



**METRO NORTH  
ORAL HEARING**

**Stage 2A Preliminary Building  
Response Report  
Rev3\_Part6**

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 2	
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop		Calc No: 10	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## **METHODOLOGY**

### **1. TunDisp Analysis**

The methodology for calculating the predicted surface settlements has been described in separate calculation data sheets contained within the Stage 1 Preliminary Ground Movement Assessment Report.

### **2. DeltaB Analysis**

The building response assessment requires input of the geometrical and structural properties of each structure requiring assessment. In addition, the degree of settlement subjected to each building needs to be defined. The methodology for establishing DeltaB input parameters is described below:

- a. Building coordinates (X, Y and Z) within the settlement influence zone have been retrieved from topographical survey drawings. In the absence of any topographical survey OS mapping has been used.
- b. Predicted settlement values and tunnel coordinates have been extracted from TunDisp output file and used to create an input data file for DeltaB.
- c. The structural characteristics of buildings have been established from building characterisation surveys and validated during a site walkover.

## **ASSUMPTIONS**

- For masonry (stone and brick) and concrete buildings stiffness values (E/G) of 2.6 and 12.5 have been adopted respectively.
- Where the building surveys could not provide any details of the building's basement, a basement depth 3m has been assumed.

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 3	
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop		Calc No: 10	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## INPUT PARAMETERS

### DELTA B:

#### Chainage 17080 to 17310 (Calculation Superseded by Calc No: 8)

<b>Area of Interest:</b>	(315650 E, 234800 N) (315960 E, 235200 N)
<b>Number of buildings:</b>	4
<b>Number of Tunnels</b>	2
<b>Building Structural characteristics-File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\DMN survey data\dmn.xls
<b>Building Coordinates- File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\Deta B data\final spreadsheet.xls
<b>Analysis directory (Building Damage Assessment):</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\delta B\Griffith Av. to St Stephen's Green\III.Parnell to O Connell\16. Parnell to Connell Bridge 1
<b>DeltaB Input File:</b>	wb16.inp
<b>Geology:</b>	Glacial Sand and Gravels

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 4		
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop			Calc No: 10		
Job No: B0307000		File: City Centre			
Made By: PN	Date: 11/03/08	Revised By:		Date:	
Checked By: DIT	Date: 11/03/08	Checked By:		Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
Gate Theatre and Assembly rooms	Parnell Square East	No	23	315744.922	235016.888	2.006	18	2.6
				315745.687	235029.089	2.010		
				315757.158	235039.176	1.475		
				315754.036	235042.875	1.877		
				315758.914	235047.307	2.145		
				315756.343	235050.470	3.316		
				315757.995	235051.703	3.586		
				315752.275	235057.373	4.102		
				315758.433	235062.498	5.001		
				315767.648	235052.411	4.494		
				315765.390	235050.484	4.408		
				315769.041	235047.815	4.481		
				315775.722	235040.467	4.180		
				315782.709	235031.038	3.871		
				315787.977	235021.615	3.426		
				315782.548	235018.330	2.006		
				315774.922	235020.998	2.006		
				315767.001	235019.005	2.006		
				315762.298	235012.878	2.006		
				315757.336	235018.819	2.006		
315756.172	235017.882	2.006						
315752.232	235022.672	2.006						
315744.922	235016.888	2.006						
1-6,9	Cavendish Row	No	16	315830.852	235072.293	4.149	16	2.6
				315833.800	235064.413	4.200		
				315812.036	235049.694	4.219		
				315815.613	235044.742	4.010		
				315829.375	235052.457	4.249		
				315832.947	235047.264	3.793		
				315828.467	235043.882	3.627		
				315830.300	235037.404	3.073		
				315831.764	235035.482	3.173		
				315825.295	235030.727	3.278		
				315827.353	235027.658	3.214		
				315834.196	235032.612	3.217		
				315845.759	235016.642	2.553		
				315828.082	235001.958	2.833		
				315795.305	235048.427	4.241		
				315831.052	235072.293	4.149		

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 5	
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop			Calc No: 10	
Job No: B0307000		File: City Centre		
Made By: PN	Date: 11/03/08	Revised By:	Date:	
Checked By: DIT	Date: 11/03/08	Checked By:	Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
Ambassador Cinema Parnell Street	Parnell Street	No	28	315765.128	234982.373	2.817	8	2.6
				315769.644	234984.437	2.924		
				315774.255	234983.940	3.002		
				315778.752	234980.558	2.872		
				315785.154	234986.329	2.879		
				315787.495	234983.688	2.874		
				315788.968	234984.978	2.889		
				315791.656	234985.873	2.910		
				315794.142	234988.306	2.938		
				315794.885	234990.161	2.965		
				315796.297	234991.397	2.986		
				315789.081	234999.744	2.960		
				315791.159	235005.522	3.153		
				315790.612	235013.976	3.271		
				315786.666	235020.598	3.329		
				315782.548	235018.330	3.329		
				315774.352	235021.060	3.000		
				315769.006	235020.078	2.700		
				315764.433	235016.813	2.400		
				315762.298	235012.878	2.000		
315760.146	235015.407	2.000						
315758.854	235012.250	2.000						
315754.165	235013.127	2.000						
315753.497	235008.287	2.000						
315749.941	235003.977	2.000						
315751.136	235002.492	2.000						
315749.190	235000.838	2.000						
315765.128	234982.373	2.817						
37-38 AIB Bank	O'Connell Street Upper	No	6	315775.221	234936.237	2.413	8	2.6
				315796.122	234953.441	2.598		
				315799.959	234952.233	2.599		
				315804.1695	234937.7065	2.517		
				315773.8526	234916.3874	2.517		
315775.221	234936.237	2.413						

# CALCULATION SHEET

Project Title: Dublin Metro North		Sheet No: 6	
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop		Calc No: 10	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## DELTA B:

### Chainage 17250 to 17600 (Calculation Superseded by Calc No: 8)

<b>Area of Interest:</b>	(317100 E, 243700 N) (317400 E, 244250 N)
<b>Number of buildings:</b>	12
<b>Number of Tunnels</b>	5
<b>Building Structural characteristics-File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\DMN survey data\dmn.xls
<b>Building Coordinates- File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\Deta B data\final spreadsheet.xls
<b>Analysis directory (Building Damage Assessment):</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\delta B\Griffith Av. to St Stephen's Green\III.Parnell to O Connell\17. Parnell to Connell Bridge 2
<b>DeltaB Input File:</b>	wb17.inp
<b>Geology:</b>	Glacial Sand and Gravels

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 7	
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop			Calc No: 10	
Job No: B0307000		File: City Centre		
Made By: PN	Date: 11/03/08	Revised By:	Date:	
Checked By: DIT	Date: 11/03/08	Checked By:	Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
1-2	O'Connell Street Upper	No	15	315926.193	234694.592	1.757	19	2.6
				315925.394	234696.842	1.757		
				315932.442	234696.391	1.757		
				315931.793	234698.642	1.757		
				315928.247	234711.644	1.740		
				315930.297	234712.194	1.740		
				315938.147	234714.493	1.740		
				315944.689	234691.590	1.740		
				315925.291	234686.141	1.757		
				315922.891	234687.241	1.757		
				315920.444	234695.492	1.757		
				315923.591	234686.791	1.757		
				315922.891	234687.241	1.757		
				315921.942	234689.992	1.757		
				315926.193	234694.592	1.757		
3-7	O'Connell Street Upper	No	9	315919.847	234697.927	1.757	19	2.6
				315917.805	234705.038	1.742		
				315918.086	234705.124	1.740		
				315909.463	234734.381	1.818		
				315920.956	234737.498	1.818		
				315932.442	234696.391	1.757		
				315926.193	234694.592	1.757		
				315925.394	234696.842	1.757		
315919.847	234697.927	1.757						
17 Cinema	O'Connell Street Upper	No	6	315909.190	234924.040	2.516	19	2.6
				315936.411	234839.977	2.516		
				315882.692	234826.245	2.516		
				315861.252	234901.158	2.494		
				315862.791	234905.042	2.516		
				315909.190	234924.040	2.516		

# CALCULATION SHEET

Project Title: Dublin Metro North			Sheet No: 8	
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop			Calc No: 10	
Job No: B0307000		File: City Centre		
Made By: PN	Date: 11/03/08	Revised By:	Date:	
Checked By: DIT	Date: 11/03/08	Checked By:	Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
20-23	O'Connell Street Upper	No	19	315893.463	234917.673	1.917	28	2.6
				315896.860	234909.171	1.917		
				315911.059	234913.220	1.917		
				315917.656	234905.819	1.917		
				315929.942	234862.862	1.707		
				315905.146	234855.530	1.678		
				315903.095	234862.715	1.718		
				315874.472	234856.054	1.677		
				315874.325	234857.199	1.678		
				315871.462	234867.351	1.718		
				315869.652	234866.791	1.707		
				315868.682	234870.111	1.730		
				315866.924	234871.889	1.713		
				315867.590	234873.847	1.750		
				315866.608	234877.204	1.770		
				315868.448	234877.876	1.772		
				315861.111	234901.997	1.905		
				315862.723	234905.286	1.917		
				315893.463	234917.673	1.917		
42-43	O'Connell Street Upper	No	5	315814.602	234898.771	2.235	17	2.6
				315820.323	234879.173	2.245		
				315761.198	234863.779	2.245		
				315756.074	234882.281	2.235		
				315814.602	234898.771	2.235		
44	O'Connell Street Upper	No	5	315822.297	234872.325	2.460	17	2.6
				315820.323	234879.173	2.445		
				315804.716	234876.353	2.445		
				315807.112	234868.375	2.460		
				315822.297	234872.325	2.460		
52-54	O'Connell Street Upper	No	11	315838.048	234816.225	2.094	16.5	2.6
				315846.939	234787.974	2.040		
				315806.436	234776.813	2.040		
				315808.594	234768.624	2.040		
				315802.633	234766.912	2.040		
				315798.748	234776.678	2.040		
				315794.437	234775.564	2.040		
				315788.134	234796.591	2.094		
				315790.656	234797.306	2.094		
				315789.158	234802.593	2.094		
				315838.048	234816.225	2.094		
57	O'Connell Street Upper	No	5	315838.675	234757.408	2.020	15	2.6
				315836.477	234764.959	2.025		
				315851.738	234769.807	2.025		
				315853.971	234762.445	2.020		
				315838.675	234757.408	2.020		

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 9		
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop			Calc No: 10		
Job No: B0307000		File: City Centre			
Made By: PN	Date: 11/03/08	Revised By:		Date:	
Checked By: DIT	Date: 11/03/08	Checked By:		Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
58	O'Connell Street Upper	No	5	315854.315	234762.668	2.020	15	2.6
				315856.775	234754.487	2.020		
				315796.976	234737.659	2.020		
				315794.778	234745.260	2.020		
				315854.315	234762.668	2.020		
59-61	O'Connell Street Upper	No	15	315862.277	234733.494	1.959	16	2.6
				315856.223	234754.322	1.870		
				315824.973	234745.408	1.870		
				315826.524	234739.607	1.959		
				315828.721	234740.008	1.959		
				315830.519	234733.606	1.959		
				315839.418	234736.005	1.959		
				315837.721	234742.756	1.870		
				315841.620	234743.806	1.870		
				315843.824	234736.941	1.959		
				315847.068	234737.805	1.959		
				315848.166	234733.704	1.959		
				315841.617	234731.754	1.959		
315842.516	234728.454	1.959						
315862.277	234733.494	1.959						
62-67	O'Connell Street Upper	No	5	315836.666	234726.904	1.959	16	2.6
				315853.699	234677.496	1.748		
				315876.635	234684.252	1.748		
				315862.277	234733.494	1.959		
				315836.666	234726.904	1.959		
68	O'Connell Street Upper	No	5	315877.810	234679.764	1.747	14	2.6
				315876.464	234684.202	1.749		
				315866.848	234681.496	1.747		
				315868.347	234676.545	1.747		
				315877.810	234679.764	1.747		

# CALCULATION SHEET

Project Title: Dublin Metro North		Sheet No: 10	
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop		Calc No: 10	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## DELTA B:

### Chainage 17540 to 17820

<b>Area of Interest:</b>	(315800 E, 234750 N) (316050 E, 234350 N)
<b>Number of buildings:</b>	9
<b>Number of Tunnels</b>	5
<b>Building Structural characteristics-File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\DMN survey data\dmn.xls
<b>Building Coordinates- File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\Deta B data\final spreadsheet.xls
<b>Analysis directory (Building Damage Assessment):</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\delta B\Griffith Av. to St Stephen's Green\III.Parnell to O Connell\18. Parnell to Connell Bridge 3
<b>DeltaB Input File:</b>	wb18.inp
<b>Geology:</b>	Limestone

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 11		
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop			Calc No: 10		
Job No: B0307000		File: City Centre			
Made By: PN	Date: 11/03/08	Revised By:		Date:	
Checked By: DIT	Date: 11/03/08	Checked By:		Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
The General Post Office	O'Connell Street Lower	No	18	315872.838	234656.811	-1.326	25	2.6
				315884.579	234660.348	-1.382		
				315891.159	234638.503	-1.472		
				315896.285	234640.047	-1.493		
				315903.482	234616.151	-1.528		
				315897.717	234614.415	-1.555		
				315904.114	234593.178	-1.657		
				315888.657	234588.523	-1.708		
				315885.223	234603.234	-1.657		
				315882.875	234611.635	-1.555		
				315872.128	234608.636	-1.555		
				315865.883	234630.289	-1.472		
				315876.596	234633.646	-1.472		
				315875.684	234637.438	-1.472		
				315876.984	234637.939	-1.472		
				315875.486	234643.440	-1.493		
315876.836	234644.040	-1.493						
315872.838	234656.811	-1.326						
78	Abbey Street Middle (The Oval)	No	5	315900.5764	234528.268	1.400	14	2.6
				315907.2468	234527.3728	1.400		
				315909.5944	234517.2707	1.400		
				315903.244	234515.7223	1.400		
				315900.5764	234528.268	1.400		
12-13	O'Connell Street Lower	No	6	315979.665	234535.416	1.228	25	2.6
				315969.630	234532.573	1.297		
				315966.921	234534.162	1.340		
				315962.727	234548.973	1.472		
				315974.194	234552.419	1.472		
315979.665	234535.416	1.228						
14-17	O'Connell Street Lower	No	6	315977.801	234574.271	1.472	18.5	2.6
				315982.644	234555.969	1.374		
				315962.659	234549.212	1.374		
				315957.288	234567.369	1.418		
				315958.646	234569.696	1.472		
315977.801	234574.271	1.472						

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 12	
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop			Calc No: 10	
Job No: B0307000		File: City Centre		
Made By: PN	Date: 11/03/08	Revised By:	Date:	
Checked By: DIT	Date: 11/03/08	Checked By:	Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
18-27	O'Connell Street Lower	No	18	315967.518	234631.080	1.680	25	2.6
				315965.570	234638.081	1.740		
				315961.967	234648.567	1.740		
				315964.475	234649.160	1.740		
				315970.105	234653.138	1.827		
				315963.332	234677.286	1.786		
				315980.231	234683.235	1.786		
				315985.259	234664.979	1.837		
				316000.000	234612.444	1.676		
				316005.576	234590.848	1.543		
				316000.000	234589.172	1.508		
				315964.437	234581.067	1.520		
				315964.580	234580.256	1.537		
				315954.175	234577.289	1.481		
				315951.974	234585.267	1.508		
				315949.241	234595.168	1.543		
				315940.819	234625.682	1.676		
				315967.518	234631.080	1.680		
28-34	O'Connell Street Lower	No	21	315943.634	234672.887	1.786	18	2.6
				315945.257	234667.167	1.837		
				315946.502	234667.518	1.837		
				315950.478	234668.726	1.836		
				315950.799	234667.538	1.837		
				315952.191	234667.914	1.837		
				315952.691	234666.064	1.837		
				315956.750	234667.159	1.837		
				315965.570	234638.081	1.740		
				315967.518	234631.080	1.680		
				315948.569	234626.081	1.680		
				315941.520	234624.282	1.680		
				315941.602	234625.898	1.680		
				315937.787	234639.721	1.740		
				315930.682	234664.960	1.827		
				315929.932	234667.677	1.837		
				315930.035	234668.528	1.836		
				315930.910	234670.096	1.825		
				315931.610	234670.685	1.815		
				315934.357	234671.474	1.786		
				315943.634	234672.887	1.786		

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 13		
Subject: Building Damage Assessment- Chainage 17080 to 17820-Parnell Stop to O Connell Bridge Stop			Calc No: 10		
Job No: B0307000		File: City Centre			
Made By: PN	Date: 11/03/08	Revised By:		Date:	
Checked By: DIT	Date: 11/03/08	Checked By:		Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
40-42	O'Connell Street Lower	No	8	315919.841	234533.631	1.787	25	2.6
				315914.164	234553.058	1.873		
				315875.757	234543.078	1.873		
				315873.707	234540.777	1.873		
				315878.646	234509.923	1.873		
				315903.244	234515.722	1.873		
				315900.576	234528.268	1.873		
				315919.841	234533.631	1.787		
43-44	O'Connell Street Lower	No	8	315907.247	234527.373	1.652	20	2.6
				315908.397	234527.923	1.652		
				315907.848	234530.372	1.791		
				315920.348	234533.817	1.791		
				315923.565	234522.863	1.652		
				315921.541	234519.265	1.599		
				315909.383	234516.186	1.579		
				315907.247	234527.373	1.652		

## OUTPUT FILE NAMES

### Chainage 17080 to 17310

Output data file:	sb01.dat
Damage category output file:	sb01.gis

### Chainage 17250 to 17600

Output data file:	cross2.dat
Damage category output file:	cross2.gis

### Chainage 17540 to 17820

Output data file:	cross2.dat
Damage category output file:	cross2.gis

Project Title: Dublin Metro North		Sheet No: 1	
Subject: Building Response adjacent to O'Connell Bridge Stop		Calc No: 11	
Job No: B0307000			File: City Centre
Made By: BA	Date: 08/02/09	Revised By:	Date:
Checked By: AL	Date: 09/02/09	Checked By:	Date:

## O'Connell Bridge Stop Building Response

### INTRODUCTION

The objective of this calculation is to determine the damage category of buildings adjacent to O'Connell Bridge Stop which have been identified for further assessment in the Stage 1 Preliminary ground Movement Report. Buildings classified as 'Moderate' or above will require further review as part of a detailed Stage 3 assessment to be undertaken by the DBFM Contractor.

### REFERENCES

Document/Drawing Ref	Rev	Title
B0307000-010\Geo.02\001	0	Design Input Statement for Predicting Ground Movements and the Response of Buildings, Infrastructure and Utilities Generated by Underground Excavation.
B03070000-010/STB.061/004	02	Stage 1 Preliminary Ground Movement Assessment Report.
BMN/0000/TU/7050	B05	Predicted Settlement Contours, south of Mater to O'Connell Bridge
BMN/0000/TU/7051	B05	Predicted Settlement Contours, O'Connell Bridge to St. Stephen's Green

### METHODOLOGY

#### A.) Structures Adjacent to Stop Boxes

Calculations have been undertaken to determine the limiting tensile strain and the corresponding predicted damage category for buildings adjacent to Stop boxes. The Building Response Assessment has been carried out taking account of the particular settlement profile predicted for each Stop (a function of construction sequencing, wall stiffness, propping arrangement and ground conditions) and geometrical and orientation characteristics of the building being considered.

The predicted damage category for each building considered has been determined using the best estimate ground movement parameters set down in 'Design Input Statement for Predicting Ground Movements and Response of Overlying Property to Underground Excavation'. The building response assessment assumes that the building deforms to the Greenfield settlement and there is no soil / structure interaction. This is considered to provide conservative predictions.

From the Stage 1 Predicted Settlement drawings zones of hogging or sagging which traverse the each building considered have been identified. For each zone the horizontal strain and bending strain excreted on the building has been calculated. The total bending strain and the total shear strain was then determined. The greater of these two values is the limiting tensile strain, which has been used to predict the damage category for the building in accordance with Boscardin and Cordin, 1989.

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 2	
Subject: Building Response adjacent to O'Connell Bridge Stop		Calc No: 11	
Job No: B0307000		File: City Centre	
Made By: BA	Date: 08/02/09	Revised By:	Date:
Checked By: AL	Date: 09/02/09	Checked By:	Date:

## Horizontal Strain

The average horizontal strain exerted on the structure has been calculated as the change in length of the building brought about by horizontal ground movements divided by the original length of the building.

The formula used is as follow:

$$\epsilon_h = \left( \frac{S_{ha} - S_{hb}}{L_o} \right)$$

Where:

- $S_{ha}$  is the horizontal movement calculated at the nearest edge of the building to the underground structure that caused the settlement (indicated as point A in the figures 1,2 and 3)
- $S_{hb}$  is the horizontal movement calculated at the furthest edge of the building to the underground structure that caused the settlement (indicated as point B in the figures 1,2 and 3)
- $L_o$  is the original length of the building, calculated as follow:  
 $L_o = L_1 + L_2$  (see Figures 1 and 2)  
 $L_o = L_1^h + L_2^h$  (hogging zone),  $L = L_1^s + L_2^s$  (sagging zone), (see Figure 3 top drawing)  
 $L_o = L$  (see Figure 3, bottom drawing)

The horizontal movement has been calculated as follow:

$$S_h = K \times S_v$$

Where:

- K is the ratio of horizontal to vertical movement (dependant on the stiffness of the surrounding soil).
- $S_v$  is the vertical movement.

Vertical movements have been obtained by trigonometry between known data points from the relevant Stage 1 Predicted Settlement Contour Drawing (see Figures 1, 2 and 3).

The ratio of horizontal movement to vertical movement (K) has been determined based on the findings of Clough & O'Rourke (1990), where for stiff to very hard clays, it is suggested that horizontal movements are equal to or will exceed the vertical movement by a ratio of 1.0 to 2.5. Given that the Dublin glacial till is much stiffer than the majority of stiff to hard clays used in the database and assuming a high horizontal support stiffness for Metro North excavations, it has been assumed that a horizontal to vertical movement ratio of 1.0 to 1.0 is appropriate for the glacial till. For excavations in sand, the horizontal to vertical movement ratio is suggested to range from 0.8 to 1.5. For the Stage 2A assessment a value of horizontal to vertical movement ratio of 1.0 has been assumed for very dense granular material and a ratio of 1.5 assumed for loose to medium dense sands.

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 3	
Subject: Building Response adjacent to O'Connell Bridge Stop		Calc No: 11	
Job No: B0307000		File: City Centre	
Made By: BA	Date: 08/02/09	Revised By:	Date:
Checked By: AL	Date: 09/02/09	Checked By:	Date:

## **Bending Strain**

The Bending Strain has been calculated by treating the building as an idealised beam of span L (length of the building) and height H (height of the building) deforming under a central point load to give a maximum deflection. The expression applied to calculate the bending strain is presented in the general form:

$$\frac{\Delta}{L} = \left( \frac{L}{12t} + \frac{3EI}{2tLHG} \right) \epsilon_b$$

Where:

- H is the height of the building
- L is the length of the building
- E and G are respectively the Young's modulus and shear modulus of the building
- I is the second moment of area of the equivalent beam (i.e.  $H^3/12$  in sagging zone and  $H^3/3$  in hogging zone)
- t is the furthest distance from the neutral axis to the edge of the beam (i.e.  $H/2$  in the sagging zone and H in the hogging zone)

The difference in the position of the neutral axis is related to the restraining effect of the foundations. For buildings in the hogging zone the neutral axis has been taken to coincide with the lower extreme fibre of the beam, i.e. the bottom of the structure. For buildings in the sagging zone mode, however, the neutral axis has been assumed to remain in the middle of the beam. Thus, the bending strain is calculated taking into account the position of the building, whether it is in the sagging zone or in the hogging zone.

For the case where the building is partially located in both hogging and sagging zones, separate analyses will be conducted to determine the bending strain attributed for each portion of the building. The larger bending strain between the two sides will be used to define the damage category of the building.

Building dimensions and their position relative to the adjacent Stop box have been obtained directly from topographical survey drawings. In the absence of any topographical survey OS mapping has been used. The predicted settlement contour drawings have been used to identify sagging and hogging zones and retrieve changes in vertical movement for each building identified.

The follow criteria have been applied to define the sagging and the hogging zones for each building considered:

- The settlement trough of the Stop box has been approximated by straight lines of same gradient that connect between subsequent contour points.
- Buildings with the edges confined within two consecutive contour lines are subjected to the horizontal strain only.
- Buildings crossed by one settlement contour line are subjected to both horizontal and bending strain (sagging or hogging).
- Buildings crossed by two settlement contour lines are subjected to both horizontal and bending strain (sagging, hogging or both).

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 4	
Subject: Building Response adjacent to O'Connell Bridge Stop		Calc No: 11	
Job No: B0307000		File: City Centre	
Made By: BA	Date: 08/02/09	Revised By:	Date:
Checked By: AL	Date: 09/02/09	Checked By:	Date:

In order to determine whether the building is in the sagging or hogging zone, the settlement contour lines crossing the building and the two directly adjacent either side of the building have been considered (Figures 1 to 3). The building is considered to be in the sagging zone if the distance between the first and the second predicted settlement contour line is larger than the distance between the second and the third and vice versa for buildings in the hogging zone. When the building is crossed by two settlement contour lines, the building is considered to be within the sagging zone if the distance between the two lines is decreasing moving away from the box. Conversely, if the distance between the contour lines increases then the building is considered to be located within the hogging zone. Where two or more contour lines cross the building the closer of the two will be used to assess the maximum bending strain of the building. In this case, the length of the building will be taken to equal to the distance between the two contour lines.

- The structural characteristics of the buildings were obtained from the relevant building characterisation survey and from site walkover notes. In particular the structural characteristics required for the calculation are building height and the ratio between the Young's modulus and the shear modulus ( $E/G$ ), which has been assumed as 2.6 for masonry buildings and 12.5 for framed buildings.

# CALCULATION SHEET

Project Title: Dublin Metro North		Sheet No: 5	
Subject: Building Response adjacent to O'Connell Bridge Stop		Calc No: 11	
Job No: B0307000		File: City Centre	
Made By: BA	Date: 08/02/09	Revised By:	Date:
Checked By: AL	Date: 09/02/09	Checked By:	Date:

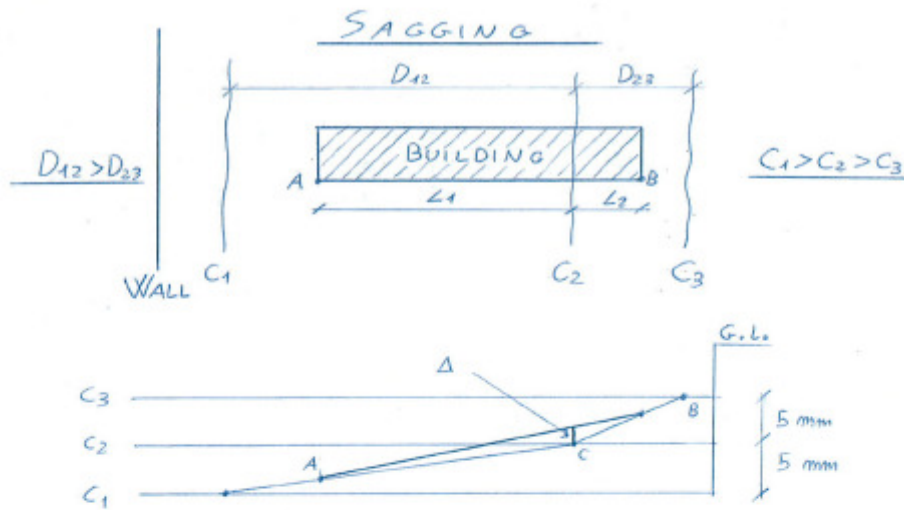


Figure. 1 – Assessment of Buildings within the Sagging Zone

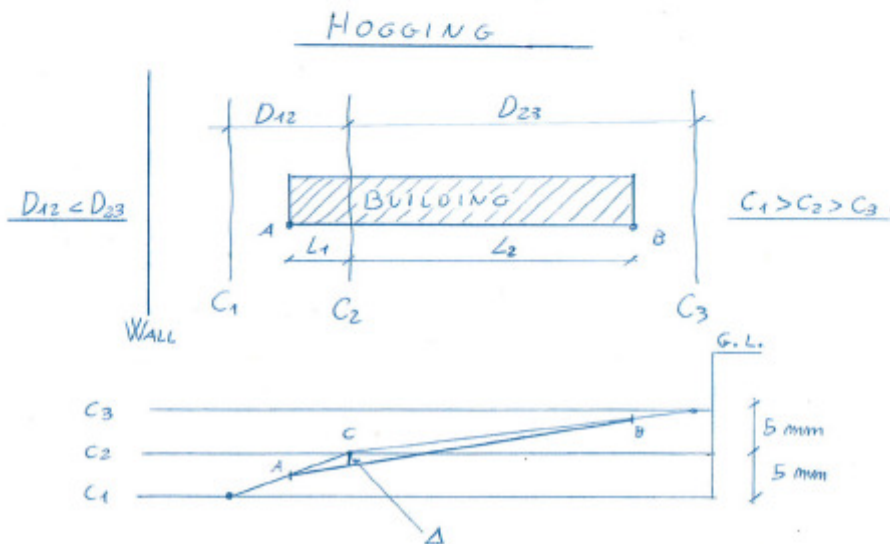


Figure. 2 – Assessment of Buildings within the Hogging Zone

Project Title: Dublin Metro North		Sheet No: 6	
Subject: Building Response adjacent to O'Connell Bridge Stop		Calc No: 11	
Job No: B0307000			File: City Centre
Made By: BA	Date: 08/02/09	Revised By:	Date:
Checked By: AL	Date: 09/02/09	Checked By:	Date:

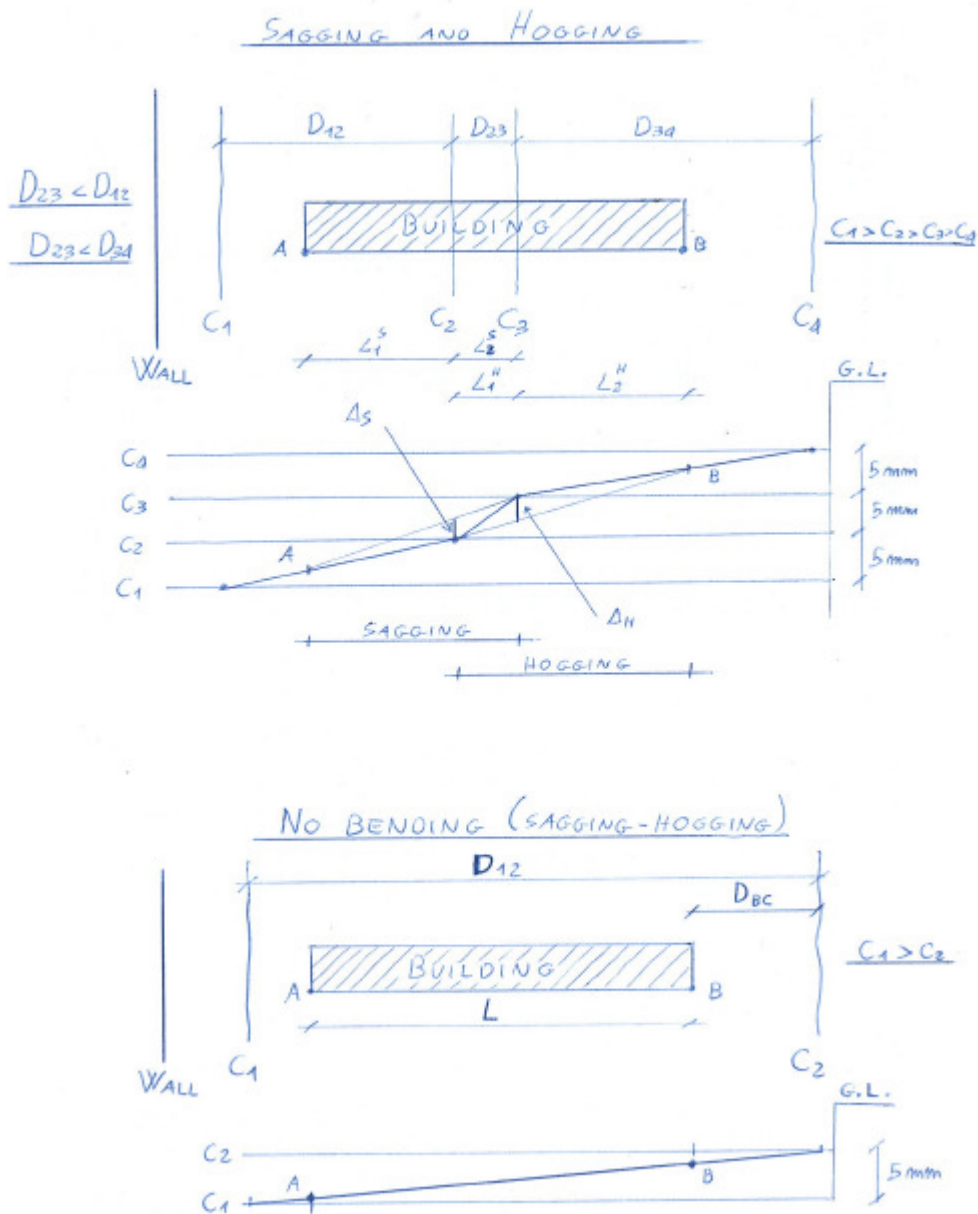


Figure. 3 – Assessment of Buildings within the Sagging and Hogging Zone

# CALCULATION SHEET



Project Title: Dublin Metro North			Sheet No: 7
Subject: Building Response adjacent to O'Connell Bridge Stop			Calc No: 11
Job No: B0307000		File: City Centre	
Made By: BA	Date: 08/02/09	Revised By:	Date:
Checked By: AL	Date: 09/02/09	Checked By:	Date:

## **B.) Buildings Adjacent to Bored Tunnels (Not Analysed by DeltaB)**

The Damage Categories of buildings adjacent to bored running tunnels that have not been assessed by DeltaB have been analysed using a validated Jacobs in-house programme (Sabrtun). The buildings assessed by this method are:

- 4 Westmoreland Street
- 5 Westmoreland Street
- 6 Westmoreland Street
- 7 Westmoreland Street

The above buildings have been identified as having similar structural features and the calculations presented within have been undertaken for a representative building giving the worst credible damage classification in terms of positioning within the settlement trough (4 Westmoreland Street). The calculated Damage Category has then been applied to neighbouring buildings.

## **VALIDATION**

The above calculation has been developed using Microsoft Excel which has been validated by hand and Subrtun Calculations

## **ASSUMPTIONS**

- For masonry (stone and brick) and concrete buildings stiffness values of 2.6 and 12.5 have been adopted respectively.
- Where the building surveys could not provide any details of the building's basement, a basement depth 3m has been assumed.

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 8	
Subject: Building Response adjacent to O'Connell Bridge Stop		Calc No: 11	
Job No: B0307000		File: City Centre	
Made By: BA	Date: 08/02/09	Revised By:	Date:
Checked By: AL	Date: 09/02/09	Checked By:	Date:

## INPUT PARAMETERS

Input Parameters	
Symbol	Definition
H.	Height of the building.
E/G	2.6 for masonry buildings (Mair and Taylor) 12.5 for framed structures (Burland and Wroth).
K	Ratio between horizontal and vertical movement.
C <sub>1</sub>	Predicted settlement at the first contour line.
C <sub>2</sub>	Predicted settlement at the second contour line.
C <sub>3</sub>	Predicted settlement at the third contour line.
D <sub>12</sub>	Distance between the first and the second predicted settlement contour line.
D <sub>23</sub>	Distance between the second and the third predicted settlement contour line.
L	Length of the building.
D <sub>bc</sub>	Distance between the end of the building and the second predicted settlement contour line.
L <sub>1</sub>	Length of the first part of the building.
L <sub>2</sub>	Length of the second part of the building

# CALCULATION SHEET



Project Title: Dublin Metro North				Sheet No: 9			
Subject: Building Response adjacent to O'Connell Bridge Stop				Calc No: 11			
Job No: B0307000		File: City Centre					
Made By: BA	Date: 08/02/09	Revised By:				Date:	
Checked By: AL	Date: 09/02/09	Checked By:				Date:	

## C.) Structures Adjacent to Stop Boxes

Building Address/Name	H (m)	E/G	K	C1 (m)	C2 (m)	C3 (m)	D12 (m)	D23 (m)	L (m)	Dbc (m)	L1 (m)	L2 (m)
43-44 O'Connell Street Lower	15	12.5	1.5	0.005	0		37.50		13.75	15.00		
78 Abbey street	15	12.5	1.5	0.005	0		37.50		6.25	8.75		
45-46 O'Connell Street Lower	27.6	2.6	1.5	0.015	0.01	0.005	11.25	12.50			3.75	12.50
47-48 O'Connell Street Lower	20.0	12.5	1.5	0.015	0.01	0.005	13.75	10.00			8.75	10.00
49 O'Connell Street Lower	20.0	2.6	1.5	0.015	0.01	0.005	13.75	11.25			7.50	11.25
50-51 O'Connell Street Lower	23.0	2.6	1.5	0.015	0.01	0.005	13.75	11.25			7.50	11.25
52 O'Connell Street Lower	18.5	2.6	1.5	0.015	0.01	0.005	12.50	13.75			10.00	13.75
53 O'Connell Street Lower	18.4	2.6	1.5	0.015	0.01	0.005	10.00	13.75			10.00	13.75
54 O'Connell Street Lower	18.4	2.6	1.5	0.015	0.01	0.005	10.00	13.75			10.00	12.50
55 O'Connell Street Lower	20.0	2.6	1.5	0.02	0.015	0.01	13.75	10.00			5.00	7.50
56 O'Connell Street Lower	20.0	2.6	1.5	0.02	0.015	0.01	13.75	10.00			6.25	2.50
30 Bachelor Walk	15.0	2.6	1.5	0.005	0		11.25		2.50	0.00		
31 Bachelor Walk	15.0	2.6	1.5	0.005	0		11.25		6.25	2.50		
32 Bachelor Walk	22.3	2.6	1.5	0.01	0.005		12.50		5.00	2.50		
33 Bachelor Walk	20.2	2.6	1.5	0.015	0.01	0.005	10.00	12.50			2.50	3.75
34 Bachelor Walk	20.2	2.6	1.5	0.015	0.01		10.00		5.00	2.50		
1-3 Eden Quay	25.0	2.6	1.5	0.01	0.01		18.75		6.25	0.00		
19-21 Aston Quay	19.0	2.6	1.5	0.01	0.005	0	21.25	16.25			6.25	13.75
26 Aston Quay	18.7	2.6	1.5	0.01	0.05		26.25		13.75	6.25		
6 D'Olier Street	20.0	2.6	1.5	0.005	0		38.75		10.00	3.75		
7 D'Olier Street	20.2	2.6	1.5	0.005	0		25.00		10.00	0.00		
8 D'Olier Street	20.4	2.6	1.5	0.005	0		23.75		5.00	0.00		
9 D'Olier Street	20.4	2.6	1.5	0.005	0		25.00		2.50	0.00		

# CALCULATION SHEET



Project Title: Dublin Metro North				Sheet No: 10			
Subject: Building Response adjacent to O'Connell Bridge Stop				Calc No: 11			
Job No: B0307000						File: City Centre	
Made By: BA		Date: 08/02/09		Revised By:			Date:
Checked By: AL		Date: 09/02/09		Checked By:			Date:

Building Address/Name	H (m)	E/G	K	C1 (m)	C2 (m)	C3 (m)	D12 (m)	D23 (m)	L (m)	Dbc (m)	L1 (m)	L2 (m)
8 Westmoreland Street	20.2	2.6	1.5	0.005	0		37.50		11.25	21.25		
9 Westmoreland Street	20.2	2.6	1.5	0.01	0.005	0	7.50	30.00			2.50	8.75
10 Westmoreland Street	20.2	2.6	1.5	0.01	0.005	0	7.50	26.25			5.00	5.00
11 Westmoreland Street	20.2	2.6	1.5	0.01	0.005	0	8.75	26.25			6.25	3.75
12 Westmoreland Street	20.2	2.6	1.5	0.01	0.005	0	8.75	31.25			5.00	6.25
13 Westmoreland Street	20.6	2.6	1.5	0.01	0.005	0	8.75	32.50			3.75	7.50
14 Westmoreland Street	23.0	2.6	1.5	0.01	0.005	0	10.00	30.00			6.25	3.75
15 Westmoreland Street	19.0	2.6	1.5	0.015	0.01	0.005	6.25	10.00			1.25	10.00
16 Westmoreland Street	19.0	2.6	1.5	0.015	0.01	0.005	8.75	10.00			3.75	7.50
17 Westmoreland Street	19.0	2.6	1.5	0.015	0.01	0.005	6.25	8.75			1.25	8.75
22 Westmoreland Street	20.2	2.6	1.5	0.015	0.01	0.005	10.00	8.75			5.00	6.25
26 Westmoreland Street	19.0	2.6	1.5	0.01	0.005	0	8.75	25.00			8.75	11.25
27 Westmoreland Street	19.0	2.6	1.5	0.01	0.005	0	10.00	23.75			10.00	10.00
28 Westmoreland Street	19.0	2.6	1.5	0.01	0.005	0	10.00	23.75			10.00	10.00
29 Westmoreland Street	19.0	2.6	1.5	0.01	0.005	0	15.00	27.50			10.00	16.25
30-34 Westmoreland Street	19.0	2.6	1.5	0.01	0.005	0	10.00	33.75			3.75	15.00
1 O'Connell Street Lower	20.7	2.6	1	0.005	0		20.00		15.00	5.00		
2-4 O'Connell Street Lower	20.7	2.6	1.5	0.01	0.005	0	7.50	18.75			0.00	13.75
5 O'Connell Street Lower	25.0	2.6	1.5	0.01	0.005	0	13.75	13.75			7.50	12.50
6-7 O'Connell Street Lower	21.0	2.6	1.5	0.01	0.005	0	11.25	15.00			7.50	12.50
8 O'Connell Street Lower	22.6	2.6	1.5	0.01	0.005	0	7.50	15.00			7.50	12.50
10-11 O'Connell Street Lower	21.0	2.6	1.5	0.01	0.005	0	11.25	15.00			7.50	12.50

# CALCULATION SHEET



Project Title: Dublin Metro North			Sheet No: 11		
Subject: Building Response adjacent to O'Connell Bridge Stop			Calc No: 11		
Job No: B0307000		File: City Centre			
Made By: BA	Date: 08/02/09	Revised By:			Date:
Checked By: AL	Date: 09/02/09	Checked By:			Date:

## D.) Structures Adjacent to Stop Boxes

Address	Building Data				Tunnel Data					
	Width (m)	Height to Eaves (m)	Foundation Depth (m)	E/G	Depth Below GL (m)	Diameter (m)	Volume Loss (%)	K	Offset from Building (m)	
									First Tunnel	Second Tunnel
4 Westmoreland Street	11.25	18.00	2.00	2.6	28.28	6.75	0.57	0.37	16.25	45.00

Project Title: Dublin Metro North		Sheet No: 1	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop		Calc No: 12	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## O'Connell Bridge Stop to St Stephens Green Stop Building Response

### INTRODUCTION

The objective of this calculation is to determine the damage category of buildings adjacent to the bored running tunnels between Chainage 17860 and 18780(O Connell Bridge stop to St Stephen's Green Stop). Buildings that have been assessed are based on those identified for further assessment in the Stage 1 Preliminary Ground Movement Assessment Report.

Buildings classified as 'Moderate' or above will require further review as part of a detailed Stage 3 assessment to be undertaken by the DBFM Contractor.

### REFERENCES

Document/Drawing Ref	Rev	Title
B0307000-010\Geo.02\001	0	Design Input Statement for Predicting Ground Movements and the Response of Buildings, Infrastructure and Utilities Generated by Underground Excavation
B03070000-010/STB.061/004	01	Stage 1 Preliminary Ground Movement Assessment Report.
BMN/0000/TU/7051	B01	Predicted Settlement Contours – O' Connell Bridge to St Stephen's Green

### ANALYTICAL TOOLS

The following analytical tools have been used in this analysis

- TunDisp (Jacobs in-house programme): used to calculate predicted ground movement.
- AutoCAD 2005 (Ver 8): used for extracting building x,y,z coordinates.
- DeltaB (Jacobs in-house programme): used to assess building damage category.

Manual calculation techniques have been used to verify ground movement predictions for specific areas along the alignment. Building damage assessment results have been validated by manual calculation techniques and the Jacobs in-house software (Sabrtun) for specific buildings along the alignment.

### METHODOLOGY

#### 1. TunDisp Analysis

The methodology for calculating the predicted surface settlements has been described in separate calculation data sheets contained within the Stage 1 Preliminary Ground Movement Assessment Report.

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 2	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop		Calc No: 12	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## 2. DeltaB Analysis

The building response assessment requires input of the geometrical and structural properties of each structure requiring assessment. In addition, the degree of settlement subjected to each building needs to be defined. The methodology for establishing DeltaB input parameters is described below:

- a. Building coordinates (X, Y and Z) within the settlement influence zone have been retrieved from topographical survey drawings. In the absence of any topographical survey OS mapping has been used.
- b. Predicted settlement values and tunnel coordinates have been extracted from TunDisp output file and used to create an input data file for DeltaB.
- c. The structural characteristics of buildings have been established from building characterisation surveys and validated during a site walkover.

## ASSUMPTIONS

- For masonry (stone and brick) and concrete buildings stiffness values (E/G) of 2.6 and 12.5 have been adopted respectively.
- Where the building surveys could not provide any details of the building's basement, a basement depth 3m has been assumed.

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 3	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop		Calc No: 12	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## INPUT PARAMETERS

### DELTA B:

#### Chainage 17860 to 18200

<b>Area of Interest:</b>	(315850 E, 234450 N) (316100 E, 233950 N)
<b>Number of buildings:</b>	12
<b>Number of Tunnels</b>	5
<b>Building Structural characteristics-File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\DMN survey data\dmn.xls
<b>Building Coordinates- File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\Deta B data\final spreadsheet.xls
<b>Analysis directory (Building Damage Assessment):</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\delta B\Griffith Av. to St Stephen's Green\IV.O Connell to St Stephen\19. Connell to St Stephen I
<b>DeltaB Input File:</b>	wb20.inp
<b>Geology:</b>	Limestone

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 4		
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop			Calc No: 12		
Job No: B0307000		File: City Centre			
Made By: PN	Date: 11/03/08	Revised By:		Date:	
Checked By: DIT	Date: 11/03/08	Checked By:		Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
4	Westmoreland Street	No	5	315963.022	234197.318	1.360	18	2.6
				315962.858	234192.982	1.360		
				315972.391	234192.907	1.465		
				315972.425	234197.396	1.465		
				315963.022	234197.318	1.360		
5	Westmoreland Street	No	5	315972.589	234210.025	2.263	20	2.6
				315972.425	234197.196	2.265		
				315960.502	234197.308	2.158		
				315956.195	234222.901	2.161		
				315972.589	234210.025	2.263		
6	Westmoreland Street	No	5	315973.051	234216.839	2.249	20	2.6
				315972.589	234210.025	2.263		
				315960.780	234210.343	2.192		
				315956.195	234222.901	2.161		
				315973.051	234216.839	2.249		
7	Westmoreland Street	No	5	315972.747	234223.727	2.220	20	2.6
				315973.051	234216.839	2.249		
				315958.709	234216.818	2.177		
				315956.195	234222.901	2.161		
				315972.747	234223.727	2.220		
8	Westmoreland Street	No	7	315973.44	234256.006	2.339	18	2.6
				315973.073	234236.666	2.285		
				315960.337	234235.248	2.26		
				315959.596	234240.712	2.266		
				315962.493	234241.109	2.286		
				315962.42	234256.142	2.245		
				315973.44	234256.006	2.339		
9	Westmoreland Street	No	5	315973.953	234268.945	2.315	18	2.6
				315973.44	234256.006	2.339		
				315962.42	234256.142	2.245		
				315962.747	234269.037	2.204		
				315973.953	234268.945	2.315		
35-41	Westmorland Street	No	9	316028.231	234231.667	1.584	20	2.6
				316028.453	234184.259	1.867		
				316024.848	234184.792	1.908		
				316024.862	234182.760	1.895		
				316005.500	234182.076	2.060		
				316005.067	234196.027	2.145		
				316005.788	234196.122	2.133		
				316006.463	234229.319	2.076		
				316028.231	234231.667	1.584		

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 5		
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop			Calc No: 12		
Job No: B0307000		File: City Centre			
Made By: PN	Date: 11/03/08	Revised By:		Date:	
Checked By: DIT	Date: 11/03/08	Checked By:		Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
19-20	Fleet Street	No	10	315954.641	234275.981	1.200	18	2.6
				315962.767	234275.811	1.383		
				315962.547	234269.037	1.404		
				315962.520	234256.242	1.445		
				315950.000	234253.500	1.440		
				315954.330	234234.494	1.437		
				315942.500	234233.900	1.437		
				315934.116	234294.395	0.963		
				315948.767	234296.064	1.176		
21	Fleet Street	No	7	315962.520	234256.242	1.445	18	2.6
				315962.493	234241.109	1.486		
				315959.696	234240.812	1.466		
				315960.337	234235.248	1.460		
				315954.330	234234.494	1.437		
				315950.000	234253.500	1.440		
33-36	Fleet Street	No	5	316056.971	234237.841	0.567	25	2.6
				316028.494	234233.628	0.961		
				316028.6907	234216.3987	0.961		
				316059.1552	234217.8487	0.567		
				316056.971	234237.841	0.567		
Bank of Ireland	1 College Green	No	16	315966.219	234171.563	1.565	12.5	2.6
				315968.794	234161.334	1.569		
				315978.666	234163.745	1.629		
				315983.552	234144.358	1.515		
				315974.711	234142.015	1.547		
				315977.566	234132.131	1.549		
				315975.616	234131.555	1.526		
				315971.797	234115.969	1.551		
				315961.394	234103.416	1.634		
				315937.600	234092.200	1.540		
				315919.987	234087.561	1.550		
				315899.942	234092.987	1.550		
				315879.200	234140.011	1.550		
				315962.501	234168.587	1.562		
315961.829	234170.697	1.562						
315966.219	234171.563	1.565						
1-2	College Street	No	6	316028.453	234184.259	1.267	25	2.6
				316060.905	234203.319	0.898		
				316060.2205	234217.5956	0.898		
				316059.1552	234217.8487	0.898		
				316028.6907	234216.3987	0.898		
				316028.453	234184.259	1.267		

# CALCULATION SHEET

Project Title: Dublin Metro North		Sheet No: 6	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop		Calc No: 12	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## DELTA B:

### Chainage 18070 to 18490

<b>Area of Interest:</b>	(315800 E, 234200 N) (316050 E, 233650 N)
<b>Number of buildings:</b>	21
<b>Number of Tunnels</b>	17
<b>Building Structural characteristics-File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\DMN survey data\dmn.xls
<b>Building Coordinates- File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\Deta B data\final spreadsheet.xls
<b>Analysis directory (Building Damage Assessment):</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\delta B\Griffith Av. to St Stephen's Green\IV.O Connell to St Stephen\20. Connell to St Stephen II
<b>DeltaB Input File:</b>	wb21.inp
<b>Geology:</b>	Limestone

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 7		
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop			Calc No: 12		
Job No: B0307000			File: City Centre		
Made By: PN	Date: 11/03/08	Revised By:	Date:		
Checked By: DIT	Date: 11/03/08	Checked By:	Date:		

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
Regent House, Chapel	College Green	No	6	316071.805	234141.484	1.258	16	2.6
				316065.728	234141.686	1.560		
				316061.159	234137.408	1.965		
				316059.885	234097.928	1.731		
				316074.397	234097.342	1.791		
				316071.805	234141.484	1.258		
32-33	College Green	No	10	315884.8026	234041.4653	1.650	22	2.6
				315887.1911	234044.3999	1.650		
				315906.4982	234045.6913	1.650		
				315907.5044	234048.0699	1.650		
				315919.731	234049.0782	1.650		
				315921.2365	234027.5905	2.120		
				315892.8615	234024.0015	2.120		
				315892.6104	234027.7834	2.120		
				315885.5279	234027.4212	2.120		
				315884.8026	234041.4653	2.120		
34	College Green	No	9	315922.1858	234015.866	2.120	18	2.6
				315935.3478	233999.8896	2.120		
				315947.3932	234017.5705	2.120		
				315946.0349	234017.7665	2.120		
				315942.8939	234049.2413	1.650		
				315938.9341	234049.7914	1.650		
				315923.7488	234048.7491	1.650		
				315919.765	234047.7389	1.650		
				315922.1858	234015.866	2.120		
35	College Green	No	5	315942.5779	234051.1418	4.65	15.5	2.6
				315951.3002	234051.6726	5.12		
				315952.8163	234025.4923	5.12		
				315945.2327	234024.9101	4.65		
				315942.5779	234051.1418	4.65		
36	College Green	No	5	315957.384	234052.1651	2.25	17	2.6
				315951.2817	234051.9	2.25		
				315952.8163	234025.4923	2.72		
				315958.8535	234032.0777	2.72		
				315957.384	234052.1651	2.25		
5-10, 11-13	Suffolk Street	No	9	315948.820	233987.871	3.449	17	2.6
				315947.030	233985.489	3.615		
				315960.671	233977.385	3.261		
				315956.860	233971.190	3.523		
				315963.360	233967.242	3.345		
				315960.499	233962.470	3.552		
				315935.142	233978.147	4.271		
				315943.416	233990.906	3.373		
				315948.820	233987.871	3.449		

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 8	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop		Calc No: 12	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
22-23	Suffolk Street	No	7	315952.315	233953.166	3.773	17	2.6
				315945.786	233942.243	3.793		
				315945.302	233943.332	3.795		
				315932.728	233925.831	3.701		
				315924.968	233930.631	3.660		
				315941.755	233959.730	3.832		
				315952.315	233953.166	3.773		
Weir and Son's	96-99 Grafton Street including 1-3 Wicklow Street	No	6	315964.820	233886.745	5.119	17.5	2.6
				315964.358	233881.622	5.263		
				315962.302	233880.489	5.318		
				315946.578	233885.763	5.269		
				315948.679	233891.822	5.169		
				315964.820	233886.745	5.119		
102-103	Grafton Street	No	5	315970.271	233934.863	2.626	20	2.6
				315969.398	233927.749	2.686		
				315957.309	233929.141	2.890		
				315958.123	233936.415	2.824		
				315970.282	233934.951	2.625		
108	Grafton Street	No	5	315974.463	233970.303	3.859	17	2.6
				315973.701	233963.394	4.059		
				315964.046	233965.828	4.242		
				315965.002	233972.123	4.091		
				315974.463	233970.303	3.859		
110	Grafton Street	No	9	315976.097	233983.362	3.493	17	2.6
				315974.463	233970.303	3.859		
				315963.731	233972.310	4.140		
				315964.661	233978.558	3.978		
				315962.790	233978.867	4.052		
				315963.982	233986.825	3.872		
				315968.043	233986.285	3.708		
				315967.828	233984.586	3.752		
				315976.097	233983.362	3.493		
111	Nassau Street	No	5	316048.415	233915.822	3.997	17	2.6
				316045.225	233902.913	4.158		
				316019.038	233909.230	4.200		
				316022.683	233922.315	4.267		
				316048.415	233915.822	3.997		
112	Grafton Street	No	7	315977.144	233991.357	3.294	19	2.6
				315975.783	233983.408	3.500		
				315967.828	233984.586	3.752		
				315968.143	233986.385	3.708		
				315960.164	233987.372	3.961		
				315961.180	233993.668	3.744		
				315977.144	233991.357	3.294		

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 9	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop		Calc No: 12	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
113-114	Grafton Street	No	5	315978.842	234003.994	3.059	19	2.6
				315977.144	233991.357	3.294		
				315961.180	233993.668	3.744		
				315963.202	234006.098	3.471		
				315978.842	234003.994	3.059		
115-116	Grafton Street	No	7	315981.769	234023.257	2.697	20	2.6
				315978.842	234003.994	3.059		
				315969.860	234005.340	3.301		
				315971.652	234016.690	3.019		
				315967.343	234017.062	3.140		
				315968.640	234024.640	2.953		
117	Grafton Street	No	11	315981.852	234030.097	2.575	12	2.6
				315981.769	234023.257	2.697		
				315968.540	234024.740	2.953		
				315967.343	234017.062	3.140		
				315971.552	234016.790	3.019		
				315969.860	234005.340	3.301		
				315957.561	234006.942	3.510		
				315958.569	234015.161	3.326		
				315950.039	234016.712	3.537		
				315959.874	234030.685	2.996		
				315981.852	234030.097	2.575		
118	Grafton Street	No	5	315972.542	234041.996	2.223	10	2.6
				315963.299	234034.959	2.275		
				315966.763	234030.501	2.568		
				315981.852	234030.097	2.648		
				315972.542	234041.996	2.223		
119	Grafton Street	No	6	315956.462	234052.501	4.652	17	2.6
				315964.483	234052.253	4.598		
				315972.542	234042.096	4.623		
				315963.299	234034.959	5.048		
				315957.642	234042	4.891		
315956.462	234052.501	4.652						
38-46	Wicklow Street	No	10	315962.880	233868.260	4.421	25	2.6
				315960.093	233860.647	4.497		
				315960.395	233860.525	4.500		
				315953.737	233841.121	4.653		
				315919.140	233853.479	4.286		
				315919.568	233854.653	4.286		
				315900.160	233861.470	4.286		
				315910.544	233888.235	4.286		
				315961.792	233870.389	4.411		
				315962.880	233868.260	4.421		

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 10	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop		Calc No: 12	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
Johnston's Court	St Teresa's Church	No	14	315877.3339	233842.106	4.986	14.5	2.6
				315883.8491	233855.3789	4.986		
				315913.6716	233843.3125	4.986		
				315900.171	233814.016	4.986		
				315914.029	233809.6692	4.986		
				315915.5334	233801.4164	4.986		
				315910.46	233787.141	4.986		
				315860.2825	233806.2001	4.986		
				315869.4923	233825.3973	4.986		
				315886.0399	233818.764	4.986		
				315899.6837	233841.0409	4.986		
				315888.1341	233845.7078	4.986		
				315884.8335	233838.9133	4.986		
				315877.3339	233842.106	4.986		

# CALCULATION SHEET

Project Title: Dublin Metro North		Sheet No: 11	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop		Calc No: 12	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## DELTA B:

### Chainage 18430 to 18780

<b>Area of Interest:</b>	(315850 E, 234450 N) (316100 E, 233950 N)
<b>Number of buildings:</b>	8
<b>Number of Tunnels</b>	5
<b>Building Structural characteristics-File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\DMN survey data\dmn.xls
<b>Building Coordinates- File Location:</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\documents and drawings\oct 07 spreadsheets\building coordinates 10.07\Deta B data\final spreadsheet.xls
<b>Analysis directory (Building Damage Assessment):</b>	P:\B0307000 Dublin Metro North\Design\Settlement Analysis - building Damage Assessment\Building Damage Assessment\delta B\Griffith Av. to St Stephen's Green\IV.O Connell to St Stephen\21. Connell to St Stephen III
<b>DeltaB Input File:</b>	wb22.inp
<b>Geology:</b>	Limestone

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 12	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop			Calc No: 12	
Job No: B0307000		File: City Centre		
Made By: PN	Date: 11/03/08	Revised By:	Date:	
Checked By: DIT	Date: 11/03/08	Checked By:	Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
71	Grafton Street	No	6	315911.282	233726.770	6.073	20	2.6
				315909.344	233721.634	6.142		
				315907.152	233720.747	6.222		
				315897.377	233724.358	6.217		
				315899.982	233731.105	6.073		
				315911.282	233726.770	6.073		
78-79	Grafton Street	No	12	315924.904	233762.940	5.618	20	2.6
				315922.768	233757.254	5.622		
				315906.888	233763.231	5.722		
				315902.879	233752.510	5.858		
				315889.314	233755.283	5.858		
				315895.077	233764.196	5.722		
				315899.835	233763.045	5.722		
				315901.656	233769.736	5.562		
				315911.028	233767.561	5.562		
				315921.040	233763.698	5.562		
				315921.338	233764.424	5.542		
				315924.904	233762.940	5.618		
7	Harry Street	No	5	315882.662	233737.732	6.373	16.5	2.6
				315899.982	233731.005	6.373		
				315897.377	233724.358	6.517		
				315880.138	233729.726	6.517		
				315882.662	233737.732	6.373		
4	Harry Street	No	6	315862.817	233724.564	6.68	6	2.6
				315854.882	233717.787	6.68		
				315853.968	233715.258	6.68		
				315867.051	233710.463	6.68		
				315871.013	233721.396	6.68		
				315862.817	233724.564	6.68		
3	Harry Street	No	5	315876.124	233719.731	7.18	13	2.6
				315872.226	233709.301	7.18		
				315878.0626	233707.2148	7.18		
				315881.795	233717.657	7.18		
				315876.124	233719.731	7.18		
58-59	Grafton Street	No	7	315885.507	233630.407	7.472	20	2.6
				315887.676	233618.622	7.528		
				315882.932	233618.274	7.569		
				315882.9636	233619.112	7.562		
				315875.572	233619.779	7.612		
				315874.065	233630.96	7.531		
				315885.507	233630.407	7.472		

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North			Sheet No: 13	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop			Calc No: 12	
Job No: B0307000		File: City Centre		
Made By: PN	Date: 11/03/08	Revised By:	Date:	
Checked By: DIT	Date: 11/03/08	Checked By:	Date:	

Building No.	Street Name	Piled (Y/N)/Cap depth, Toe depth	Number of Building Points	Building Coordinates X,Y,Z			Building Height (m)	Stiffness of Structure (E/G)
64	Grafton Street	No	7	315877.985	233681.017	7.033	16	2.6
				315877.138	233679.318	7.061		
				315878.752	233678.715	7.087		
				315876.451	233672.063	7.193		
				315859.138	233674.596	7.087		
				315863.178	233685.31	7.087		
				315877.985	233681.017	7.033		
Gaeity Theatre	King Street South	No	7	315828.969	233654.25	7.5	15	2.6
				315864.388	233644.753	7.5		
				315852.298	233603.48	7.5		
				315818.652	233614.384	7.5		
				315827.51	233643.349	7.5		
				315825.807	233643.927	7.5		
				315828.969	233654.25	7.5		

# CALCULATION SHEET



Project Title: Dublin Metro North		Sheet No: 14	
Subject: Building Damage Assessment- Chainage 17860 to 18780-O Connell Bridge to St Stephen's Green Stop		Calc No: 12	
Job No: B0307000		File: City Centre	
Made By: PN	Date: 11/03/08	Revised By:	Date:
Checked By: DIT	Date: 11/03/08	Checked By:	Date:

## OUTPUT FILE NAMES

### Chainage 17860 to 18200

<b>Output data file:</b>	cross2.dat
<b>Damage category output file:</b>	cross2.gis

### Chainage 18070 to 18490

<b>Output data file:</b>	cross2.dat
<b>Damage category output file:</b>	cross2.gis

### Chainage 18430 to 18780

<b>Output data file:</b>	cross2.dat
<b>Damage category output file:</b>	cross2.gis

Project Title: Dublin Metro North		Sheet No: 1	
Subject: Building Response adjacent to St Stephen's Green Stop		Calc No: 13	
Job No: B0307000			File: City Centre
Made By: AL	Date: 15/01/09	Revised By:	Date:
Checked By: LR	Date: 15/01/09	Checked By:	Date:

## St Stephen's Green Stop Building Response

### INTRODUCTION

The objective of this calculation is to determine the damage category of buildings adjacent to St Stephen's Green Stop which have been identified for further assessment in the Stage 1 Preliminary ground Movement Report.

Buildings classified as 'Moderate' or above will require further review as part of a detailed Stage 3 assessment to be undertaken by the DBFM Contractor.

### REFERENCES

Document/Drawing Ref	Rev	Title
B0307000-010\Geo.02\001	0	Design Input Statement for Predicting Ground Movements and the Response of Buildings, Infrastructure and Utilities Generated by Underground Excavation.
B03070000-010/STB.061/004	02	Stage 1 Preliminary Ground Movement Assessment Report.
BMN/0000/TU/7051	B05	Predicted Settlement Contours, O'Connell Bridge to St. Stephen's Green

### METHODOLOGY

Calculations have been undertaken to determine the limiting tensile strain and the corresponding predicted damage category for buildings adjacent to Stop boxes. The Building Response Assessment has been carried out taking account of the particular settlement profile predicted for each Stop (a function of construction sequencing, wall stiffness, propping arrangement and ground conditions) and geometrical and orientation characteristics of the building being considered.

The predicted damage category for each building considered has been determined using the best estimate ground movement parameters set down in 'Design Input Statement for Predicting Ground Movements and Response of Overlying Property to Underground Excavation'. The building response assessment assumes that the building deforms to the Greenfield settlement and there is no soil / structure interaction. This is considered to provide conservative predictions.

From the Stage 1 Predicted Settlement drawings zones of hogging or sagging which traverse the each building considered have been identified. For each zone the horizontal strain and bending strain exerted on the building has been calculated. The total bending strain and the total shear strain was then determined. The greater of these two values is the limiting tensile strain, which has been used to predict the damage category for the building in accordance with Boscardin and Cordin, 1989.

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 2	
Subject: Building Response adjacent to St Stephen's Green Stop		Calc No: 13	
Job No: B0307000		File: City Centre	
Made By: AL	Date: 15/01/09	Revised By:	Date:
Checked By: LR	Date: 15/01/09	Checked By:	Date:

## Horizontal Strain

The average horizontal strain exerted on the structure has been calculated as the change in length of the building brought about by horizontal ground movements divided by the original length of the building.

The formula used is as follow:

$$\epsilon_h = \left( \frac{S_{ha} - S_{hb}}{L_o} \right)$$

Where:

- $S_{ha}$  is the horizontal movement calculated at the nearest edge of the building to the underground structure that caused the settlement (indicated as point A in the figures 1,2 and 3)
- $S_{hb}$  is the horizontal movement calculated at the furthest edge of the building to the underground structure that caused the settlement (indicated as point B in the figures 1,2 and 3)
- $L_o$  is the original length of the building, calculated as follow:  
 $L_o = L_1 + L_2$  (see Figures 1 and 2)  
 $L_o = L_1^h + L_2^h$  (hogging zone),  $L = L_1^s + L_2^s$  (sagging zone), (see Figure 3 top drawing)  
 $L_o = L$  (see Figure 3, bottom drawing)

The horizontal movement has been calculated as follow:

$$S_h = K \times S_v$$

Where:

- K is the ratio of horizontal to vertical movement (dependant on the stiffness of the surrounding soil).
- $S_v$  is the vertical movement.

Vertical movements have been obtained by trigonometry between known data points from the relevant Stage 1 Predicted Settlement Contour Drawing (see Figures 1, 2 and 3).

The ratio of horizontal movement to vertical movement (K) has been determined based on the findings of Clough & O'Rourke (1990), where for stiff to very hard clays, it is suggested that horizontal movements are equal to or will exceed the vertical movement by a ratio of 1.0 to 2.5. Given that the Dublin glacial till is much stiffer than the majority of stiff to hard clays used in the database and assuming a high horizontal support stiffness for Metro North excavations, it has been assumed that a horizontal to vertical movement ratio of 1.0 to 1.0 is appropriate for the glacial till. For excavations in sand, the horizontal to vertical movement ratio is suggested to range from 0.8 to 1.5. For the Stage 2A assessment a value of horizontal to vertical movement ratio of 1.0 has been assumed for very dense granular material and a ratio of 1.5 assumed for loose to medium dense sands.

# CALCULATION SHEET

**JACOBS**

Project Title: Dublin Metro North		Sheet No: 3	
Subject: Building Response adjacent to St Stephen's Green Stop		Calc No: 13	
Job No: B0307000		File: City Centre	
Made By: AL	Date: 15/01/09	Revised By:	Date:
Checked By: LR	Date: 15/01/09	Checked By:	Date:

## **Bending Strain**

The Bending Strain has been calculated by treating the building as an idealised beam of span L (length of the building) and height H (height of the building) deforming under a central point load to give a maximum deflection. The expression applied to calculate the bending strain is presented in the general form:

$$\frac{\Delta}{L} = \left( \frac{L}{12t} + \frac{3EI}{2tLHG} \right) \epsilon_b$$

Where:

- H is the height of the building
- L is the length of the building
- E and G are respectively the Young's modulus and shear modulus of the building
- I is the second moment of area of the equivalent beam (i.e.  $H^3/12$  in sagging zone and  $H^3/3$  in hogging zone)
- t is the furthest distance from the neutral axis to the edge of the beam (i.e.  $H/2$  in the sagging zone and H in the hogging zone)

The difference in the position of the neutral axis is related to the restraining effect of the foundations. For buildings in the hogging zone the neutral axis has been taken to coincide with the lower extreme fibre of the beam, i.e. the bottom of the structure. For buildings in the sagging zone mode, however, the neutral axis has been assumed to remain in the middle of the beam. Thus, the bending strain is calculated taking into account the position of the building, whether it is in the sagging zone or in the hogging zone.

For the case where the building is partially located in both hogging and sagging zones, separate analyses will be conducted to determine the bending strain attributed for each portion of the building. The larger bending strain between the two sides will be used to define the damage category of the building.

Building dimensions and their position relative to the adjacent Stop box have been obtained directly from topographical survey drawings. In the absence of any topographical survey OS mapping has been used. The predicted settlement contour drawings have been used to identify sagging and hogging zones and retrieve changes in vertical movement for each building identified.

The follow criteria have been applied to define the sagging and the hogging zones for each building considered:

- The settlement trough of the Stop box has been approximated by straight lines of same gradient that connect between subsequent contour points.
- Buildings with the edges confined within two consecutive contour lines are subjected to the horizontal strain only.
- Buildings crossed by one settlement contour line are subjected to both horizontal and bending strain (sagging or hogging).
- Buildings crossed by two settlement contour lines are subjected to both horizontal and bending strain (sagging, hogging or both).

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