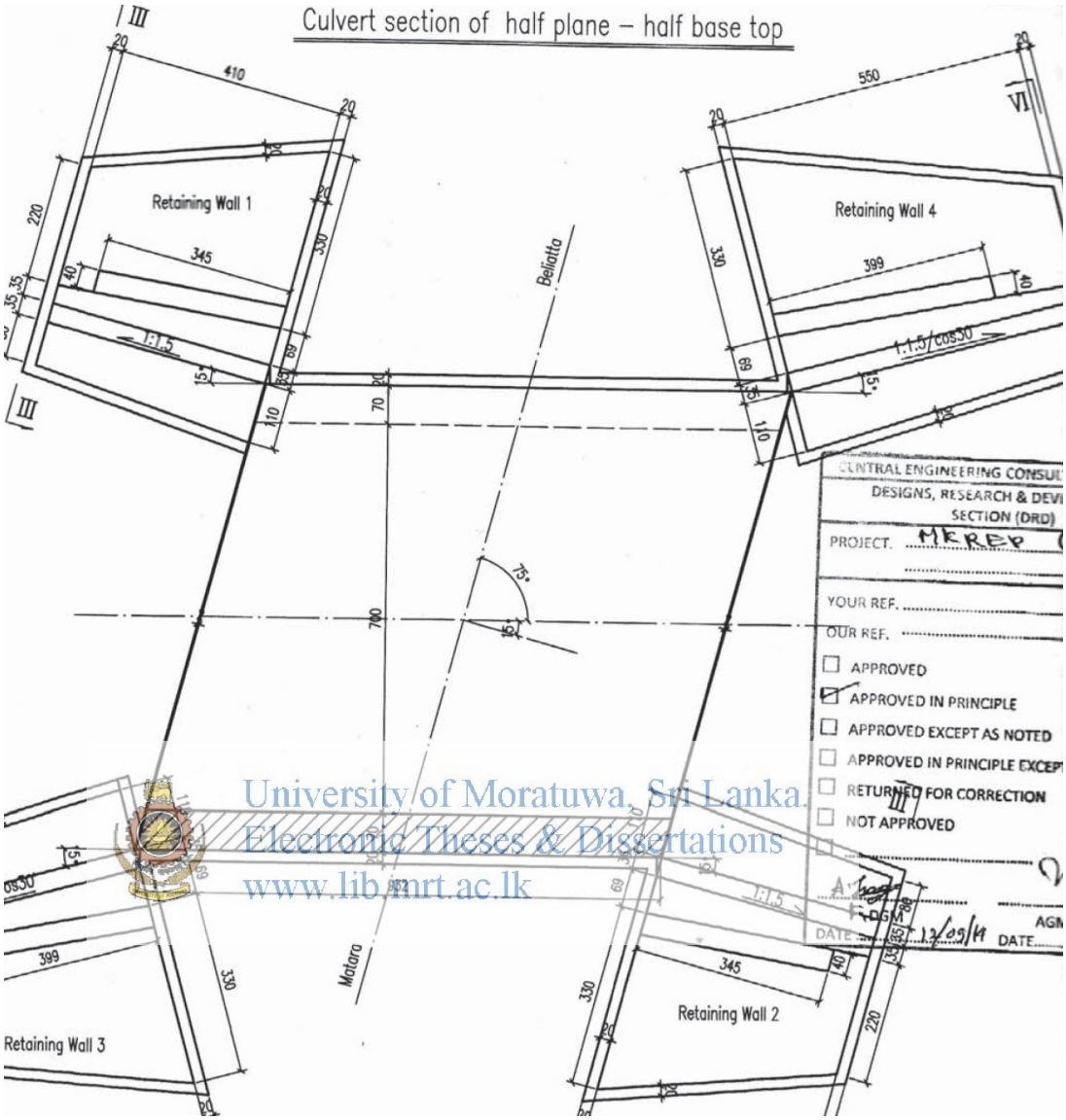
Appendix A: General arrangement of concrete box structures

Drawings used in Matara-Beliatta Railway project in Sri Lanka are shown in this appendix A.1 to A.3. In A.4 shows the culvert details related to experiment done in the University of Tennessee [18].

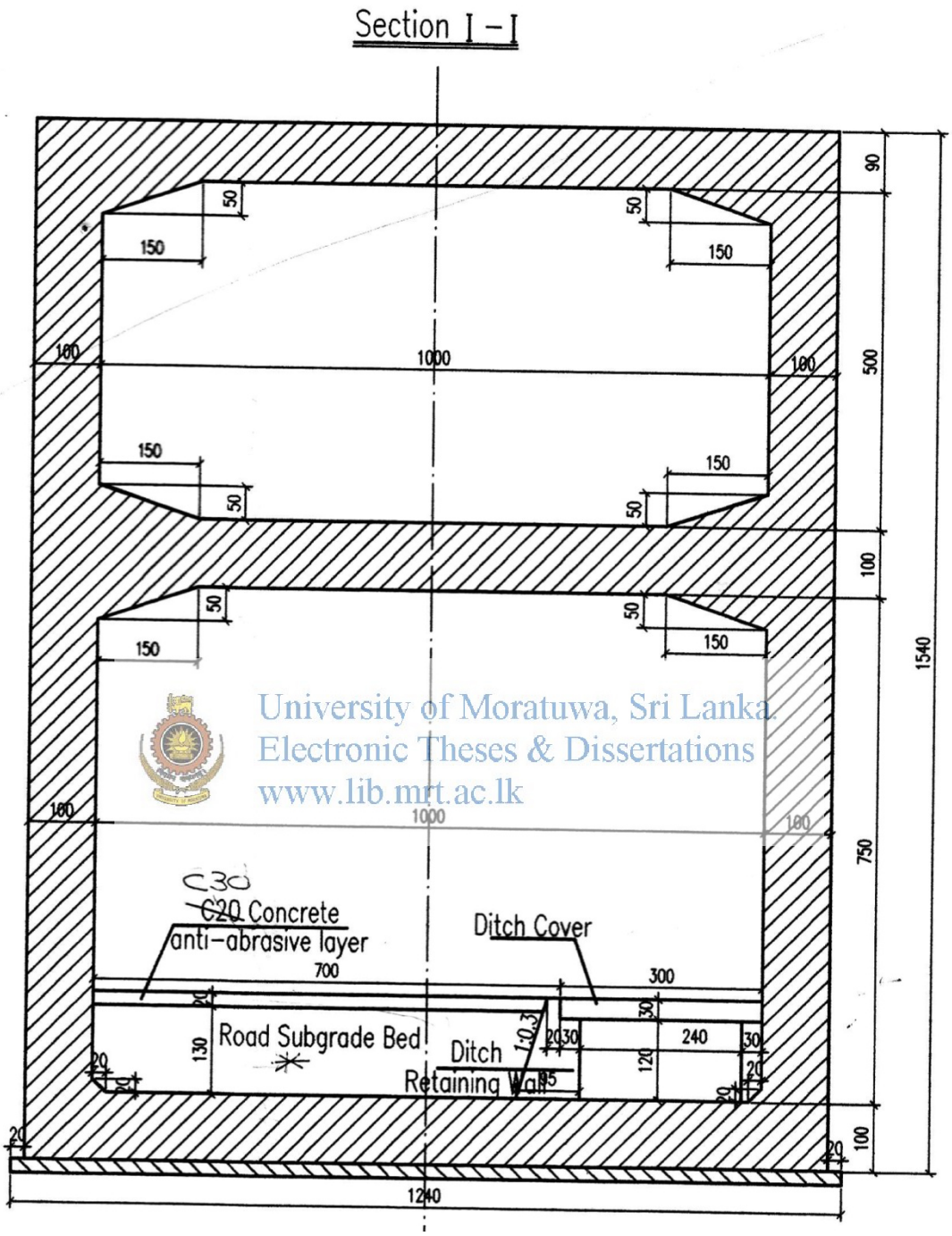
A.1 Single cell



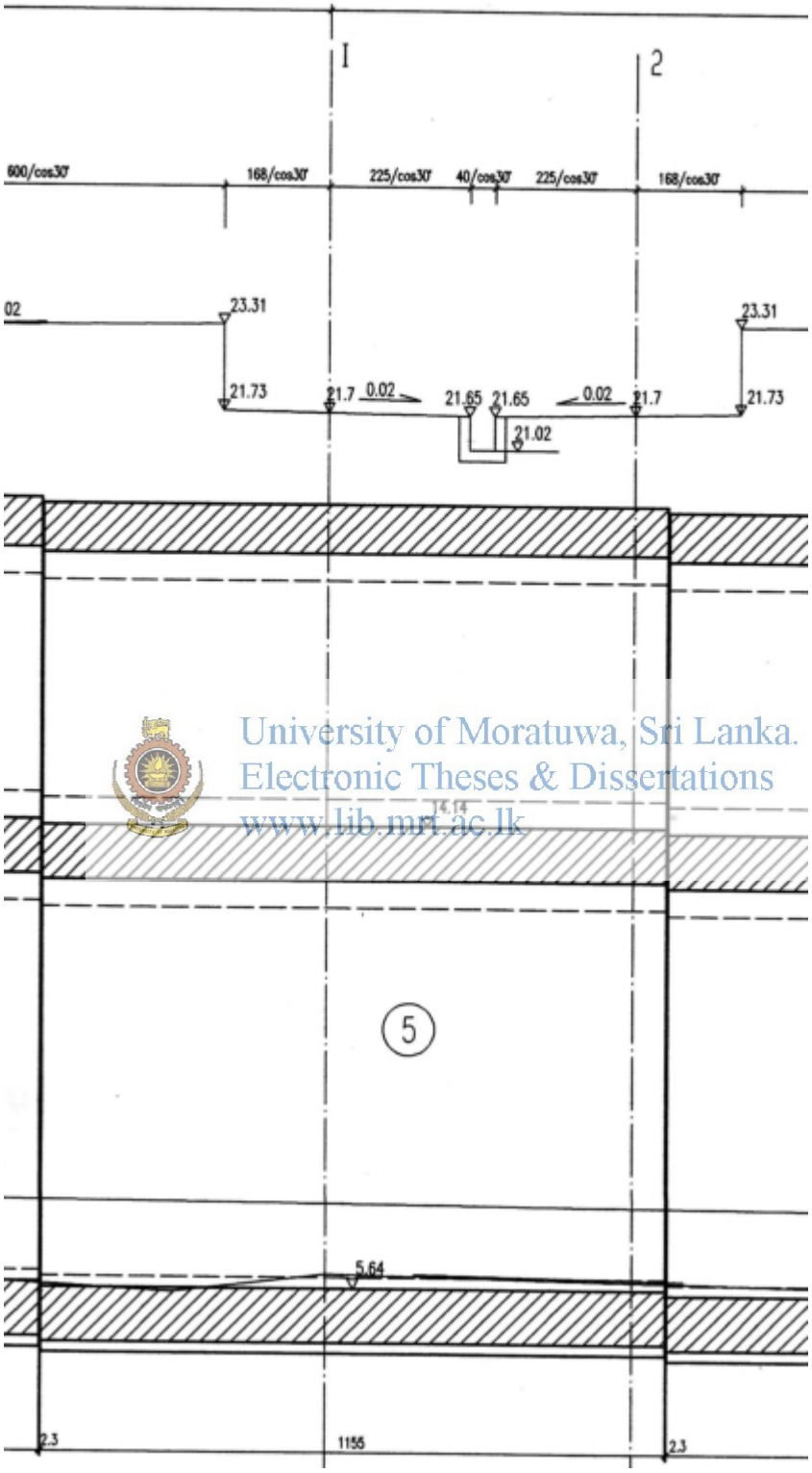




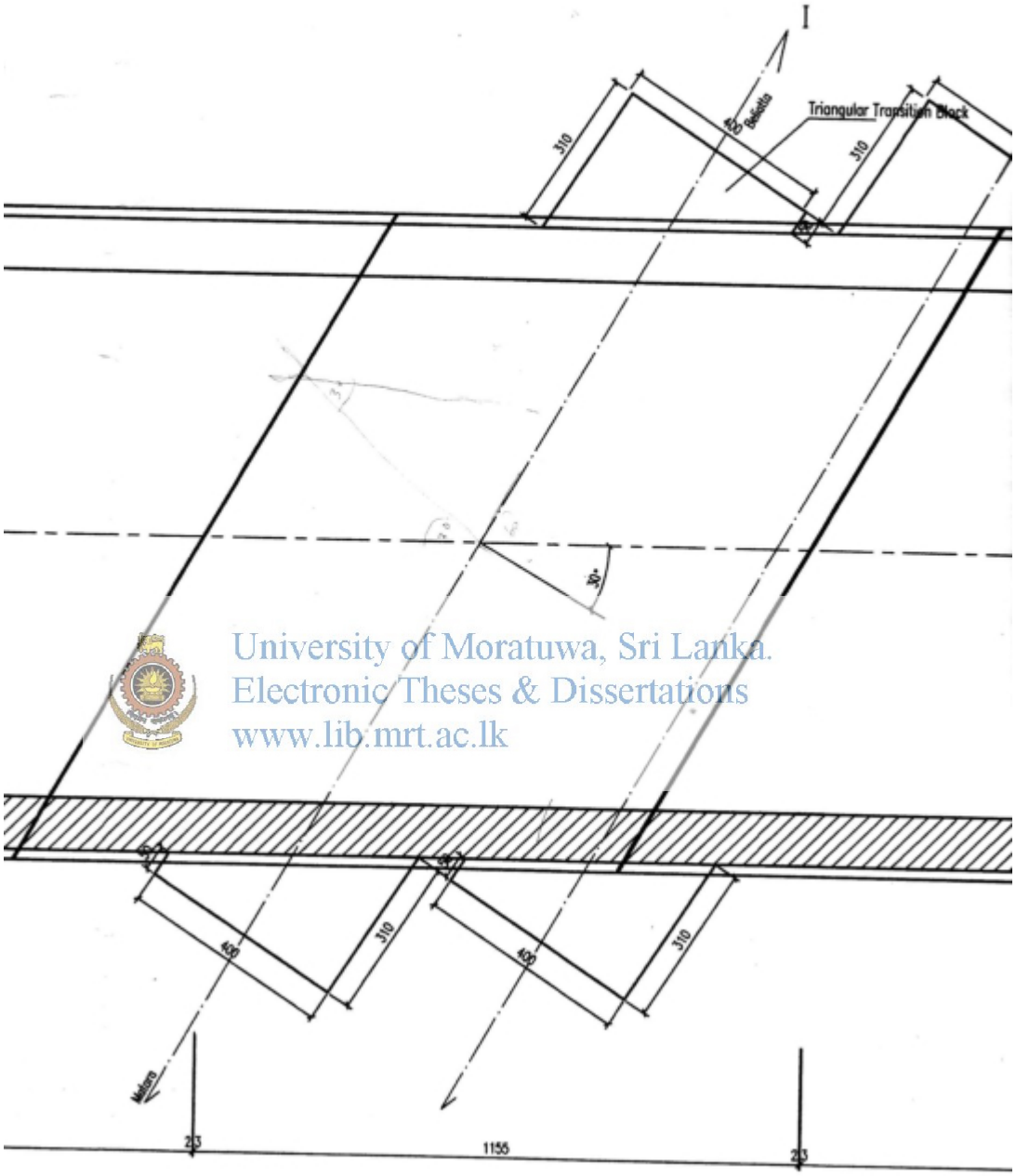
A.2 Story cell



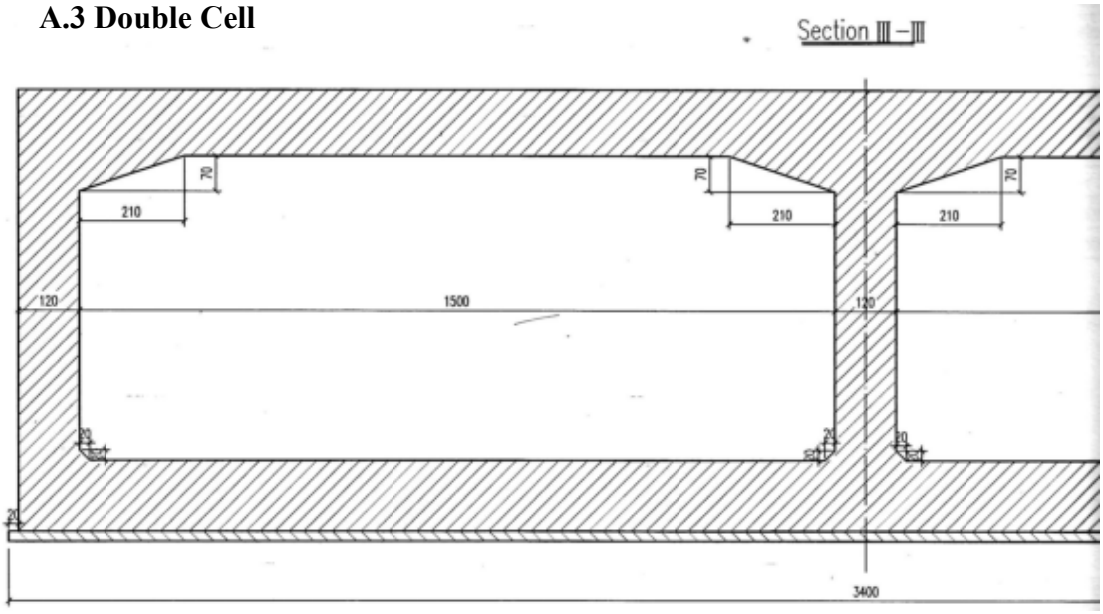
Centre line of culvert vertical section

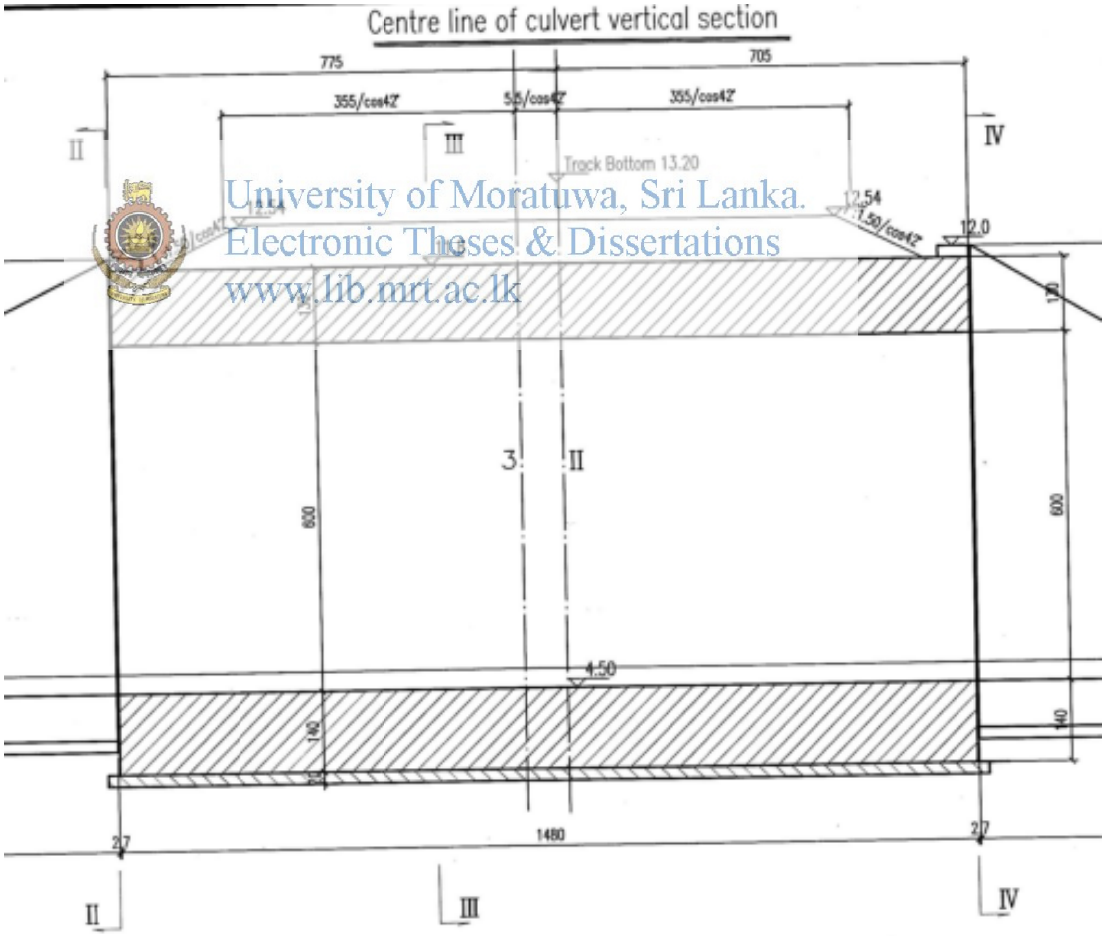


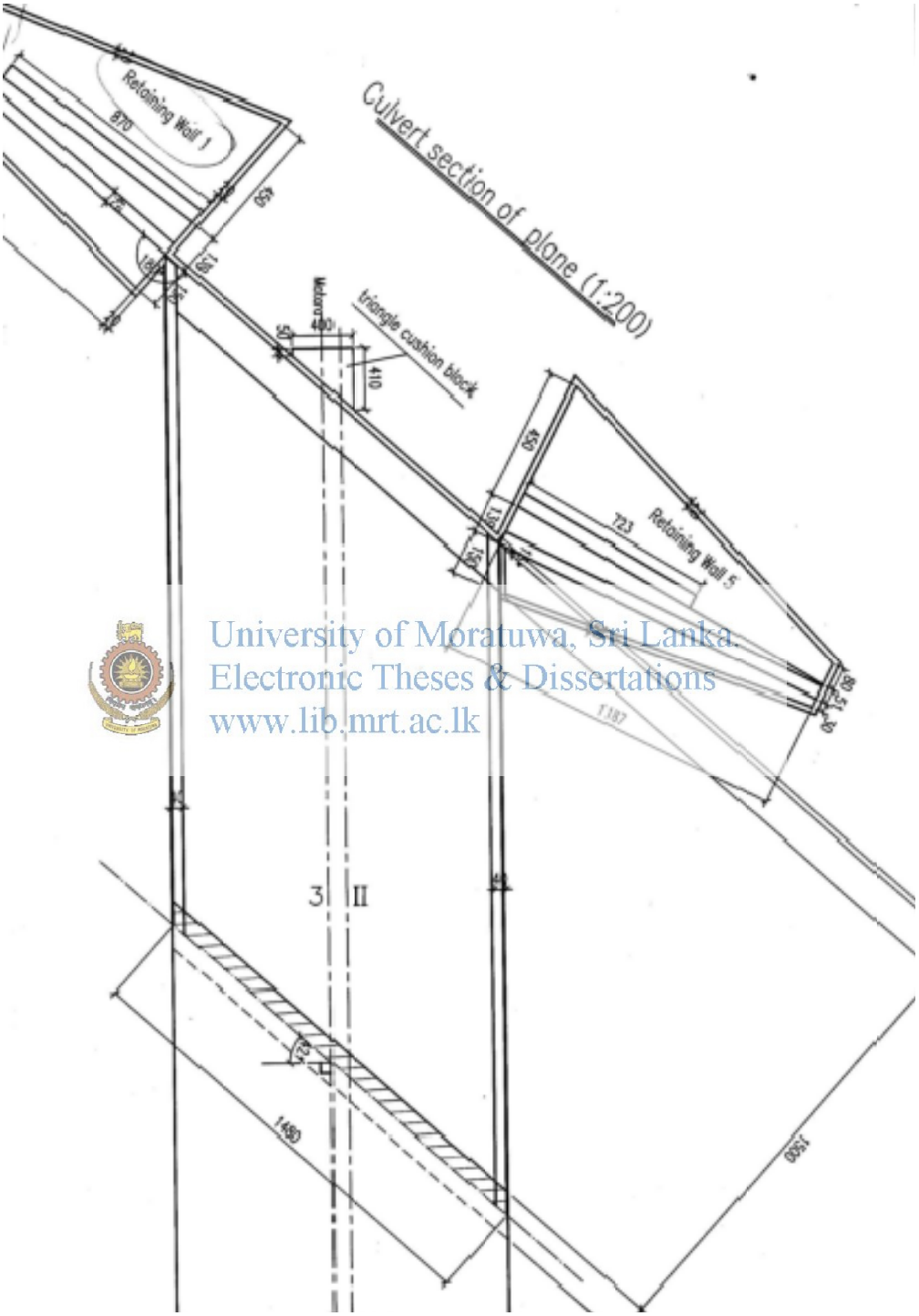
Half Plan–Half Foundation Top



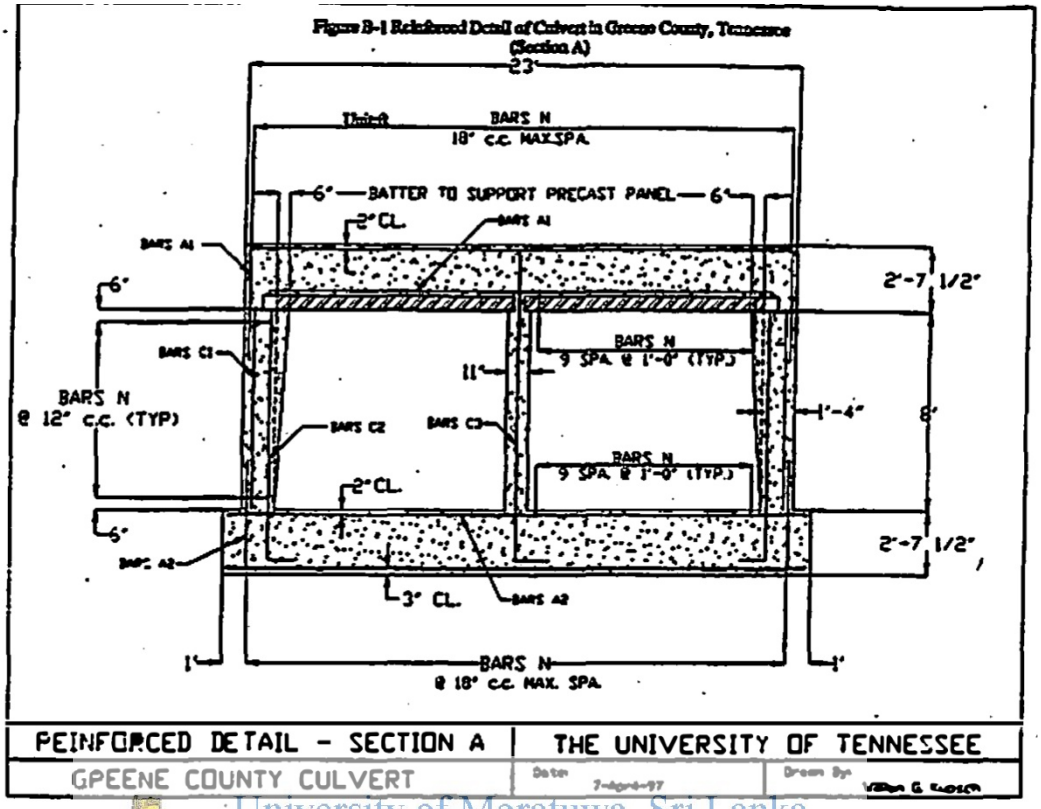
A.3 Double Cell

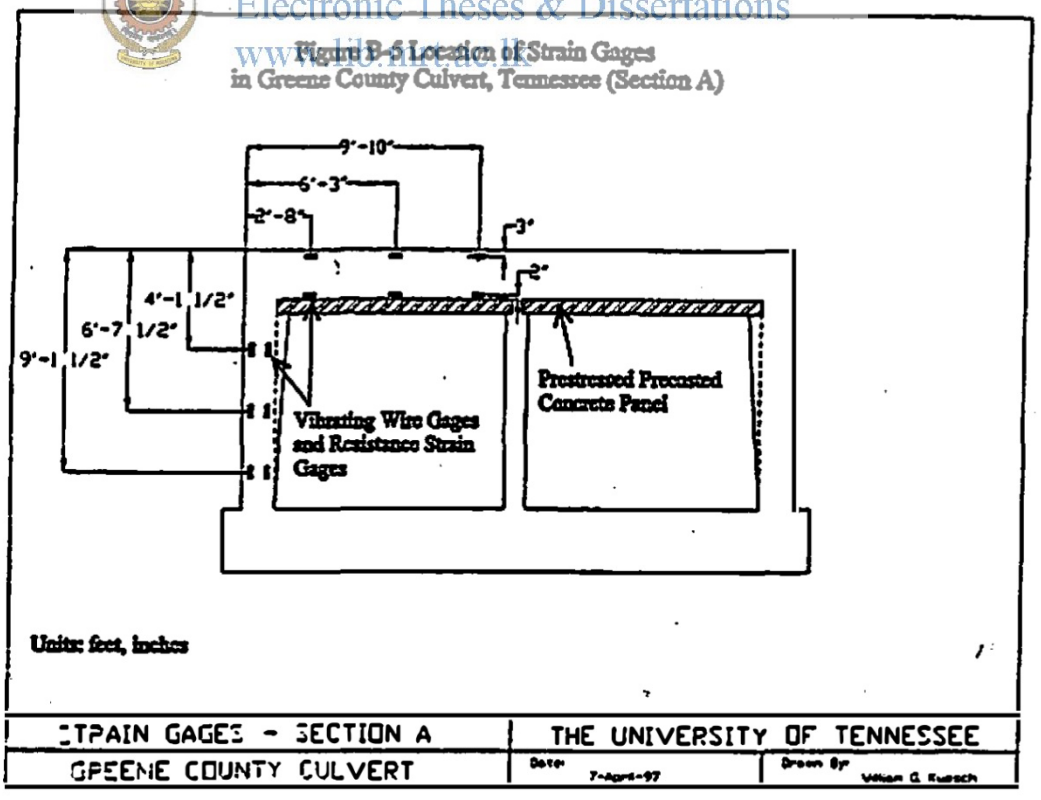






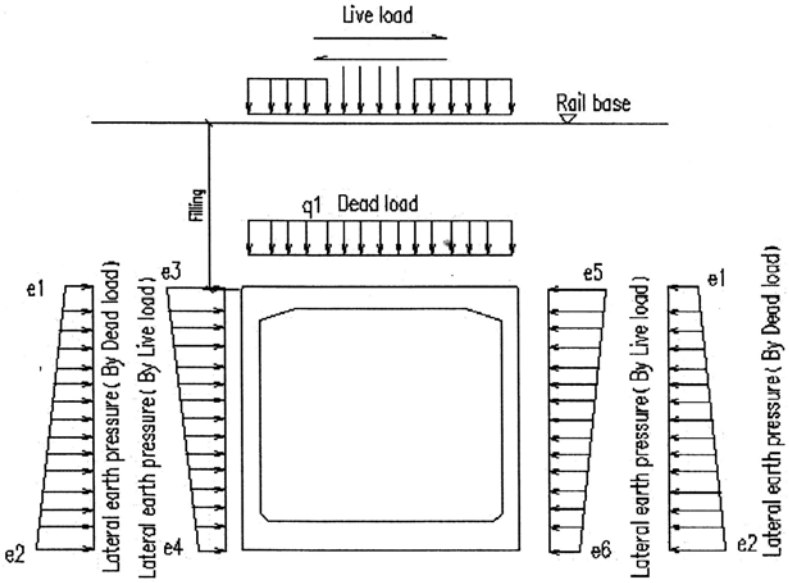
A.4 Test culvert details [18]





Appendix B: Loads

B.1 load cases

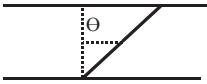


Load cases	Notation
Self weight	SW
Super Dead loads-Ballast	SIDL-S
Super Dead loads-Soil fill	SIDL-F
Live load -all spans	LL
Live load -alternate spans	LL1
Earth Pressure-Active	ERTKA
Earth Pressure-At rest	ERTK0
Live surcharge	LLSK0A
Traction or Braking	BREKAA

B.2 Load combinations

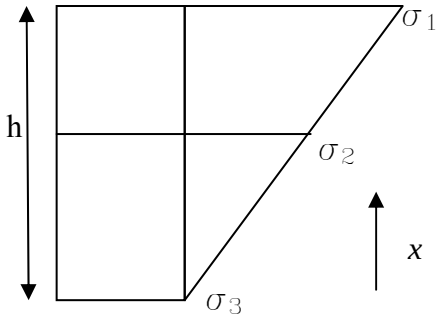
Load cases	SLS1	SLS2	SLS3	SLS4	ULS1	ULS2	ULS3	ULS4
SW	1	1	1	1	1.15	1.15	1	1.15
SIDL-S	1.2	1.2	1	1.2	1.75	1.75	1	1.75
SIDL-F	1	1	1	1	1.2	1.2	1	1.2
LL	1.1	1.1	0	0	1.4	1.4	0	0
LL1	0	0	0	1.1	0	0	0	1.4
ERTKA	1	0	0	1	1	0	0	1
ERTK0	0	1	1	0	0	1.5	1.5	0
LLSK0A	1	1	0	1	1.5	1.5	0	1.5
BREKAA	1	1	0	1	1.4	1.4	0	1.4

B.3 Load calculation sheet

Reference	Calculation				Outputs
	density- Concrete	$\gamma_{concrete}$	=	25 kN/m^3	
	density- soil	γ_{soil}	=	18 kN/m^3	
	density- Ballast	γ_{ball}	=	20 kN/m^3	
	track angle		=	15 deg	
			=	0.26 rad	
	box culvert dimensions	h	=	4.6 m	
		b	=	7 m	
		t_t	=	700 mm	
		t_b	=	800 mm	
		t_w	=	700 mm	
	fill+ballast	h_f	=	1 m	
	Ballast thickness	h_b	=	0.7 m	
BD3101					
cl 3.1.2		β	=	1.15	
		q_1	=	18.10 kN/m^2	
		q_2	=	6.21 kN/m^2	
	internal friction angle	ϕ	=	35 deg	
			=	0.61 rad	
		K_0	=	0.43	
		e_1	=	10.37 kN/m^2	
		e_2	=	57.19 kN/m^2	
BD3101					
cl3.2.7		L_L	=	8.70 m	
bs5400-2-2006		Kt	=	0.95	
tb18	nominal traction force		=	340.71 kN	
bs5400-2-2006		Ft	=	323.88 kN	
cl 8.2.10	2/3 and sl loads		=	190.01 kN	
	Distributed force per m		=	56.78 kN/m	
	Dynamic factor Ru loading		=	1.52	
uic776 cl2.4.2.4	culvert top	ϕu	=	1.52	
cl 5.8.2	culvert bottom	ϕu	=	0.91	
bs5400-2-2006					
	loaded length (sleeper size)	B	=	3.00 m	
		Qli	=	48.16	
		e_3	=	12.35	
		e_4	=	5.03	
		KA/K0	=	0.635	

Appendix C: Bending moment Derivation from stresses

C.1 Mesh density 2

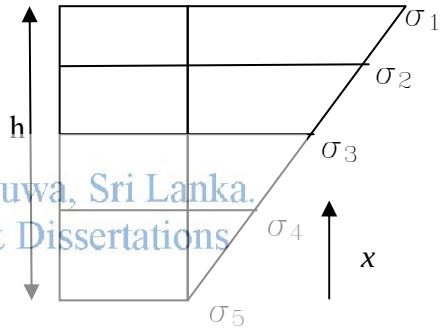


$$M = \int \sigma A \, dx$$

$$M = \sigma_2 \frac{h}{2}\frac{h}{2}\frac{1}{2} - \sigma_3 \frac{h}{2}\frac{h}{2}\frac{1}{2} + \frac{(\sigma_1 - \sigma_2)}{2}\frac{h}{2}\frac{h}{2}\frac{2}{3} - \frac{(\sigma_2 - \sigma_3)}{2}\frac{h}{2}\frac{h}{2}\frac{1}{3}$$

$$M = \frac{h^2}{12}(\sigma_1 - \sigma_3)$$

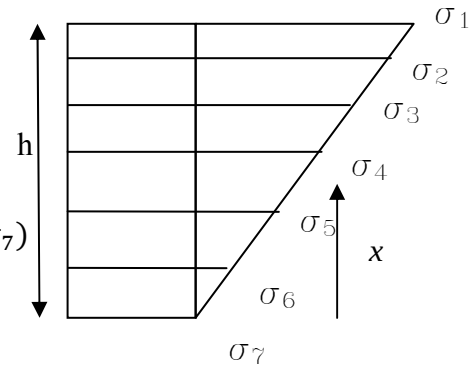
C.2 Mesh density 4



$$M = \int \sigma A \, dx$$

$$M = \frac{h^2}{96}(5\sigma_1 + 6\sigma_2 - 6\sigma_4 - 5\sigma_5)$$

C.3 Mesh density 6



$$M = \int \sigma A \, dx$$

$$M = \frac{h^2}{108}(4\sigma_1 + 6\sigma_2 + 3\sigma_3 - 3\sigma_5 - 6\sigma_6 - 4\sigma_7)$$

C.4 Mesh density 8

Similarly,

$$M = \frac{h^2}{384}(11\sigma_1 + 18\sigma_2 + 12\sigma_3 + 6\sigma_4 - 6\sigma_6 - 12\sigma_7 - 18\sigma_8 - 11\sigma_9)$$

Appendix D: Computer models and variables

Table D.1: Single Cell model variables

Model No /Variable	Mesh density	Skew angle (degrees)	Soil fill height (m)	Wall thickness (m)	Span Length (m)	Transverse width (m)	Haunch Thickness (mm)	Vertical Soil springs (MN/m^2)
1-Real	4	42	1	0.7	8.4	9.3	0	15
2-Mesh2	6	42	1	0.7	8.4	9.3	0	15
3-Mesh3	8	42	1	0.7	8.4	9.3	0	15
4-Angle0	1	0	1	0.7	8.4	9.3	0	15
5-Angle30	1	30	1	0.7	8.4	9.3	0	15
6-Fill0	1	42	0	0.7	8.4	9.3	0	15
7-Fill6	1	42	6	0.7	8.4	9.3	0	15
8-Wall0.5	1	42	1	0.35	8.4	9.3	0	15
9-Wall1.5	1	42	1	1.05	8.4	9.3	0	15
10-B0.75	1	42	1	0.7	6.3	9.3	0	15
11-B1.5	1	42	1	0.7	12.6	9.3	0	15
12-L0.5	1	42	1	0.7	8.4	4.65	0	15
13-L1.5	1	42	1	0.7	8.4	14	0	15
14-Haunch	1	42	1	0.7	8.4	9.3	400	15
15-Spring0.5	1	42	1	0.7	8.4	9.3	0	7.5
16-Spring1.5	1	42	1	0.7	8.4	9.3	0	22.5

Table D.2: Double Cell model variables

Model No /Variable	Mesh density	Skew angle (degrees)	Soil fill height (m)	Wall thickness (m)	Span Length (m)	Transverse width (m)	Haunch Thickness (mm)	Vertical Soil springs (MN/m^2)
1-Real	4	15	2.1	1.2	33.6	14.8	0	15
2-Mesh2	6	15	2.1	1.2	33.6	14.8	0	15
3-Mesh3	8	15	2.1	1.2	33.6	14.8	0	15
4-Angle0	1	0	2.1	1.2	33.6	14.8	0	15
5-Angle30	1	30	2.1	1.2	33.6	14.8	0	15
6-Fill0	1	15	0	1.2	33.6	14.8	0	15
7-Fill6	1	15	6	1.2	33.6	14.8	0	15
8-Wall0.5	1	15	2.1	0.35	33.6	14.8	0	15
9-Wall1.5	1	15	2.1	1.05	33.6	14.8	0	15
10-B0.75	1	15	2.1	1.2	25	14.8	0	15
11-B1.5	1	15	2.1	1.2	47.4	14.8	0	15
12-L0.5	1	15	2.1	1.2	33.6	4.65	0	15
13-L1.5	1	15	2.1	1.2	33.6	14	0	15
14-Haunch	1	15	2.1	1.2	33.6	14.8	700	15
15-Spring0.5	1	15	2.1	1.2	33.6	14.8	0	7.5
16-Spring1.5	1	15	2.1	1.2	33.6	14.8	0	22.5

Table D.3: Story Cell model variables

Model No /Variable	Mesh density	Skew angle (degrees)	Soil fill height (m)	Wall thickness (m)	Span Length (m)	Transverse width (m)	Haunch Thickness (mm)	Vertical Soil springs (MN/m^2)
1-Real	4	30	2.7	1	12	11.6	0	15
2-Mesh2	6	30	2.7	1	12	11.6	0	15
3-Mesh3	8	30	2.7	1	12	11.6	0	15
4-Angle0	1	0	2.7	1	12	11.6	0	15
5-Angle30	1	45	2.7	1	12	11.6	0	15
6-Fill0	1	30	0	1	12	11.6	0	15
7-Fill6	1	30	6	1	12	11.6	0	15
8-Wall0.5	1	30	2.7	0.5	12	11.6	0	15
9-Wall1.5	1	30	2.7	1.5	12	11.6	0	15
10-B0.75	1	30	2.7	1	10	11.6	0	15
11-B1.5	1	30	2.7	1	14	11.6	0	15
12-L0.5	1	30	2.7	1	12	5.8	0	15
13-L1.5	1	30	2.7	1	12	17.4	0	15
14-Haunch	1	30	2.7	1	12	11.6	500	15
15-Spring0.5	1	30	2.7	1	12	11.6	0	7.5
16-Spring1.5	1	30	2.7	1	12	11.6	0	22.5

Appendix E: Bending moments in critical sections

E.1 Single cell

Table E.1: Top slab bending moment (kNm)

Model No	General shell model						Modified shell model				Solid model			
/Variable	SLS			ULS			SLS		ULS		SLS		ULS	
	Min	Max	face	Min	Max	face	Min	Max	Min	Max	Min	Max	Min	Max
1-Real	-543	433	303	-697	528	416	-526	316	-676	431	-503	339	-650	468
2-Mesh2	-543	438	309	-697	519	423	-525	314	-676	428	-500	330	-647	456
3-Mesh3	-543	437	306	-697	518	420	-525	313	-676	426	-502	330	-650	457
4-Angle0	-548	416	275	-705	554	377	-532	303	-684	412	-511	321	-660	440
5-Angle45	-512	440	324	-655	462	442	-491	318	-629	432	-477	360	-615	500
6-Fill0	-546	446	313	-704	532	429	-529	321	-683	438	-508	346	-659	478
7-Fill6	-865	587	412	-1072	778	559	-837	443	-1039	597	-804	473	-1000	647
8-Wall0.5	-648	234	185	-842	340	277	-640	194	-833	288	-604	249	-698	337
9-Wall1.5	-449	647	381	-571	653	503	-422	400	-537	524	-391	394	-500	527
10-B0.75	-348	284	208	-453	389	296	-333	213	-433	301	-319	241	-418	344
11-B1.5	-807	790	517	-1036	805	689	-793	607	-1018	794	-758	594	-977	781
12-L0.5	-550	431	318	-707	502	436	-534	321	-687	437	-505	335	-653	464
13-L1.5	-535	428	297	-687	539	407	-516	310	-663	423	-496	332	-641	457
14-Haunch	-555	429	301	-711	520	411	-536	312	-688	424	-514	325	-663	447
15-Spring0.5	-562	441	317	-722	538	433	-544	325	-699	443	-525	350	-678	482
16-Spring1.5	-508	413	289	-653	507	398	-493	298	-635	409	-465	318	-602	442

Table E.2: Bottom slab bending moment (kNm)-single cell

Model No /Variable	General shell model						Modified shell model				Solid model			
	SLS			ULS			SLS		ULS		SLS		ULS	
	Min	Max	face	Min	Max	face	Min	Max	Min	Max	Min	Max	Min	Max
1-Real	-543	433	303	-697	528	416	-526	316	-676	431	-503	339	-650	468
2-Mesh2	-543	438	309	-697	519	423	-525	314	-676	428	-500	330	-647	456
3-Mesh3	-543	437	306	-697	518	420	-525	313	-676	426	-502	330	-650	457
4-Angle0	-548	416	275	-705	554	377	-532	303	-684	412	-511	321	-660	440
5-Angle45	-512	440	324	-655	462	442	-491	318	-629	432	-477	360	-615	500
6-Fill0	-546	446	313	-704	532	429	-529	321	-683	438	-508	346	-659	478
7-Fill6	-865	587	412	-1072	778	559	-837	443	-1039	597	-804	473	-1000	647
8-Wall0.5	-648	234	185	-842	340	277	-640	194	-833	288	-604	249	-698	337
9-Wall1.5	-449	647	381	-571	653	503	-422	400	-537	524	-391	394	-500	527
10-B0.75	-348	284	208	-453	389	296	-333	213	-433	301	-319	241	-418	344
11-B1.5	-807	790	517	-1036	805	689	-793	607	-1018	794	-758	594	-977	781
12-L0.5	-550	431	318	-707	502	436	-534	321	-687	437	-505	335	-653	464
13-L1.5	-535	428	297	-687	539	407	-516	310	-663	423	-496	332	-641	457
14-Haunch	-555	429	301	-711	520	411	-536	312	-688	424	-514	325	-663	447
15-Spring0.5	-562	441	317	-722	538	433	-544	325	-699	443	-525	350	-678	482
16-Spring1.5	-508	413	289	-653	507	398	-493	298	-635	409	-465	318	-602	442

Table E.3: Walls bending moment (kNm)-single cell

Model No /Variable	General shell model						Modified shell model				Solid model			
	SLS			ULS			SLS		ULS		SLS		ULS	
	Min	Max	face	Min	Max	face	Min	Max	Min	Max	Min	Max	Min	Max
1-Real	239	494	434	319	666	578	255	470	339	626	245	473	325	634
2-Mesh2	240	495	446	320	667	595	256	470	340	627	248	474	329	635
3-Mesh3	240	495	435	320	667	580	256	470	340	627	245	476	325	637
4-Angle0	229	451	379	305	600	503	243	401	323	529	233	402	309	534
5-Angle45	251	539	493	333	730	660	268	522	355	698	229	531	284	656
6-Fill0	242	504	454	322	681	609	258	480	342	642	248	484	330	650
7-Fill6	364	760	646	476	983	816	392	709	510	899	378	700	492	893
8-Wall0.5	32	279	230	49	391	319	39	241	58	335	36	260	52	332
9-Wall1.5	403	651	599	528	838	775	430	643	562	830	403	592	528	784
10-B0.75	91	321	263	128	439	358	102	278	142	378	98	287	136	392
11-B1.5	649	1097	1012	846	1448	1327	678	1066	883	1398	689	1115	898	1465
12-L0.5	236	518	456	315	697	607	253	478	337	637	243	489	323	655
13-L1.5	236	470	428	315	634	571	252	451	334	600	241	453	320	607
14-Haunch	242	531	466	320	717	624	259	486	341	650	254	482	335	641
15-Spring0.5	243	495	445	324	667	594	259	471	344	628	251	474	333	636
16-Spring1.5	231	493	443	309	664	590	247	468	329	624	233	471	310	630

E.2 Double cell

Table E.4a: Top slab bending moment (kNm)-double cell

Model No /Variable	General shell model									
	SLS					ULS				
	Min	Max edge	face edge	Max mid	Face mid	Min	Max edge	face edge	Max mid	Face mid
1-Real	-1746	1737	807	2527	2433	-2201	2243	1074	3179	3050
2-Mesh2	-1734	1561	934	2664	2664	-2186	2006	1234	3338	3338
3-Mesh3	-1731	1432	738	2424	2424	-2183	1841	987	3037	3037
4-Angle0	-1634	1184	625	3173	2648	-2059	1502	817	3979	3337
5-Angle45	-1673	1385	712	2752	2576	-2108	1800	954	3459	3235
6-Fill0	-1559	1648	597	2397	1867	-1995	2136	767	3062	2383
7-Fill6	-2949	2978	1412	4217	3985	-3629	3766	1853	5178	4910
8-Wall0.5	-2254	1656	440	3457	3421	-2852	2102	640	4356	4312
9-Wall1.5	-1476	2008	790	1961	1615	-1860	2544	1035	2465	2016
10-B0.75	-946	744	189	1407	1190	-1197	1019	310	1767	1482
11-B1.5	-3708	4638	3324	5797	5797	-4660	5856	4212	7282	7282
12-L0.5	-2100	2507	1165	3498	2775	-2644	3214	1468	4403	3487
13-L1.5	-1592	1094	668	2060	2060	-2005	1427	898	2583	2583
14-Haunch	-1561	1762	773	3681	3321	-1968	2302	998	4621	4158
15-Spring0.5	-1749	1717	798	2586	2516	-2207	2236	1075	3250	3146
16-Spring1.5	-1742	1742	814	2488	2384	-2196	2236	1075	3131	2993

Table E.4b: Top slab bending moment (kNm)-double cell

Model No /Variable	Modified shell model						Solid model					
	SLS			ULS			SLS			ULS		
	Min	Max edge	Max mid	Min	Max edge	Max mid	Min	Max edge	Max mid	Min	Max edge	Max mid
1-Real	-1646	1226	3091	-2076	1615	3877	-1639	1233	2811	-2066	1595	3530
2-Mesh2	-1634	1225	2789	-2061	1558	3496	-1670	1193	2686	-2105	1544	3372
3-Mesh3	-1632	1232	2628	-2058	1568	3292	-1676	1201	2692	-2113	1558	3380
4-Angle0	-1573	766	2780	-1982	975	3503	-1526	886	2559	-1925	1123	3230
5-Angle45	-1606	1135	2829	-2023	1440	3552	-1582	990	2611	-1994	1292	3283
6-Fill0	-1468	1096	2807	-1879	1416	3582	-1461	1095	2478	-1870	1417	3170
7-Fill6	-2783	2177	5068	-3427	2809	6248	-2771	2119	4541	-3410	2704	5608
8-Wall0.5	-2161	1553	2997	-2734	1974	3791	-2270	1414	3630	-2871	1798	4577
9-Wall1.5	-1365	1360	2363	-1720	1741	2952	-1258	1364	2114	-1586	1717	2647
10-B0.75	-887	617	1497	-1122	794	1865	-875	504	1426	-1107	651	1781
11-B1.5	-3537	4477	7051	-4445	5662	8857	-3407	3911	5661	-4280	4912	7075
12-L0.5	-1964	2050	4146	-2475	2645	5202	-1936	1953	3407	-2440	2479	4279
13-L1.5	-1506	1000	2336	-1897	1270	2927	-1468	868	2218	-1850	1138	2783
14-Haunch	-1494	1319	3957	-1883	1673	4956	-1365	1562	4210	-1722	2013	5287
15-Spring0.5	-1656	1194	3177	-2089	1571	3976	-1648	1220	2824	-2079	1592	3538
16-Spring1.5	-1642	1253	3041	-2070	1635	3820	-1631	1239	2690	-2056	1597	3381

Table E.5a: Bottom slab bending moment (kNm)-double cell

Model No /Variable	General shell model									
	SLS					ULS				
	Min	Max edge	face edge	Max mid	Face mid	Min	Max edge	face edge	Max mid	Face mid
1-Real	-1553	1464	1072	2301	1906	-1940	1857	1405	2876	2368
2-Mesh2	-1553	1464	1072	2301	1906	-1940	1857	1405	2876	2368
3-Mesh3	-1546	1263	1040	2102	1902	-1931	1601	1360	2625	2364
4-Angle0	-1666	1483	913	2986	2434	-2085	1881	1176	3727	3059
5-Angle45	-1582	1358	1053	2517	2171	-1978	1700	1377	3149	2707
6-Fill0	-1421	1493	894	2176	1668	-1799	1902	1179	2759	2105
7-Fill6	-2077	1960	1376	3266	2723	-2531	2479	1789	3996	3335
8-Wall0.5	-1714	1073	470	2495	2274	-2157	1332	691	3136	2850
9-Wall1.5	-1464	2150	1118	2020	1437	-1815	2685	1428	2512	1774
10-B0.75	-1102	815	768	1347	1109	-1367	1079	1030	1695	1378
11-B1.5	-1637	2465	1372	3354	2956	-2052	3105	1778	4189	3683
12-L0.5	-1751	1968	1247	3080	2373	-2183	2469	1631	3853	2937
13-L1.5	-1364	1060	924	1888	1633	-1692	1372	1210	2357	2033
14-Haunch	-1570	1389	1076	2391	1992	-1957	1756	1406	2982	2471
15-Spring0.5	-1808	1644	1232	2514	2063	-2249	2075	1603	3147	2562
16-Spring1.5	-1364	1341	943	2127	1780	-1707	1707	1244	2656	2213

Table E.5b: Bottom slab bending moment (kNm)-double cell

Model No /Variable	Modified shell model						Solid model					
	SLS			ULS			SLS			ULS		
	Min	Max edge	Max mid	Min	Max edge	Max mid	Min	Max edge	Max mid	Min	Max edge	Max mid
1-Real	-1476	1139	2062	-1842	1478	2611	-1378	1044	2073	-1706	1389	2608
2-Mesh2	-1469	1034	1941	-1833	1343	2453	-1398	1011	1949	-1731	1346	2426
3-Mesh3	-1468	1016	1767	-1832	1247	2236	-1402	1015	1952	-1735	1351	2430
4-Angle0	-1612	996	2569	-2018	1279	3230	-1489	919	2360	-1869	1190	2973
5-Angle45	-1529	1139	2112	-1909	1479	2672	-1440	1061	2148	-1791	1403	2684
6-Fill0	-1349	1000	1931	-1707	1301	2481	-1239	902	1798	-1560	1203	2299
7-Fill6	-1979	1507	2951	-2447	1907	3651	-2263	1722	3233	-2800	2277	4002
8-Wall0.5	-1631	1067	2093	-2050	1322	2624	-1588	874	2465	-2003	1096	3089
9-Wall1.5	-1384	1443	1798	-1715	1804	2266	-1228	1140	1716	-1512	1447	2154
10-B0.75	-1034	781	1027	-1283	1036	1274	-1011	783	1166	-1250	1066	1450
11-B1.5	-1584	1717	3024	-1985	2157	3805	-1403	1469	2906	-1764	1861	3614
12-L0.5	-1686	1568	2946	-2102	1972	3724	-1551	1172	2355	-1931	1566	2976
13-L1.5	-1310	1057	1567	-1625	1367	1980	-1237	937	1669	-1531	1238	2081
14-Haunch	-1496	1140	2180	-1861	1476	2753	-1416	1050	2010	-1752	1392	2530
15-Spring0.5	-1737	1275	2295	-2155	1651	2916	-1668	1218	2193	-2067	1612	2772
16-Spring1.5	-1303	1040	1856	-1630	1353	2347	-1172	922	1804	-1472	1232	2247

Table E.6: Edge Walls bending moment (kNm)-double cell

Model No /Variable	General shell model						Modified shell model				Solid model			
	SLS			ULS			SLS		ULS		SLS		ULS	
	Min	Max	face	Min	Max	face	Min	Max	Min	Max	Min	Max	Min	Max
1-Real	1372	1674	1646	1740	2140	2085	1450	1749	1836	2215	1391	1679	1757	2130
2-Mesh2	1372	1674	1646	1740	2140	2085	1463	1755	1852	2222	1394	1698	1762	2153
3-Mesh3	1382	1676	1659	1753	2141	2101	1465	1756	1854	2224	1395	1703	1763	2159
4-Angle0	956	1499	1274	1228	1900	1582	1019	1372	1306	1701	962	1212	1233	1529
5-Angle30	1143	1684	1461	1455	2172	1833	1219	1515	1550	1898	1156	1445	1467	1854
6-Fill0	1240	1514	1488	1586	1960	1926	1308	1614	1672	2046	1260	1525	1610	1974
7-Fill6	2236	2940	2783	2780	3684	3411	2357	2968	2931	3647	2223	2820	2743	3463
8-Wall0.5	263	783	563	352	1086	761	284	594	377	801	332	665	434	913
9-Wall1.5	2421	2796	2796	3059	3467	3467	2540	3096	3214	3833	2284	2391	2870	2981
10-B0.75	584	1257	1096	761	1652	1395	629	1103	817	1398	624	1127	805	1467
11-B1.5	2376	4657	4392	2963	5864	5535	2590	4640	3226	5847	2080	4303	2629	5426
12-L0.5	1442	2084	1969	1822	2640	2499	1509	2089	1911	2649	1509	1964	1900	2493
13-L1.5	1224	1769	1589	1561	2283	2004	1282	1619	1626	2037	1233	1561	1568	2013
14-Haunch	1332	1661	1645	1688	2150	2074	1409	1704	1782	2113	1396	1757	1757	2235
15-Spring0.5	1476	1815	1815	1878	2298	2289	1546	1932	1965	2399	1522	1835	1924	2352
16-Spring1.5	1288	1711	1673	1634	2163	2118	1363	1777	1728	2249	1278	1708	1606	2164

Table E.7: Middle Wall bending moment (kNm)-double cell

Model No /Variable	General shell model						Modified shell model				Solid model			
	SLS			ULS			SLS		ULS		SLS		ULS	
	Min	Max	face	Min	Max	face	Min	Max	Min	Max	Min	Max	Min	Max
1-Real	-1596	1084	-1463	-2063	1312	-1885	-1609	1160	-2070	1413	-1335	867	-1728	1049
2-Mesh2	-1596	1084	-1463	-2063	1312	-1885	-1640	1188	-2111	1447	-1358	891	-1757	1083
3-Mesh3	-1593	1083	-1487	-2059	1311	-1914	-1645	1192	-2117	1453	-1364	896	-1764	1089
4-Angle0	-520	262	-447	-695	373	-594	-481	229	-639	327	-473	219	-630	313
5-Angle30	-1251	658	-1150	-1628	767	-1491	-1276	742	-1652	887	-1054	532	-1372	637
6-Fill0	-1623	864	-1461	-2122	1050	-1903	-1614	947	-2100	1163	-1386	697	-1811	858
7-Fill6	-2277	2056	-2106	-2878	2489	-2653	-2337	2125	-2942	2589	-1859	1665	-2355	2001
8-Wall0.5	-535	251	-478	-704	306	-627	-566	283	-742	312	-542	250	-713	324
9-Wall1.5	-2217	1671	-2080	-2847	2039	-2662	-2320	1851	-2960	2271	-1756	1308	-2261	1608
10-B0.75	-902	534	-824	-1190	610	-1081	-918	567	-1202	642	-735	407	-975	470
11-B1.5	-3546	2838	-3197	-4516	3520	-4066	-3487	2865	-4434	3559	-2585	2431	-3300	3017
12-L0.5	-1968	1451	-1636	-2552	1763	-2116	-1835	1351	-2380	1642	-1577	1091	-2053	1322
13-L1.5	-1329	816	-1236	-1718	979	-1592	-1380	940	-1773	1141	-1137	679	-1471	826
14-Haunch	-1532	961	-1389	-1992	1151	-1800	-1512	1005	-1960	1212	-1398	876	-1814	1056
15-Spring0.5	-1638	1112	-1508	-2121	1338	-1946	-1657	1193	-2137	1446	-1366	886	-1772	1074
16-Spring1.5	-1581	1077	-1443	-2040	1308	-1856	-1587	1149	-2040	1403	-1324	862	-1710	1048

E.3 Story Cell

Table E.8: Top slab bending moment (kNm)-story cell

Model No /Variable	General Shell model						Modified shell model				Solid model			
	SLS			ULS			SLS		ULS		SLS		ULS	
	Min	Max	face	Min	Max	face	Min	Max	Min	Max	Min	Max	Min	Max
1-Real	107	100	73	107	88	73	99	96	100	95	99	96	100	95
2-Mesh2	-732	1734	1331	-935	2261	1809	-680	1686	-868	2284	-695	1857	-886	2535
3-Mesh3	-732	1679	1344	-934	2205	1828	-679	1650	-867	2236	-697	1867	-889	2548
4-Angle0	-790	1121	799	-999	1432	1024	-735	861	-931	1101	-734	880	-928	1128
5-Angle45	-658	1983	1276	-864	2164	1772	-605	2302	-796	3149	-613	2356	-803	3257
6-Fill0	-578	1497	1102	-757	1820	1516	-540	1429	-704	1959	-547	1486	-716	2052
7-Fill6	-1144	2625	1912	-1425	3122	2563	-1067	2523	-1328	3368	-1074	2641	-1338	3554
8-Wall0.5	-1111	1456	776	-1427	1672	1111	-1055	1287	-1351	1792	-1070	1768	-1372	2435
9-Wall1.5	-644	1755	1421	-821	2135	1905	-599	1770	-764	2367	-568	1625	-724	2201
10-B0.75	-527	1307	927	-679	1601	1286	-489	1205	-635	1661	-525	1383	-684	1917
11-B1.5	-1003	2387	1803	-1279	2851	2413	-941	2341	-1200	3128	-942	2344	-1202	3152
12-L0.5	-786	2036	1141	-1005	2225	1530	-726	1803	-929	2425	-709	1754	-910	2377
13-L1.5	-754	1597	1324	-963	1989	1794	-701	1528	-896	2061	-719	1635	-923	2221
14-Haunch	-622	2148	1751	-791	2758	2387	-591	2192	-753	2979	-551	2180	-718	2974
15-Spring0.5	-732	1834	1359	-935	2229	1850	-680	1775	-869	2406	-687	1860	-875	2542
16-Spring1.5	-738	1784	1305	-942	2146	1773	-686	1708	-876	2313	-690	1776	-881	2422

Table E.9: Bottom slab bending moment (kNm)-story cell

Model No /Variable	General Shell model						Modified shell model				Solid model			
	SLS			ULS			SLS		ULS		SLS		ULS	
	Min	Max	face	Min	Max	face	Min	Max	Min	Max	Min	Max	Min	Max
1-Real	-1381	1706	1680	-1713	2331	2305	-1315	1615	-1630	2208	-1204	1804	-1499	2513
2-Mesh2	-1378	1680	1680	-1709	2306	2306	-1310	1554	-1625	2125	-1214	1817	-1511	2529
3-Mesh3	-1377	1679	1679	-1708	2305	2305	-1309	1528	-1624	2090	-1217	1817	-1515	2529
4-Angle0	-1352	1818	1327	-1685	2342	1756	-1281	1432	-1599	1883	-1144	1379	-1435	1827
5-Angle45	-1420	1766	1737	-1783	2472	2428	-1383	1608	-1760	2243	-1289	1907	-1670	2709
6-Fill0	-1243	1462	1462	-1573	2008	2008	-1184	1401	-1490	1916	-1077	1550	-1370	2162
7-Fill6	-1770	2287	2209	-2162	3124	3025	-1682	2132	-2054	2909	-1564	2410	-1912	3349
8-Wall0.5	-1571	1498	1241	-1984	2158	1821	-1507	1221	-1903	1766	-1446	1708	-1838	2476
9-Wall1.5	-1338	1936	1569	-1642	2076	2076	-1271	1618	-1563	2076	-1091	1617	-1359	2201
10-B0.75	-1112	1464	1411	-1389	2020	1965	-1043	1345	-1300	1867	-990	1586	-1248	2236
11-B1.5	-1559	1929	1929	-1933	2622	2622	-1501	1866	-1860	2526	-1361	2022	-1692	2791
12-L0.5	-1464	1814	1814	-1817	2490	2490	-1399	1714	-1733	2344	-1257	1885	-1562	2636
13-L1.5	-1313	1688	1560	-1630	2289	2134	-1237	1546	-1536	2107	-1143	1700	-1426	2357
14-Haunch	-1349	2317	2110	-1670	3163	2889	-1291	2055	-1598	2801	-1106	2019	-1402	2783
15-Spring0.5	-1501	1737	1737	-1856	2376	2376	-1422	1661	-1758	2263	-1326	1866	-1646	2590
16-Spring1.5	-1277	1680	1630	-1588	2301	2243	-1221	1575	-1518	2158	-1101	1751	-1374	2446

Table E.10: Middle slab bending moment (kNm)-story cell

Model No /Variable	General Shell model						Modified shell model				Modified shell model			
	SLS			ULS			SLS		ULS		SLS		ULS	
	Min	Max	face	Min	Max	face	Min	Max	Min	Max	Min	Max	Min	Max
1-Real	-684	1478	1352	-1034	2129	1959	-642	1813	-971	2623	-823	1841	-1248	2668
2-Mesh2	-684	1501	1352	-1034	2160	1959	-639	1754	-963	2539	-825	1865	-1250	2704
3-Mesh3	-683	1462	1365	-1034	2105	1979	-639	1713	-964	2481	-824	1873	-1250	2714
4-Angle0	-190	574	487	-272	791	686	-181	511	-264	718	-179	531	-266	745
5-Angle45	-913	1397	1397	-1379	2037	2037	-846	2186	-1275	3171	-1067	2390	-1616	3472
6-Fill0	-575	1365	1242	-864	1953	1789	-549	1659	-818	2386	-659	1661	-999	2392
7-Fill6	-971	1814	1673	-1467	2638	2445	-920	2252	-1389	3286	-1199	2333	-1815	3411
8-Wall0.5	-710	1674	1404	-1071	2437	2062	-522	1938	-788	2832	-828	2130	-1254	3094
9-Wall1.5	-448	1141	1102	-688	1620	1575	-453	1472	-688	2103	-609	1397	-931	2012
10-B0.75	-644	1323	1196	-960	1926	1752	-599	1594	-888	2332	-791	1674	-1189	2448
11-B1.5	-685	1608	1479	-1055	2288	2118	-654	1984	-1004	2837	-812	1967	-1251	2822
12-L0.5	-833	1471	1031	-1254	2028	1486	-723	1746	-1092	2509	-1009	1710	-1525	2469
13-L1.5	-578	1326	1312	-867	1907	1896	-557	1594	-832	2309	-640	1609	-975	2327
14-Haunch	-1036	1997	1822	-1563	2880	2643	-949	2321	-1424	3357	-1338	2823	-2025	4097
15-Spring0.5	-721	1522	1392	-1087	2191	2017	-675	1864	-1016	2697	-875	1908	-1322	2765
16-Spring1.5	-651	1441	1317	-989	2075	1909	-614	1768	-931	2558	-779	1784	-1185	2585

Table E.11: Walls bending moment (kNm)- story cell

Model No /Variable	General Shell model						Modified shell model				Solid model			
	SLS			ULS			SLS		ULS		SLS		ULS	
	Min	Max	face	Min	Max	face	Min	Max	Min	Max	Min	Max	Min	Max
1-Real	-740	2217	1780	-936	2930	2310	-834	1823	-1054	2356	-762	1816	-958	2435
2-Mesh2	-741	2221	1784	-938	2936	2315	-837	1831	-1058	2365	-760	1819	-955	2438
3-Mesh3	-741	2222	1785	-938	2937	2316	-838	1832	-1059	2367	-759	1819	-953	2438
4-Angle0	-365	1868	1465	-567	2407	1843	-392	1570	-599	1972	-355	1465	-545	1864
5-Angle45	-891	2730	2196	-1122	3678	2917	-974	2153	-1229	2840	-940	2213	-1201	2967
6-Fill0	-687	1990	1605	-888	2648	2099	-771	1642	-996	2140	-700	1574	-901	2087
7-Fill6	-931	2843	2271	-1146	3848	2942	-1055	2344	-1298	3118	-999	2637	-1250	3466
8-Wall0.5	-421	1663	1229	-632	2381	1745	-426	1367	-605	1938	-428	1397	-610	1990
9-Wall1.5	-815	2655	2178	-1036	3401	2722	-943	2277	-1193	2867	-834	2090	-1046	2745
10-B0.75	-499	1830	1410	-723	2507	1860	-566	1463	-738	1968	-552	1550	-744	2116
11-B1.5	-998	2617	2145	-1252	3428	2762	-1122	2201	-1407	2822	-1003	2380	-1252	3153
12-L0.5	-685	2299	1792	-875	3059	2333	-806	1831	-1023	2367	-721	1911	-907	2550
13-L1.5	-682	2205	1720	-867	2966	2271	-765	1781	-971	2348	-685	1797	-865	2411
14-Haunch	-918	2454	1965	-1155	3315	2610	-987	2046	-1235	2719	-860	1759	-1102	2359
15-Spring0.5	-772	2284	1840	-972	3012	2382	-867	1879	-1093	2423	-807	1850	-1017	2483
16-Spring1.5	-713	2158	1728	-904	2873	2247	-805	1774	-1021	2319	-728	1786	-916	2394

Appendix F: Support Reactions

F.1 Single cell

Table F.1: Total soil support reactions –single cell (kN)

Model No /Variable	Load case													
	General or Modified shell model							Solid model						
	BRKEA	ERTK0	LL	LLSK0A	SIDL-f	SIDL-S	SW	BRKEA	ERTK0	LL	LLSK0A	SIDL-f	SIDL-S	SW
1-Real	452	328	3452	-430	444	1296	4162	510	445	3765	-525	484	1414	4172
2-Mesh2	452	329	3452	-430	444	1296	4162	510	443	3765	-522	484	1414	4172
3-Mesh3	452	328	3452	-431	444	1296	4162	510	446	3765	-525	484	1414	4172
4-Angle0	473	3	3480	-430	444	1296	4162	516	3	3797	-522	484	1414	4172
5-Angle45	388	678	3344	-430	444	1296	4162	493	929	3648	-522	484	1414	4172
6-Fill0	526	302	3838	-462	0	1296	4162	591	413	4187	-564	0	1414	4172
7-Fill6	36	814	831	-206	8894	1296	4162	45	1107	906	-240	9702	1414	4172
8-Wall0.5	452	328	3452	-430	444	1296	3343	510	443	3608	-525	464	1355	3352
9-Wall1.5	452	328	3452	-430	444	1296	4980	510	446	3922	-525	505	1473	4993
10-B0.75	378	295	2724	-430	323	943	3473	440	415	3064	-525	363	1060	3482
11-B1.5	617	328	4792	-430	686	2003	5539	678	397	5215	-525	747	2180	5668
12-L0.5	226	152	1726	-215	222	648	2081	255	171	1883	-263	242	707	2086
13-L1.5	677	424	5177	-645	666	1944	6242	765	587	5648	-788	727	2121	6259
14-Haunch	452	328	3452	-430	444	1296	4321	510	444	3765	-525	484	1414	4285
15-Spring0.5	452	328	3452	-430	444	1296	4162	510	445	3765	-525	484	1414	4172
16-Spring1.5	452	328	3452	-430	444	1296	4162	510	445	3765	-525	484	1414	4172

F.2 Double cell

Table F.2: Total soil support reactions –double cell (kN)

Model No	Load case															
	General or Modified shell model								Solid model							
	BRKEA	ERTK0	LL	LL1	LLSK0A	SIDL-f	SIDL-S	SW	BRKEA	ERTK0	LL	LL1	LLSK0A	SIDL-f	SIDL-S	SW
1	1012	3831	11077	5538	-758	13906	8679	39628	1014	4538	11487	5949	-897	14421	9001	39065
2	1012	3831	11077	5538	-758	13906	8679	39628	1014	4542	11487	5949	-897	14421	9001	39065
3	1012	3832	11077	5538	-758	13906	8679	39628	1014	4543	11487	5949	-897	14421	9001	39065
4	1347	101	11748	5874	-758	13906	8679	39628	1346	145	12183	6309	-897	14421	9001	39065
5	1175	2352	11413	5706	-758	13906	8679	39628	1171	2777	11835	6129	-897	14421	9001	39065
6	1611	2945	18126	9063	-1028	0	8679	39653	1609	3494	18797	9734	-1218	0	9001	39065
7	422	6719	2877	1439	-431	59556	8679	39628	420	7957	2984	1545	-511	61762	9001	39065
8	1012	3819	11077	5538	-758	13906	8679	35047	1014	4514	11487	5846	-897	14421	9001	35309
9	1012	3829	11077	5538	-758	13906	8679	44261	1014	4545	11487	6051	-897	14421	9001	42821
10	1000	3751	8630	4315	-758	10215	6376	31577	1000	4449	9065	4750	-897	10730	6697	30989
11	1026	3840	14906	7453	-758	19829	12376	52612	1024	4550	14626	7360	-897	19829	12376	50897
12	506	1913	5538	2769	-379	6953	4340	19827	507	2255	5744	2974	-449	7211	4500	19532
13	1518	5598	16615	8308	-1137	20859	13019	59480	1522	6648	17231	8923	-1346	21632	13501	58597
14	1012	3825	11077	5538	-758	13906	8679	41156	1401	4537	11487	5949	-897	14421	9001	40039
15	1012	3818	11077	5538	-758	13906	8679	39653	1014	4522	11487	5949	-897	14421	9001	39065
16	1012	3833	11077	5538	-758	13906	8679	39653	1014	4552	11487	5949	-897	14421	9001	39065

F.3 Story Cell

Table F.3: Total soil support reactions –story cell (kN)

Model No /Variable	Load case											
	General or Modified shell model						Solid model					
	BRKEA	ERTK0	LL	LLSK0A	SIDL-f	SW	BRKEA	ERTK0	LL	LLSK0A	SIDL-f	SW
1-Real	415	5785	3659	-1139	5260	16504	450	6204	3895	-1254	5738	16231
2-Mesh2	415	5796	3659	-1139	5260	16504	450	6211	3895	-1254	5738	16231
3-Mesh3	415	5798	3659	-1139	5260	16504	449	6213	3895	-1254	5738	16231
4-Angle0	417	25	3723	-1139	5260	16503	455	35	4061	-1219	5738	16231
5-Angle45	408	9305	3456	-1139	5260	16504	441	10059	3687	-1254	5738	16231
6-Fill0	644	4573	5400	-1364	0	16504	685	4906	5766	-1521	0	16231
7-Fill6	171	8200	1715	-868	15780	16504	198	8793	1816	-941	17214	16231
8-Wall0.5	415	5778	3659	-1139	5260	12581	450	6184	3732	-1254	5499	12445
9-Wall1.5	415	5786	3659	-1139	5260	20425	450	6216	4057	-1254	5977	20018
10-B0.75	345	5599	3170	-1139	4304	14930	380	6109	3476	-1254	4861	14788
11-B1.5	484	5825	4129	-1139	6216	18077	517	6207	4366	-1254	6694	17805
12-L0.5	207	2797	1830	-570	2630	8252	225	2964	1947	-627	2869	8116
13-L1.5	622	7864	5489	-1709	7890	24754	674	8651	5842	-1882	8607	24347
14-Haunch	415	5786	3659	-1139	5260	17784	581	6190	3895	-1254	5738	17097
15-Spring0.5	415	5783	3659	-1139	5260	16504	450	6202	3895	-1254	5738	16231
16-Spring1.5	415	5787	3659	-1139	5260	16504	450	6206	3895	-1254	5738	16231

F.4 Shell model Reactions variation vs. solid model

Table F.3: Total soil support reactions variation – (%)

Model No /Variable	Load case																			
	Single cell							Story cell							Double cell						
	BRKEA	ERTK0	LL	LLSK0A	SIDL-f	SIDL-S	SW	BRKEA	ERTK0	LL	LLSK0A	SIDL-f	SW	BRKEA	ERTK0	LL	LL1	LLSK0A	SIDL-f	SIDL-S	SW
1-Real	89	74	92	82	92	92	100	92	93	94	91	92	102	100	84	96	93	84	96	96	101
2-Mesh2	89	74	92	82	92	92	100	92	93	94	91	92	102	100	84	96	93	85	96	96	101
3-Mesh3	89	74	92	82	92	92	100	92	93	94	91	92	102	100	84	96	93	85	96	96	101
4-Angle0	92	93	92	82	92	92	100	92	73	92	93	92	102	100	70	96	93	84	96	96	101
5-Angle45	79	73	92	82	92	92	100	92	92	94	91	92	102	100	85	96	93	84	96	96	101
6-Fill0	89	73	92	82	-	92	100	94	93	94	90	-	102	100	84	96	93	84	0	96	102
7-Fill6	81	74	92	86	92	92	100	86	93	94	92	92	102	100	84	96	93	84	96	96	101
8-Wall0.5	89	74	96	82	96	96	100	92	93	98	91	96	101	100	85	96	95	84	96	96	99
9-Wall1.5	89	74	88	82	88	88	100	92	93	90	91	88	102	100	84	96	92	84	96	96	103
10-B0.75	86	71	89	82	89	89	100	91	92	91	91	89	101	100	84	95	91	84	95	95	102
11-B1.5	91	83	92	82	92	92	98	94	94	95	91	93	102	100	84	102	101	84	100	100	103
12-L0.5	89	89	92	82	92	92	100	92	94	94	91	92	102	100	85	96	93	84	96	96	102
13-L1.5	89	72	92	82	92	92	100	92	91	94	91	92	102	100	84	96	93	84	96	96	102
14-Haunch	89	74	92	82	92	92	101	71	93	94	91	92	104	72	84	96	93	84	96	96	103
15-Spring0.5	89	74	92	82	92	92	100	92	93	94	91	92	102	100	84	96	93	84	96	96	102
16-Spring1.5	89	74	92	82	92	92	100	92	93	94	91	92	102	100	84	96	93	84	96	96	102

Appendix G: ULS Bending moment envelops

G.1 Skew angle 30^0 models

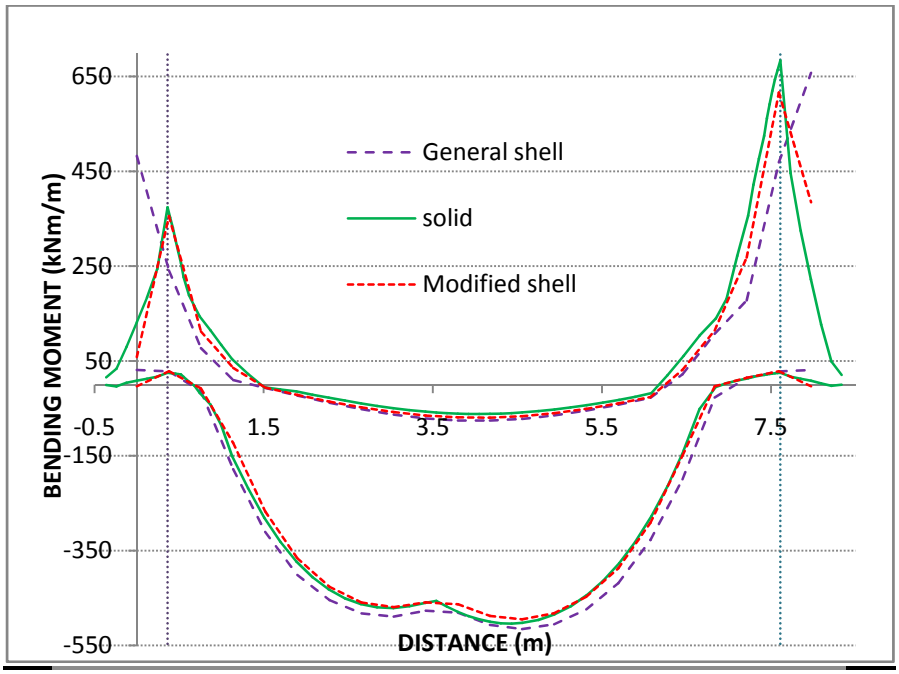


Figure F.1: BME of Top slab-Single cell (model no: 5)

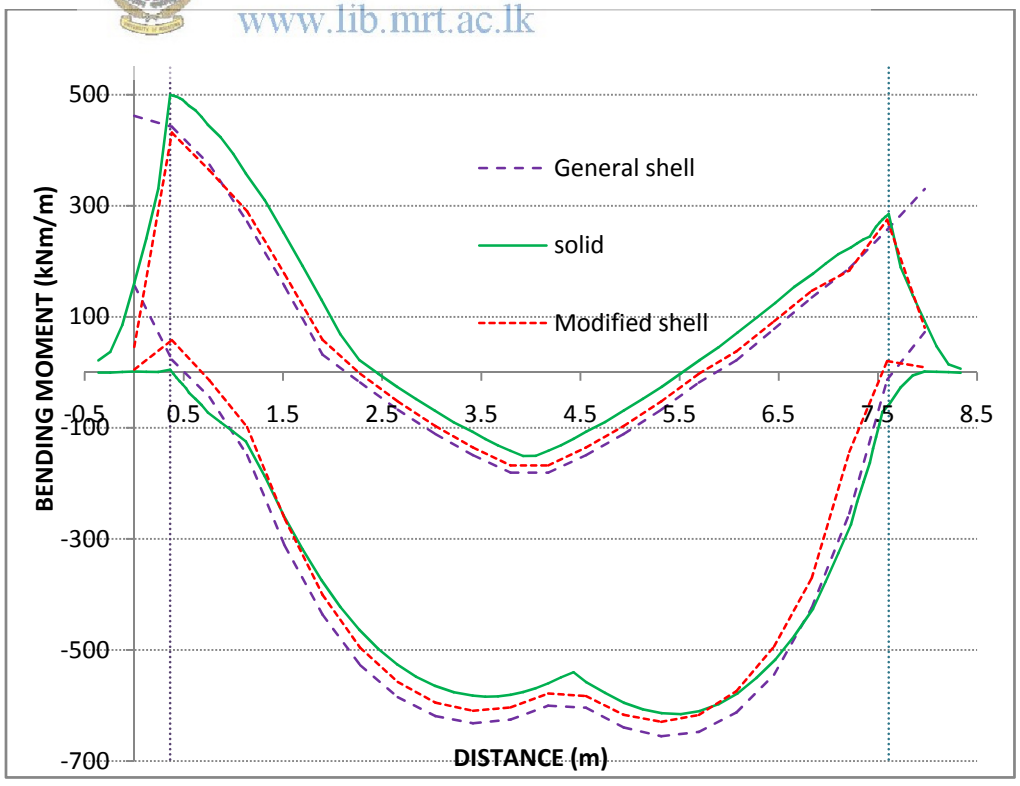


Figure F.2: BME of Bottom slab-Single cell (model no: 5)

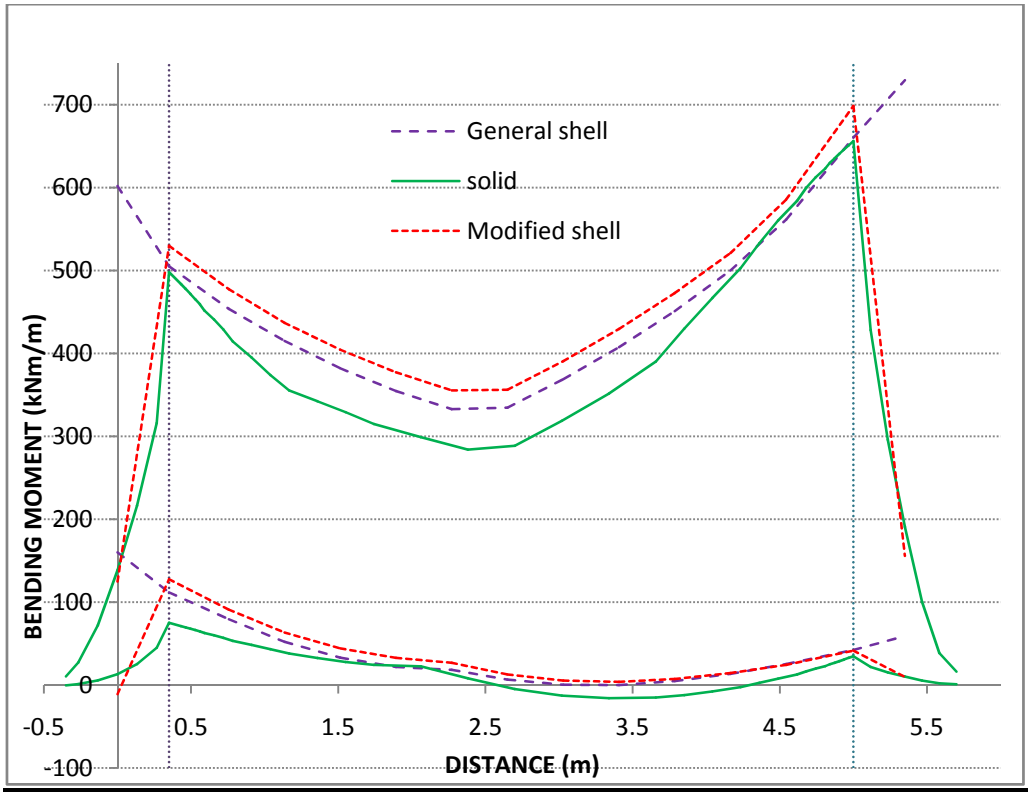


Figure F.3: BME of Walls-Single cell (model no: 5)

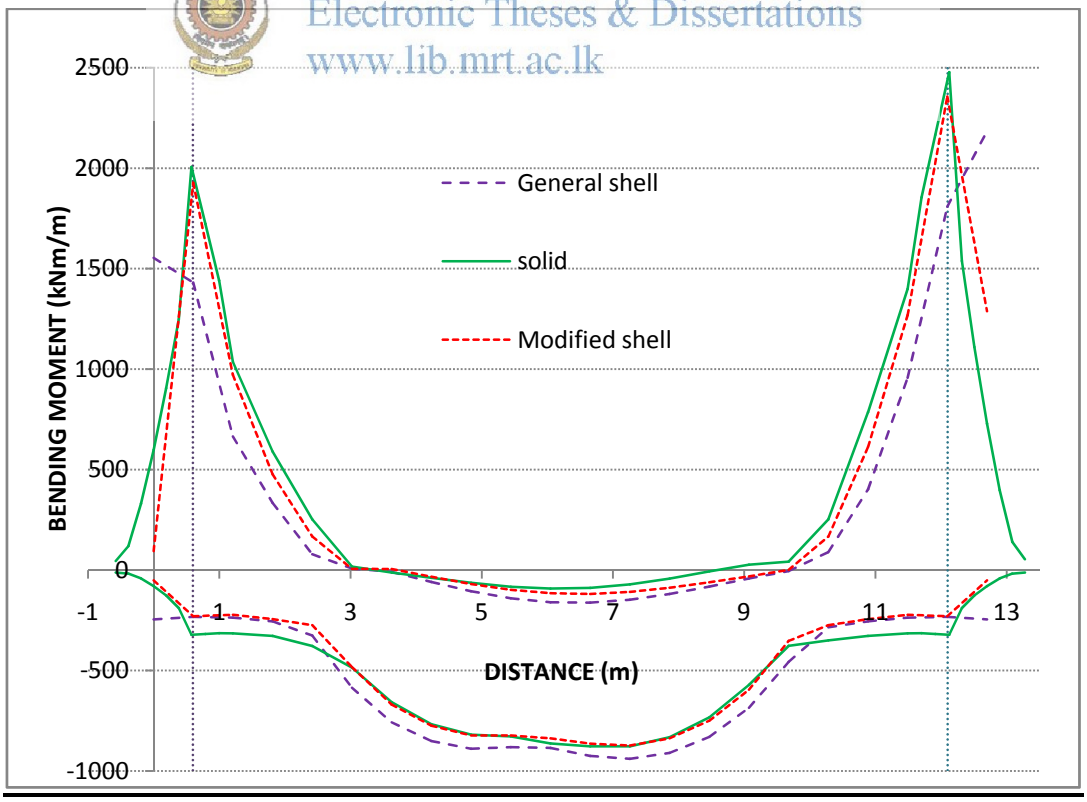


Figure F.4: BME of Top slab-Story cell (model no: 1)

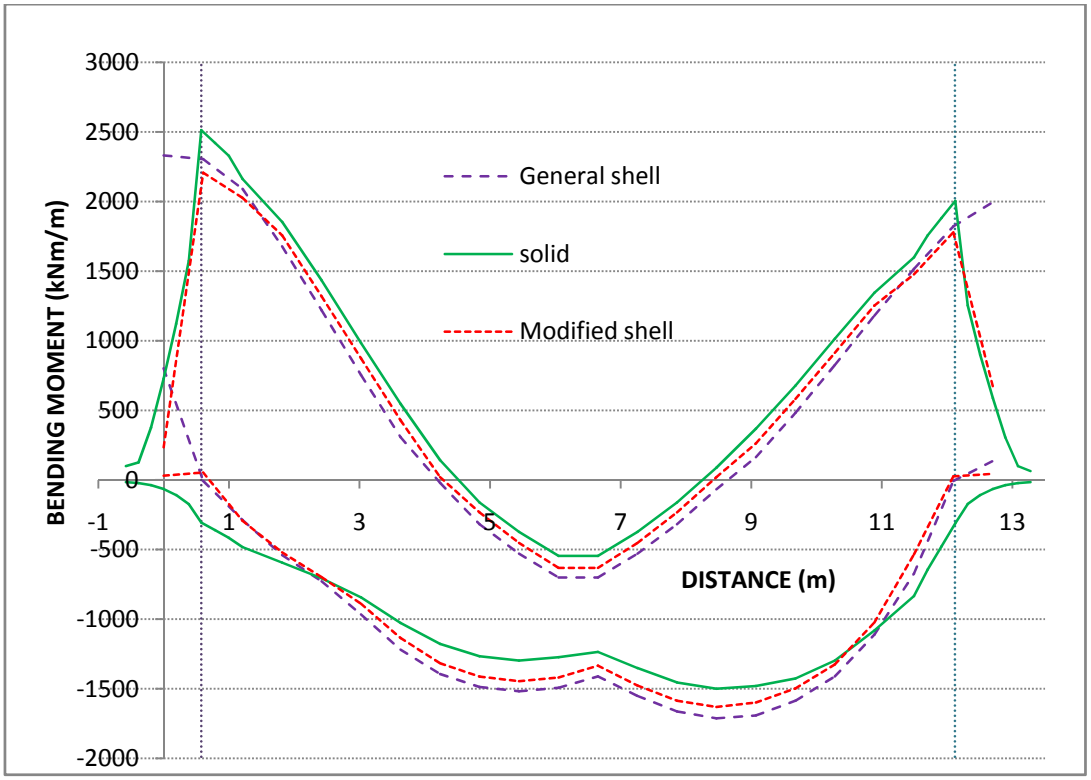


Figure F.5: BME of Bottom slab-Story cell (model no: 1)

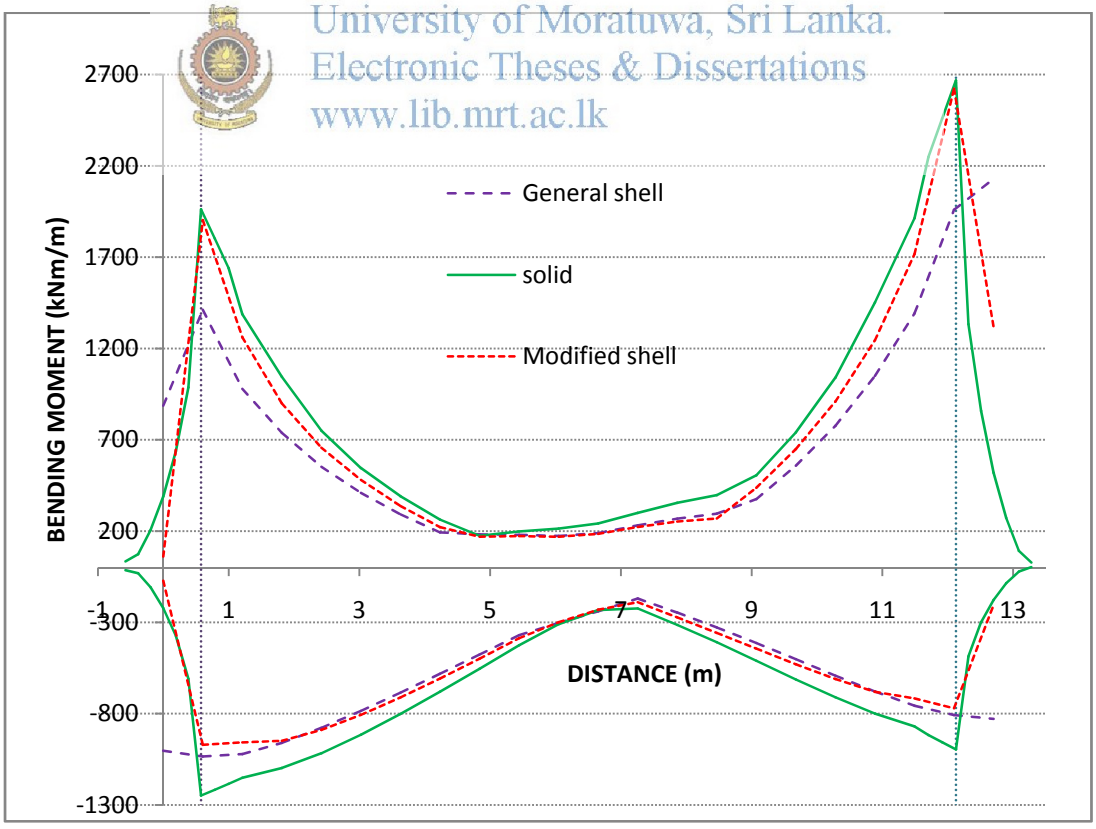


Figure F.6: BME of Middle slab-Story cell (model no: 1)

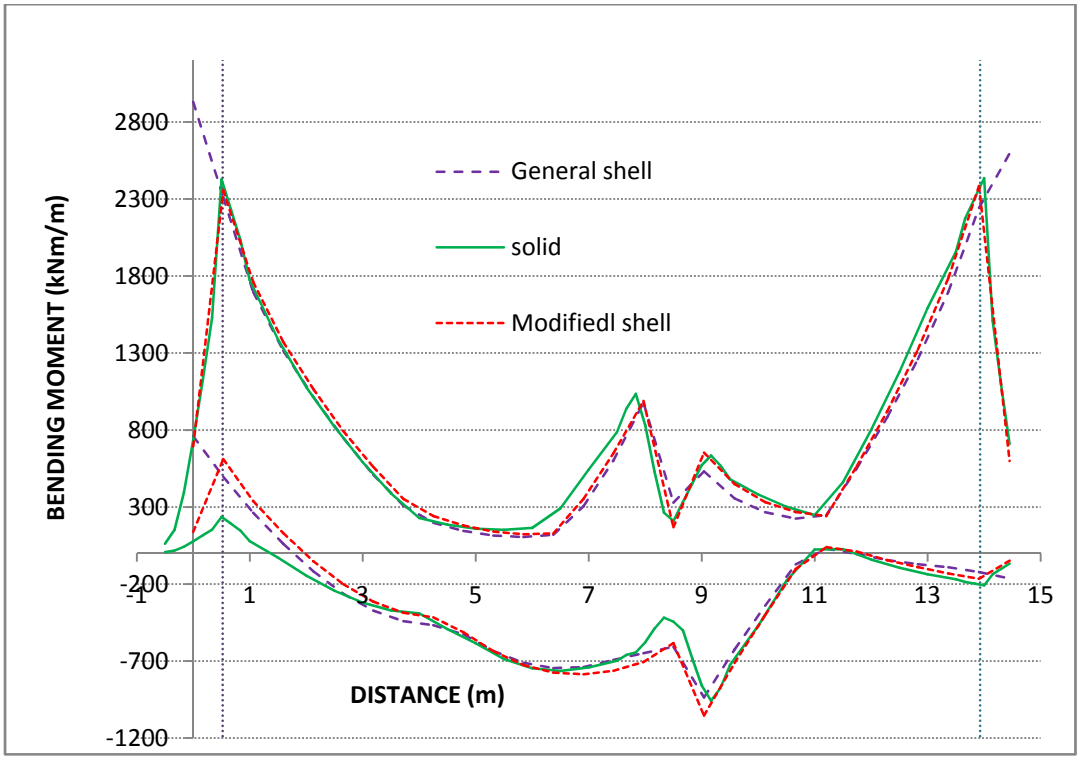


Figure F.7: BME of Walls-Story cell (model no: 1)

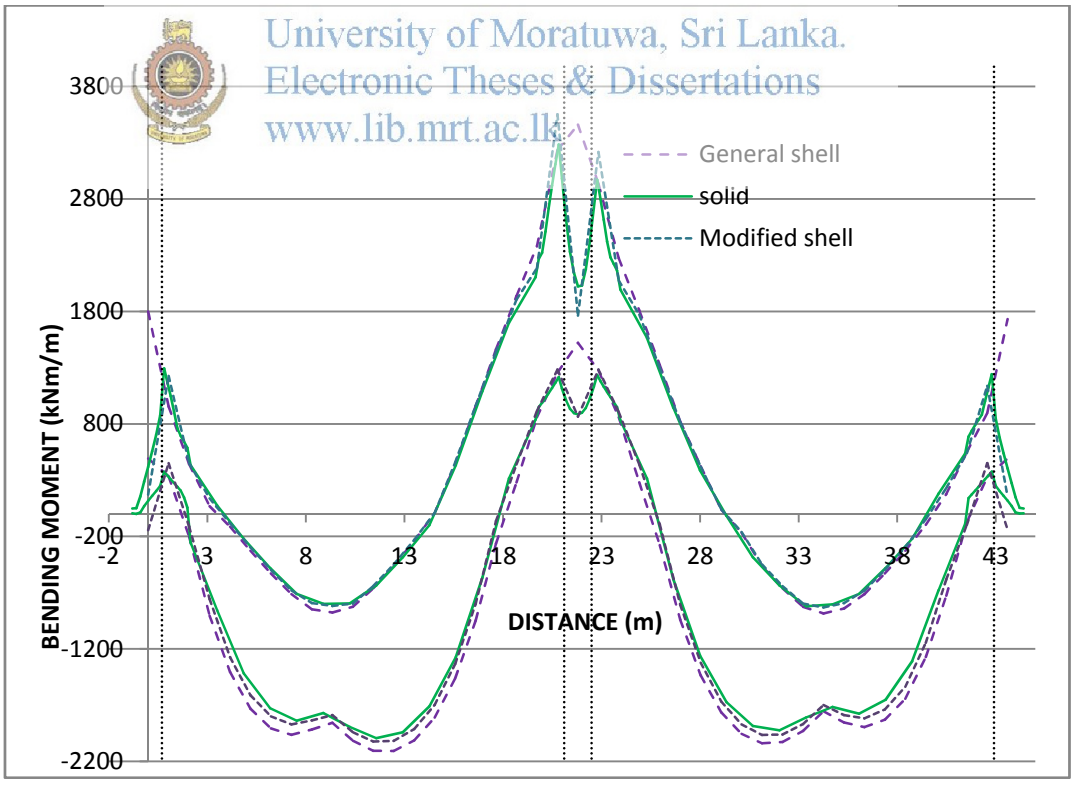


Figure F.8: BME of Top slab-Double cell (model no: 5)

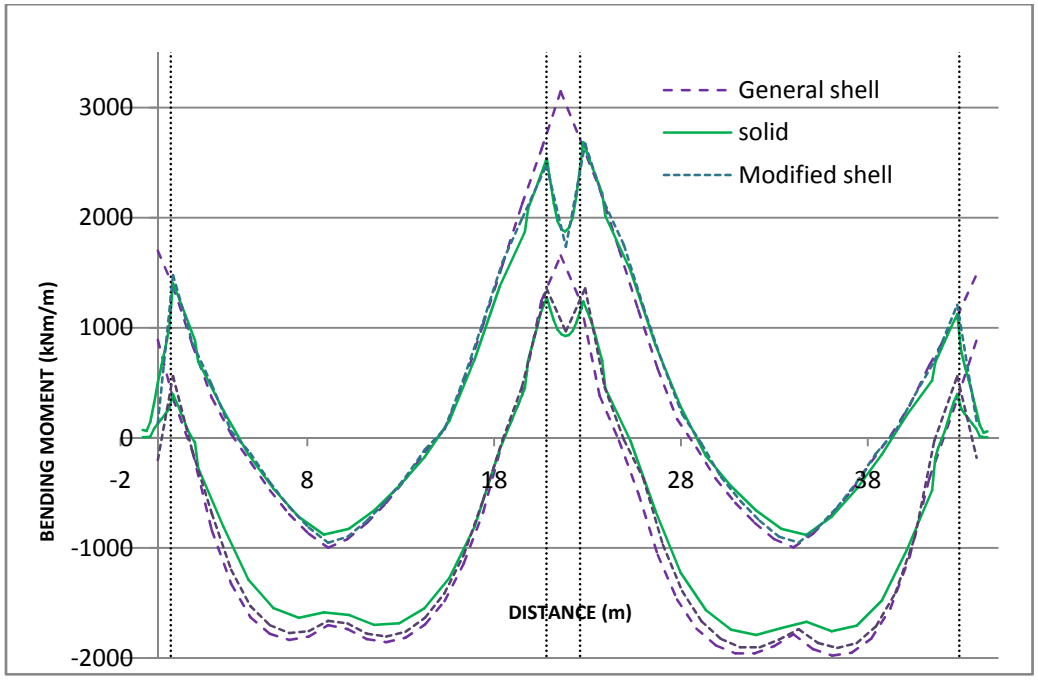


Figure F.9: BME of Bottom slab-Double cell (model no: 5)

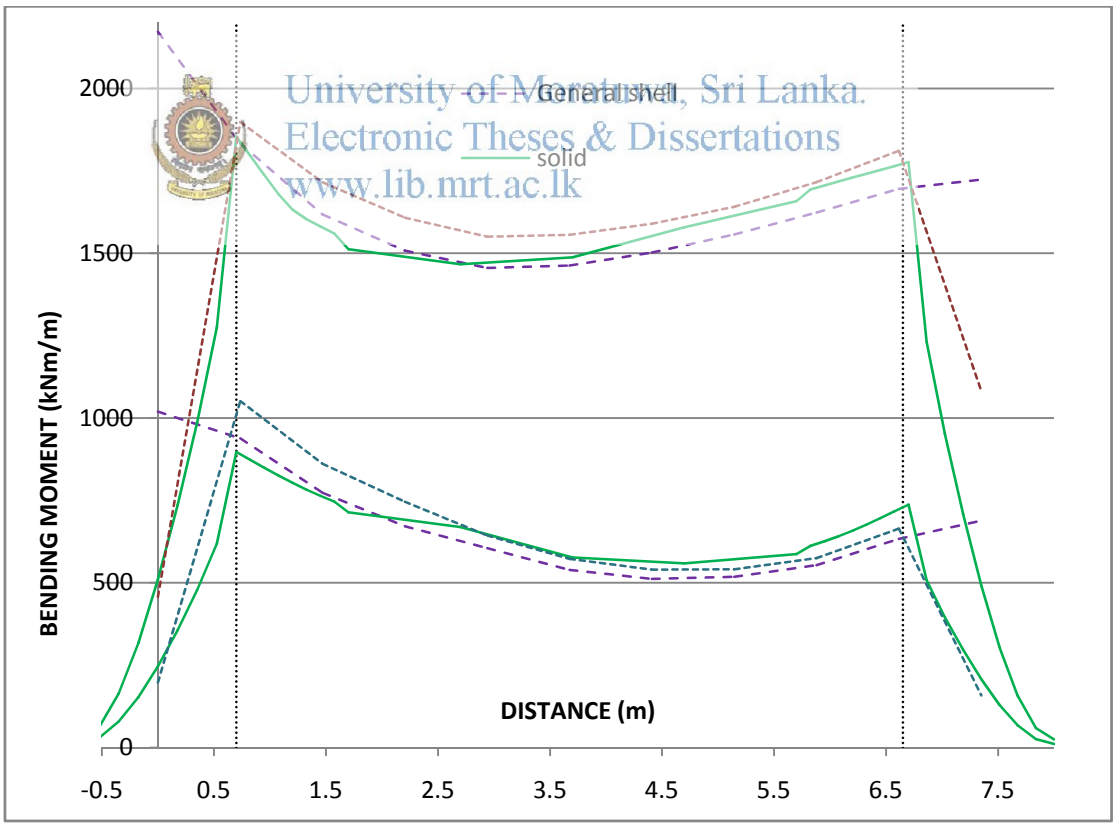


Figure F.10: BME of Outside walls-Double cell (model no: 5)

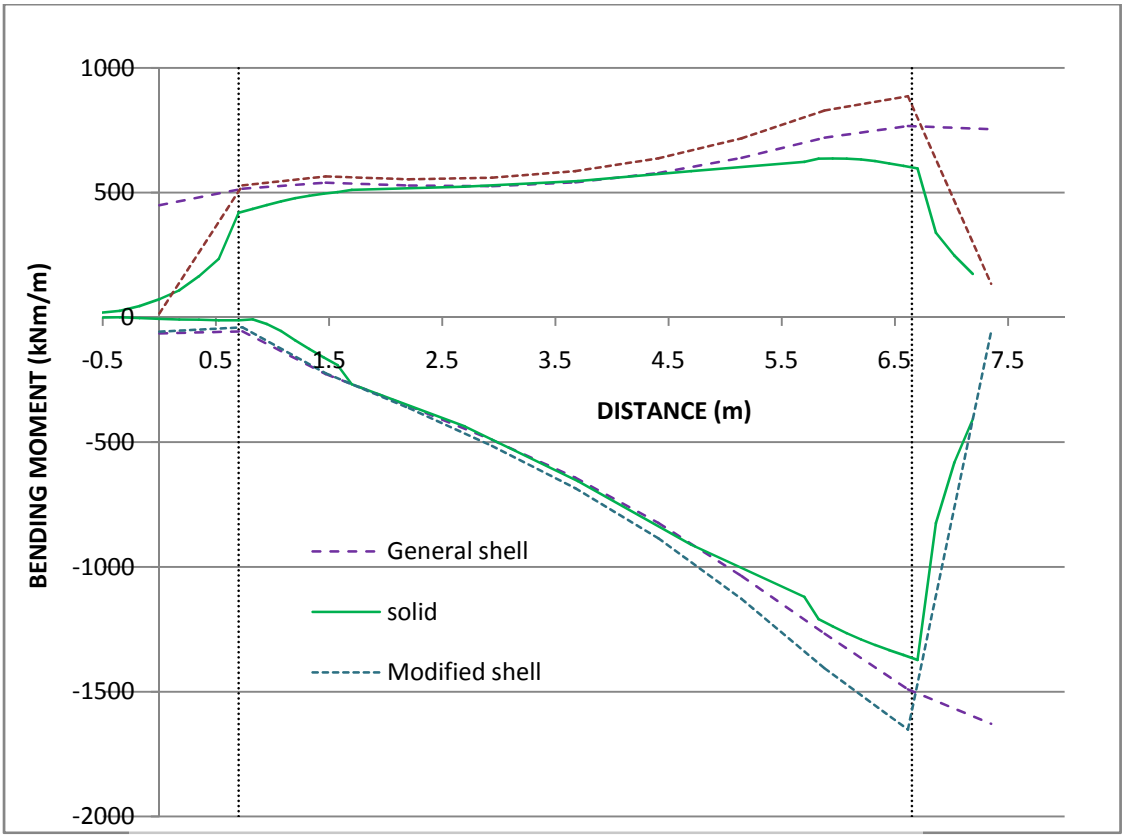
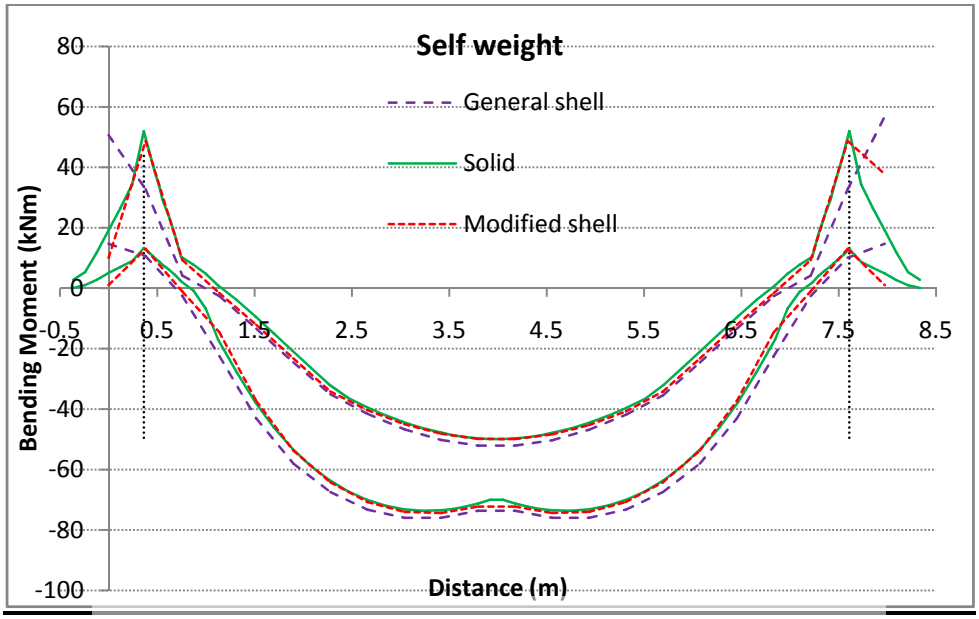


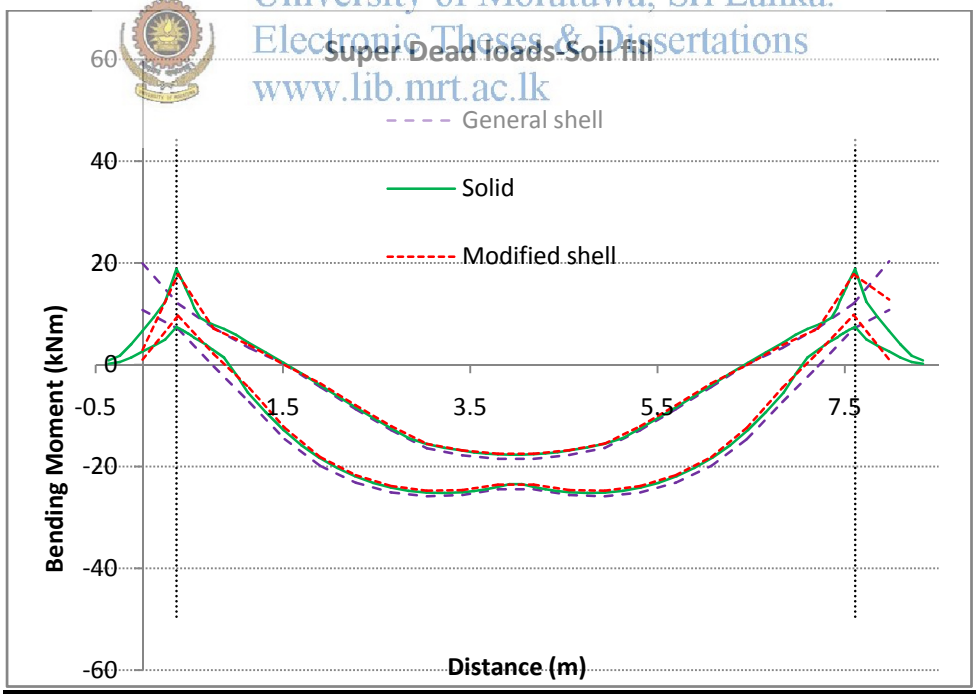
Figure F.11: BME of Inside walls-Double cell (model no: 5)

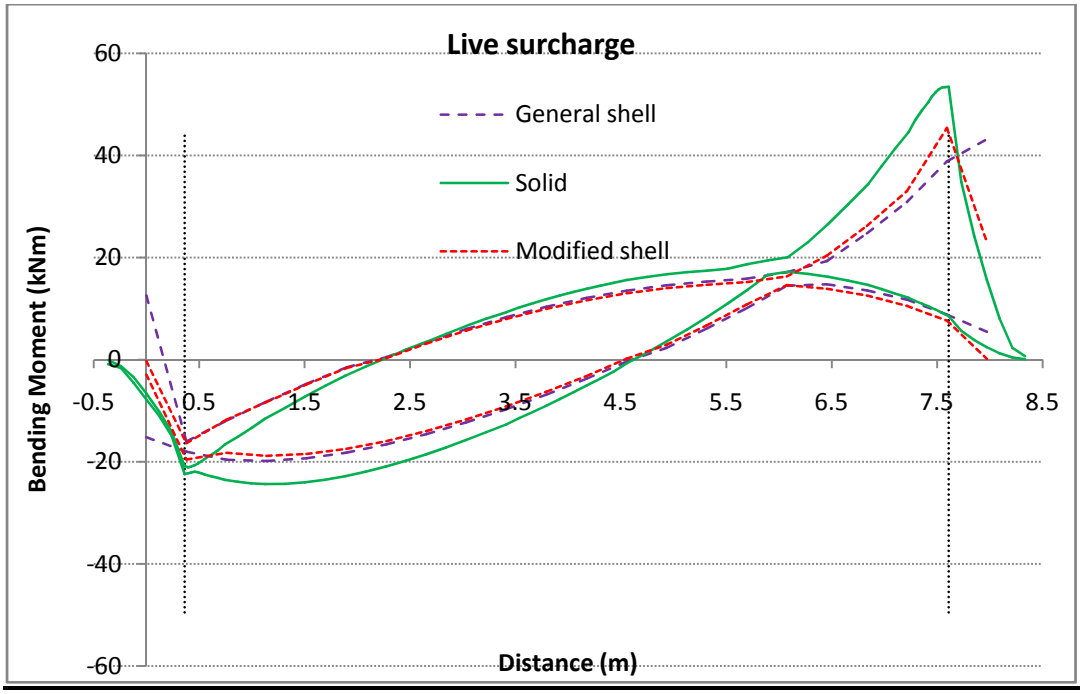
Appendix H: Bending moment envelops for Load cases

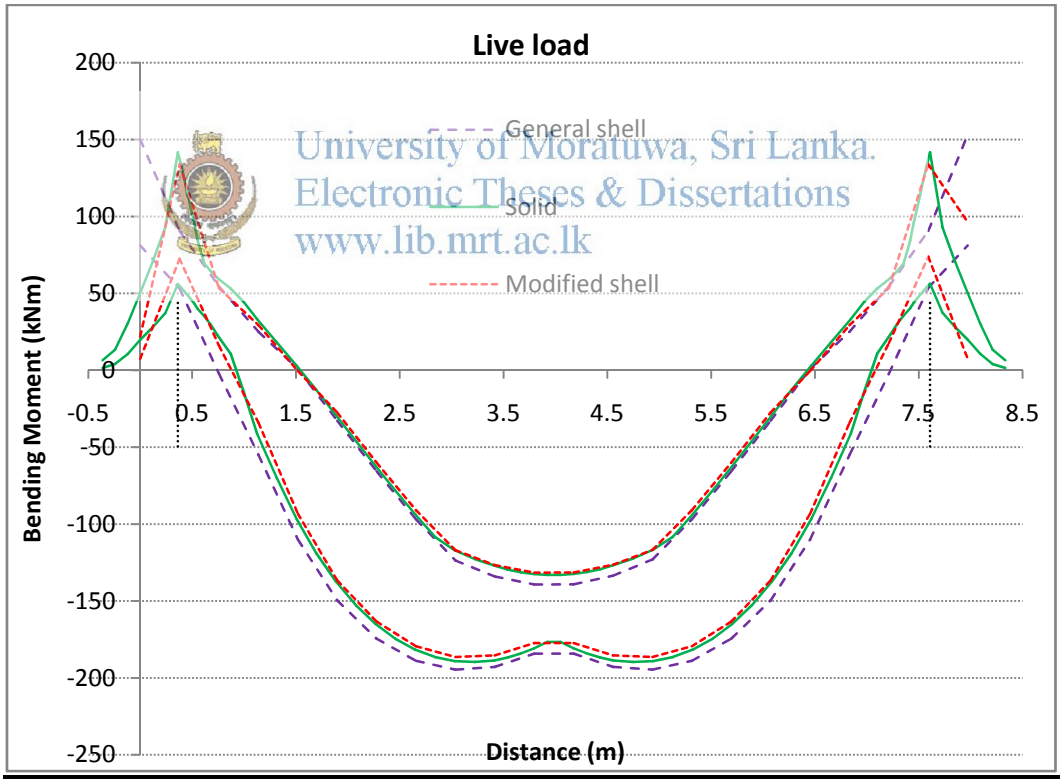
H.1 Skew angle 30^0 models

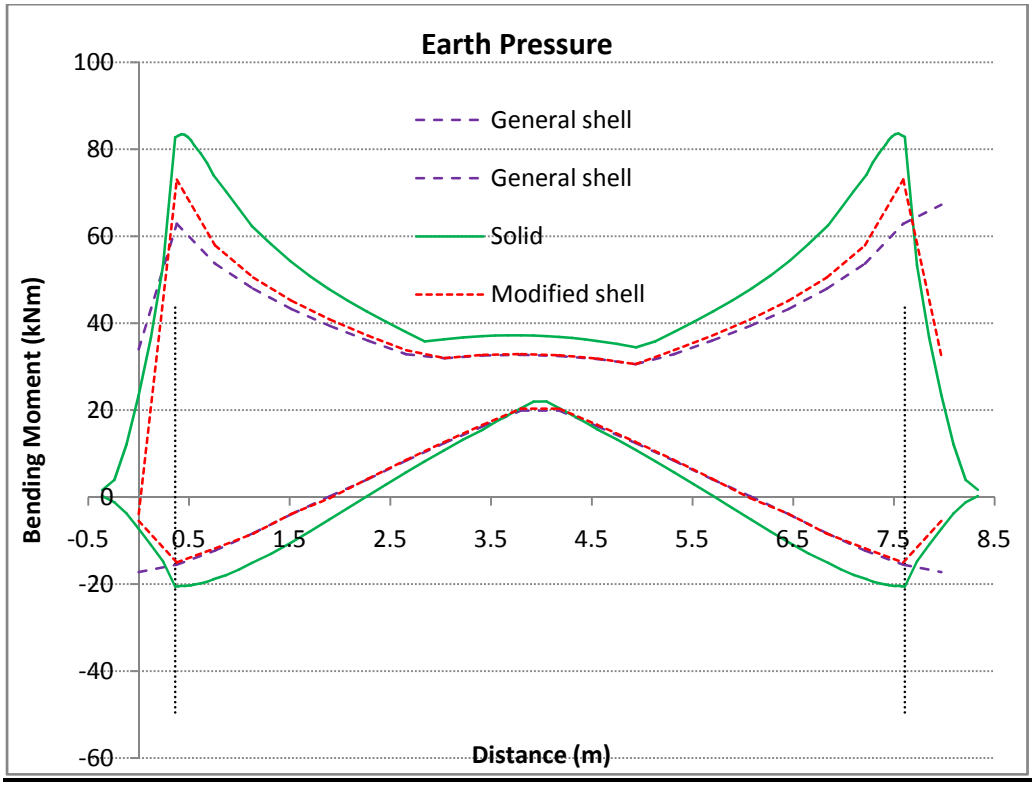
H.1.1 BME of Top slab-Single cell (model no: 5)

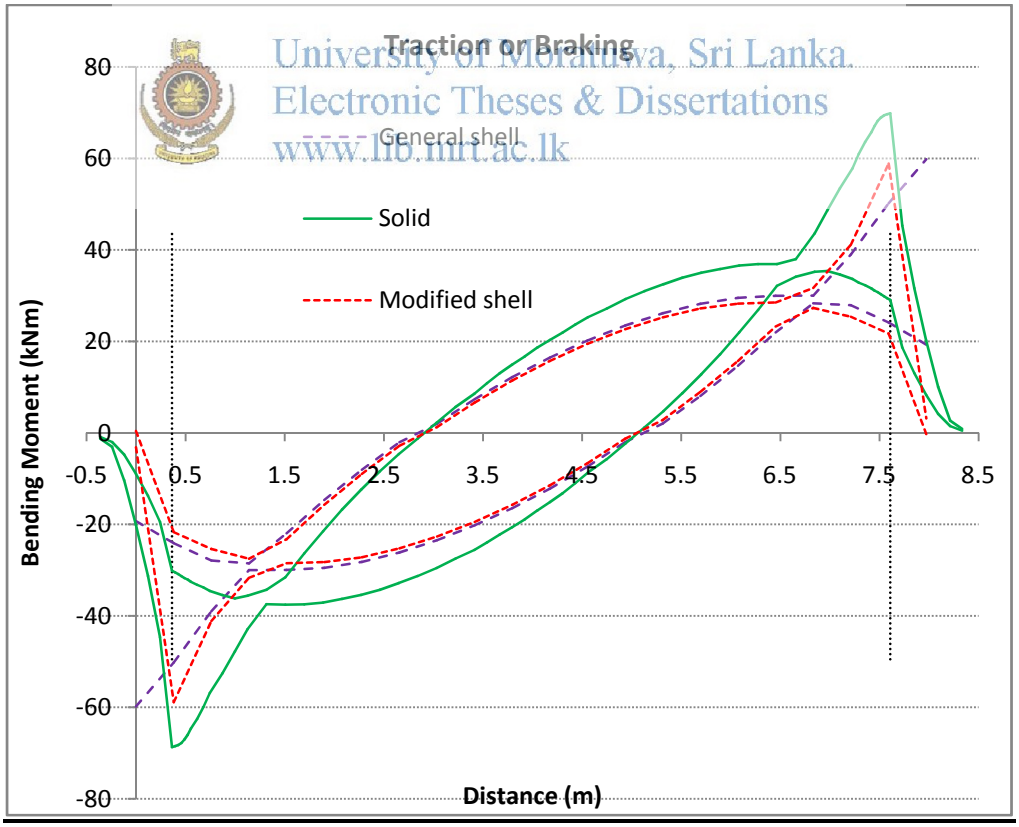




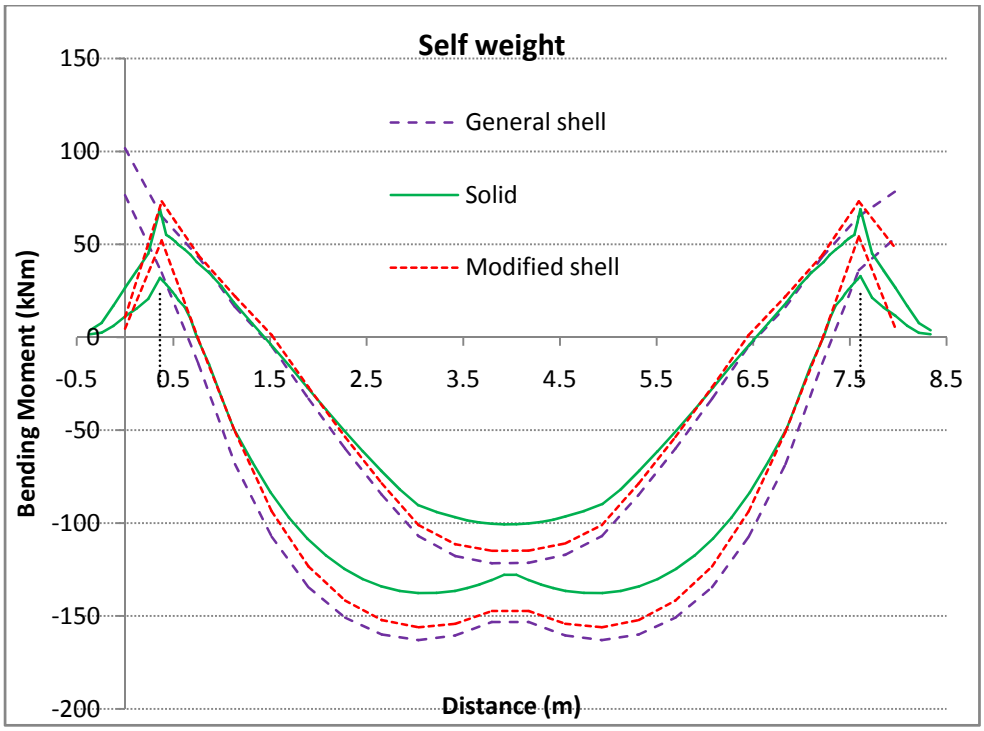


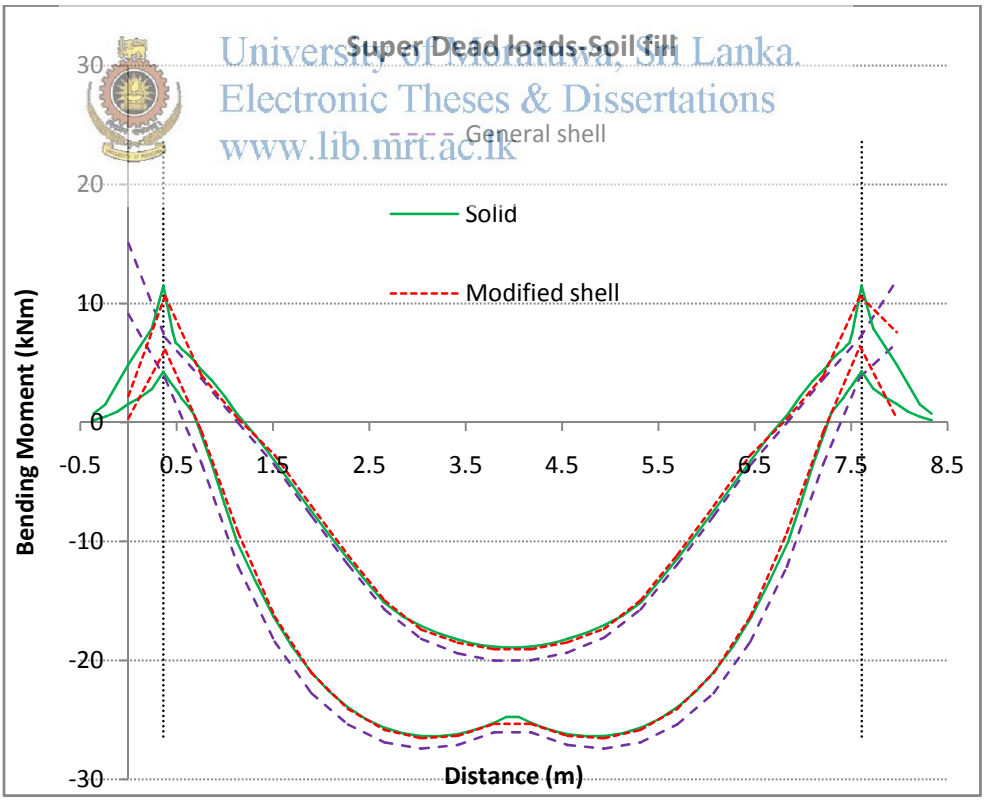


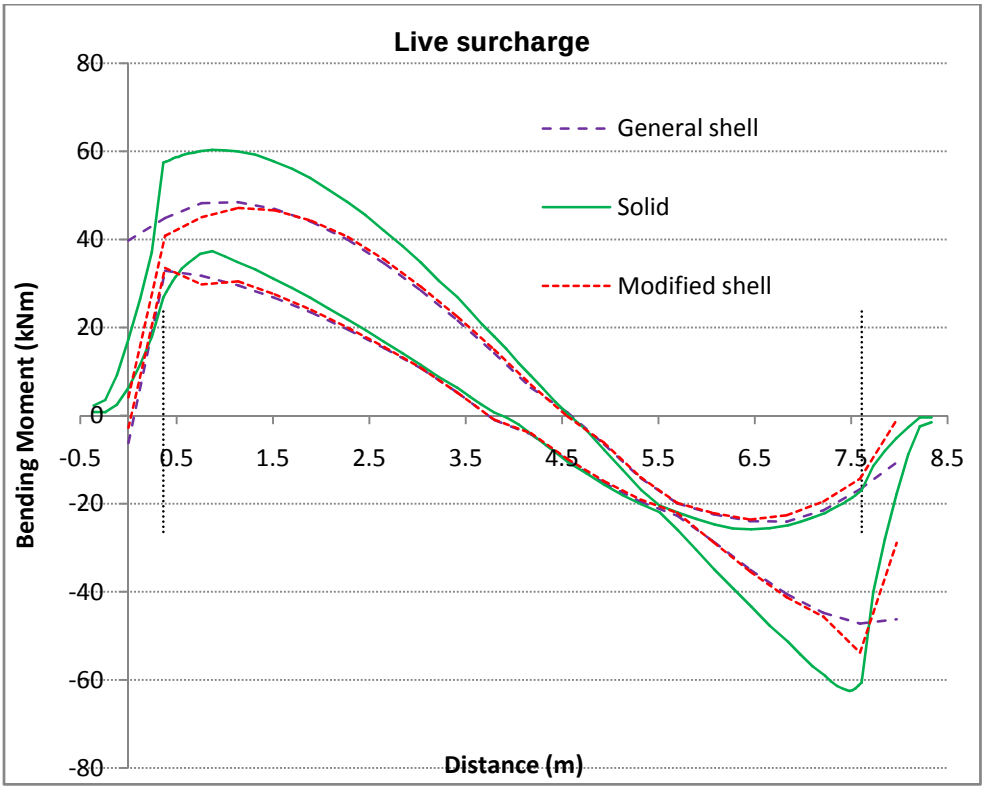


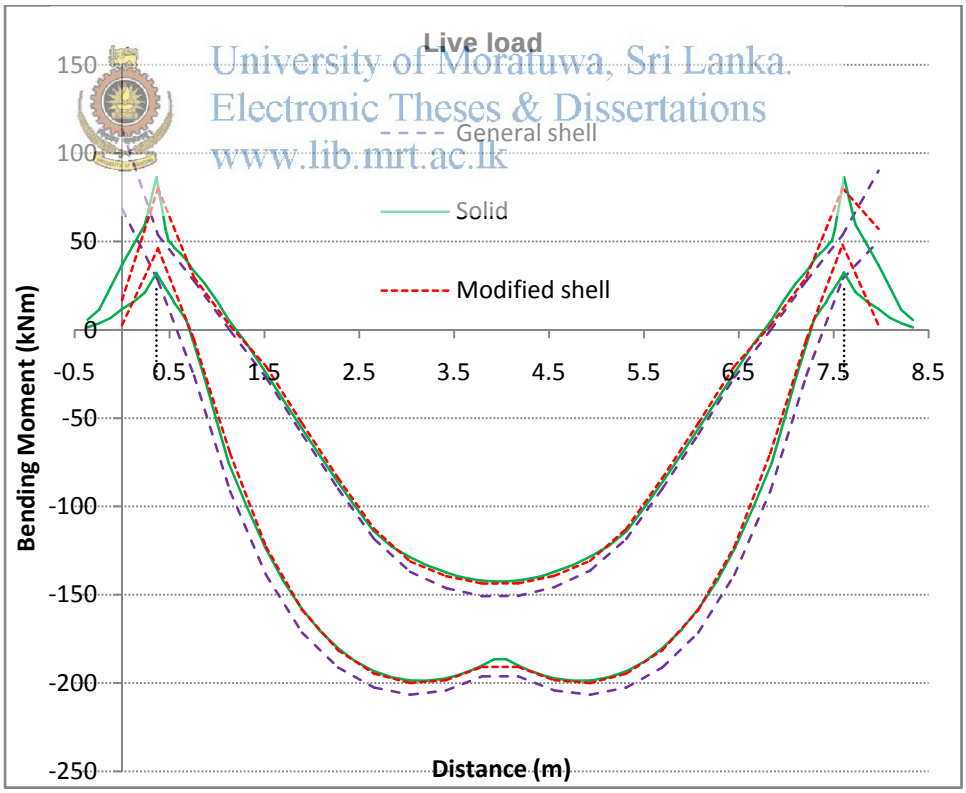


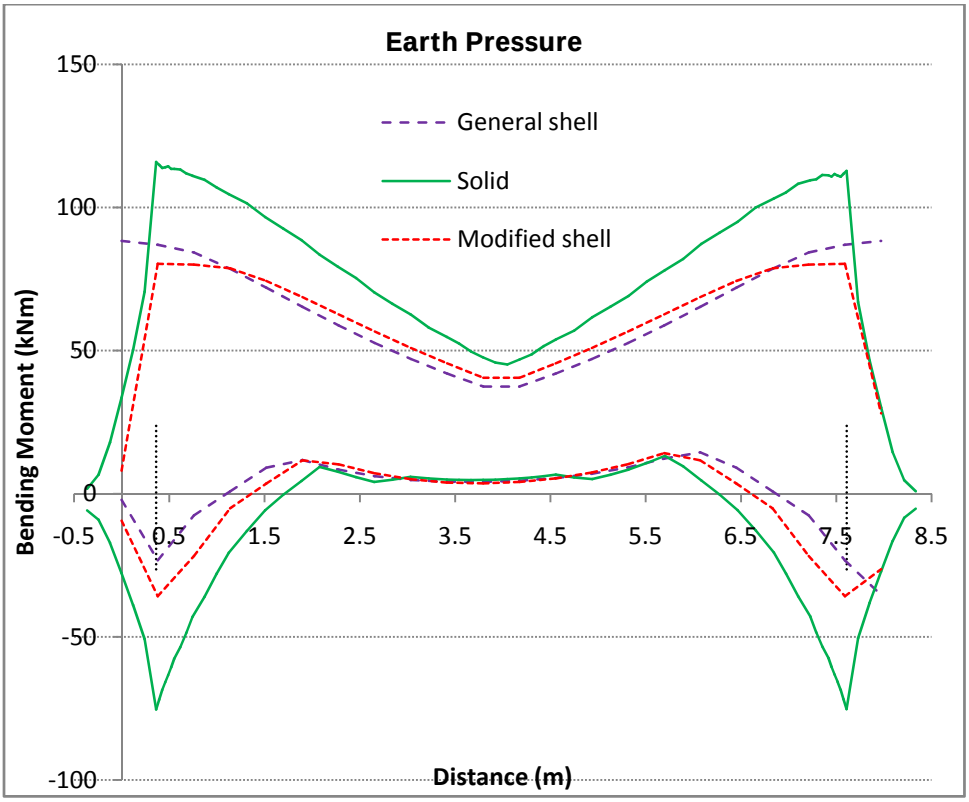
H.1.2: BMD of Bottom slab-Single cell (model no: 5)

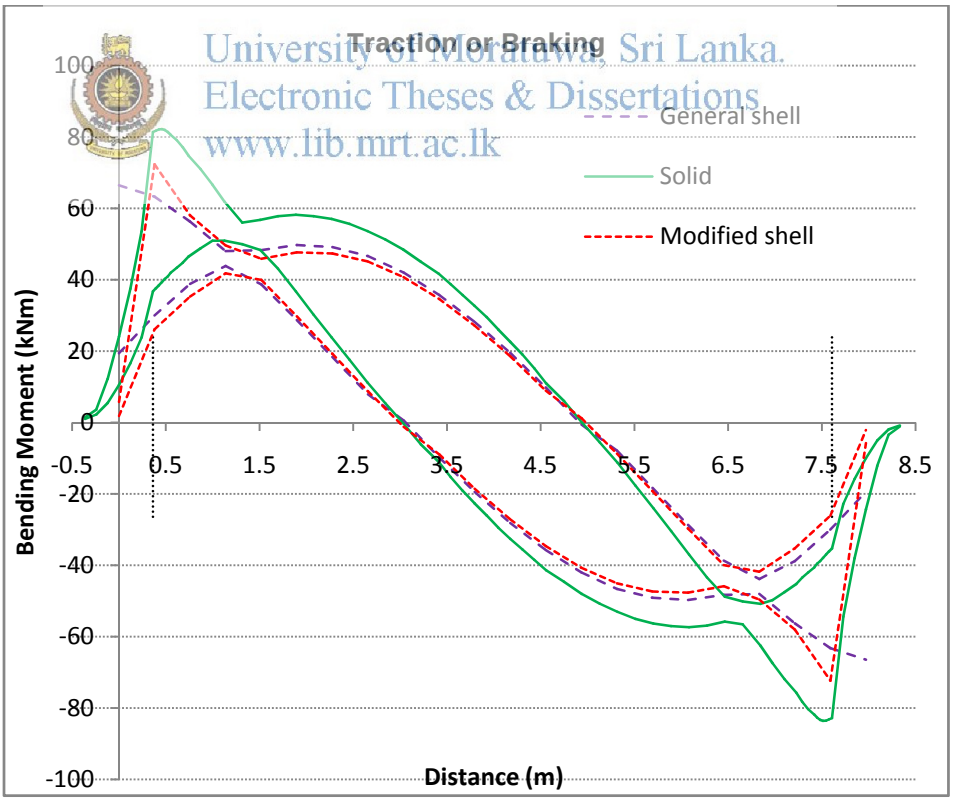




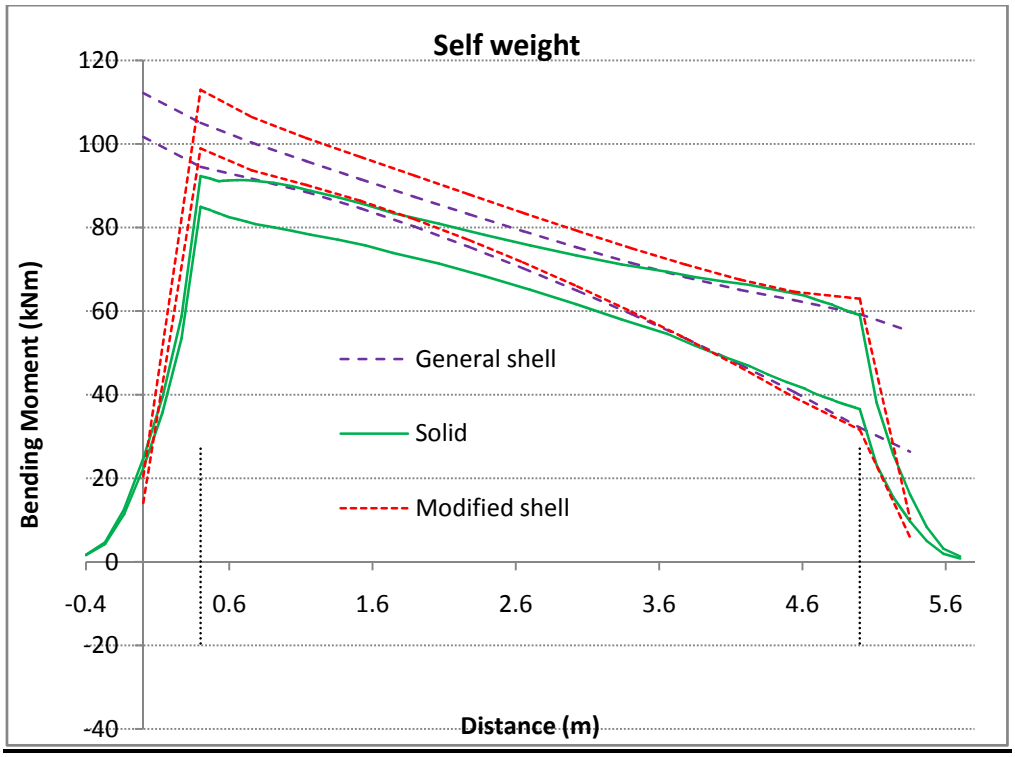


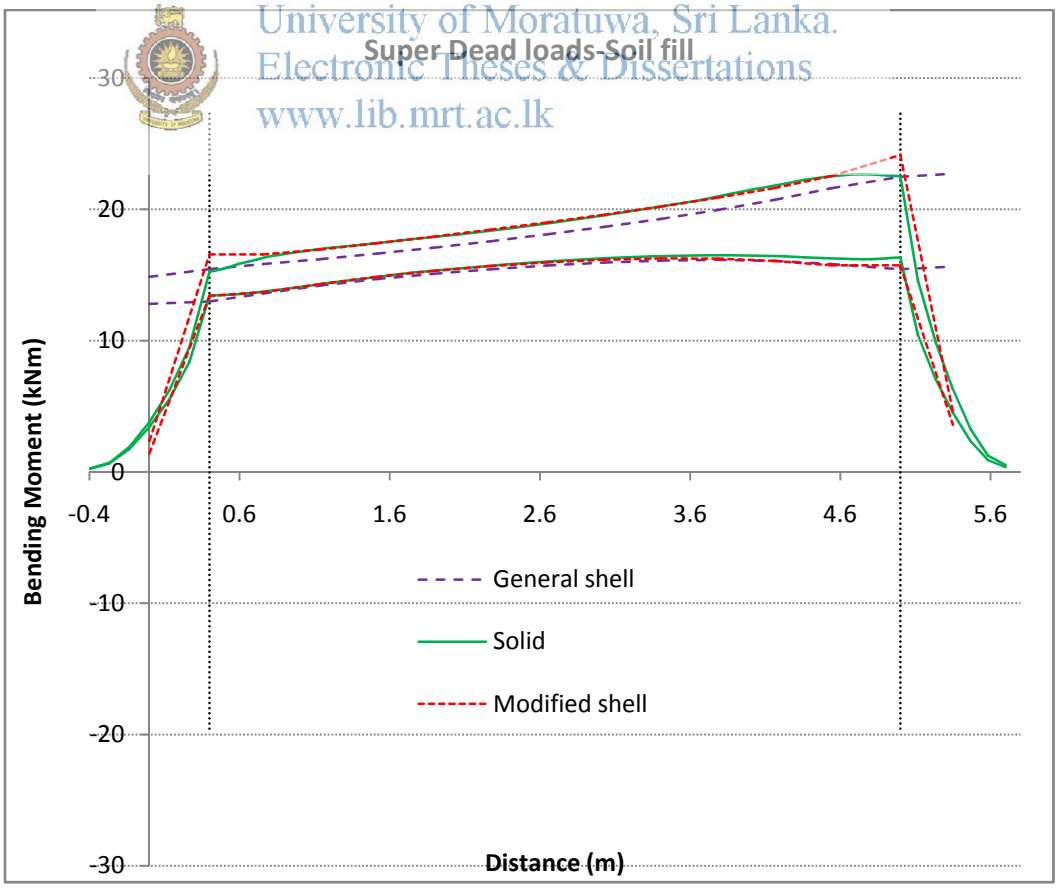


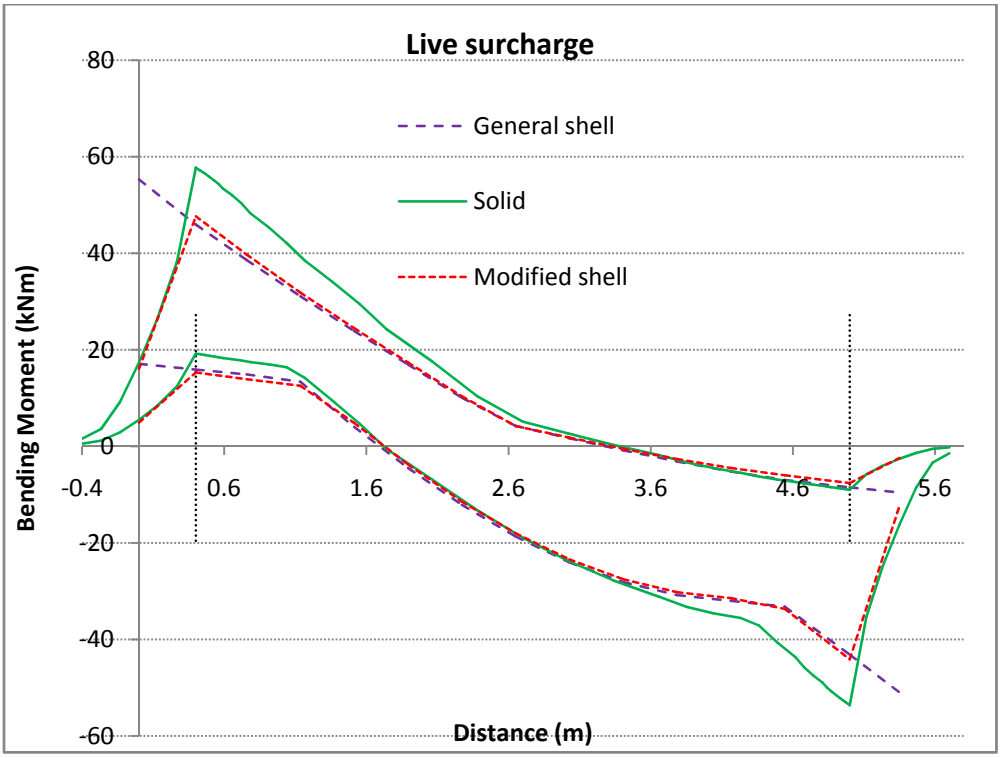


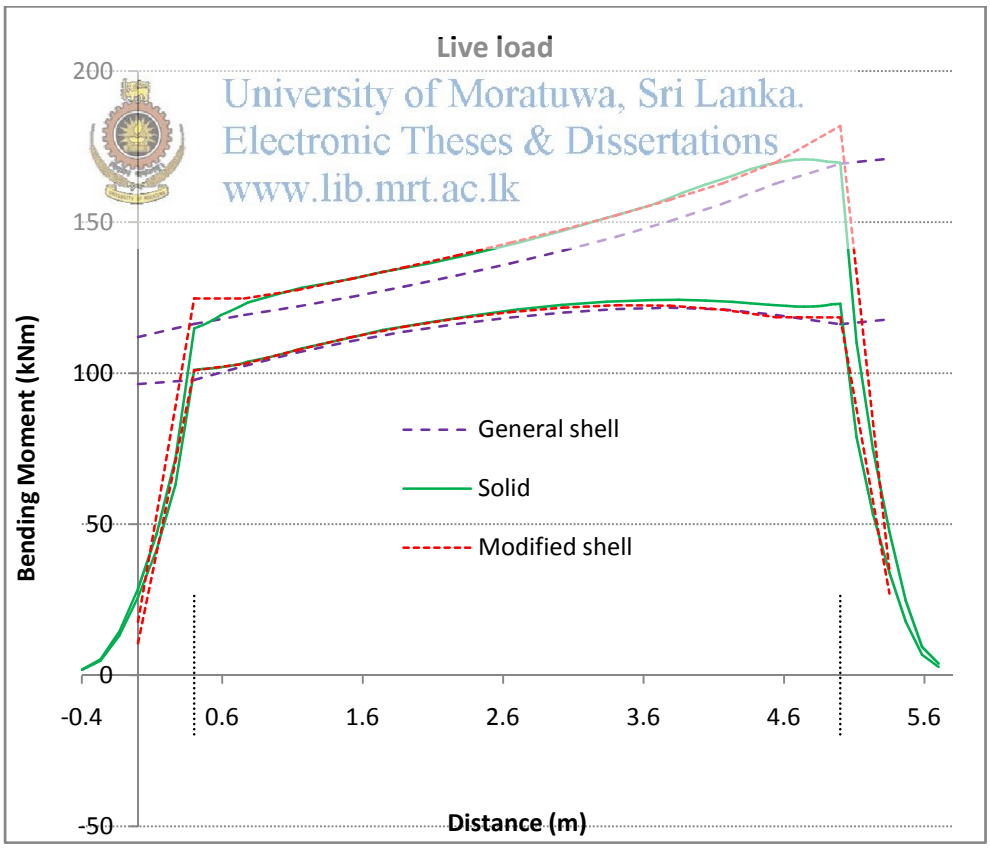


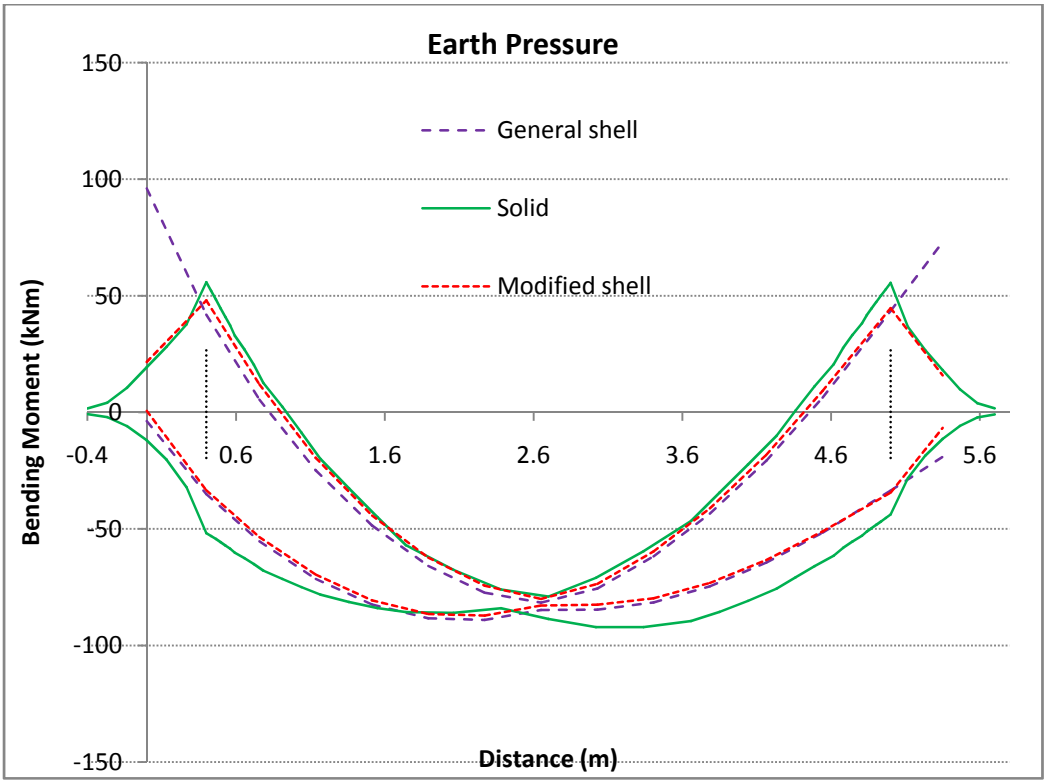
H.1.3: BMD of Walls-Single cell (model no: 5)

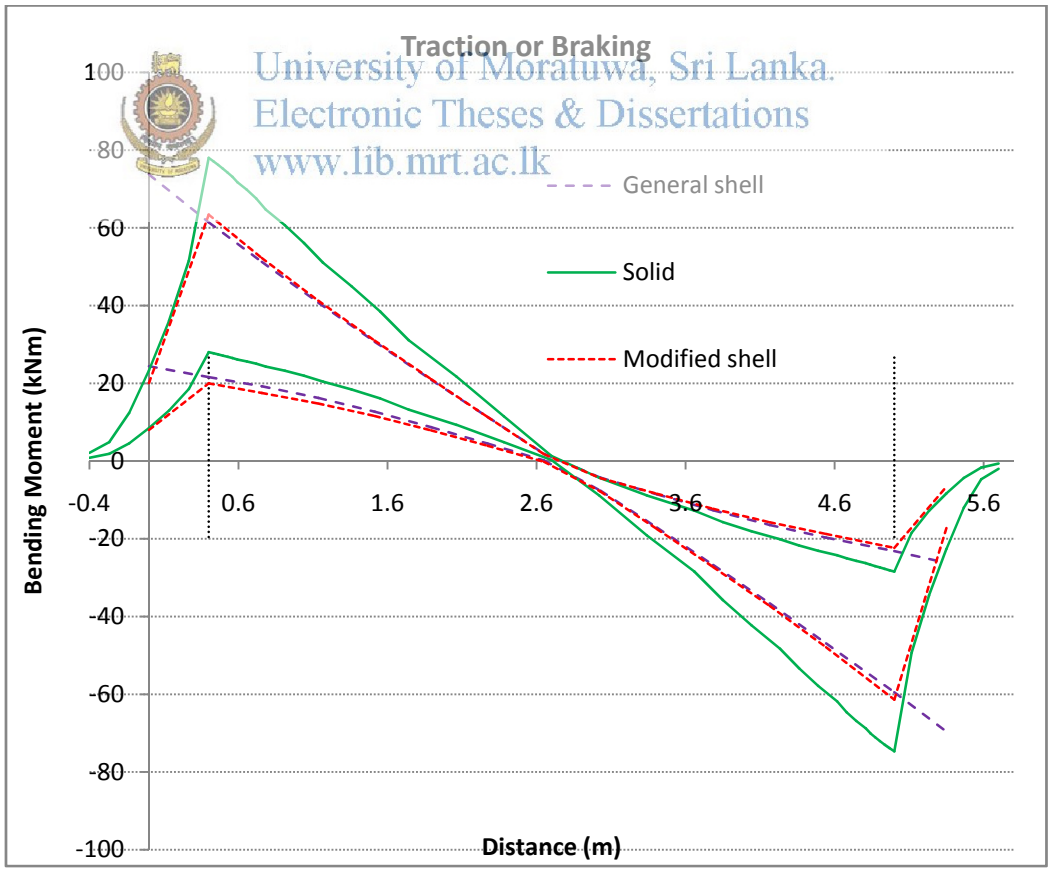




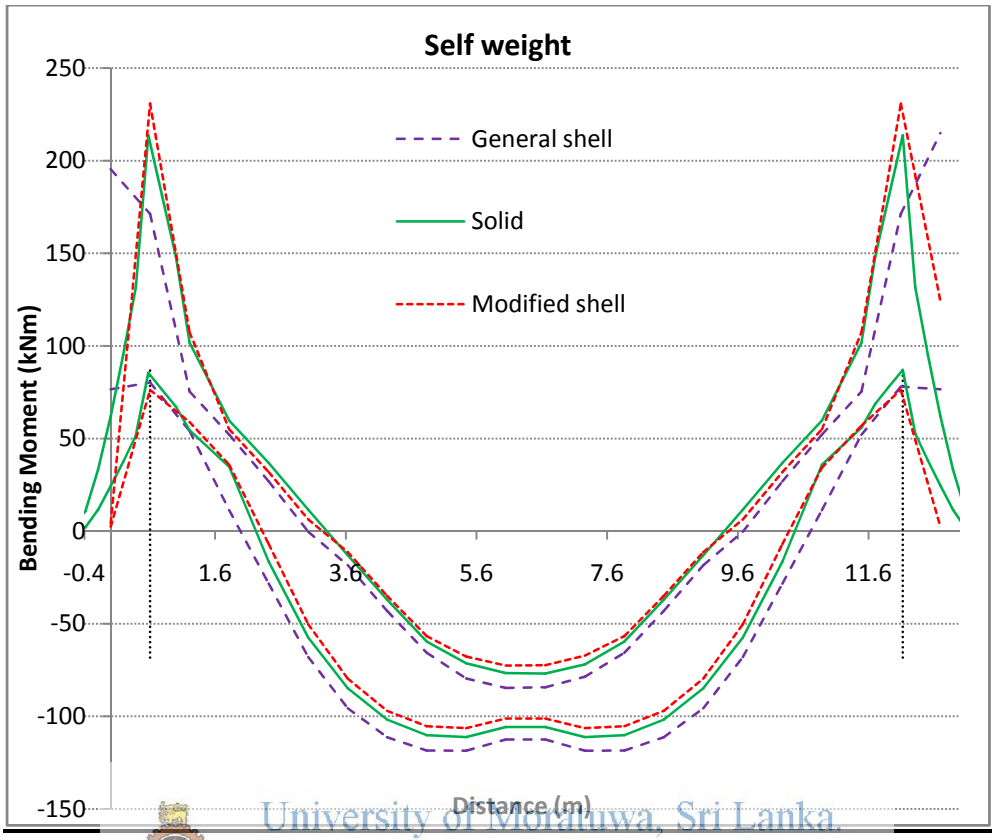


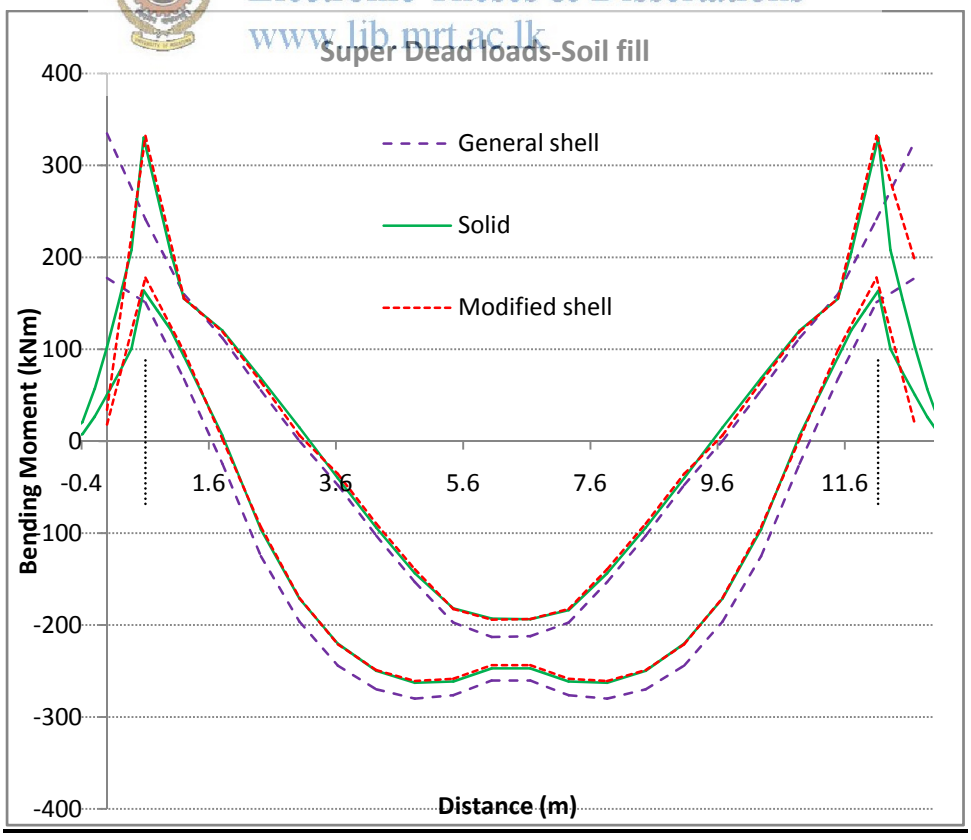


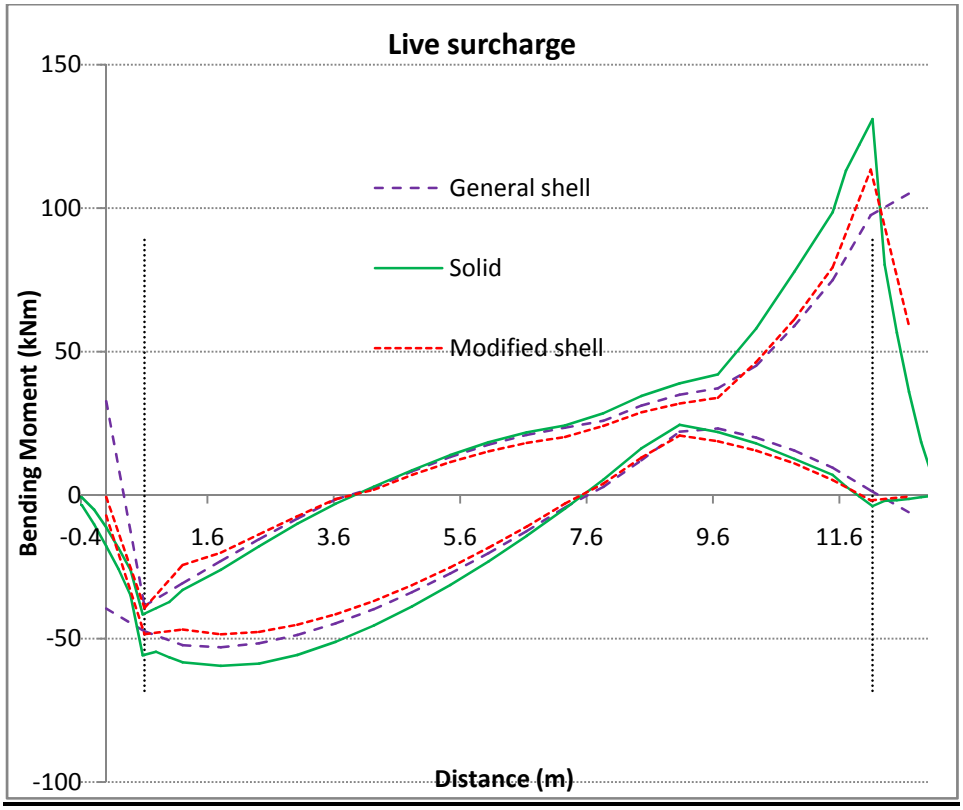


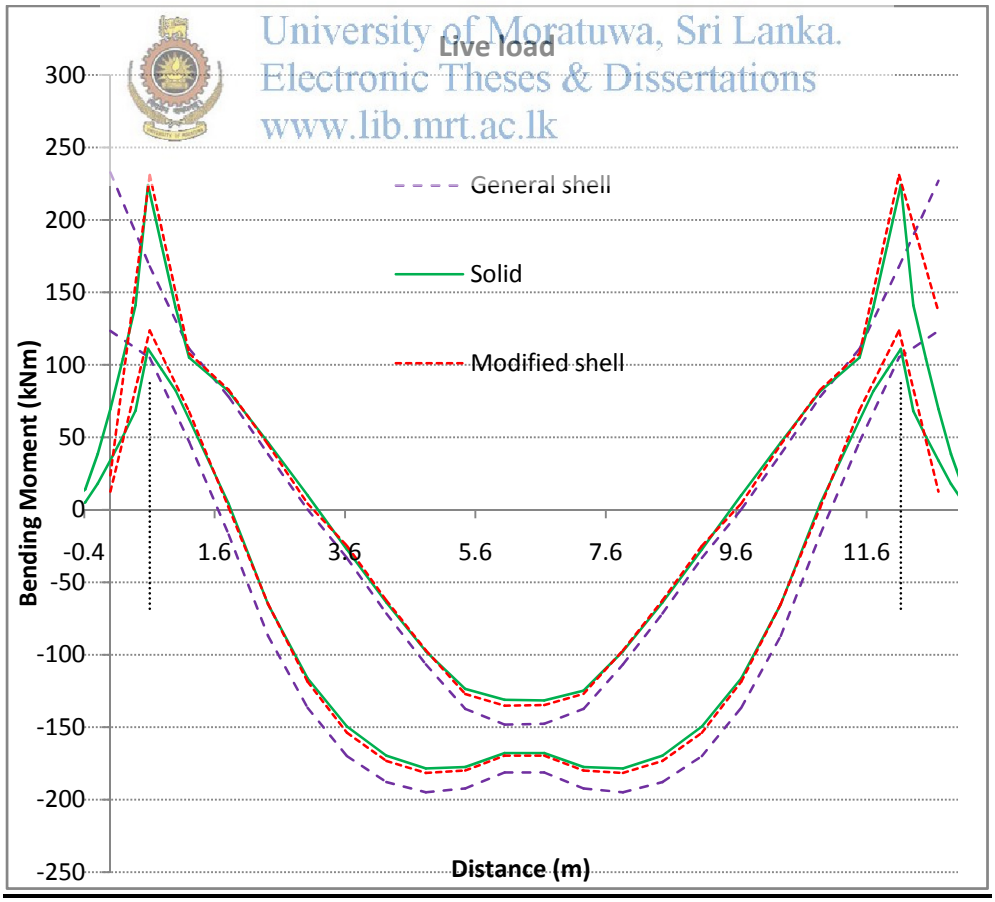


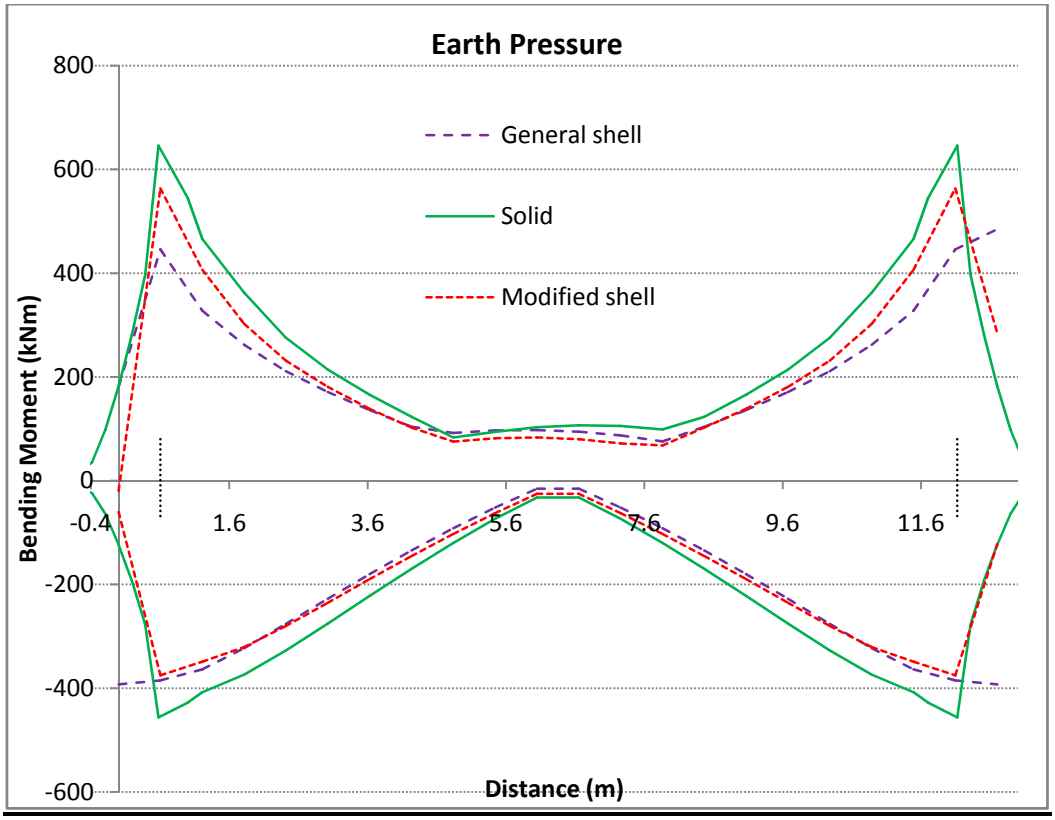
H.1.4: BMD of Top slab-Story cell (model no: 1)

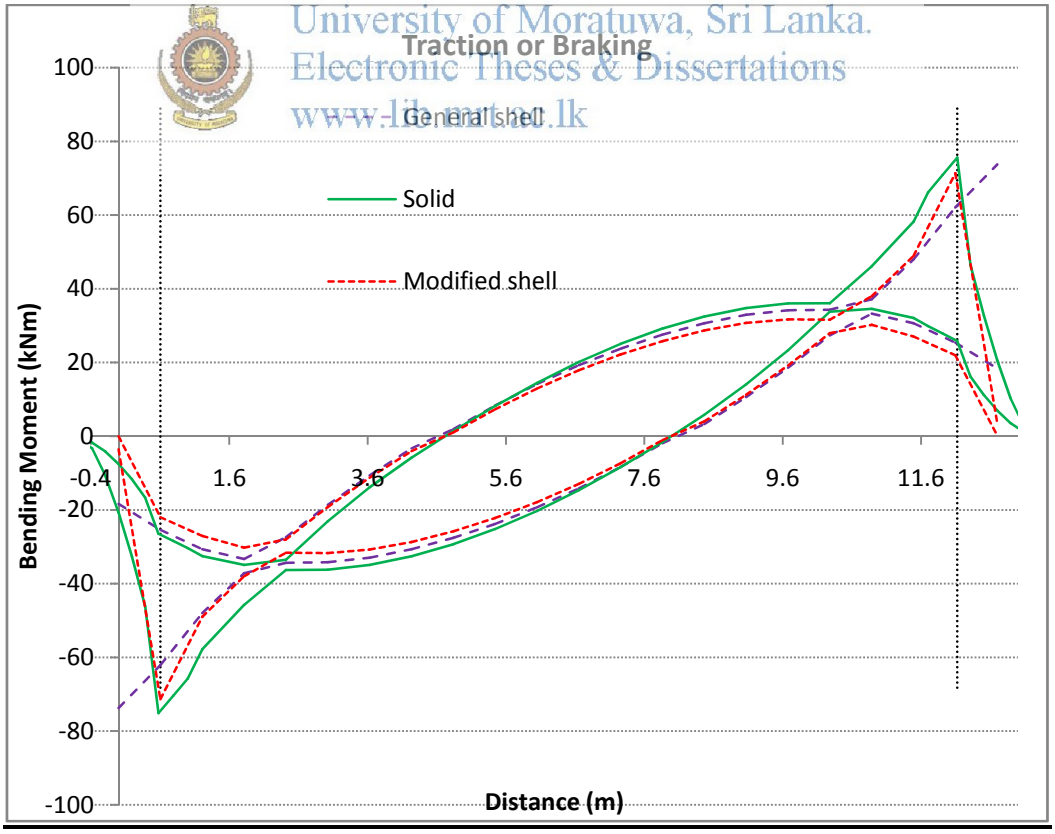




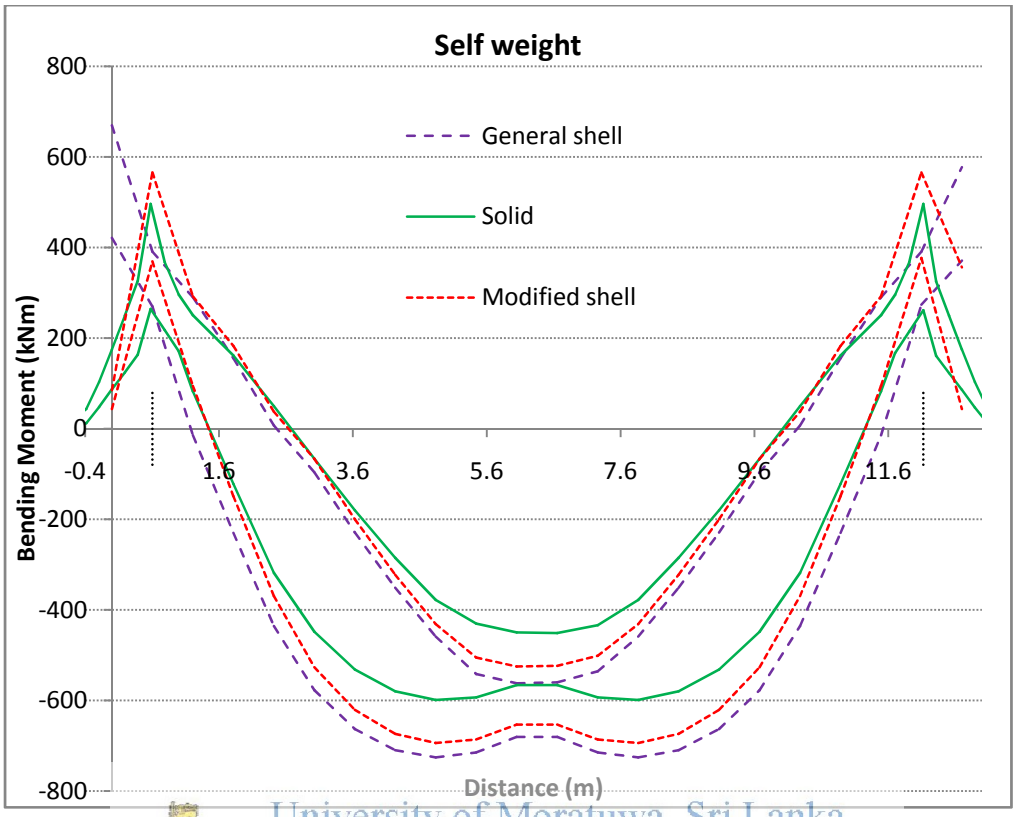


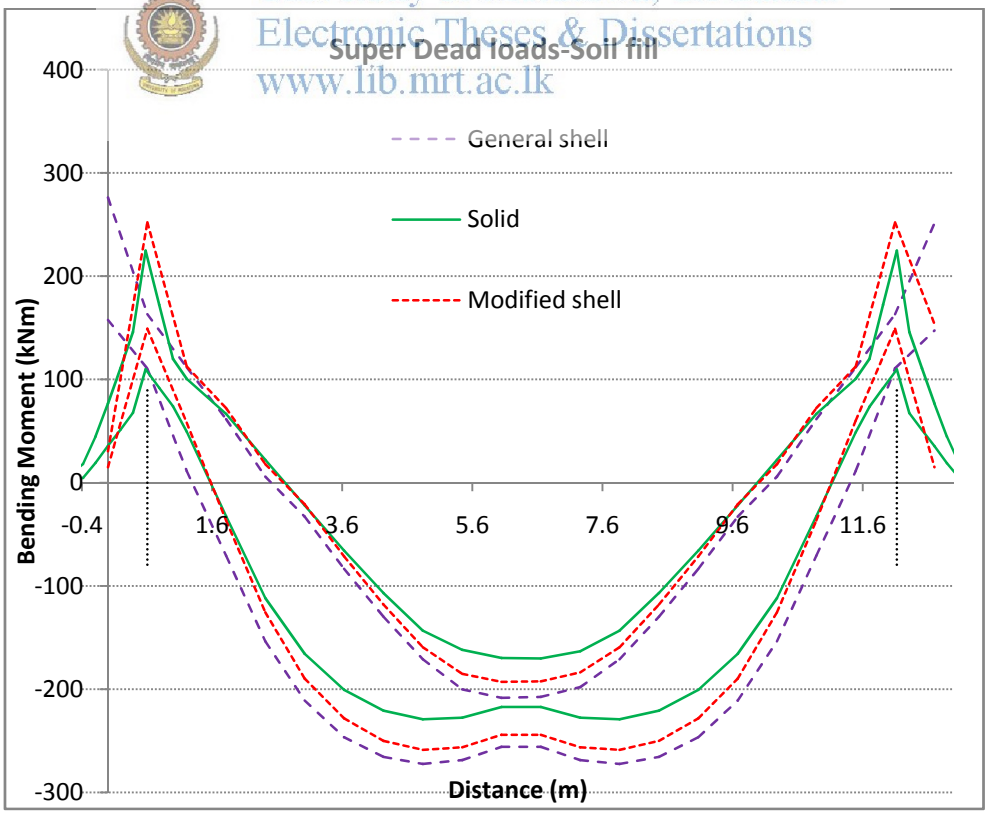


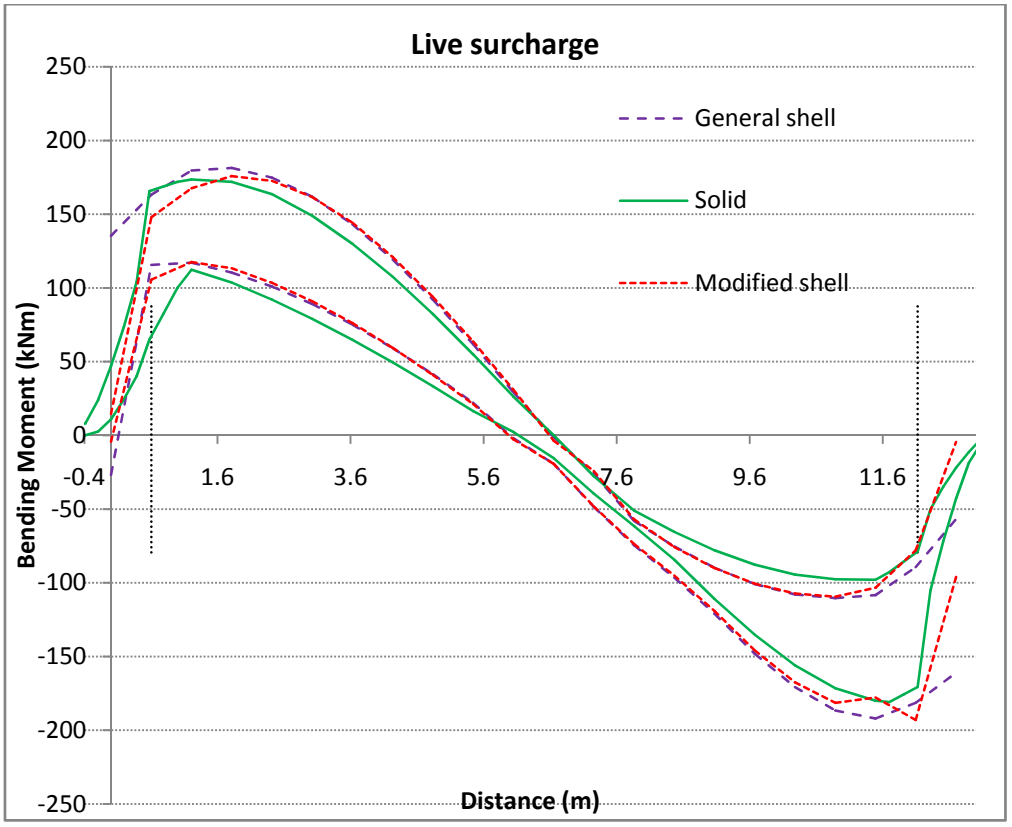


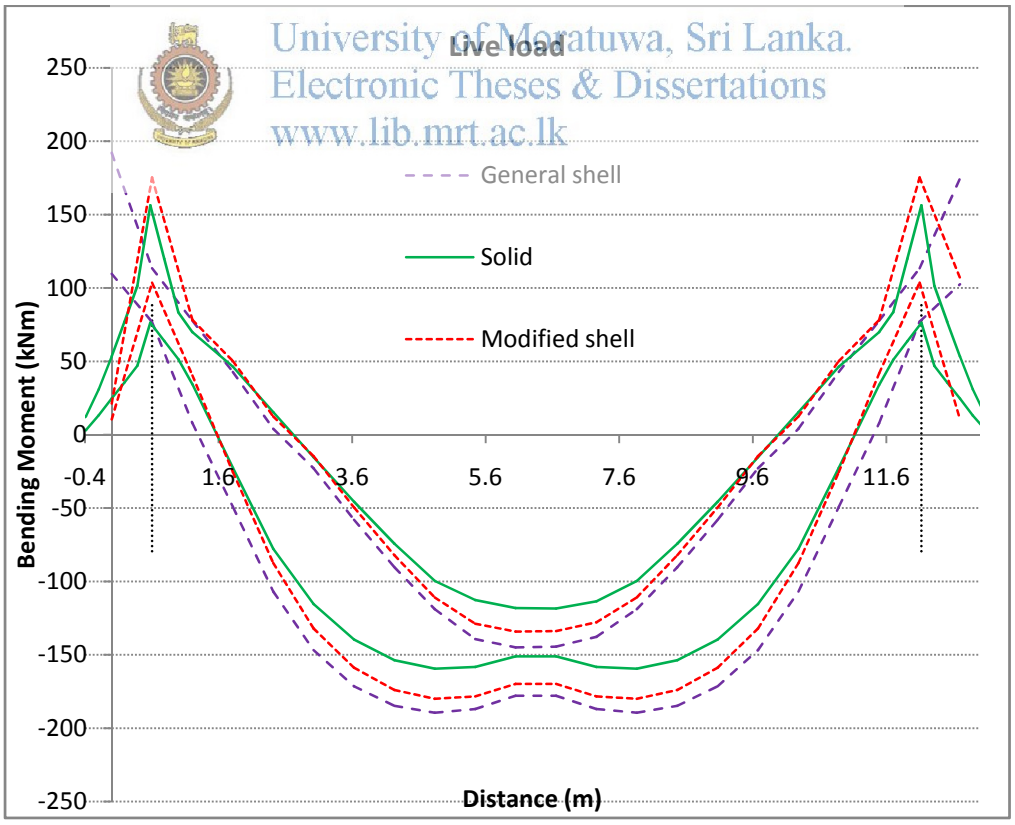


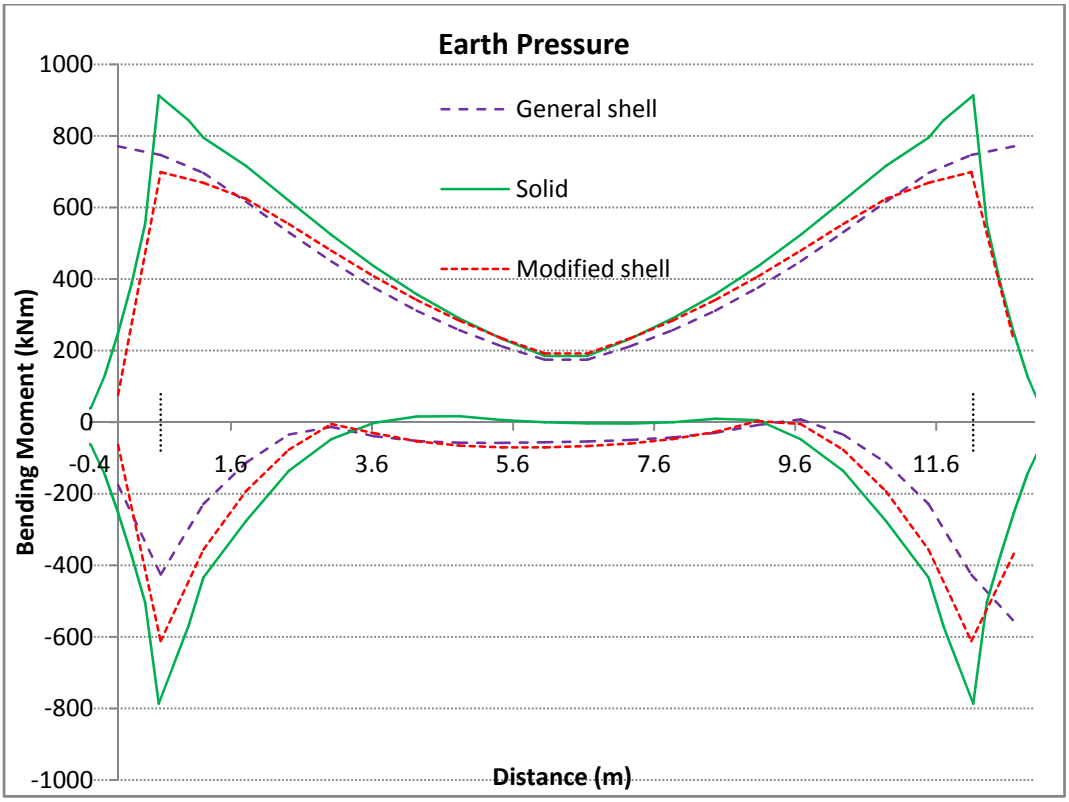
H.1.5: BMD of Bottom slab-Story cell (model no: 1)

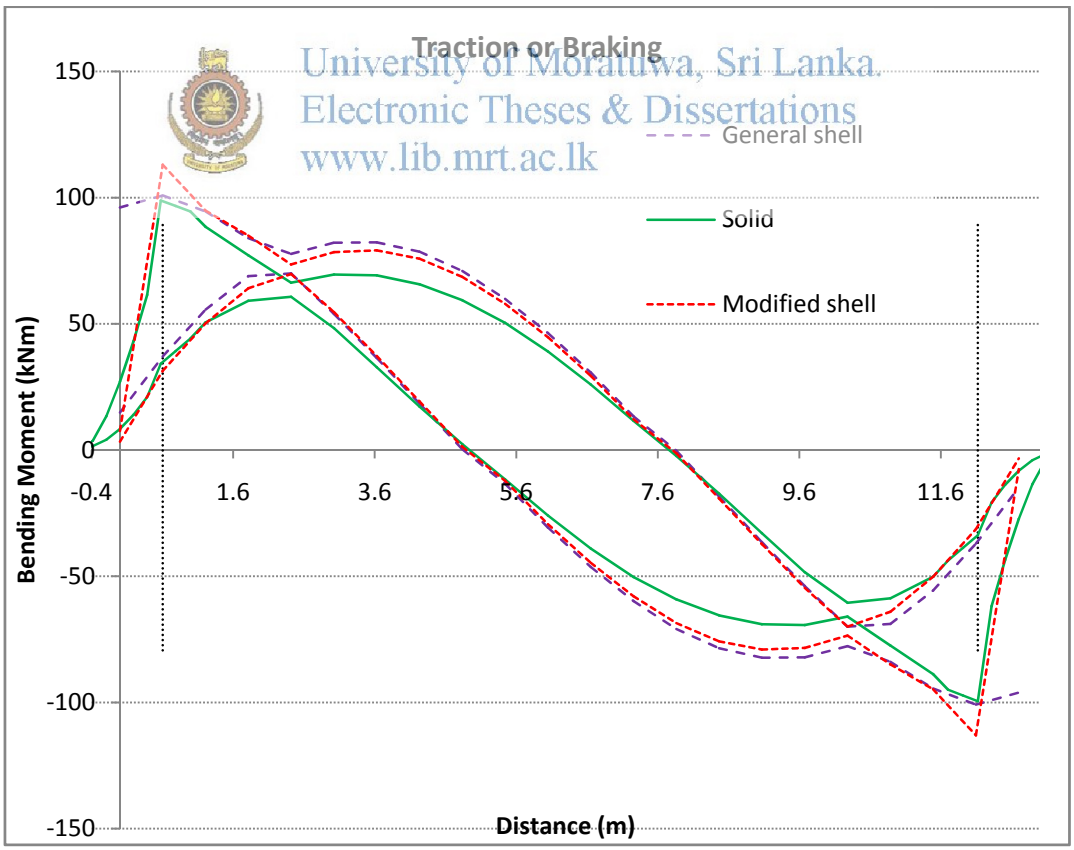




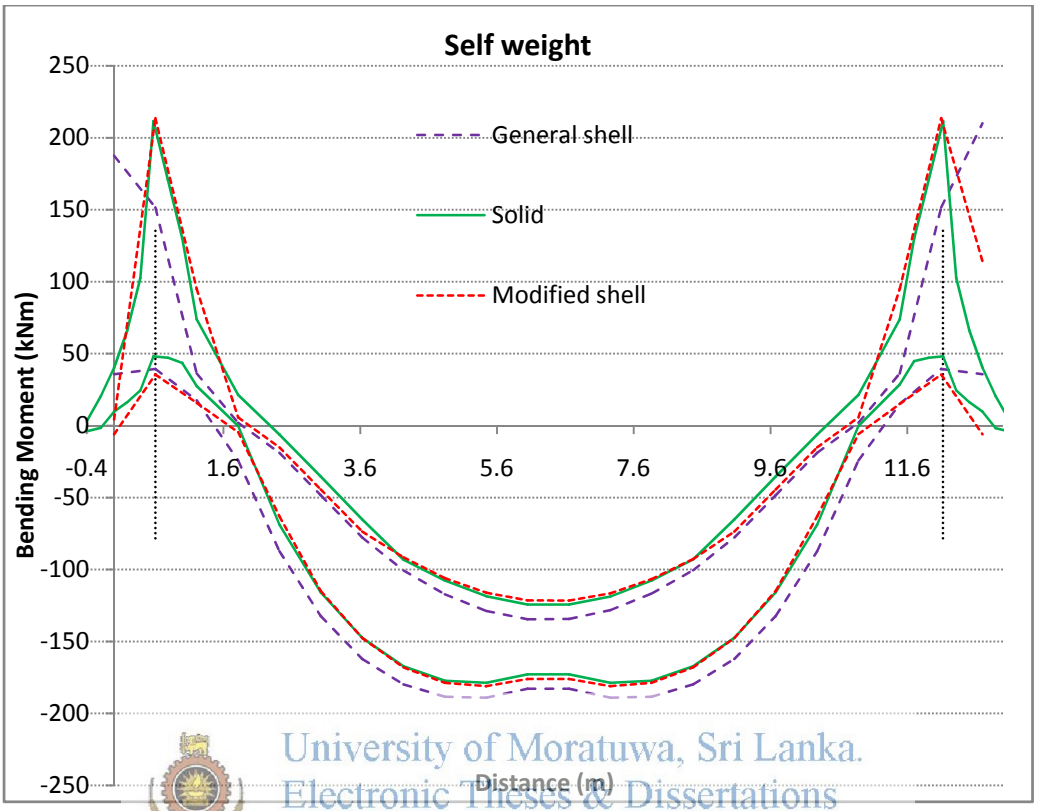


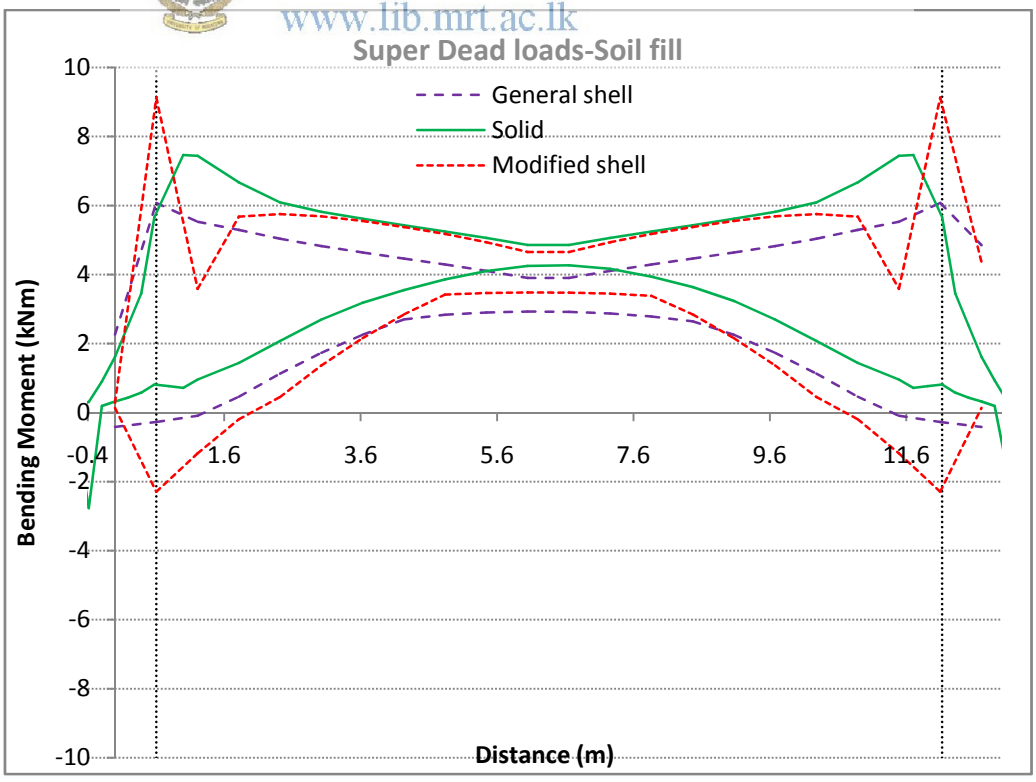


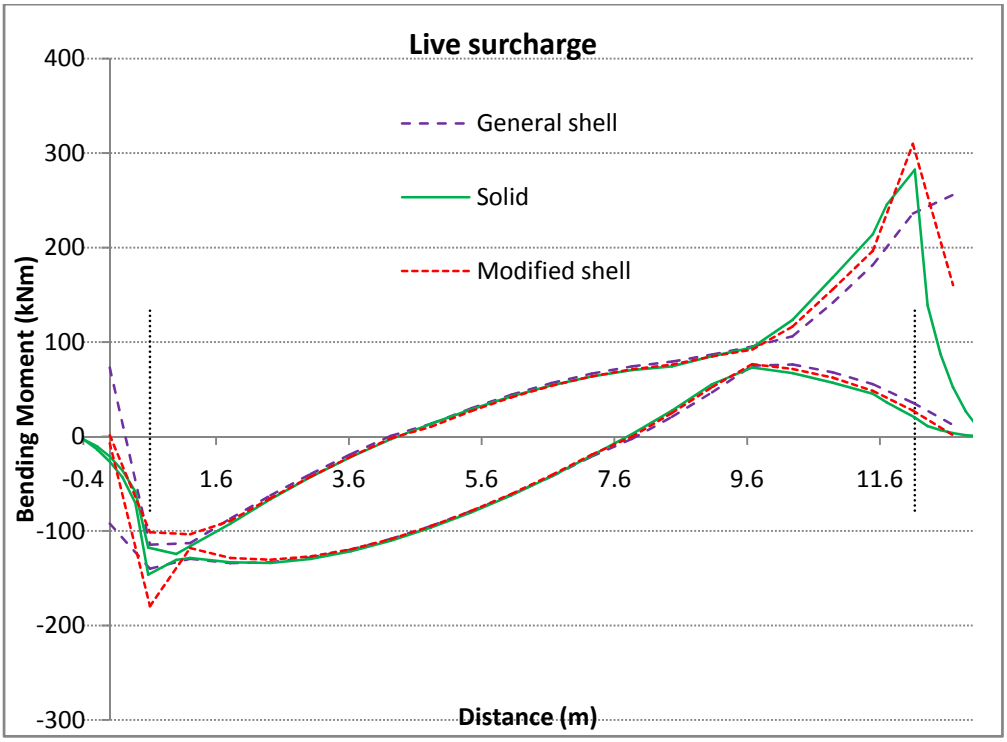


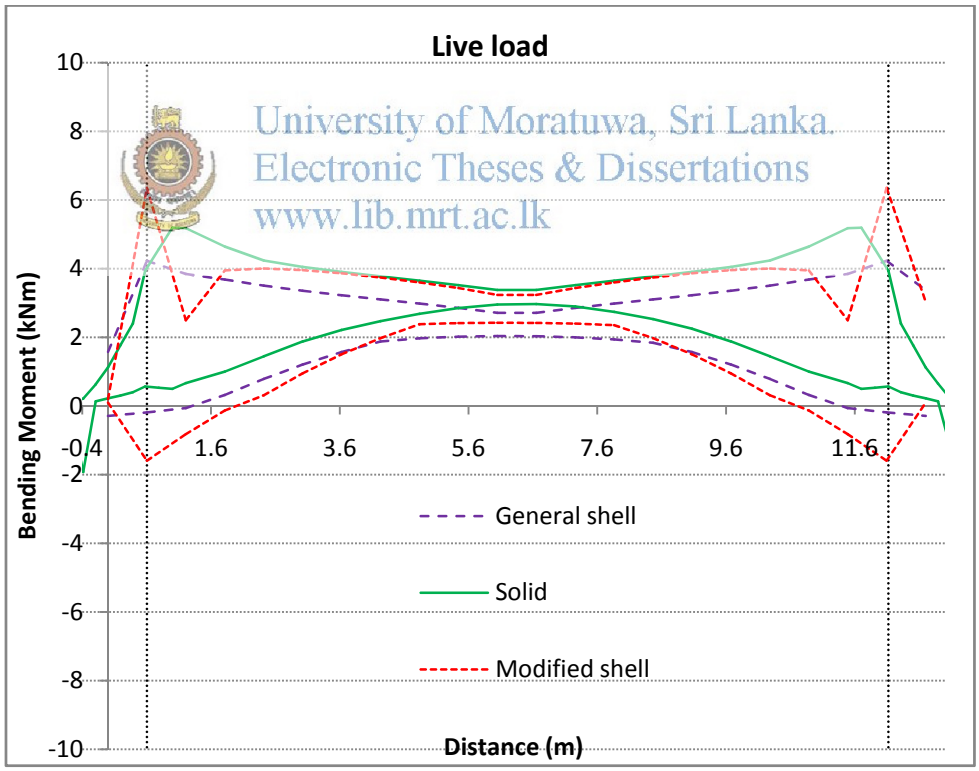


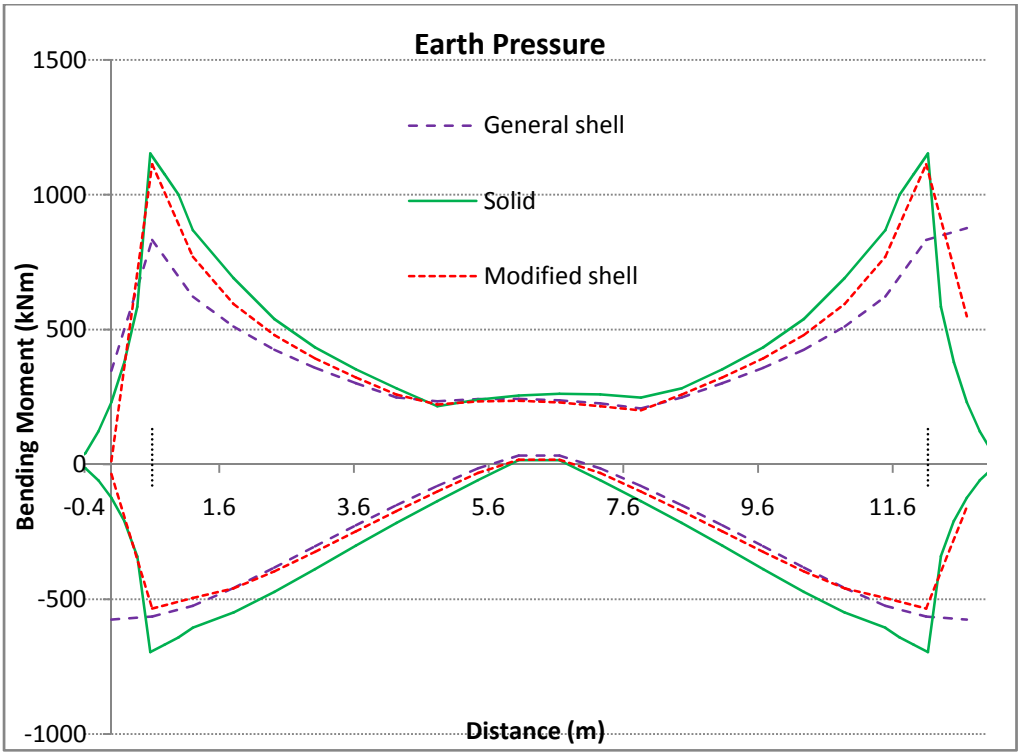
H.1.6: BMD of Middle slab-Story cell (model no: 1)

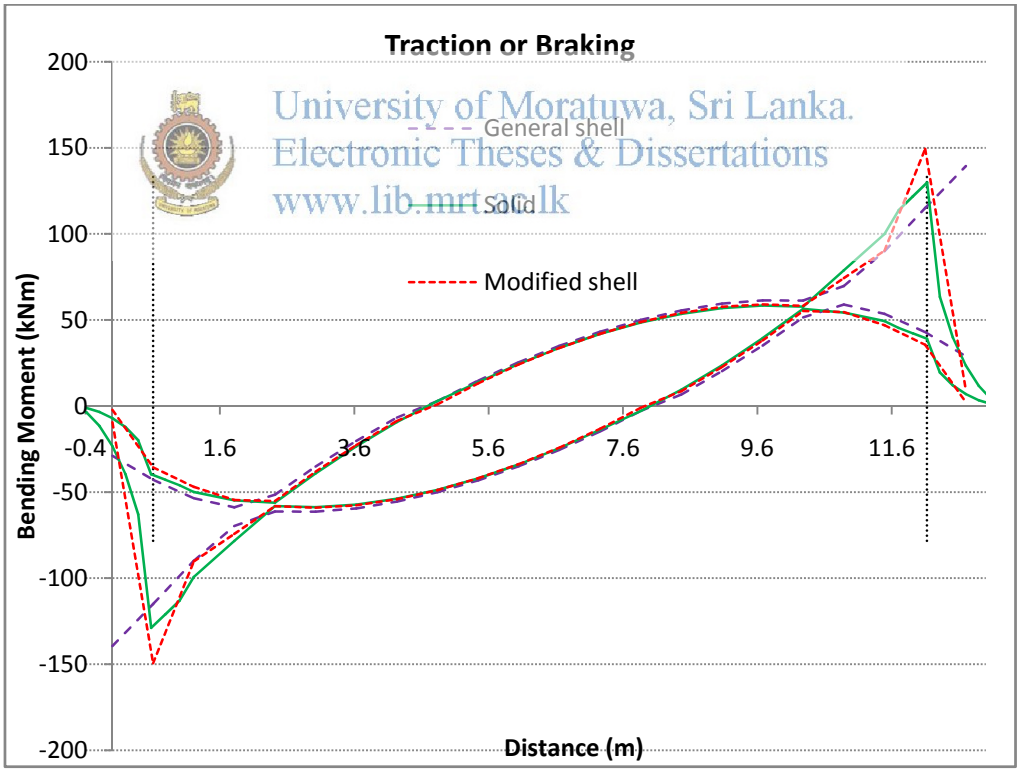




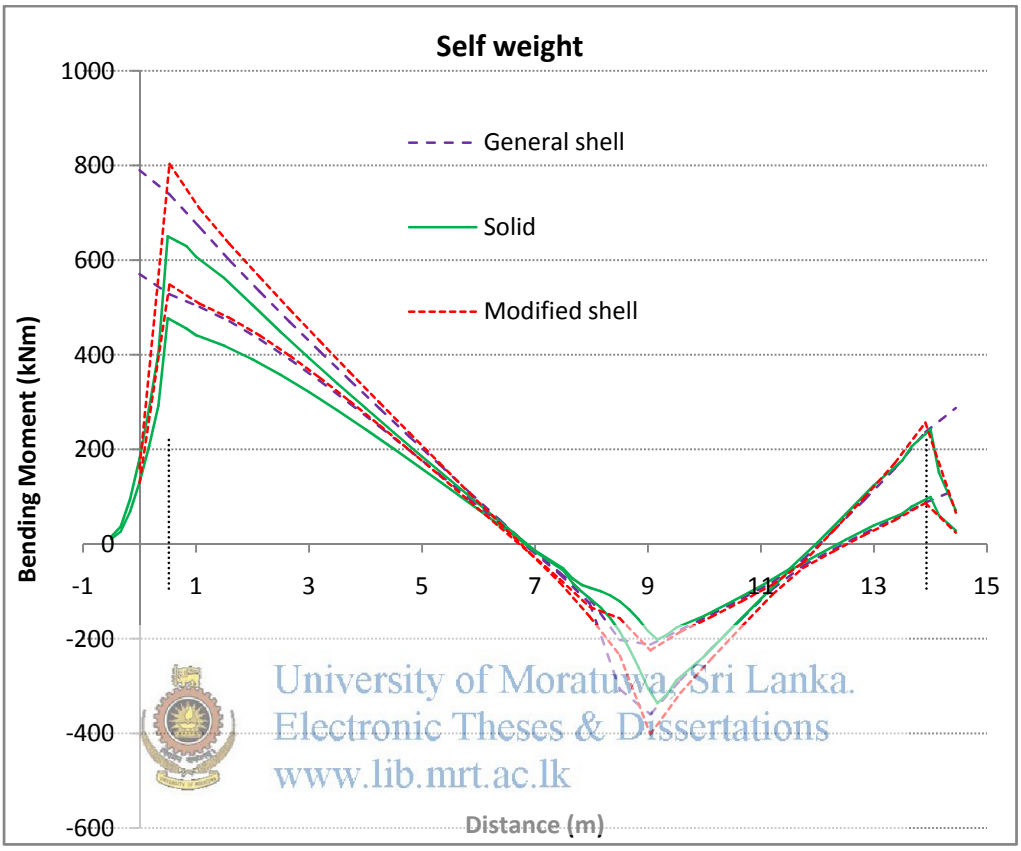


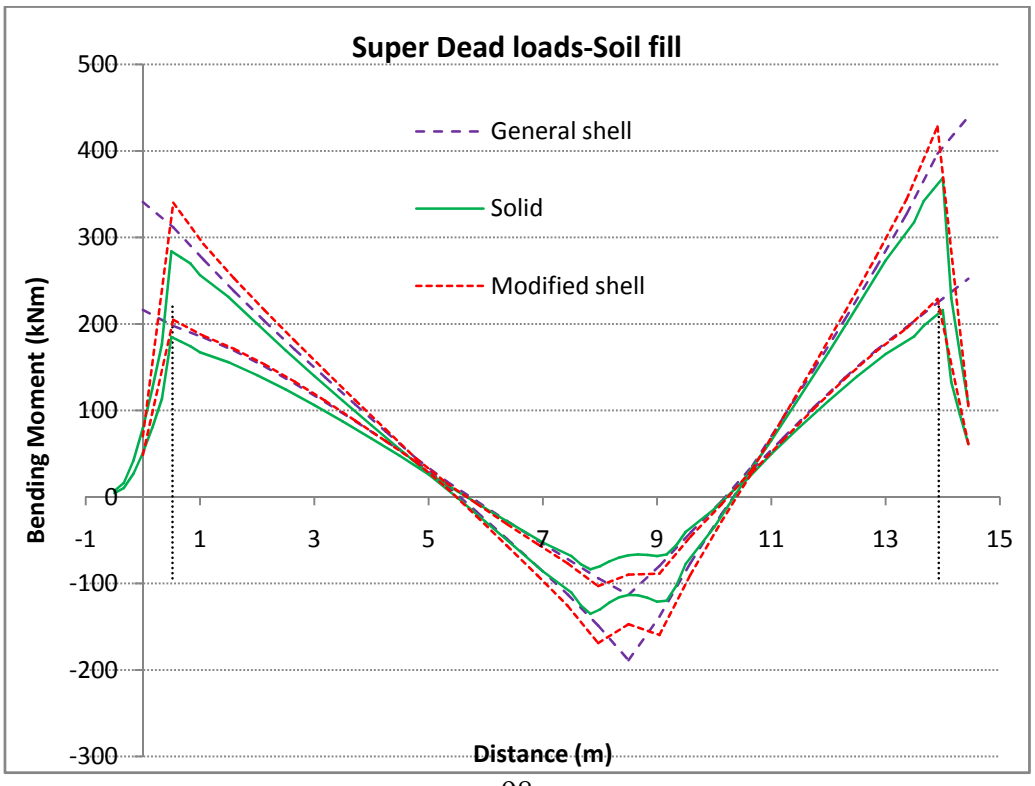


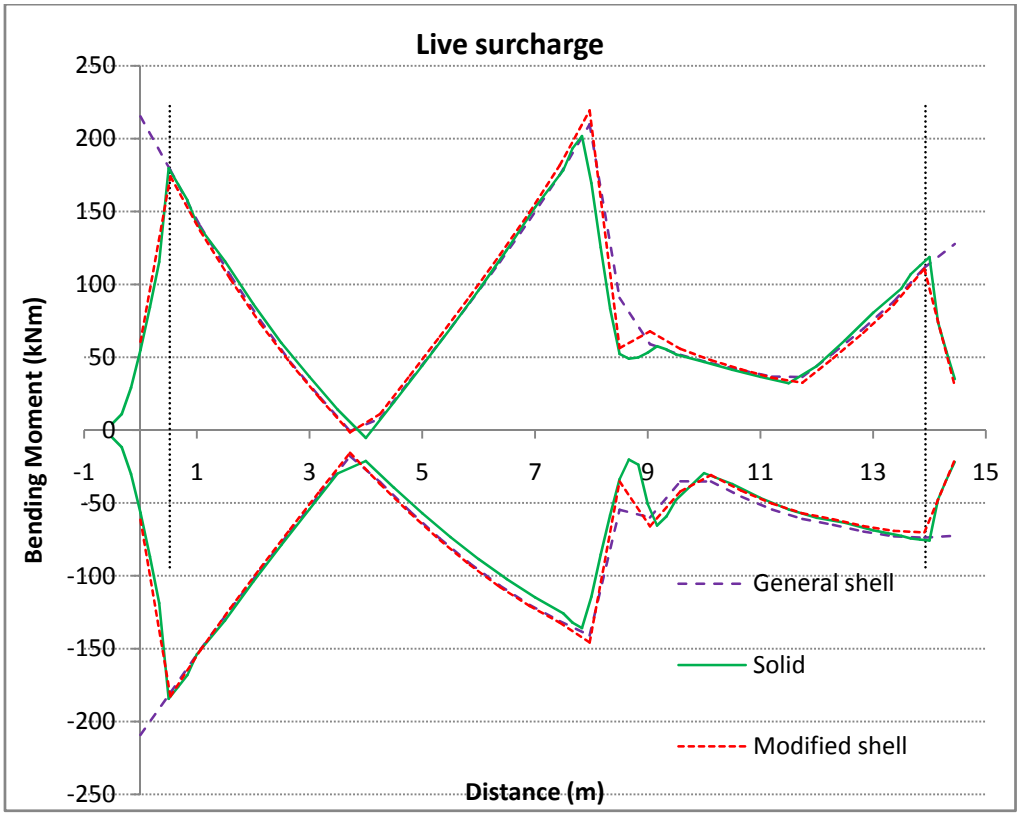


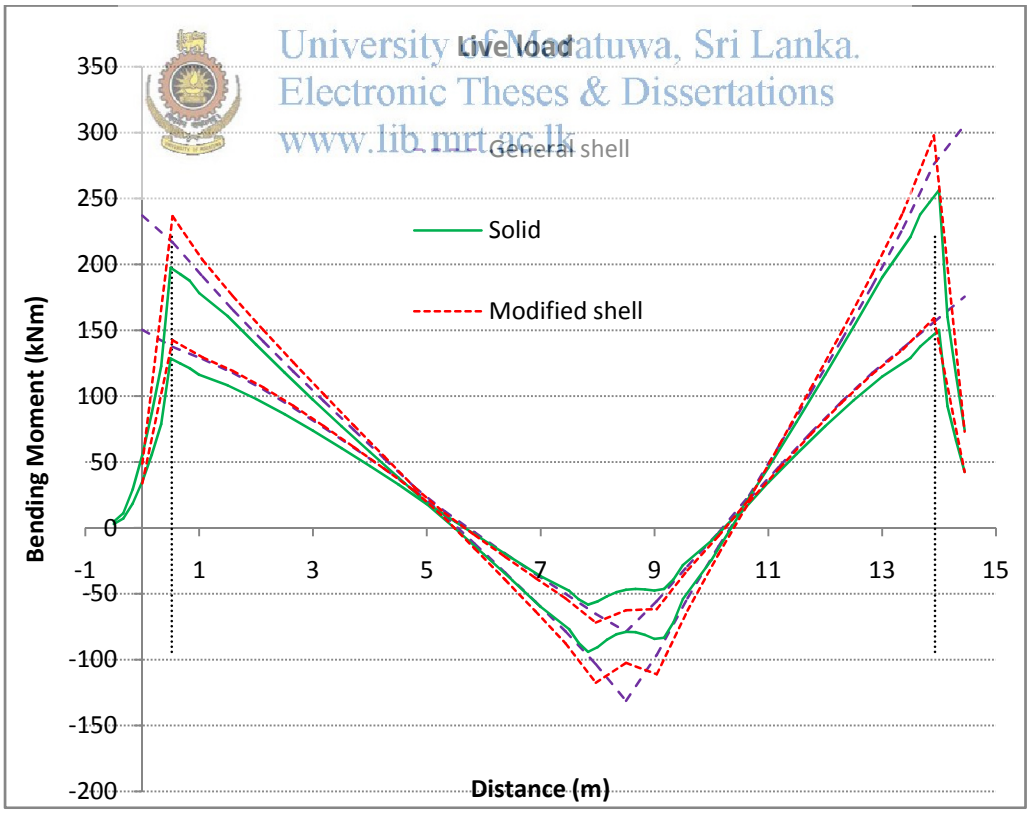


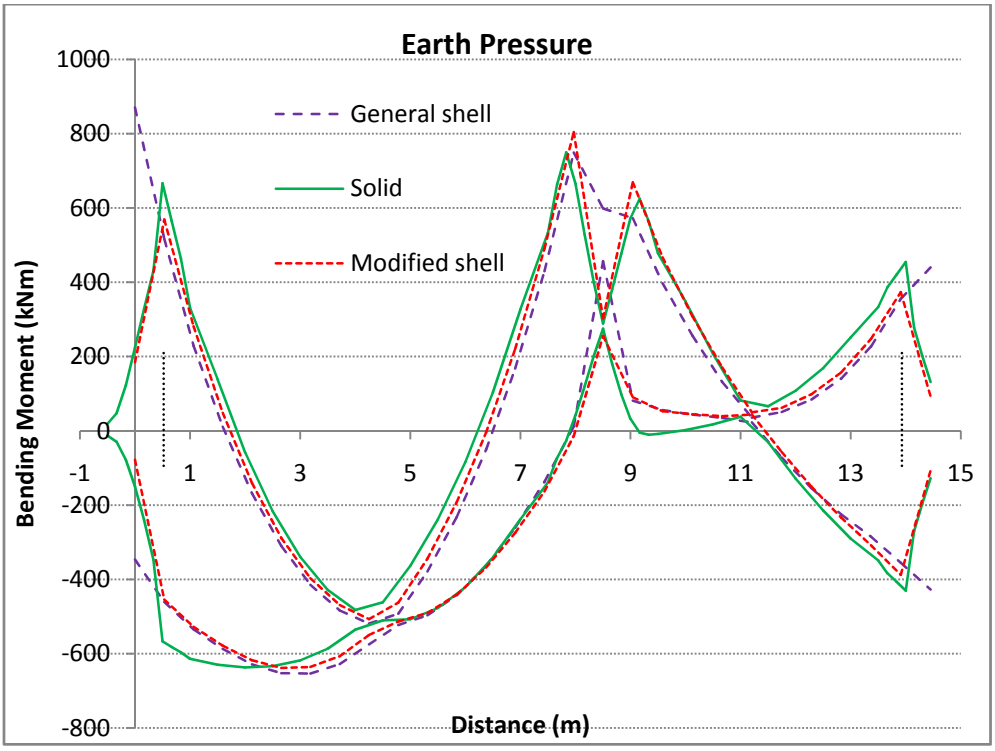
H.1.7: BMD of Walls-Story cell (model no: 1)

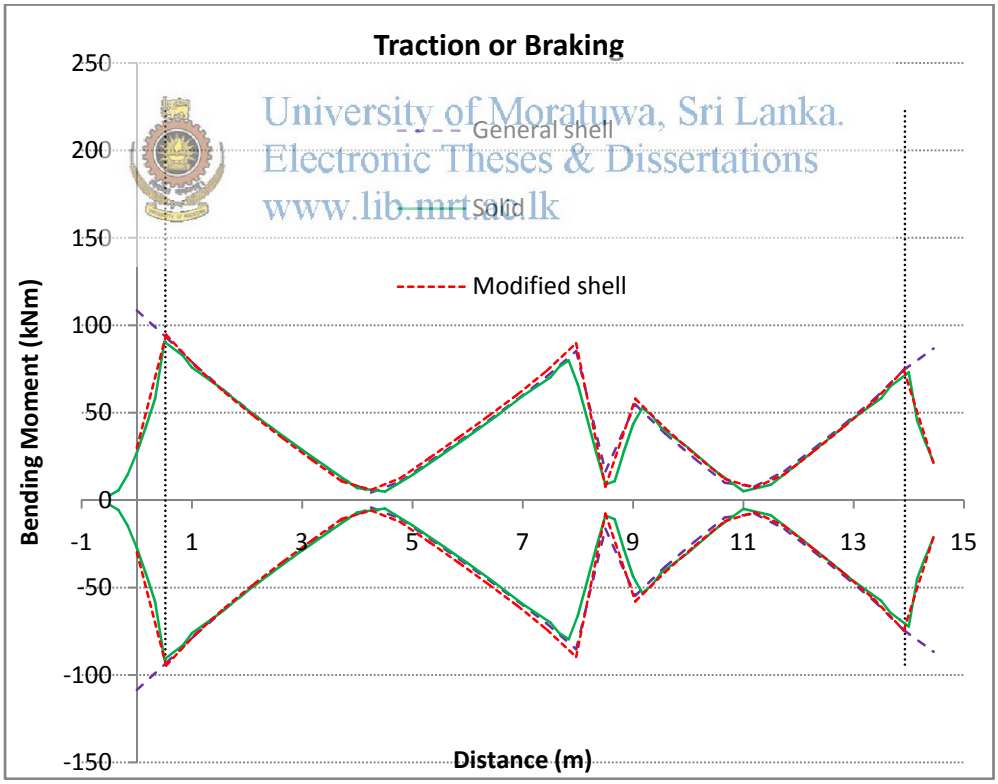




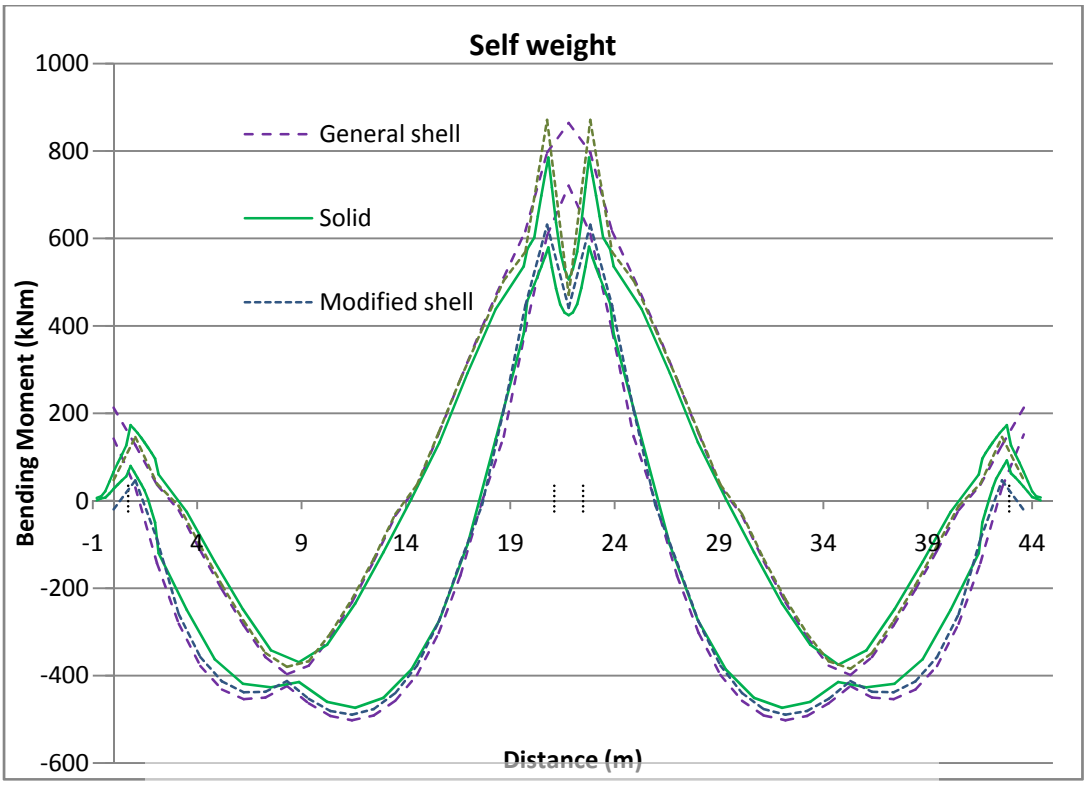


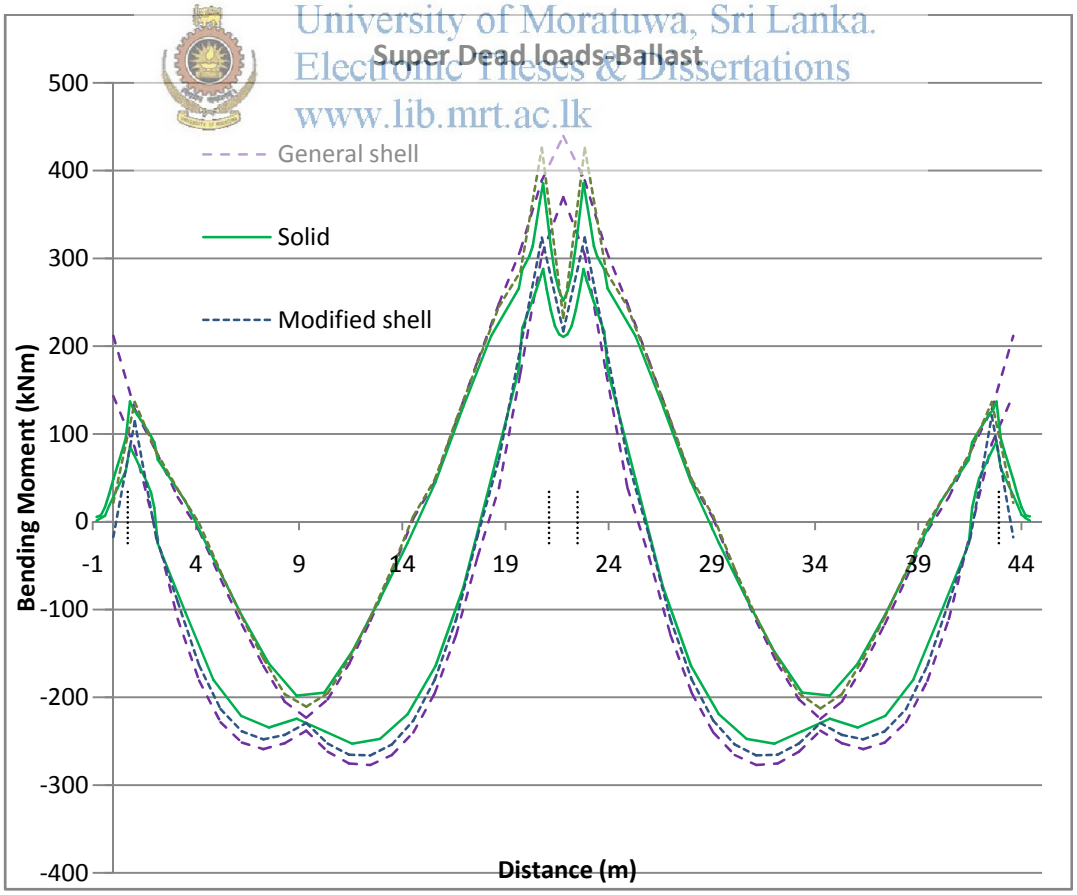


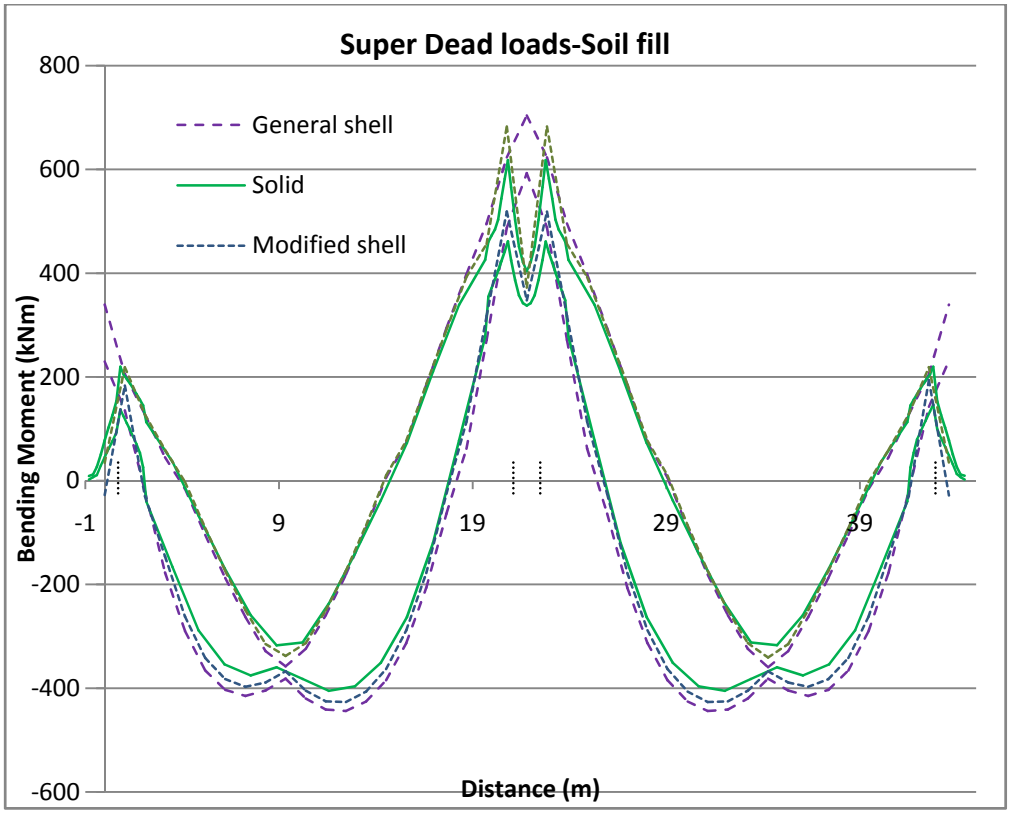


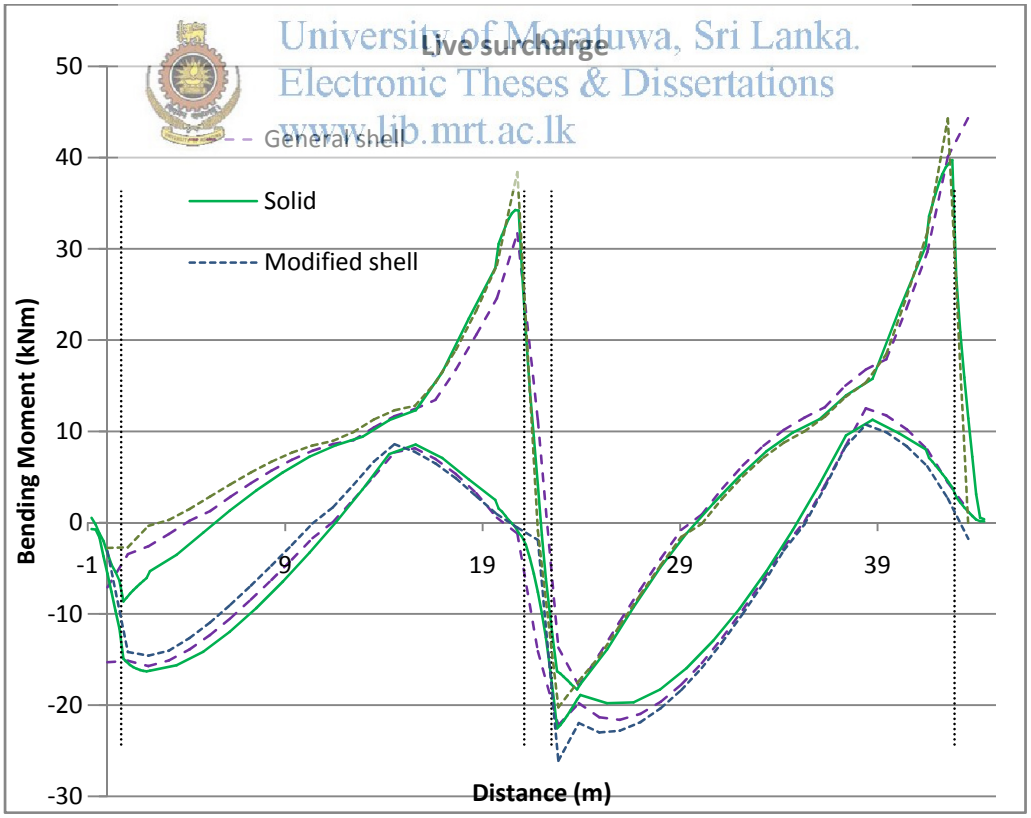


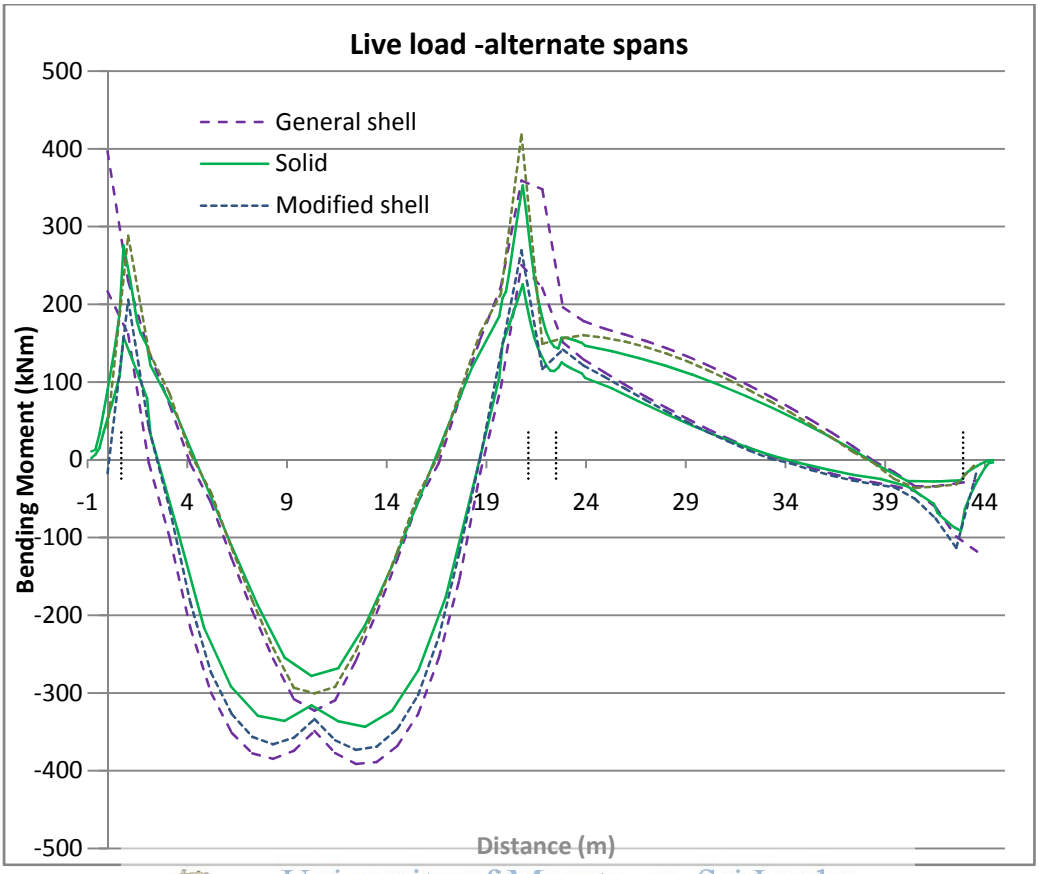
H.1.8: BMD of Top slab-Double cell (model no: 5)

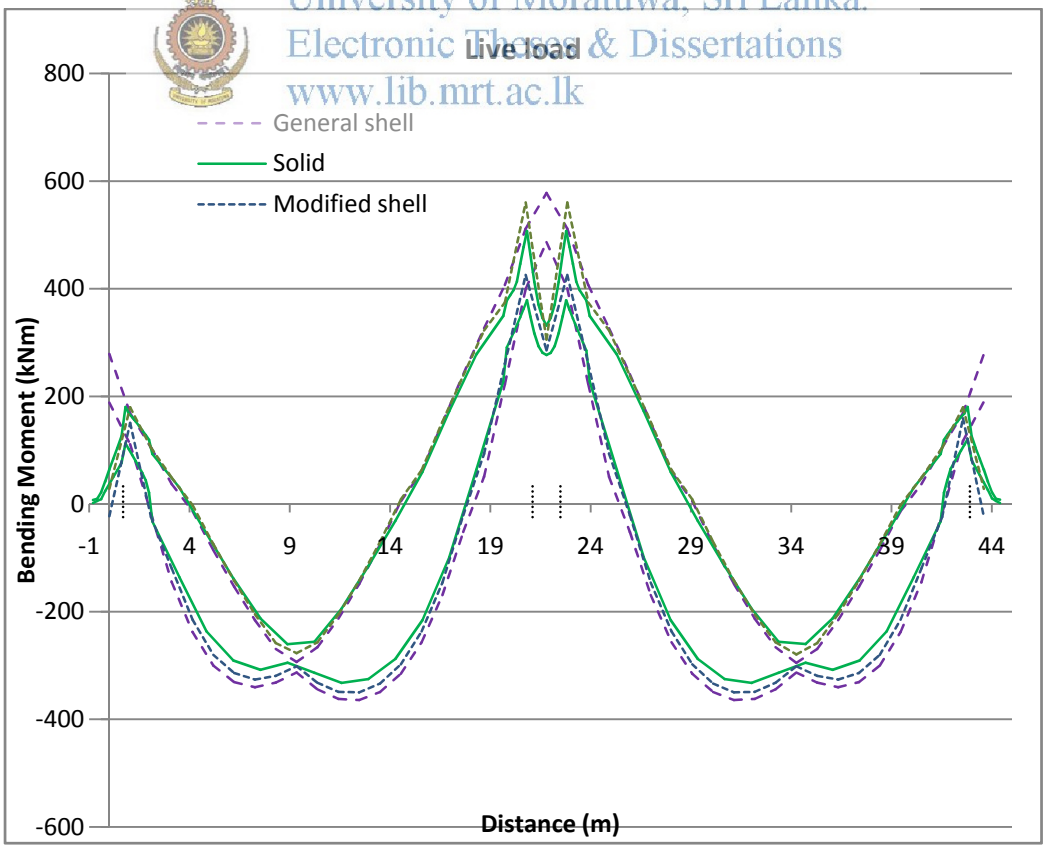


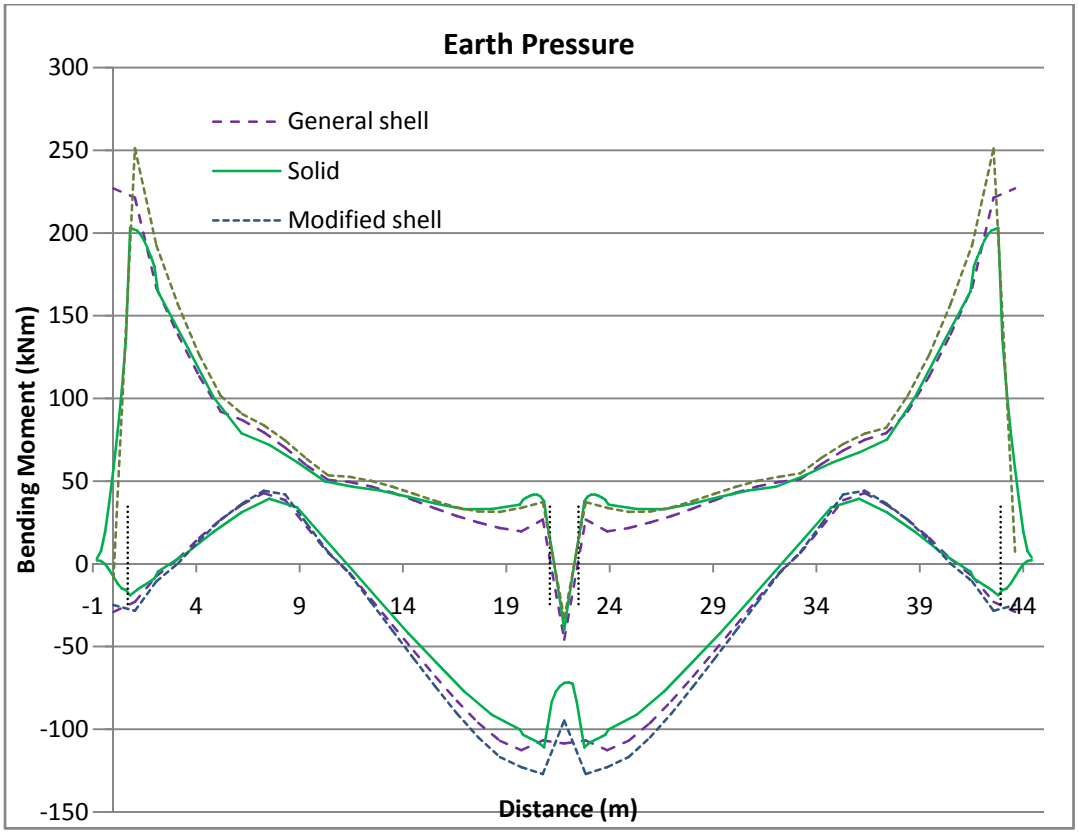


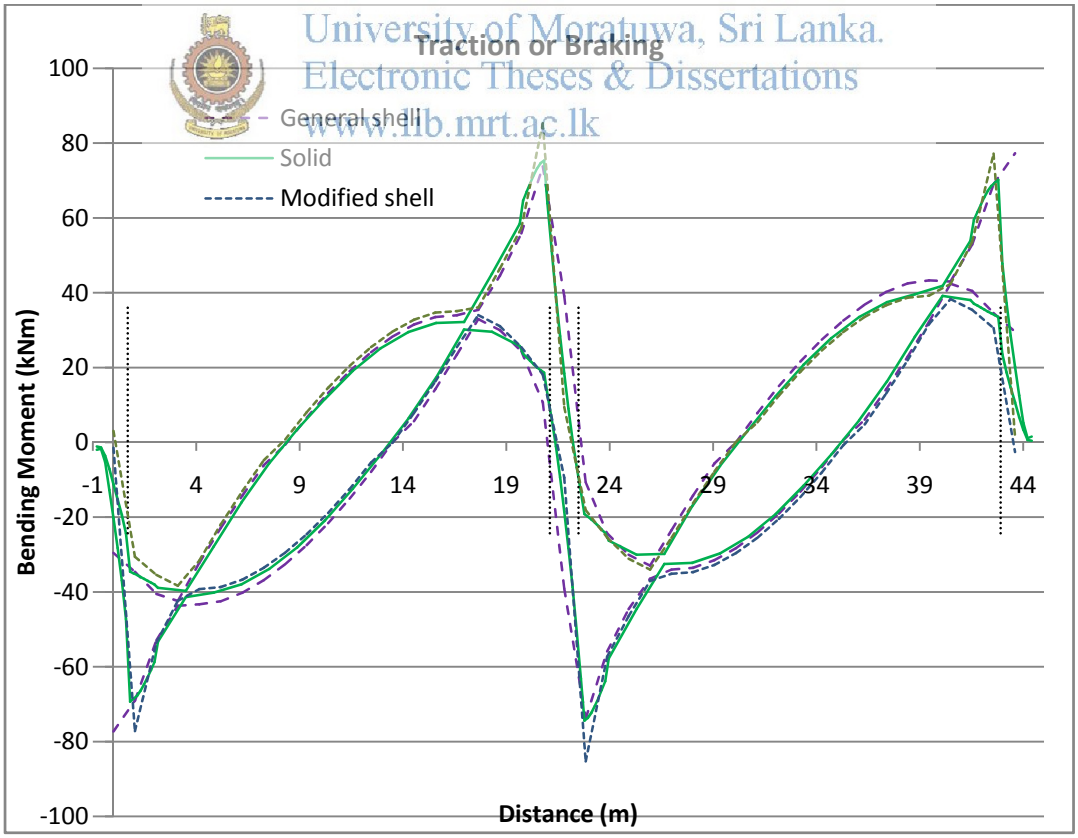




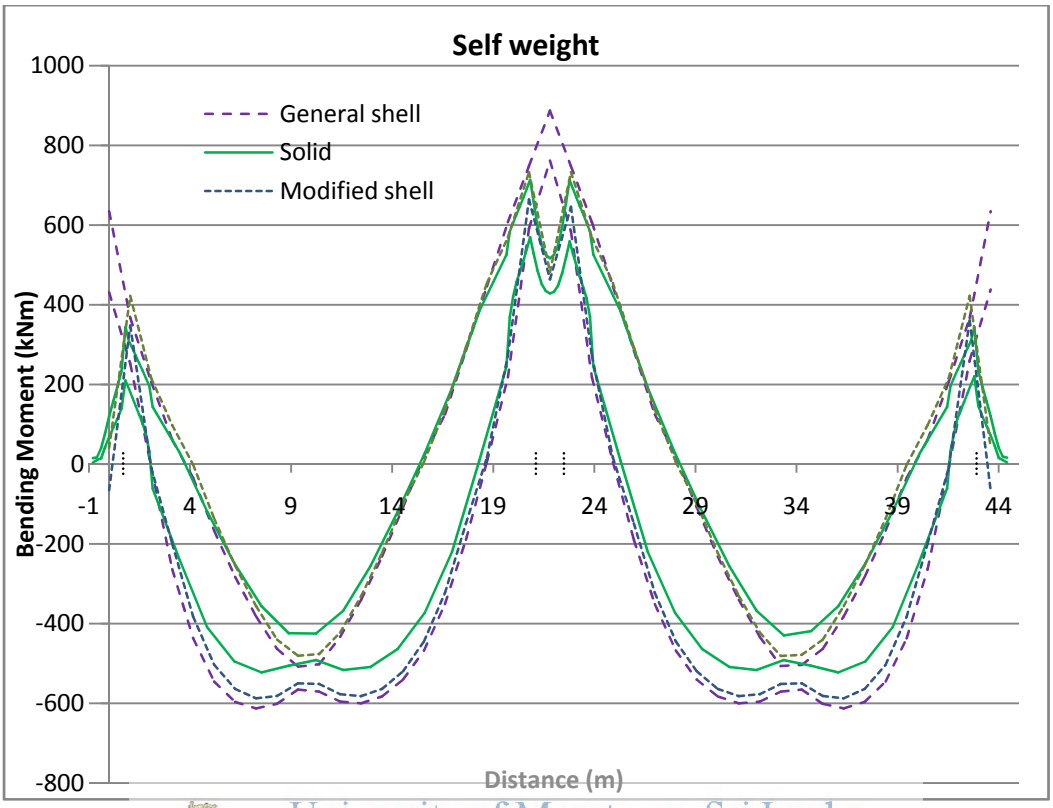


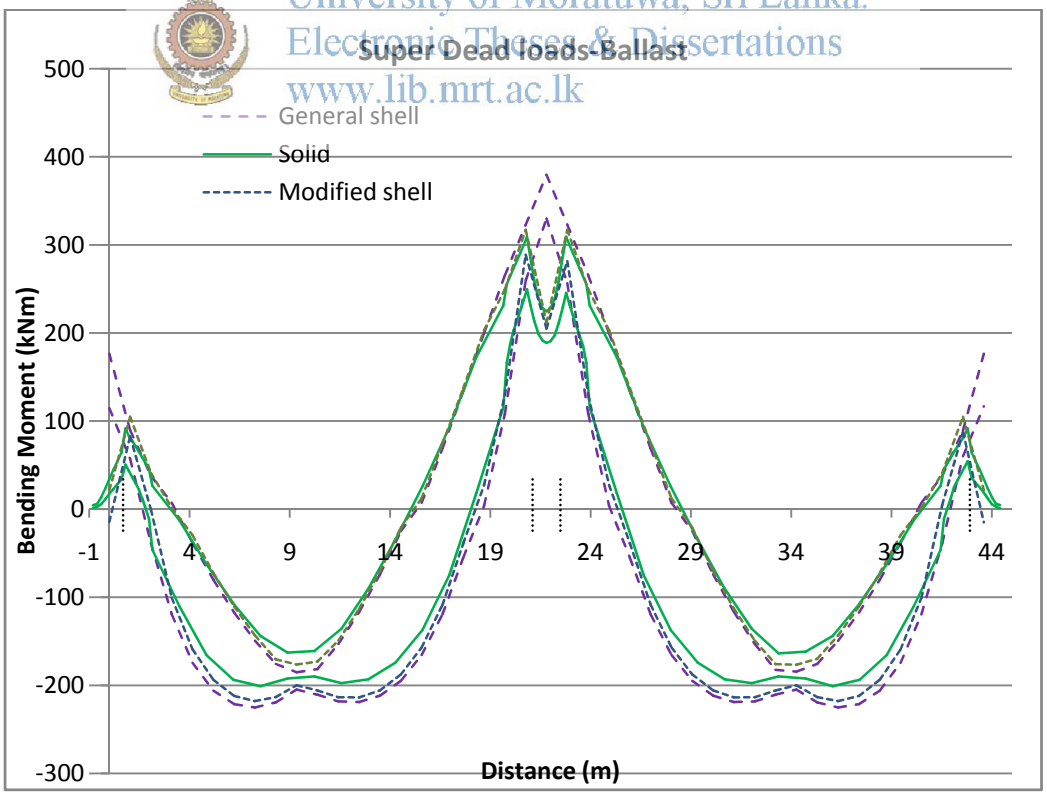


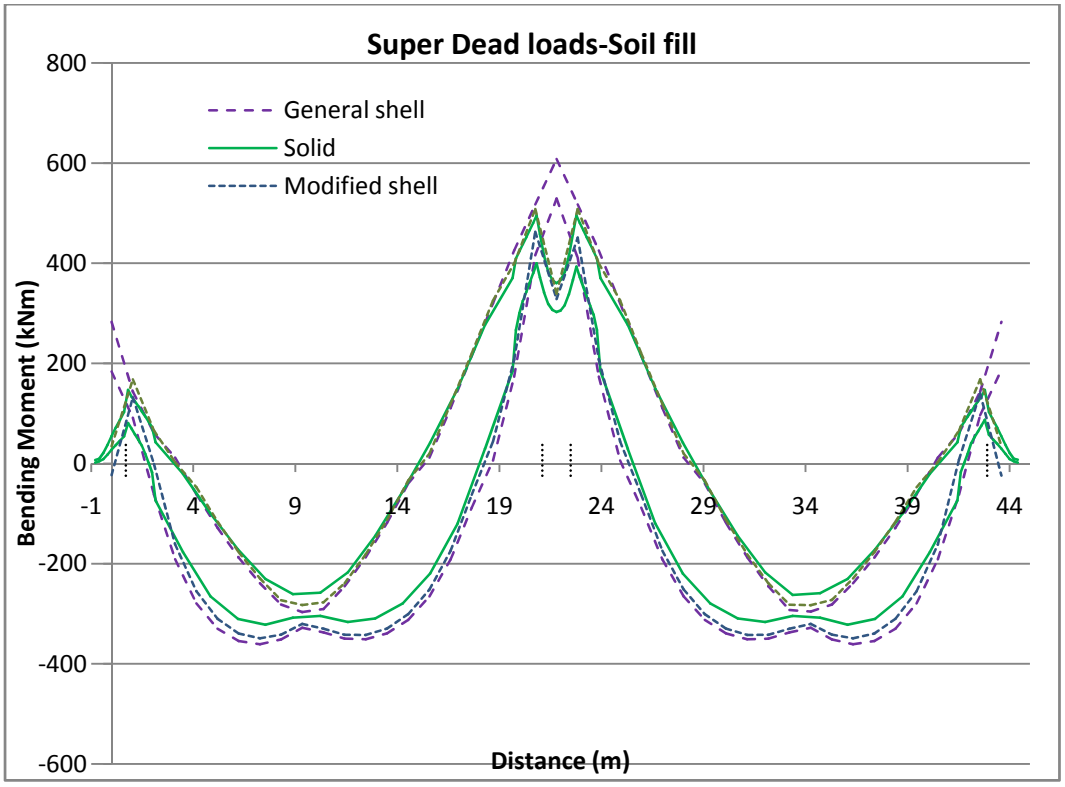


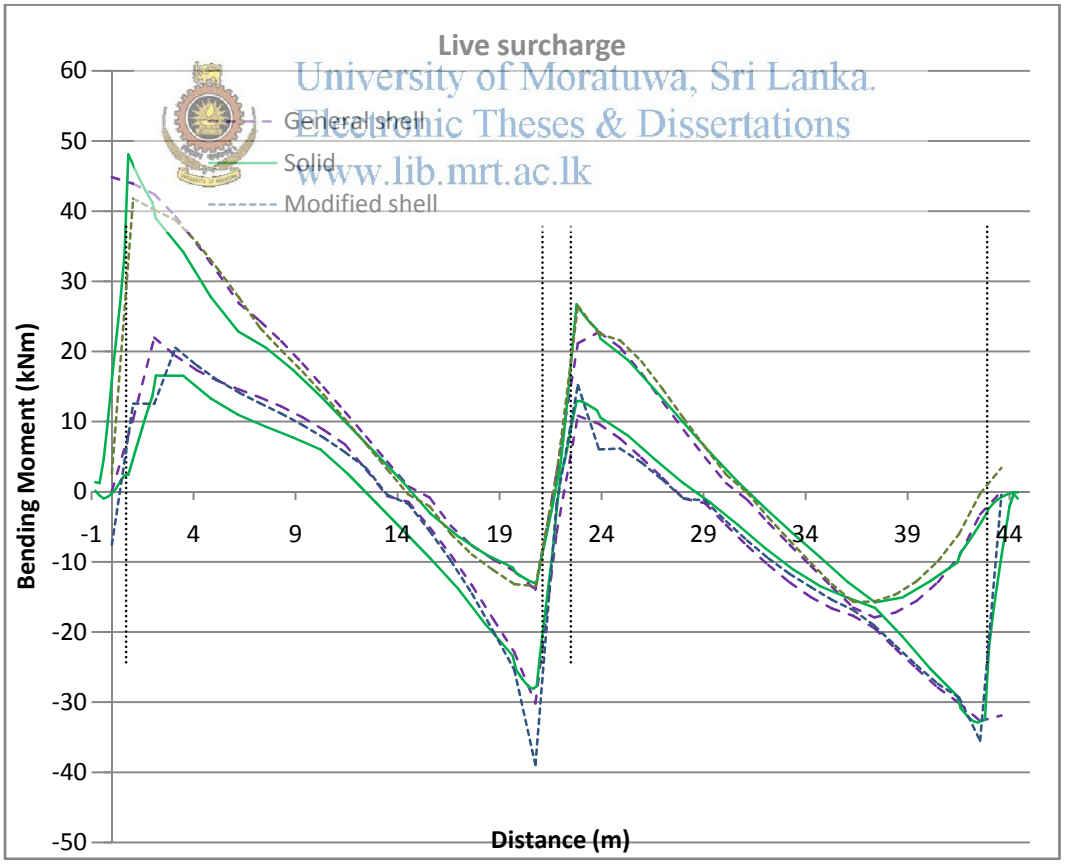


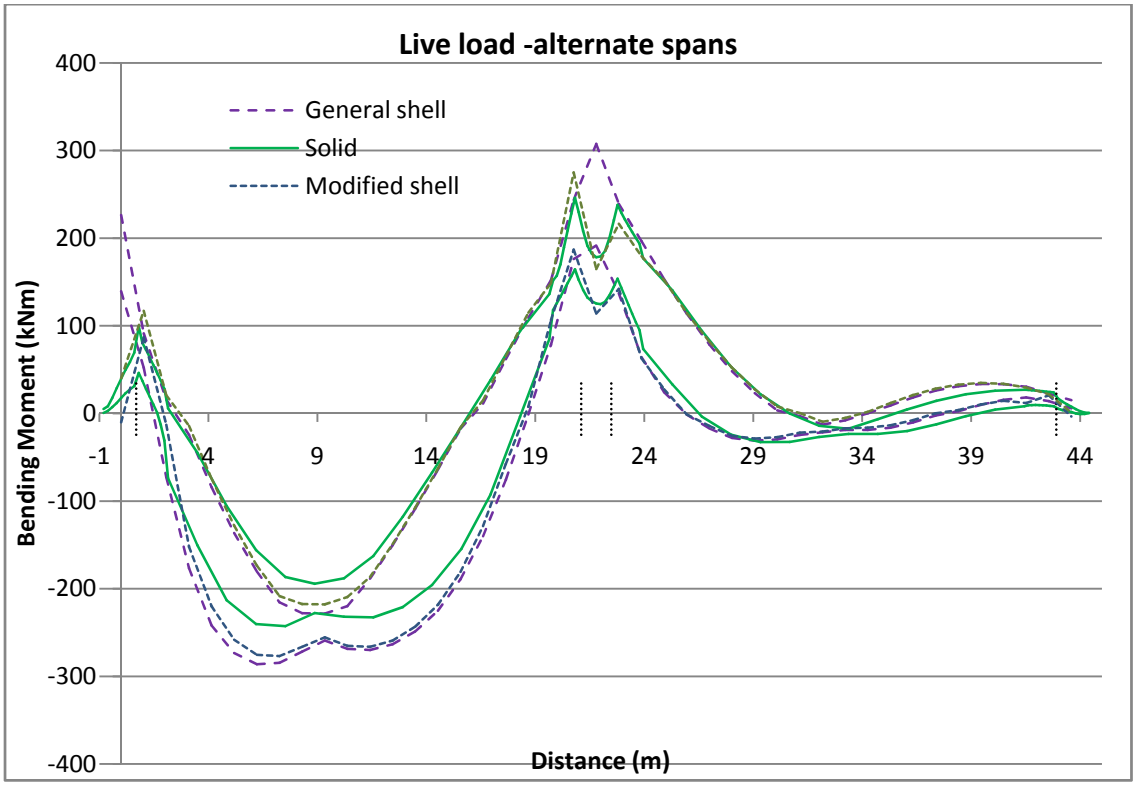
H.1.9: BMD of Bottom slab-Double cell (model no: 5)

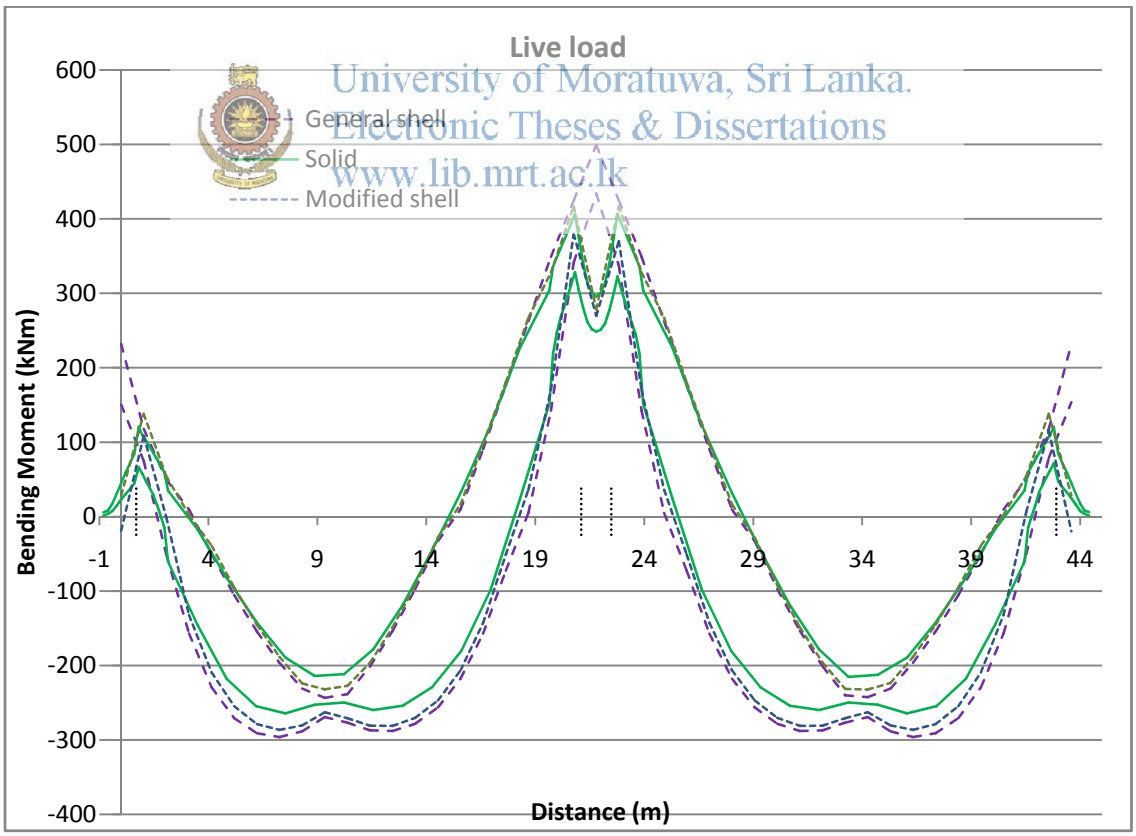


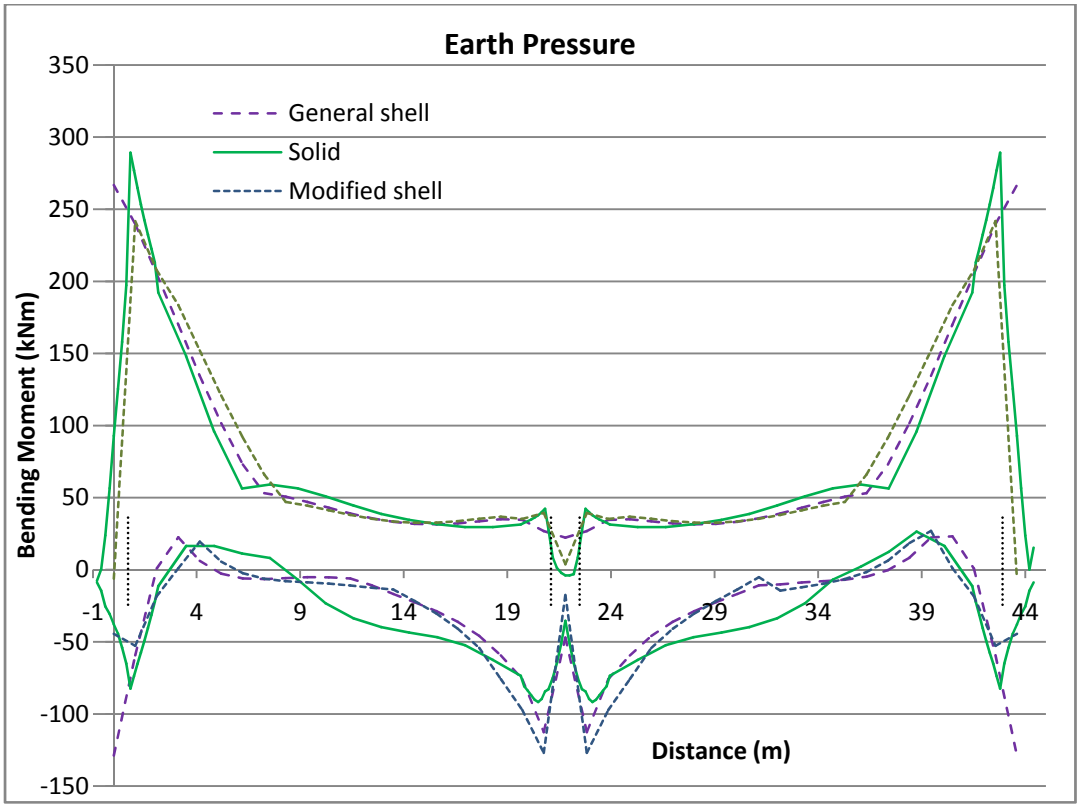


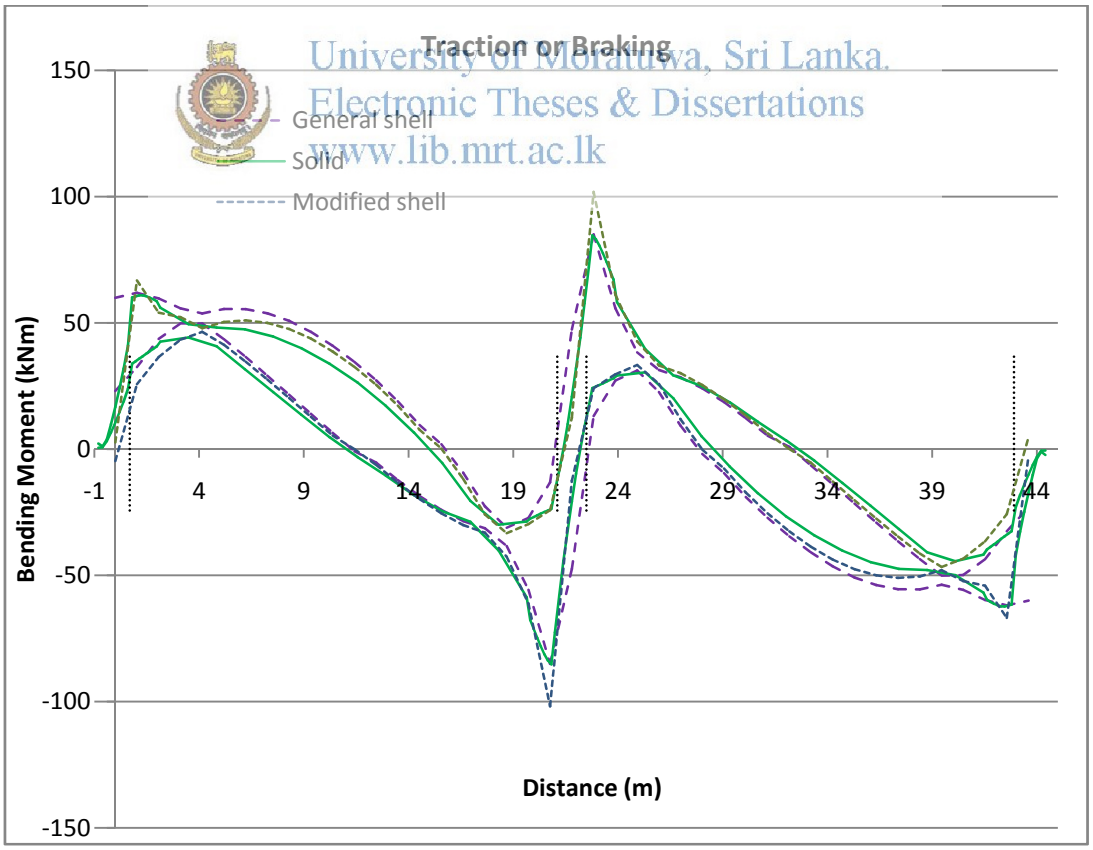




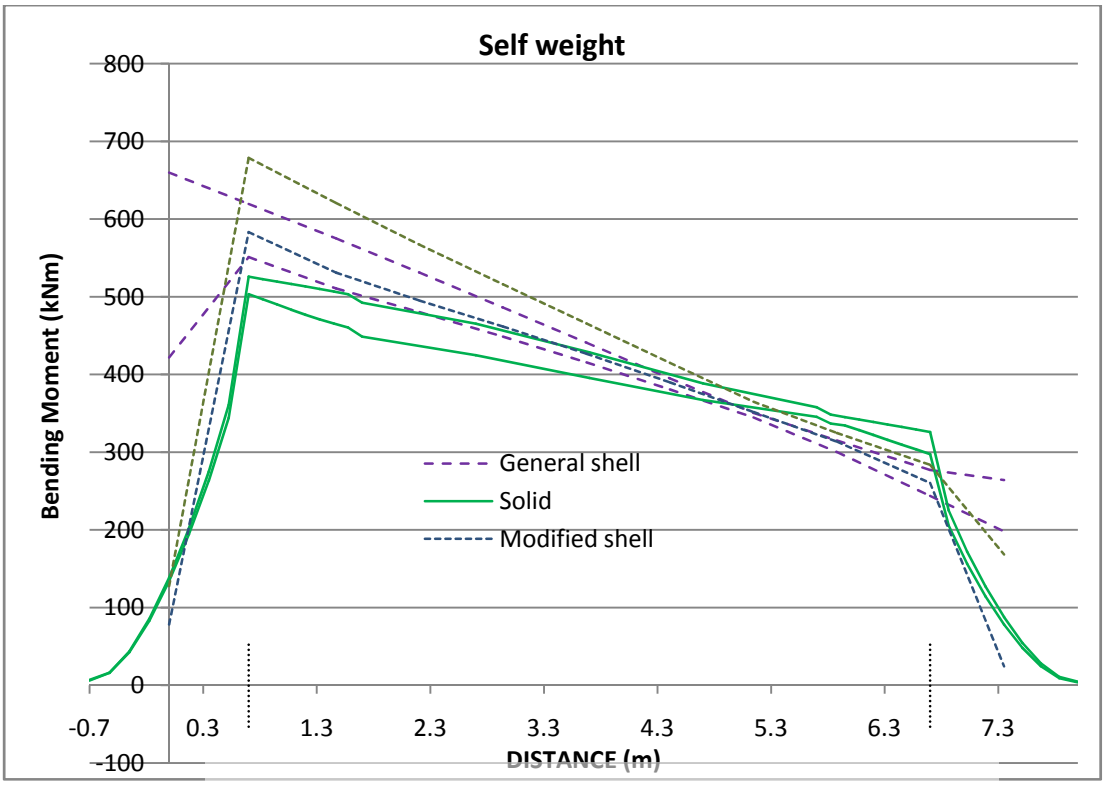


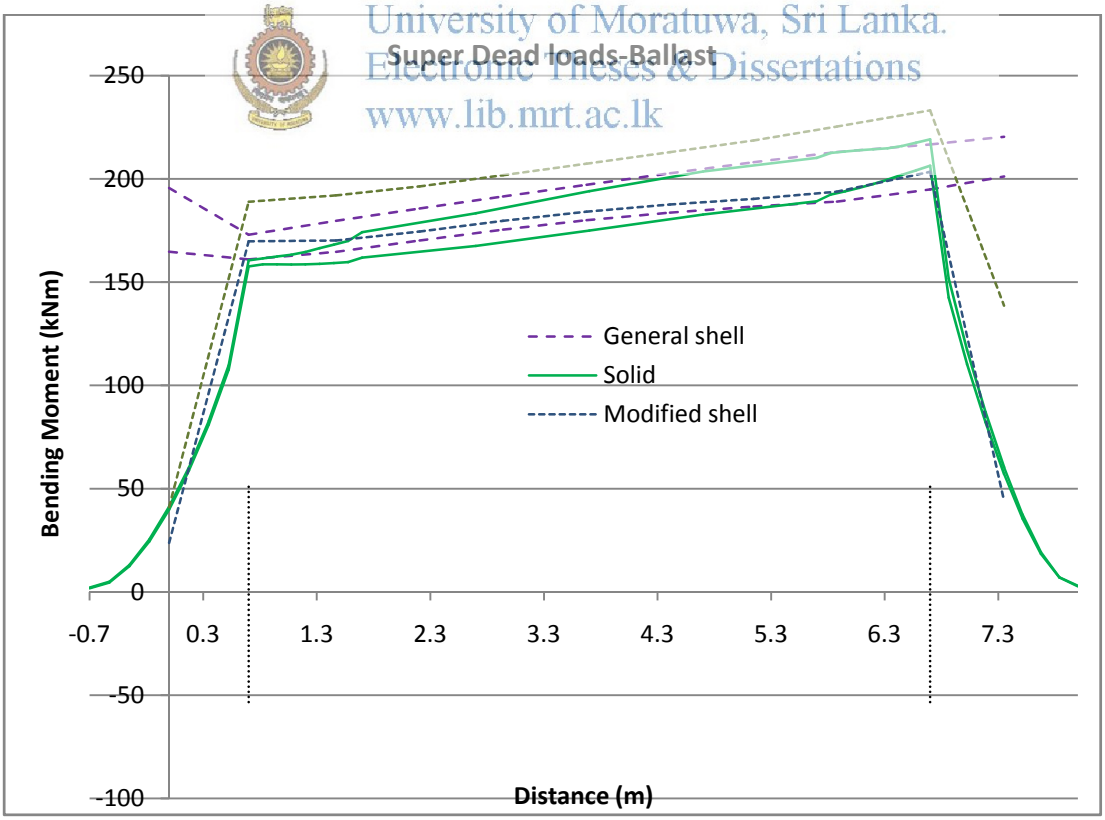


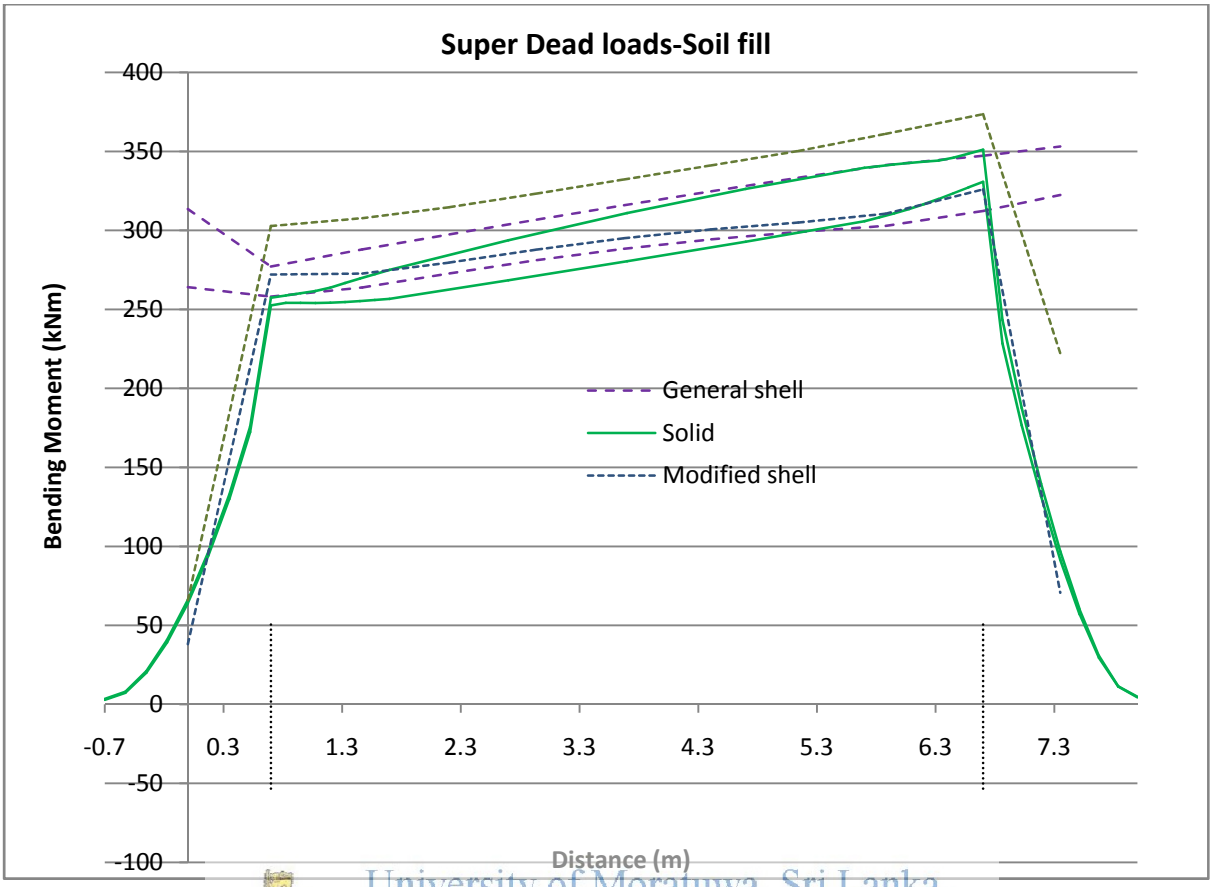


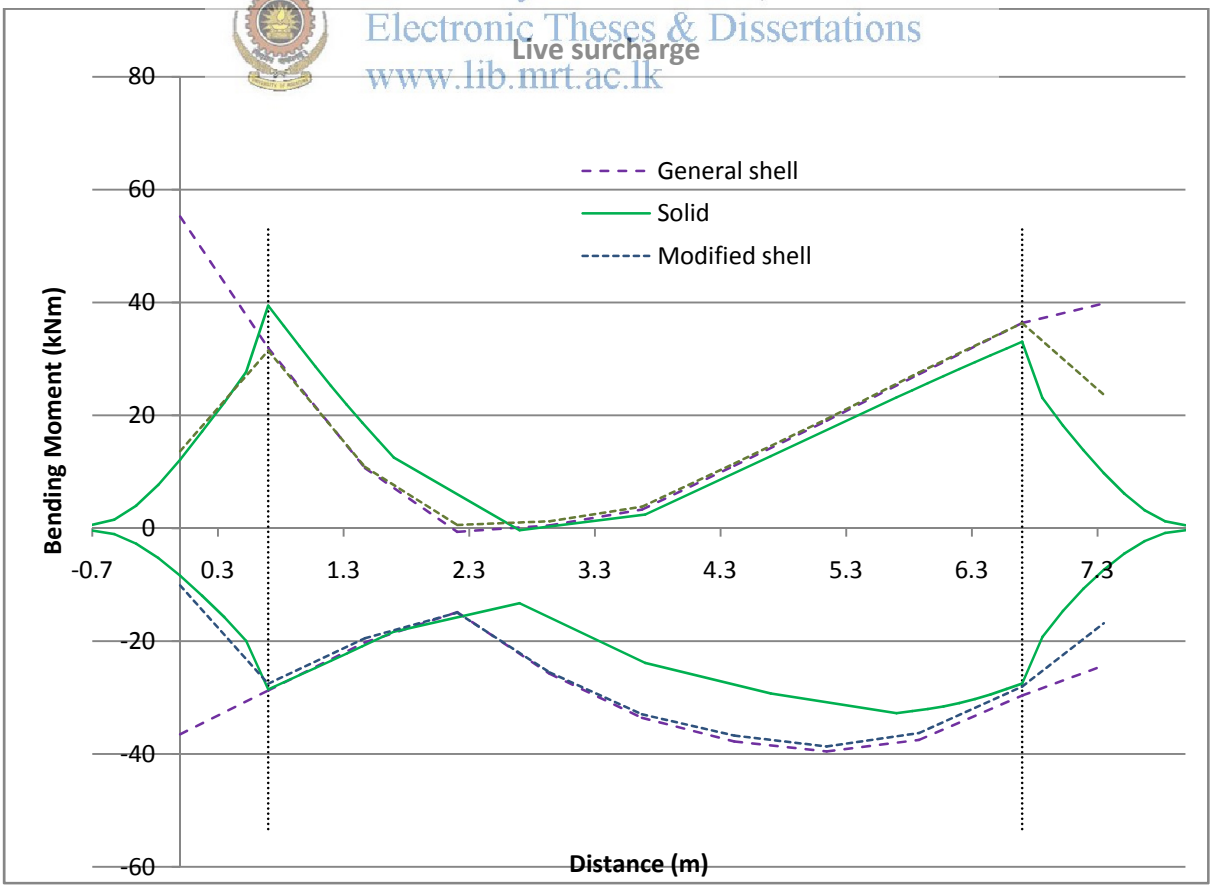


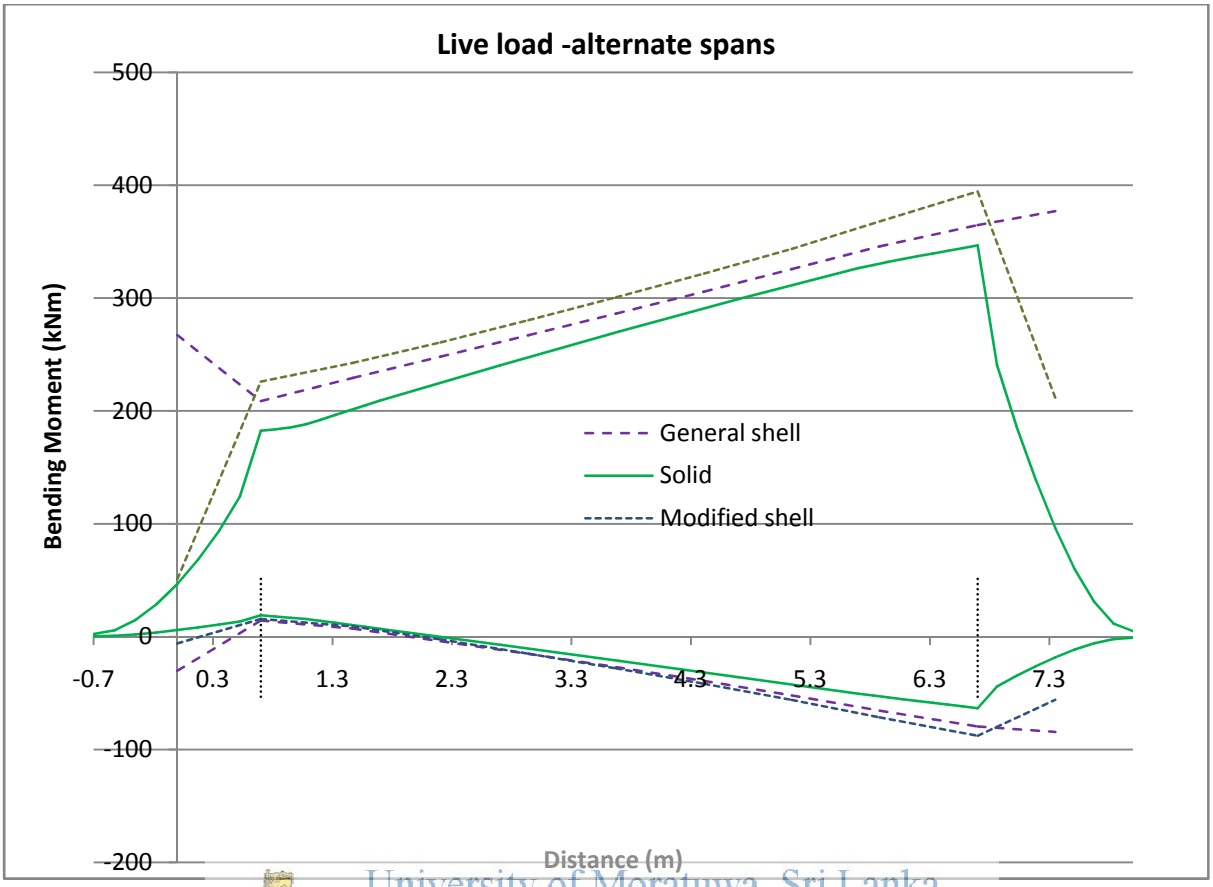
H.1.10: BME of Outside walls-Double cell (model no: 5)

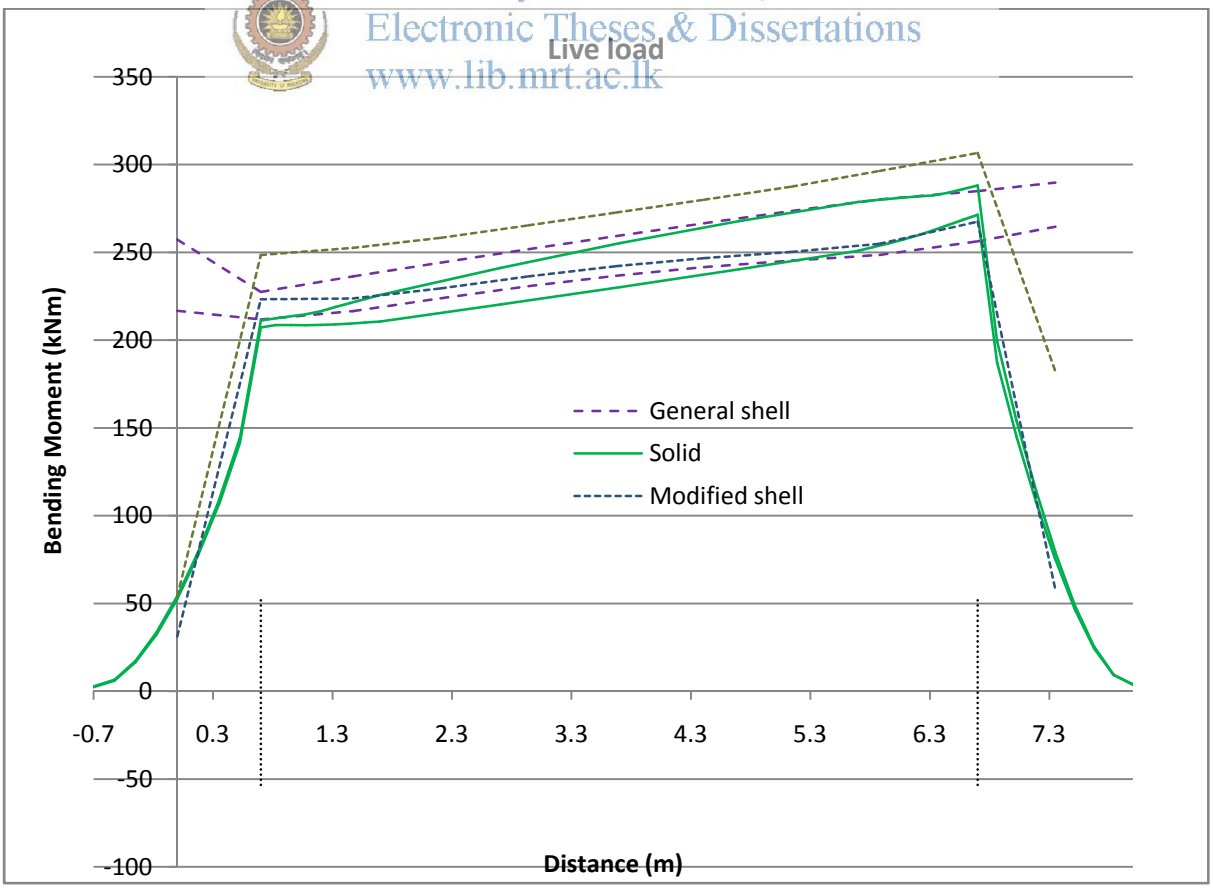


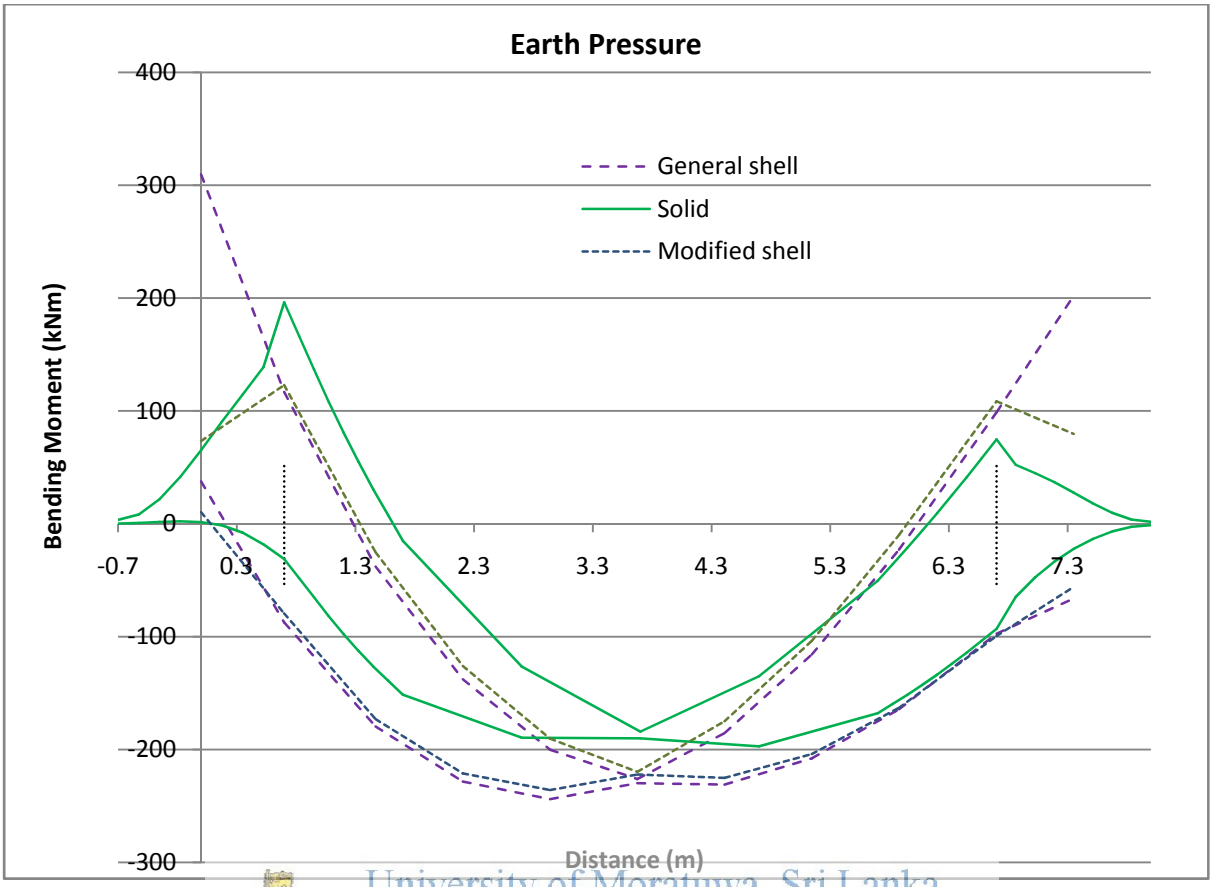


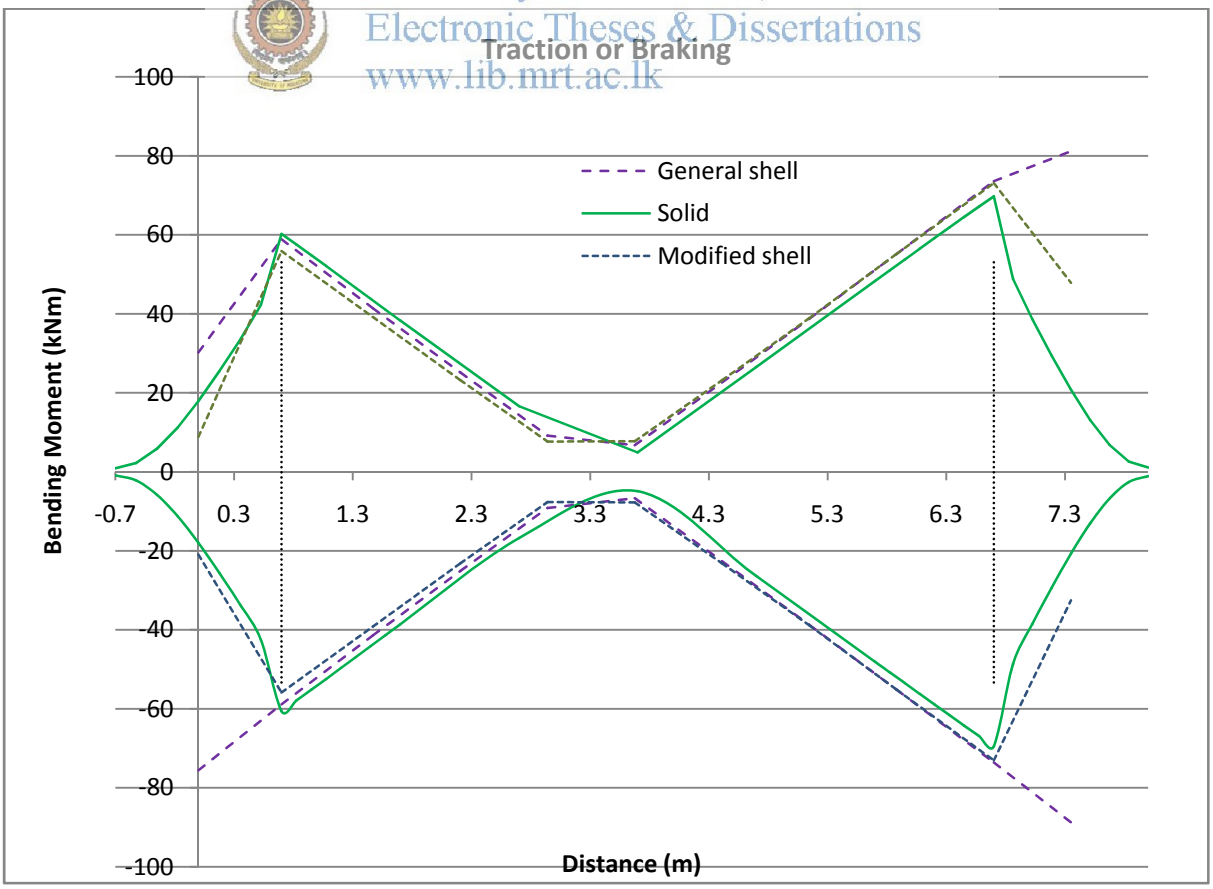












H.1.11: BME of Inside walls-Double cell (model no: 5)