	Project			File location
FORTH ROAD BRIDGE	**Cable Band Bolt - Factor of Safety**			BC04_Cable_Bands
				Calc sheet no. / rev
	Drawing Ref	Calc by	Date	Chk by / Date
	33111/AB/20	**DB**	**Jul2011**	

Ref	Calculations	Output

Determine FOS of Cable Band Bolt

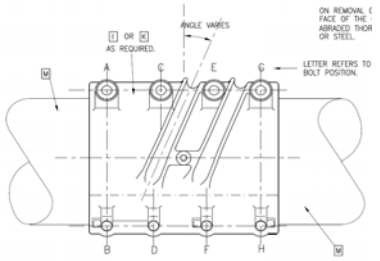
The cable band bolts on the FRB were replaced between 2000 and 2001. Since the installation of the cable band bolts several defects have been found with the new system which has resulted in concerns in regards to the FOS to prevent slipping of the cable bands. The following defects have been noted:

1, Several cable band nuts have cracked and thus failed releasing the tensile load within the bolt.
2, The actual load achieved during tensioning of the bolt group was less than specified.

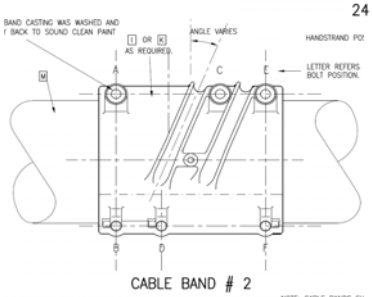
The tension within the bolts prevents slipping of the cable bands through friction, therefore any loss of tension will result in a reduction in the FOS. These calcs determine the achieved FOS.

There are 3 arrangement of cable band bolts, drawings and details can be found in the following file:
G:\DRAWINGS\BC 16 suspenders\Replacement of Hangers
Drawing No: 33111/AB/20

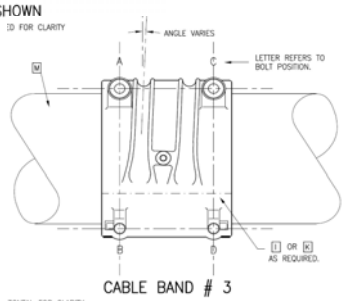
Arangement details given below for refereneece:



CABLE BAND # 1
24 No. AS SHOWN



CABLE BAND # 2
40 No. AS SHOWN



CABLE BAND # 3
128 No. AS SHOWN

Specifications details of the cable bands can be found here:
G:\filing\BC_FILES\BC04_Cable_Bands\Original Bolt Spec

	Project	File location
FORTH ROAD BRIDGE	**Cable Band Bolt - Factor of Safety**	BC04_Cable_Bands
		Calc sheet no / rev

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Ref	Calculations	Output

Determine FOS of Cable Band Bolt

Calculate the angle of applied load

Angle of load transvered to cable band varies throughout its length. From Report on loading a survey of the cable was undertaken in 1986 and can be found in the FRB 'blue book' Vol vi verification part F.

From the survey information a graph was plotted to determine the equation of the main cable line and has been determined as follows:

Main Span Equation:

$f(x) = 0.000358x^2 - 0.3556x + 154.13$ (see attached graph for verification) — Equ 1

Side Span South Equation:

$f(x) = 0.0.000493x^2 + 0.0865x + 50.075$ (see attached graph for verification) — Equ 2

Side Span North Equation:

$f(x) = 0.0.000501x^2 - 0.4626x + 153.64$ (see attached graph for verification) — Equ 3

These second order polynominal equations are used to calculate the slope at any given Panel Point Number.

Example - Determine slope at first hanger south Main Span:

f'(x) = 0.00072 x - 0.3556
f'(18.288) = -0.34208 x= 18.882 PP 48S — **MS Max Slope**
f'(182.88) = 0.34187 x= 974.118 PP 66N

Side Span South

f'(x) = 0.00099 x + 0.0865 — **SS S Max Slope**
f'(18.882) = 0.44122 x= 359.758 PP 42S — 0.4412

Side Span North
f'(x) = 0.00099 x - 0.4601
f'(18.882) = -0.44148 x= 18.882 PP 42S — **SS NMax Slope**

	Project			File location
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Ref	Calculations	Output

Determine the live load applied to Hanger

In accordance with the FRB ICE proceedings section 2.113 the hangers were designed to accommodate the following loads:

Main Span Design Loads

Combination 1 - KEL, UDL 657ft loaded length
Dead Load = 113 tons
Live Load = 45 tons

Total = 1550 kN

Side Span Design Loads

Combination 1 - KEL, UDL 657ft loaded length
Dead Load = 167 tons
Live Load = 50 tons

Total = 2128.8 kN

BSALL Loading

Note that hanger loads used by MB were less than original live loads; 380kN used opposed to 490.5kN Side Span and 442kN Main Span.

Calculations undertaken by MB stated that Hanger tensions were calculated from PP32 and extrapolated to others.

However in November 2008 W.A.Fairhurst & Partners determined the hanger loads at each panel point. Appendix B attached for Ref.

Using these hanger loads it can be seen that for both the side span and the main span the factor of safety can be seen to drop slightly as shown in summary table 3.

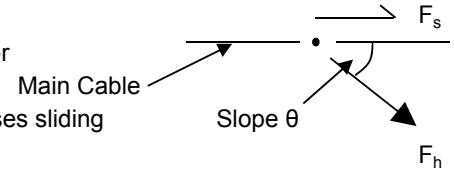
It can be seen that the increase in dead load of the structure presumably from an increase in superimposed dead loads is the largest contributor to the increase in load.

Determine Slip Force

F_h = Load from Hanger

F_s = Force which causes sliding

$F_s = F_h \cos\theta$



PP 48S Example

Slope = 0.342 ∴ $\theta = \tan^{-1}(1/0.342)$ = 71.1152 °

Assume F_h = 1550 kN

∴ F_s = 1550 *cos 71.115 = 501.68 kN →

PP 48S
F_s = 502 kN

	Project			File location
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Ref	Calculations	Output

Determine the Slip Factor/Coefficient of Friction

The slip factor will have a direct and very significant impact on the capacity of the cable band to resist sliding forces. The friction capacity of the cable band is given by:

$P_D = F_v.\mu.N$ Where:

P_D = Friction Capacity (kN)
F_v = Prestress Load of cable band bolt (kN)
μ = Slip factor
N = No. of bolts

Unfortunately no tests were carried out during construction to determine the friction between cable band bolts and main cables.

From the FRB ICE proceedings friction between the wires of the main cable and metal sprayed surfaces of the saddles was assumed to be equal to 15%. The Proceedings state that practical test made by the Contractor gave results of 30% however no details of these are provided.

Results from these tests would suggest that slip factor up to 30% could be justified.

Testing has been carried out for other suspension bridges for example for the Delaware River Bridge full size test was carried out by Lehigh University. The conclusion of these test were that bulging of the main cable contributed significantly to resisting slip.
It can be seen however that during the test the replica of the main cable was not under any force. Insitu however the main cable will be under considerable tensile force which will prevent the majority of bulging that was experienced during the test. Therefore it is assumed that there is no additional friction as a result of bulging.

Tests of individual galvanised wires also carried out by Lehigh University show that for a smooth surface an average of 20.4% slip factor was achieved. Rougher surfaces of galvanised wire resulted in a reduction in friction. A "rough surface, 17 cuts per inch" achieved a slip factor of only 16.9%.

BS 5400 part 3 clause 14.5.4.4 gives slip factors at friction surfaces for HSFG bolts.
For surfaces with sprayed zinc μ = 0.40 has been specified.

Ref	Calculations	Output

Determine the Slip Factor/Coefficient of Friction (cont)

Neither BS 5400 or the Eurocodes provide a slip factor for galvanised surfaces. Various tests have been carried out for galvanised surface and results range significantly. The Galvanisers Association specifies the following slip factors are achieved depending on the preparation of the surface:

Preparation Technique	μ
As galvanised	0.14
Weathered galvanised	0.20
Galvanised-wire brush	0.31
Galvanised-grit blasted	0.31
Bare steel, as-rolled	0.35

Galvanised surfaces slip factor range quite significantly depending on the surface preparation however as the section were galvanised during construction during in the 1960's the surface preparation could be described as weathered.
This would confirm the results from the Delaware river bridge of 20.4%.

Some time after the connection is made the Galvanisers Association states that galvanised joints will develop a characteristic known as 'lock-up' The 'lock-up' is a result of friction between the two galvanized surfaces during dynamic movements. After 'lock up' a friction coefficient equal to that of bare steel can be achieved as above (35%).
It is assumed for these calculations that no dynamic movement can occur at the connection interface during construction as this would result in failure of the joint and therefore 'lock up' of the joint is not achieved.

Assumed Slip Factor

For these calculations a slip factor μ = 0.200

μ = 0.200

Determine Capacity of Connection to Resist Slip

$P_D = F_v.\mu.N$

Example PP 48S

F_v = 800 kN (assumed, see later section for actual prestress force)
N = 6 No.

P_D = 800 x 0.200 x 6 = 960 kN

P_D = 960 kN

	Project	File location
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Ref	Calculations	Output
	Determine the FOS against Slip	
	Example PP48 S	FOS with μ = 0.20
	FOS = Capacity to Resist Slip / Slip Force = 960 / 501.677 =	1.9136
	For comparison the FOS against slip with μ = 0.3 is given below	
	FOS with slip of 0.3 = 2.87	
	Determine the Required FOS against Slip	
BS 5400 Part 1 Table 1	Dead Load (steel) y_{fl} = 1.05 $y_{fl}*y_{f3}$ =	y_{FDL} = 1.05
	Superimposed Dead y_{fl} = 1.2 $y_{fl}*y_{f3}$ =	y_{FSD} = 1.2
	Live Load y_{fl} = 1.5 $y_{fl}*y_{f3}$ =	y_{FLL} = 1.5
	Side Span	
As per WAF Hanger load App B	Dead Load Percentage of total load = 66.52% * y_{FDL} = 0.698	
	Superimposed load % of total load = 14.17% * y_{FSD} = 0.170	
	Live load Percentage of total load = 19.31% * y_{FLL} = 0.290	
	∑ 100.00% y_F = 1.158	
BS5400 Table 2 Cl 14.5.4.2	In accordance with BS 5400 Part-3 the Partial Factor of safety applied to the friction capacity of HSFG is:	
	y_{f3} = 1.1	
	y_{m1} = Is partial factor for characteristic yield stress	
	y_{m2} = Is partial factor for modelling uncertainties	
	y_m = $y_{m1}*y_{m2}$ = 1.3 Friction capacity of HSFG	
	This partial factor of safety is assumed appropriate to prevent slip of the cable band bolts.	
	Side Span required FOS must be > $y_F*y_m*y_{F3}$ =	**1.6561**
	Note that current practices for the design of a suspension bridge cable will adopt a material factor of 1.67 for tension in the cable.	
	Recalculating the FOS required for using 1.67 = $1.67*y_F$ =	**2.1275**
	Main Span	
As per WAF Hanger load App B	Dead Load Percentage of total load = 56.93% * y_{DL} = 0.598	
	Superimposed load % of total load = 17.81% * y_{SD} = 0.214	
	Live load Percentage of total load = 25.26% * y_{LL} = 0.379	
	∑ 100.00% 1.190	
	Main Span required FOS must be > y_m*y_F =	**1.7023**
	Recalculating the FOS required for using 1.67 = $1.67*y_F$ =	**2.1868**
	Conclusion	
	If FOS using μ = 0.20 > y_m*y_F then capacity is sufficent	
	Therefore capcity is sufficient if y_m of 1.3 is used but insufficient if material factor is taken as 1.67	

	Project			File location
FORTH ROAD BRIDGE	**Cable Band Bolt - Factor of Safety**			BC04_Cable_Bands
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Ref	Calculations	Output

Determine Tensile Force in Cable Band Bolts

$E = \sigma/\varepsilon$

ε = Strain = $\Delta L / L$

σ = Stress = F_v/A

E = Youngs Modulus

$\therefore$

$F_v = E*A*(\Delta L/L)$ - Relaxation of Stress

Original specified force was 800kN. Measurements taken during installation resulted in a force between 770kN and 800kN.

Extensions of bolts were re-measured by FRB in 2007 and 2008. Results showed a decrease in the amount of force within cable band bolts. The reduced force within he cable band has been used to calculate the Factor of safety at each hanger location.

	Project			File location
FORTH ROAD BRIDGE	**Cable Band Bolt - Factor of Safety**			BC04_Cable_Bands
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Ref | Calculations | Output

Determine Factor of Safety against slip **μ = 0.3**

Table 1 - Input Values as MB Calcs

	Panel Point	Angle Radians	No Bolts	Bolt Tension (kN)	Dead Load, nom (kN)	Live Load, nom (kN)	Total Load, nom (kN)	FoS
Side Span	2	0.0865	4	800	1540	380	1920	5.788
	4	0.1061	4	800	1540	380	1920	4.721
	6	0.1236	4	800	1540	380	1920	4.056
	8	0.1411	4	800	1540	380	1920	3.555
	10	0.1580	4	800	1540	380	1920	3.178
	12	0.1762	4	800	1540	380	1920	2.852
	14	0.1938	4	800	1540	380	1920	2.596
	16	0.2113	4	800	1540	380	1920	2.384
	18	0.2289	6	800	1540	380	1920	3.305
	20	0.2465	6	800	1540	380	1920	3.074
	22	0.2641	6	800	1540	380	1920	2.873
	24	0.2817	6	800	1540	380	1920	2.698
	26	0.2994	6	800	1540	380	1920	2.543
	28	0.3170	6	800	1540	380	1920	2.406
	30	0.3347	6	800	1540	380	1920	2.283
	32	0.3524	8	800	1540	380	1920	2.897
	34	0.3701	8	800	1540	380	1920	2.765
	36	0.3878	8	800	1540	380	1920	2.644
	38	0.4056	8	800	1540	380	1920	2.534
	40	0.4233	8	800	1540	380	1920	2.434
	42	0.4432	8	800	1540	380	1920	2.332
	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	46	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Main Span	46	0.3473	6	800	1050	380	1430	2.959
	48	0.3326	6	800	1050	380	1430	3.084
	50	0.3194	6	800	1050	380	1430	3.207
	52	0.3063	4	800	1050	380	1430	2.226
	54	0.2932	4	800	1050	380	1430	2.323
	56	0.2800	4	800	1050	380	1430	2.429
	58	0.2669	4	800	1050	380	1430	2.545
	60	0.2538	4	800	1050	380	1430	2.674
	62	0.2408	4	800	1050	380	1430	2.815
	64	0.2277	4	800	1050	380	1430	2.974
	66	0.2146	4	800	1050	380	1430	3.152
	68	0.2016	4	800	1050	380	1430	3.353
	70	0.1885	4	800	1050	380	1430	3.583
	72	0.1755	4	800	1050	380	1430	3.845
	74	0.1625	4	800	1050	380	1430	4.149
	76	0.1494	4	800	1050	380	1430	4.510
	78	0.1364	4	800	1050	380	1430	4.937
	80	0.1234	4	800	1050	380	1430	5.454
	82	0.1104	4	800	1050	380	1430	6.093
	84	0.0974	4	800	1050	380	1430	6.903
	86	0.0844	4	800	1050	380	1430	7.964
	88	0.0714	4	800	1050	380	1430	9.410
	90	0.0584	4	800	1050	380	1430	11.502
	92	0.0454	4	800	1050	380	1430	14.792
	94	0.0325	4	800	1050	380	1430	20.660
	96	0.0195	4	800	1050	380	1430	34.429
	98	0.0065	4	800	1050	380	1430	103.282

Side Span Minimum FOS = 2.283

Side Span Minimum FOS = 2.226

1. Hanger tension calculated for PP32 and extrapolated to others
2. BSALL (175m), KEL, ftwy: 5kN/m2 2 bays, BSFLL (175m)
3. Assumes "slope" was meant to be angle in radians.

Note that if you assume that the "Slope" provided by MB is an angle in radians then calculated values are exactly the same as per MB Calcs. The angle provided however is a slope and not an angle it can therefore be seen that MB calcs are incorrect. See next sheet for justification

FORTH ROAD BRIDGE

Project	File location
Cable Band Bolt - Factor of Safety	BC04_Cable_Bands
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Ref | Calculations | Output

Determine Factor of Safety against slip **μ = 0.3**

Table 2 - Check MB Angle Against Calculated Angle

	Panel Point	MB Slope	Calculate Angle (°) Assume MB Slope	Calculate Angle (°) Assume MB Angel in Radians	Slope Determined From Survey	Calculate Angle (°) From Survey	% Difference if MB is Slope	% Difference if MB is Angle
	2	0.087	4.944	4.956	0.069	3.955	20.010%	20.209%
	4	0.106	6.056	6.079	0.088	5.015	17.201%	17.509%
	6	0.124	7.046	7.082	0.106	6.071	13.832%	14.267%
	8	0.141	8.031	8.084	0.125	7.124	11.298%	11.880%
	10	0.158	8.979	9.053	0.144	8.172	8.985%	9.731%
	12	0.176	9.993	10.096	0.162	9.214	7.794%	8.731%
	14	0.194	10.968	11.104	0.181	10.250	6.543%	7.687%
Side Span	16	0.211	11.931	12.107	0.199	11.280	5.459%	6.829%
	18	0.229	12.893	13.115	0.218	12.302	4.584%	6.200%
	20	0.247	13.847	14.123	0.237	13.316	3.836%	5.716%
	22	0.264	14.794	15.132	0.255	14.322	3.191%	5.352%
	24	0.282	15.733	16.140	0.274	15.319	2.629%	5.089%
	26	0.299	16.668	17.154	0.293	16.306	2.168%	4.943%
	28	0.317	17.589	18.163	0.311	17.284	1.732%	4.838%
	30	0.335	18.505	19.177	0.330	18.251	1.373%	4.826%
	32	0.352	19.412	20.191	0.348	19.208	1.053%	4.868%
	34	0.370	20.310	21.205	0.367	20.154	0.767%	4.958%
	36	0.388	21.196	22.219	0.386	21.088	0.510%	5.091%
	38	0.406	22.077	23.239	0.404	22.011	0.302%	5.285%
	40	0.423	22.943	24.253	0.423	22.922	0.092%	5.490%
	42	0.443	23.903	25.393	0.441	23.821	0.344%	6.194%
	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	46	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	48	0.347	19.152	19.899	0.342	18.885	1.396%	5.096%
	50	0.333	18.397	19.057	0.329	18.189	1.134%	4.555%
	52	0.319	17.713	18.300	0.315	17.487	1.281%	4.446%
	54	0.306	17.030	17.550	0.302	16.779	1.472%	4.390%
	56	0.293	16.341	16.799	0.288	16.067	1.680%	4.361%
	58	0.280	15.642	16.043	0.274	15.349	1.877%	4.327%
	60	0.267	14.944	15.292	0.261	14.626	2.128%	4.357%
	62	0.254	14.241	14.542	0.247	13.898	2.406%	4.424%
	64	0.241	13.539	13.797	0.234	13.166	2.754%	4.571%
	66	0.228	12.828	13.046	0.220	12.430	3.103%	4.727%
	68	0.215	12.112	12.296	0.207	11.689	3.494%	4.936%
Main Span	70	0.202	11.398	11.551	0.193	10.944	3.984%	5.254%
	72	0.189	10.675	10.800	0.180	10.195	4.492%	5.600%
	74	0.176	9.954	10.055	0.166	9.443	5.130%	6.087%
	76	0.163	9.230	9.311	0.153	8.688	5.871%	6.687%
	78	0.149	8.497	8.560	0.139	7.930	6.679%	7.365%
	80	0.136	7.767	7.815	0.126	7.168	7.710%	8.276%
	82	0.123	7.035	7.070	0.112	6.405	8.958%	9.416%
	84	0.110	6.300	6.325	0.099	5.638	10.499%	10.860%
	86	0.097	5.563	5.581	0.085	4.870	12.451%	12.726%
	88	0.084	4.824	4.836	0.072	4.101	15.003%	15.204%
	90	0.071	4.084	4.091	0.058	3.329	18.482%	18.620%
	92	0.058	3.342	3.346	0.045	2.557	23.506%	23.593%
	94	0.045	2.599	2.601	0.031	1.783	31.403%	31.450%
	96	0.033	1.861	1.862	0.018	1.009	45.795%	45.814%
	98	0.020	1.117	1.117	0.004	0.234	79.009%	79.012%
	100	0.007	0.372	0.372	-0.009	179.460	-48087.850%	-48087.171%

Significant difference

1. Hanger tension calculated for PP32 and extrapolated to others
2. BSALL (175m), KEL, ftwy: 5kN/m2 2 bays, BSFLL (175m)
3. Slope as per MB calculations

Much better correlation if MB column is slope rather than angle in radians.

As can be seen from the table the slope from MB calculations correspond well with the slope determined from survey dimension taken in 1886. Significant difference are detected if the slope is used as and angle in radians.

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Cable Band Bolt - Factor of Safety	BC04_Cable_Bands
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Ref | Calculations | Output

Determine Factor of Safety Against Slip $\mu = 0.3$

Table 2 - Re-calculated with HA and BSALL As per Hanger report

Ref	Panel Point	Slope	No Bolts	Bolt Tension (kN)	Dead + HA Loads + Footway (BD 37/01)	HA FOS	Dead + BSALL (2006) + Footway (BD 37/01)	BSALL FoS	Output
	2	0.0691	4	800	2560	5.438	2180	6.385	
	4	0.0877	4	800	2110	5.205	1920	5.720	
	6	0.1064	4	800	2160	4.202	1970	4.607	
	8	0.1250	4	800	2030	3.813	1850	4.184	
	10	0.1436	4	800	2090	3.231	1900	3.555	
	12	0.1622	4	800	2110	2.841	1930	3.106	
	14	0.1808	4	800	2150	2.509	1960	2.752	
Side Span	16	0.1995	4	800	2130	2.304	1930	2.543	
	18	0.2181	6	800	2140	3.158	1940	3.484	
	20	0.2367	6	800	2150	2.908	1940	3.223	
	22	0.2553	6	800	2140	2.720	1930	3.016	
	24	0.2739	6	800	2170	2.512	1960	2.781	**HA Side Span**
	26	0.2925	6	800	2170	2.363	1970	2.603	**Minimum FOS**
	28	0.3112	6	800	2140	2.265	1940	2.498	FOS = 2.139
	30	0.3298	6	800	2150	2.139	1950	2.358	
	32	0.3484	8	800	2180	2.677	1980	2.947	
	34	0.3670	8	800	2120	2.629	1930	2.887	
	36	0.3856	8	800	2110	2.529	1940	2.751	
	38	0.4042	8	800	2130	2.405	1950	2.627	**BSALL Side Span**
	40	0.4229	8	800	2150	2.293	1980	2.490	**Minimum FOS**
	42	0.4415	8	800	2170	2.191	2020	2.353	FOS = 2.353
	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	46	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	48	0.3421	6	800	1370	3.247	1310	3.396	
	50	0.3286	6	800	1530	3.015	1390	3.319	
	52	0.3150	6	800	1590	3.014	1420	3.375	
	54	0.3015	4	800	1610	2.065	1420	2.342	
	56	0.2880	4	800	1660	2.090	1460	2.376	
	58	0.2745	4	800	1690	2.146	1480	2.451	
	60	0.2610	4	800	1680	2.263	1470	2.586	
	62	0.2474	4	800	1680	2.379	1470	2.719	
	64	0.2339	4	800	1740	2.422	1520	2.773	
	66	0.2204	4	800	1720	2.593	1500	2.973	
	68	0.2069	4	800	1680	2.821	1470	3.223	
Main Span	70	0.1934	4	800	1710	2.957	1500	3.371	
	72	0.1798	4	800	1680	3.228	1470	3.689	
	74	0.1663	4	800	1690	3.462	1480	3.953	
	76	0.1528	4	800	1720	3.695	1510	4.209	
	78	0.1393	4	800	1670	4.167	1460	4.766	
	80	0.1258	4	800	1700	4.525	1490	5.163	
	82	0.1122	4	800	1710	5.033	1500	5.737	
	84	0.0987	4	800	1700	5.748	1490	6.558	**HA Side Span**
	86	0.0852	4	800	1710	6.612	1500	7.538	**Minimum FOS**
	88	0.0717	4	800	1660	8.088	1450	9.259	FOS = 2.065
	90	0.0582	4	800	1710	9.667	1500	11.021	
	92	0.0447	4	800	1710	12.586	1500	14.348	
	94	0.0311	4	800	1680	18.364	1470	20.988	
	96	0.0176	4	800	1720	31.695	1510	36.103	**Side Span**
	98	0.0041	4	800	1720	136.376	1500	156.378	**Minimum FOS**
	100	-0.0094	4	800	1670	60.983	1460	69.755	FOS = 2.342

1. Hanger tension taken from W.A. Fairhurst Hanger Loads Report
2. Slope calculated from historic survey see sheet 3 for calculation details.

FORTH ROAD BRIDGE

Project	File location
Cable Band Bolt - Factor of Safety	BC04_Cable_Bands
	Calc sheet no. / rev

Drawing Ref	Calc by	Date	Chk by	Date
33111/AB/20	**DB**	**Jul2011**		

Ref | Calculations | Output

Determine Factor of Safety Against Slip **μ = 0.3**

Table 4 - Re-calculated with amended Bolt Tension

	Panel Point	Slope	No Bolts	Bolt Tension (kN)	Dead + HA Loads + Footway (BD 37/01)	HA FOS	Dead + BSALL (2006) + Footway (BD 37/01)	BSALL FoS
	2	0.0691	4	660.00	2560	4.486	2180	5.268
	4	0.0877	4	660.00	2110	4.294	1920	4.719
	6	0.1064	4	660.00	2160	3.467	1970	3.801
	8	0.1250	4	660.00	2030	3.146	1850	3.452
	10	0.1436	4	660.00	2090	2.666	1900	2.933
	12	0.1622	4	660.00	2110	2.344	1930	2.563
	14	0.1808	4	660.00	2150	2.070	1960	2.271
Side Span	16	0.1995	4	660.00	2130	1.901	1930	2.098
	18	0.2181	6	660.00	2140	2.606	1940	2.874
	20	0.2367	6	660.00	2150	2.399	1940	2.659
	22	0.2553	6	660.00	2140	2.244	1930	2.488
	24	0.2739	6	660.00	2170	2.072	1960	2.294
	26	0.2925	6	660.00	2170	1.950	1970	2.148
	28	0.3112	6	660.00	2140	1.868	1940	2.061
	30	0.3298	6	660.00	2150	1.764	1950	1.945
	32	0.3484	8	660.00	2180	2.209	1980	2.432
	34	0.3670	8	660.00	2120	2.169	1930	2.382
	36	0.3856	8	660.00	2110	2.086	1940	2.269
	38	0.4042	8	660.00	2130	1.984	1950	2.167
	40	0.4229	8	660.00	2150	1.892	1980	2.054
	42	0.4415	8	660.00	2170	1.807	2020	1.942
	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	46	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	48	0.3421	6	629.08	1370	2.554	1310	2.671
	50	0.3286	6	693.17	1530	2.613	1390	2.876
	52	0.3150	6	725.62	1590	2.734	1420	3.061
	54	0.3015	4	658.69	1610	1.701	1420	1.928
	56	0.2880	4	717.70	1660	1.875	1460	2.131
	58	0.2745	4	699.08	1690	1.875	1480	2.141
	60	0.2610	4	666.67	1680	1.886	1470	2.155
	62	0.2474	4	673.45	1680	2.003	1470	2.289
	64	0.2339	4	693.15	1740	2.099	1520	2.402
	66	0.2204	4	666.80	1720	2.161	1500	2.478
	68	0.2069	4	692.23	1680	2.441	1470	2.789
Main Span	70	0.1934	4	660.25	1710	2.441	1500	2.782
	72	0.1798	4	666.73	1680	2.690	1470	3.075
	74	0.1663	4	679.20	1690	2.939	1480	3.356
	76	0.1528	4	647.64	1720	2.991	1510	3.407
	78	0.1393	4	626.23	1670	3.262	1460	3.731
	80	0.1258	4	635.39	1700	3.594	1490	4.101
	82	0.1122	4	650.55	1710	4.093	1500	4.666
	84	0.0987	4	595.89	1700	4.281	1490	4.884
	86	0.0852	4	732.49	1710	6.054	1500	6.902
	88	0.0717	4	695.43	1660	7.030	1450	8.049
	90	0.0582	4	602.79	1710	7.284	1500	8.304
	92	0.0447	4	657.67	1710	10.346	1500	11.795
	94	0.0311	4	643.95	1680	14.782	1470	16.894
	96	0.0176	4	624.01	1720	24.723	1510	28.161
	98	0.0041	4	638.54	1720	108.852	1500	124.817
	100	-0.0094	4	625.66	1670	47.693	1460	54.553

HA Side Span Minimum FOS
FOS = 1.764

BSALL Side Span Minimum FOS
FOS = 1.942

HA Side Span Minimum FOS
FOS = 1.701

Side Span Minimum FOS
FOS = 1.928

1. Hanger tension taken from W.A. Fairhurst Hanger Loads Report
2. Slope calculated from historic survey see sheet 3 for calculation details.
3. Tension in bolts as per FRB measurements 2007/2008.

FORTH ROAD BRIDGE	Project: **Cable Band Bolt - Factor of Safety**			File location: BC04_Cable_Bands	
				Calc sheet no.	rev
	Drawing Ref: 33111/AB/20	Calc by: **DB**	Date: **Jul2011**	Chk by	Date

Ref | Calculations | Output

Determine Factor of Safety Against Slip μ = **0.204**

Table 5 - Re-calculated with amended Bolt Tension and Reduced Slip Factor

	Panel Point	Slope	No Bolts	Bolt Tension (kN)	Dead + HA Loads + Footway (BD 37/01)	HA FOS	Dead + BSALL (2006) + Footway (BD 37/01)	BSALL FoS
↑ Side Span	2	0.0691	4	660.00	2560	3.050	2180	3.582
	4	0.0877	4	660.00	2110	2.920	1920	3.209
	6	0.1064	4	660.00	2160	2.357	1970	2.585
	8	0.1250	4	660.00	2030	2.139	1850	2.347
	10	0.1436	4	660.00	2090	1.813	1900	1.994
	12	0.1622	4	660.00	2110	1.594	1930	1.743
	14	0.1808	4	660.00	2150	1.408	1960	1.544
	16	0.1995	4	660.00	2130	1.293	1930	1.427
	18	0.2181	6	660.00	2140	1.772	1940	1.954
	20	0.2367	6	660.00	2150	1.631	1940	1.808
	22	0.2553	6	660.00	2140	1.526	1930	1.692
	24	0.2739	6	660.00	2170	1.409	1960	1.560
	26	0.2925	6	660.00	2170	1.326	1970	1.461
	28	0.3112	6	660.00	2140	1.271	1940	1.402
	30	0.3298	6	660.00	2150	1.200	1950	1.323
	32	0.3484	8	660.00	2180	1.502	1980	1.654
	34	0.3670	8	660.00	2120	1.475	1930	1.620
	36	0.3856	8	660.00	2110	1.419	1940	1.543
	38	0.4042	8	660.00	2130	1.349	1950	1.474
	40	0.4229	8	660.00	2150	1.286	1980	1.397
↓	42	0.4415	8	660.00	2170	1.229	2020	1.320
	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	46	N/A	N/A	N/A	N/A	N/A	N/A	N/A
↑ Main Span	48	0.3421	6	629.08	1370	1.736	1310	1.816
	50	0.3286	6	693.17	1530	1.777	1390	1.955
	52	0.3150	6	725.62	1590	1.859	1420	2.082
	54	0.3015	4	658.69	1610	1.156	1420	1.311
	56	0.2880	4	717.70	1660	1.275	1460	1.449
	58	0.2745	4	699.08	1690	1.275	1480	1.456
	60	0.2610	4	666.67	1680	1.282	1470	1.466
	62	0.2474	4	673.45	1680	1.362	1470	1.556
	64	0.2339	4	693.15	1740	1.427	1520	1.634
	66	0.2204	4	666.80	1720	1.470	1500	1.685
	68	0.2069	4	692.23	1680	1.660	1470	1.897
	70	0.1934	4	660.25	1710	1.660	1500	1.892
	72	0.1798	4	666.73	1680	1.830	1470	2.091
	74	0.1663	4	679.20	1690	1.999	1480	2.282
	76	0.1528	4	647.64	1720	2.034	1510	2.317
	78	0.1393	4	626.23	1670	2.218	1460	2.537
	80	0.1258	4	635.39	1700	2.444	1490	2.789
	82	0.1122	4	650.55	1710	2.783	1500	3.173
	84	0.0987	4	595.89	1700	2.911	1490	3.321
	86	0.0852	4	732.49	1710	4.117	1500	4.693
	88	0.0717	4	695.43	1660	4.781	1450	5.473
	90	0.0582	4	602.79	1710	4.953	1500	5.647
	92	0.0447	4	657.67	1710	7.036	1500	8.021
	94	0.0311	4	643.95	1680	10.052	1470	11.488
	96	0.0176	4	624.01	1720	16.811	1510	19.149
	98	0.0041	4	638.54	1720	74.019	1500	84.875
↓	100	-0.0094	4	625.66	1670	32.431	1460	37.096

1. Hanger tension taken from W.A. Fairhurst Hanger Loads Report
2. Slope calculated from historic survey see sheet 3 for calculation details.
3. Tension in bolts as per FRB measurements 2007/2008.

HA Side Span Minimum FOS
FOS = 1.200

BSALL Side Span Minimum FOS
FOS = 1.320

HA Side Span Minimum FOS
FOS = 1.156

Side Span Minimum FOS
FOS = 1.311

FORTH ROAD BRIDGE

Project	File location
Cable Band Bolt - Factor of Safety	BC04_Cable_Bands
	Calc sheet no. / rev

Drawing Ref	Calc by	Date	Chk by	Date
33111/AB/20	**DB**	**Jul2011**		

Ref | Calculations | Output

Determine Factor of Safety Against Slip μ = **0.204**

Table 5 - Re-calculated with Reduced load using Bridge Specific Footway Loading

	Panel Point	Slope	No Bolts	Bolt Tension (kN)	Dead + HA Loads + Footway (BD37/01)	HA FOS	Dead + BSALL (2006) + Footway (BSFLL)	BSALL FoS
↑	2	0.0691	4	660.00	2560	3.050	2142.94	3.644
	4	0.0877	4	660.00	2110	2.920	1887.36	3.264
	6	0.1064	4	660.00	2160	2.357	1936.51	2.629
	8	0.1250	4	660.00	2030	2.139	1818.55	2.388
	10	0.1436	4	660.00	2090	1.813	1867.7	2.029
	12	0.1622	4	660.00	2110	1.594	1897.19	1.773
	14	0.1808	4	660.00	2150	1.408	1926.68	1.571
Side Span	16	0.1995	4	660.00	2130	1.293	1897.19	1.451
	18	0.2181	6	660.00	2140	1.772	1907.02	1.988
	20	0.2367	6	660.00	2150	1.631	1907.02	1.839
	22	0.2553	6	660.00	2140	1.526	1897.19	1.721
	24	0.2739	6	660.00	2170	1.409	1926.68	1.587
	26	0.2925	6	660.00	2170	1.326	1936.51	1.486
	28	0.3112	6	660.00	2140	1.271	1907.02	1.426
	30	0.3298	6	660.00	2150	1.200	1916.85	1.346
	32	0.3484	8	660.00	2180	1.502	1946.34	1.682
	34	0.3670	8	660.00	2120	1.475	1897.19	1.648
	36	0.3856	8	660.00	2110	1.419	1907.02	1.570
	38	0.4042	8	660.00	2130	1.349	1916.85	1.499
	40	0.4229	8	660.00	2150	1.286	1946.34	1.421
↓	42	0.4415	8	660.00	2170	1.229	1985.66	1.343
	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	46	N/A	N/A	N/A	N/A	N/A	N/A	N/A
↑	48	0.3421	6	629.08	1370	1.736	1310	1.816
	50	0.3286	6	693.17	1530	1.777	1390	1.955
	52	0.3150	6	725.62	1590	1.859	1420	2.082
	54	0.3015	4	658.69	1610	1.156	1388.05	1.341
	56	0.2880	4	717.70	1660	1.275	1427.15	1.483
	58	0.2745	4	699.08	1690	1.275	1446.7	1.490
	60	0.2610	4	666.67	1680	1.282	1436.925	1.499
	62	0.2474	4	673.45	1680	1.362	1436.925	1.592
	64	0.2339	4	693.15	1740	1.427	1485.8	1.671
	66	0.2204	4	666.80	1720	1.470	1466.25	1.724
	68	0.2069	4	692.23	1680	1.660	1436.925	1.940
Main Span	70	0.1934	4	660.25	1710	1.660	1466.25	1.935
	72	0.1798	4	666.73	1680	1.830	1436.925	2.139
	74	0.1663	4	679.20	1690	1.999	1446.7	2.335
	76	0.1528	4	647.64	1720	2.034	1476.025	2.370
	78	0.1393	4	626.23	1670	2.218	1427.15	2.595
	80	0.1258	4	635.39	1700	2.444	1456.475	2.853
	82	0.1122	4	650.55	1710	2.783	1466.25	3.246
	84	0.0987	4	595.89	1700	2.911	1456.475	3.398
	86	0.0852	4	732.49	1710	4.117	1466.25	4.801
	88	0.0717	4	695.43	1660	4.781	1417.375	5.599
	90	0.0582	4	602.79	1710	4.953	1466.25	5.777
	92	0.0447	4	657.67	1710	7.036	1466.25	8.205
	94	0.0311	4	643.95	1680	10.052	1436.925	11.752
	96	0.0176	4	624.01	1720	16.811	1476.025	19.590
	98	0.0041	4	638.54	1720	74.019	1466.25	86.829
↓	100	-0.0094	4	625.66	1670	32.431	1427.15	37.950

1. Hanger tension taken from W.A. Fairhurst Hanger Loads Report
2. Slope calculated from historic survey see sheet 3 for calculation details.
3. Tension in bolts as per FRB measurements 2007/2008.
4. Bridge specific footway live loading used

HA Side Span Minimum FOS
FOS = 1.200

BSALL Side Span Minimum FOS
FOS = 1.343

HA Side Span Minimum FOS
FOS = 1.156

Side Span Minimum FOS
FOS = 1.341

FORTH ROAD BRIDGE	Project: **Cable Band Bolt - Factor of Safety**			File location: BC04_Cable_Bands	
				Calc sheet no.	rev
	Drawing Ref: 33111/AB/20	Calc by: **DB**	Date: **Jul2011**	Chk by	Date

Ref	Calculations	Output

Discussion

Table 1 -
Shows the calculations with input values as per WAF. Note that
To achieve the same answers as MB calc, the slope has to be taken as an angle in radians.

Table 2 -
This Table shows the difference in slope between the calculated values using survey information and values from MB. Table shows that survey corresponds to the slope as stated on MB calculations. It can therefore seen that slope should not be assumed to be angle in radians.

Table 3 -
Calculations were undertaken using specific hanger loads as stated from WAF hanger loads report. Only marginal changes were noted between assumed loading and calculated loading for hangers.
In addition calculations were undertaken to show the theoretical FOS if HA loading was applied instead of the bridge specific loading. As suspected this reduced the FOS of the hangers however the FOS for these calculated hanger are still above the required FOS.

Table 4 -
Calculations were undertaken using the re-measured tension in the cable band bolts. This significantly reduced the FOS to 1.9424 for the side span and 1.928 for the MS. This is below the required FOS as calculated previously for a ym of 1.67 however above the FOS if ym of 1.30 is assumed assumed.

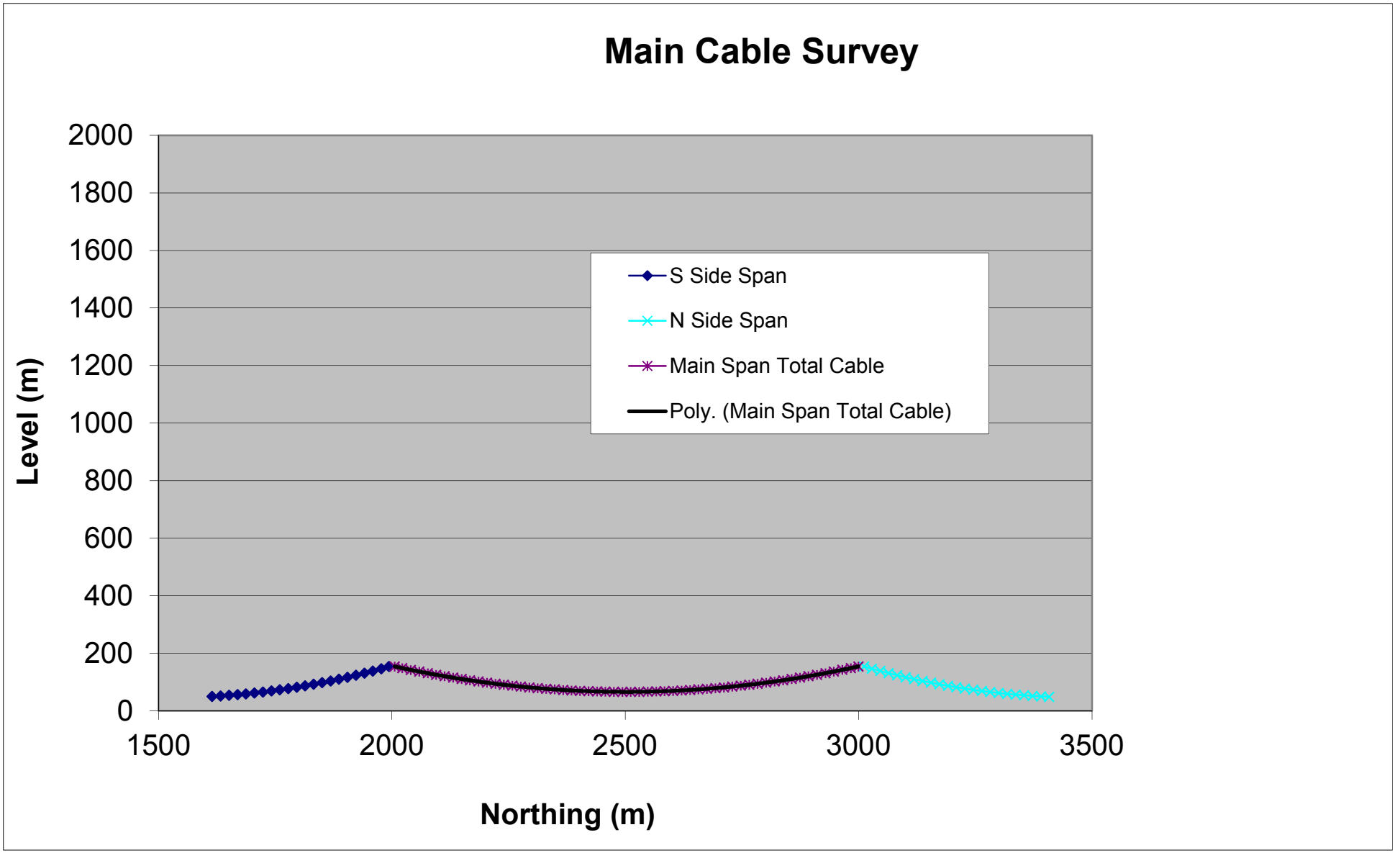
Table 5 -
Shows the FOS achieved if a reduced slip factor is used. Results show that for the majority of hanger locations the cable band bolts do not have a sufficient FOS.

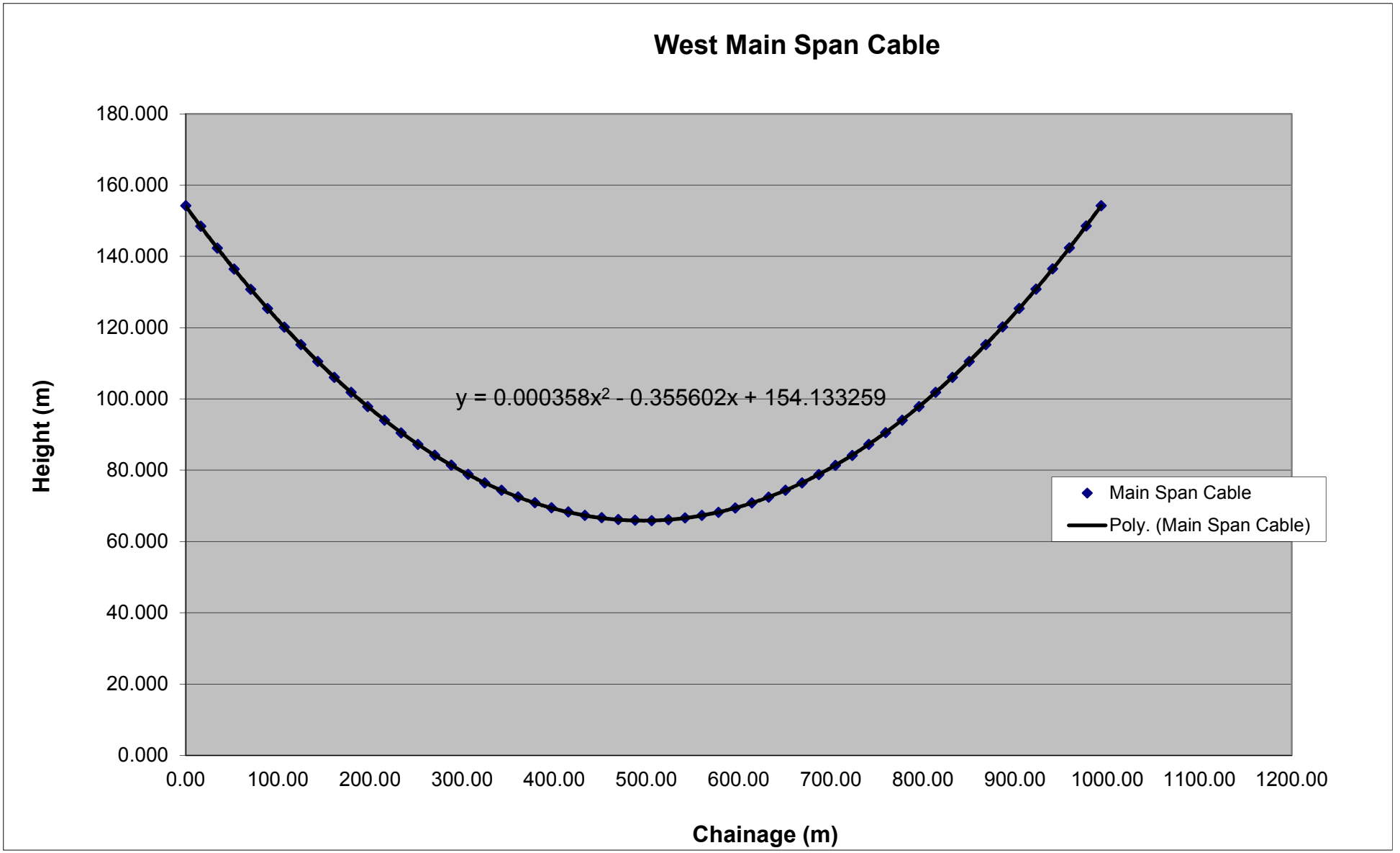
Table 6 -
This table shows the FOS as calculated in table 5 with a reduced hanger load calculated by substituting BD37/01 footway live load for the bridge specific footway live loading. Note that the reduction in load is minimal due to the large loaded length.

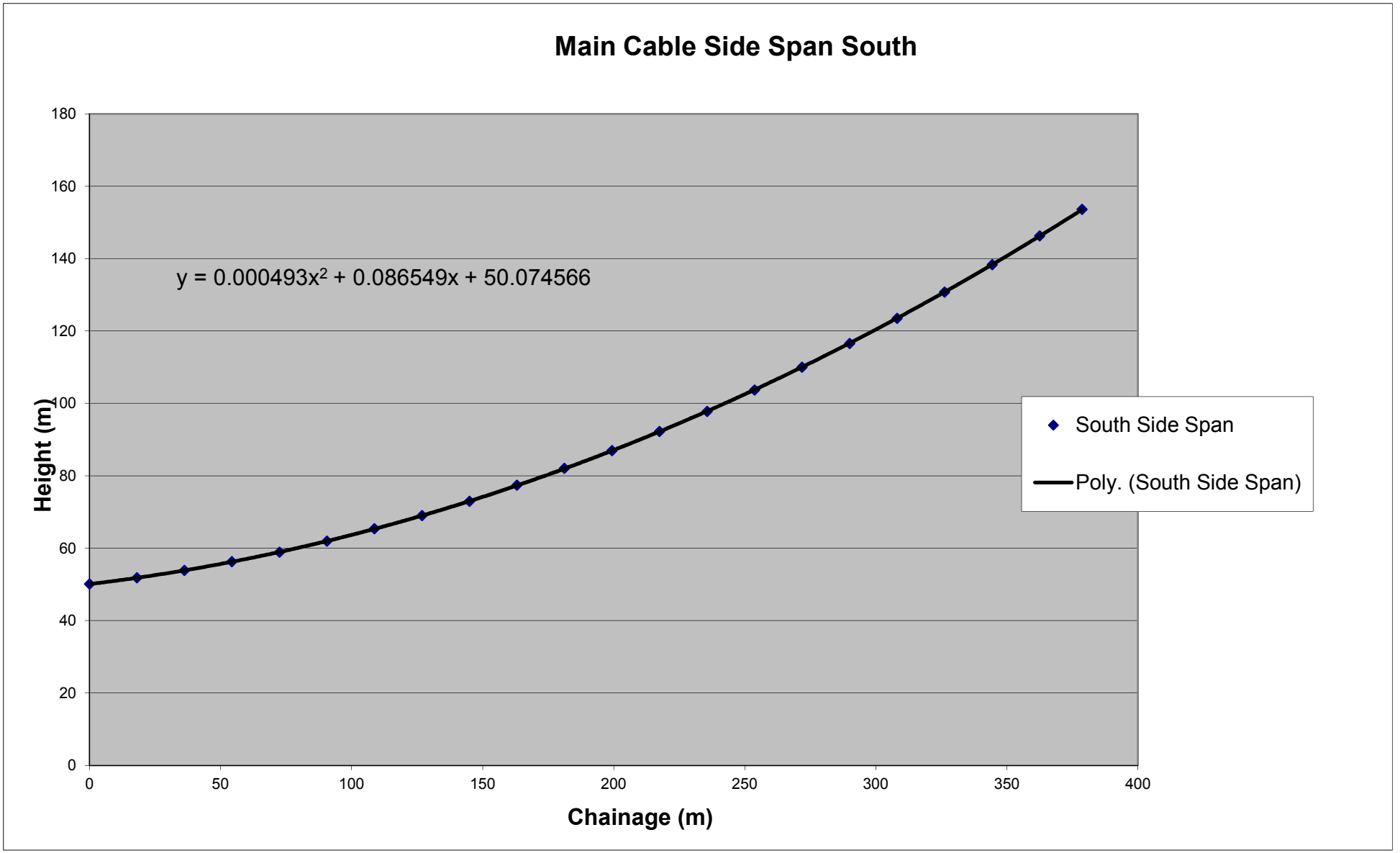
	Project			File location
FORTH ROAD BRIDGE	**Cable Band Bolt - Factor of Safety**			BC04_Cable_Bands
				Calc sheet no. / rev
	Drawing Ref	Calc by	Date	Chk by / Date
	33111/AB/20	**DB**	**Jul2011**	

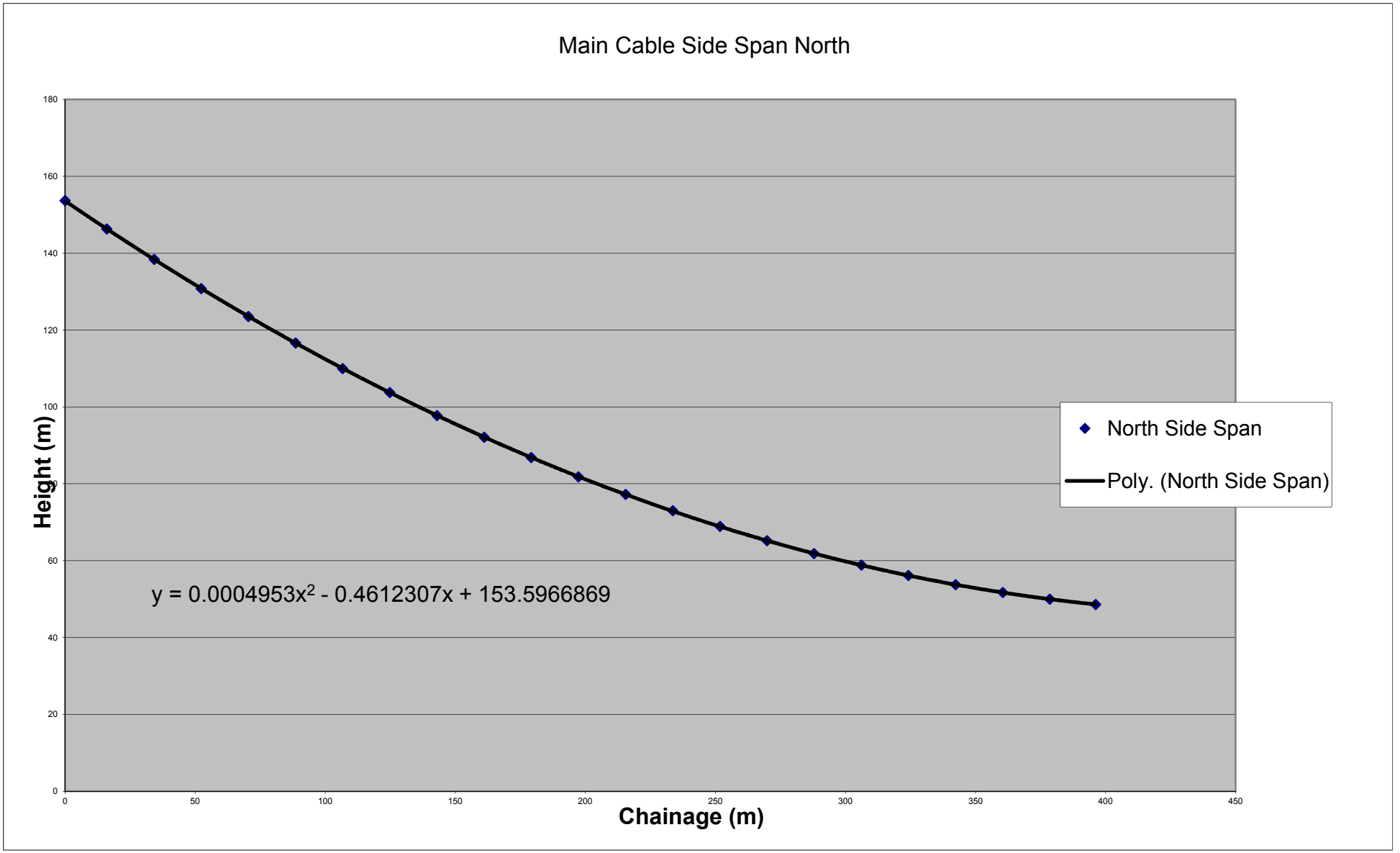
Ref	Calculations	Output

Appendix A


Main Cable Survey
Level (m)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1500
2000
2500
3000
3500
Northing (m)
S Side Span
N Side Span
Main Span Total Cable
Poly. (Main Span Total Cable)


West Main Span Cable
Height (m)
180.000
160.000
140.000
120.000
100.000
80.000
60.000
40.000
20.000
0.000
y = 0.000358x² - 0.355602x + 154.133259
Main Span Cable
Poly. (Main Span Cable)
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00
900.00
1000.00
1100.00
1200.00
Chainage (m)


Main Cable Side Span South
y = 0.000493x2 + 0.086549x + 50.074566
Height (m)
Chainage (m)
0
20
40
60
80
100
120
140
160
180
0
50
100
150
200
250
300
350
400
South Side Span
Poly. (South Side Span)


Main Cable Side Span North
Height (m)
Chainage (m)
y = 0.0004953x² - 0.4612307x + 153.5966869
North Side Span
Poly. (North Side Span)
0
20
40
60
80
100
120
140
160
180
0
50
100
150
200
250
300
350
400
450

Survey of Main cable and Deck - West Side

Point	Date	Level	Northing		
200	840520	46.546	1588.044		
201	840520	40.802	1572.096	cable	
202	840520	35.158	1556.311	S Back Stay	
203	840520	29.544	1540.472		
204	840520	23.981	1524.632		
205	840520	18.45	1508.781		
206	840520	12.959	1492.898		
230	840520	48.531	1597.505		
231	840520	49.937	1615.1		
232	840520	51.698	1633.215		
233	840520	53.772	1651.336		South Tower Northing =
234	840520	56.175	1669.45		North Tower Northing =
235	840520	58.892	1687.569		
236	840520	61.916	1705.692		
237	840520	65.288	1723.811		
238	840520	68.966	1741.929		
239	840520	72.926	1760.061	cable	
240	840520	77.261	1778.17	S side Span	
241	840520	81.907	1796.282		
242	840520	86.854	1814.416		
243	840520	92.14	1832.545		
244	840520	97.793	1850.65		
245	840520	103.677	1868.803		
246	840520	109.981	1886.916		
247	840520	116.56	1905.041		
248	840520	123.501	1923.197		
249	840520	130.738	1941.29		
250	840520	138.326	1959.423		
251	840520	146.238	1977.55		
252	840520	153.601	1993.713		
260	840520	66.012	2493.958		
261	840520	66.245	2475.825		
262	840520	66.694	2457.704		
263	840520	67.376	2439.57		
264	840520	68.333	2421.463		
265	840520	69.449	2403.325		
266	840520	70.9	2385.222		
267	840520	72.542	2367.095		
268	840520	74.375	2348.964		
269	840520	76.475	2330.842		
270	840520	78.795	2312.718		
271	840520	81.419	2294.604	cable	
272	840520	84.277	2276.49	S half Main Span	
273	840520	87.235	2258.338		
274	840520	90.529	2240.212		
275	840520	94.057	2222.088		
276	840520	97.83	2203.961		
277	840520	101.84	2185.835		
278	840520	106.06	2167.706		

279	840520	110.524	2149.57	
280	840520	115.229	2131.423	
281	840520	120.186	2113.296	
282	840520	125.372	2095.177	
283	840520	130.781	2077.029	
284	840520	136.428	2058.881	
285	840520	142.341	2040.756	
286	840520	148.48	2022.633	
287	840520	154.19	2006.408	
400	840617	13.02	3512.679	
401	840617	18.516	3496.775	
402	840617	24.038	3480.969	cable
403	840617	29.59	3465.189	N back Stay
404	840617	35.191	3449.397	
405	840617	40.817	3433.643	
406	840617	46.58	3417.768	
431	840617	65.659	2511.996	
432	840617	65.924	2530.107	
433	840617	66.375	2548.238	
434	840617	67.088	2566.351	
435	840617	68.02	2584.476	
436	840617	69.207	2602.598	
437	840617	70.644	2620.718	
438	840617	72.26	2638.846	
439	840617	74.138	2656.965	
440	840617	76.237	2675.095	
441	840617	78.573	2693.217	cable
442	840617	81.198	2711.334	N side span
443	840617	84.005	2729.466	
444	840617	87.074	2747.598	
445	840617	90.366	2765.723	
446	840617	93.904	2783.842	
447	840617	97.665	2801.978	
448	840617	101.683	2820.106	
449	840617	105.938	2838.244	
450	840617	110.421	2856.364	
451	840617	115.151	2874.495	
452	840617	120.127	2892.621	
453	840617	125.325	2910.752	
454	840617	130.759	2928.887	
455	840617	136.446	2947.026	
456	840617	142.367	2965.155	
457	840617	148.512	2983.273	
458	840617	154.251	2999.504	
459	840617	153.657	3012.111	
460	840617	146.302	3028.252	
461	840617	138.336	3046.37	
462	840617	130.764	3064.487	
463	840617	123.497	3082.611	
464	840617	116.566	3100.746	
465	840617	109.948	3118.853	
466	840617	103.656	3136.978	
467	840617	97.719	3155.116	

468	840617	92.073	3173.228	cable
469	840617	86.78	3191.36	N half of Main span
470	840617	81.811	3209.488	
471	840617	77.131	3227.613	
472	840617	72.829	3245.736	
473	840617	68.831	3263.86	
474	840617	65.148	3281.991	
475	840617	61.794	3300.108	
476	840617	58.771	3318.257	
477	840617	56.058	3336.361	
478	840617	53.708	3354.501	
479	840617	51.667	3372.622	
480	840617	49.953	3390.745	
481	840617	48.578	3408.331	

deck S side Span

2006.408
2999.514

Main Cable Transposed Values Main Span					
Point	Date	Level		Northing	Chainage
260	840520	66.012	2493.958	487.550	
261	840520	66.245	2475.825	469.417	
262	840520	66.694	2457.704	451.296	
263	840520	67.376	2439.57	433.162	
264	840520	68.333	2421.463	415.055	
265	840520	69.449	2403.325	396.917	
266	840520	70.9	2385.222	378.814	
267	840520	72.542	2367.095	360.687	
268	840520	74.375	2348.964	342.556	
269	840520	76.475	2330.842	324.434	
270	840520	78.795	2312.718	306.310	
271	840520	81.419	2294.604	288.196	
272	840520	84.277	2276.49	270.082	
273	840520	87.235	2258.338	251.930	
274	840520	90.529	2240.212	233.804	
275	840520	94.057	2222.088	215.680	
276	840520	97.83	2203.961	197.553	
277	840520	101.84	2185.835	179.427	
278	840520	106.06	2167.706	161.298	
279	840520	110.524	2149.57	143.162	
280	840520	115.229	2131.423	125.015	
281	840520	120.186	2113.296	106.888	
282	840520	125.372	2095.177	88.769	

Main Cable
Point

283	840520	130.781	2077.029	70.621
284	840520	136.428	2058.881	52.473
285	840520	142.341	2040.756	34.348
286	840520	148.48	2022.633	16.225
287	840520	154.19	2006.408	0.000

Main Cable Point
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252

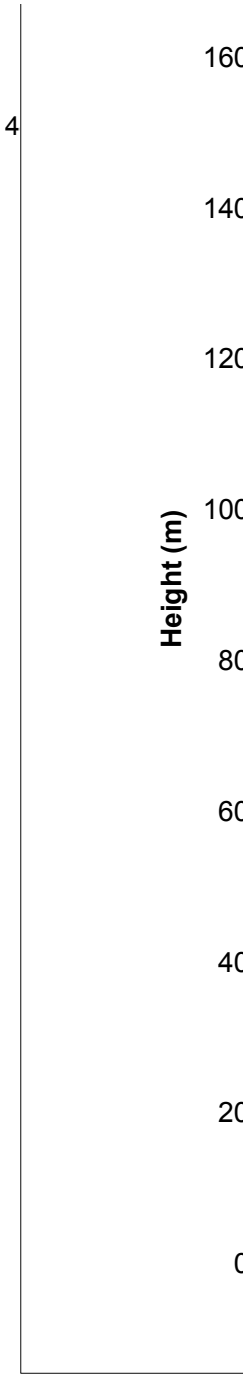
252		153.601	1993.713	0
251		146.238	1977.55	16.163
250		138.326	1959.423	34.29

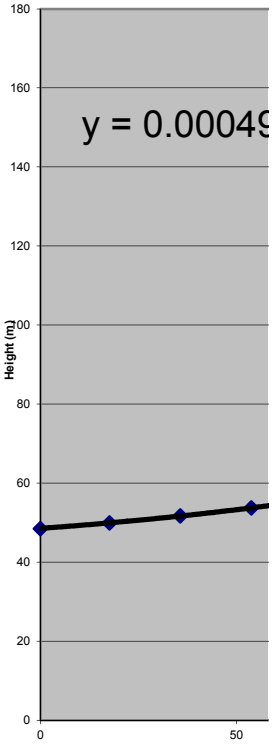
249		130.738	1941.29	52.423
248		123.501	1923.167	70.546
247		116.56	1905.041	88.672
246		109.981	1886.916	106.797
245		103.677	1868.803	124.91
244		97.793	1850.65	143.063
243		92.14	1832.545	161.168
242		86.854	1814.416	179.297
241		81.907	1796.282	197.431
240		77.261	1778.17	215.543
239		72.926	1760.061	233.652
238		68.966	1741.929	251.784
237		65.288	1723.811	269.902
236		61.916	1705.692	288.021
235		58.892	1687.569	306.144
234		56.175	1669.45	324.263
233		53.772	1651.336	342.377
232		51.698	1633.215	360.498
231		49.937	1615.1	378.613
230		48.531	1597.505	396.208

Transposed Values South Side Span

Date	Level	Northing	Chainage

Transposed Values North Side Span			
Date	Level	Northing	Chainage
	48.531	1597.505	0
	49.937	1615.1	17.595
	51.698	1633.215	35.71
	53.772	1651.336	53.831
	56.175	1669.45	71.945
	58.892	1687.569	90.064
	61.916	1705.692	108.187
	65.288	1723.811	126.306
	68.966	1741.929	144.424
	72.926	1760.061	162.556
	77.261	1778.17	180.665
	81.907	1796.282	198.777
	86.854	1814.416	216.911
	92.14	1832.545	235.04
	97.793	1850.65	253.145
	103.677	1868.803	271.298
	109.981	1886.916	289.411
	116.56	1905.041	307.536
	123.501	1923.167	325.662
	130.738	1941.29	343.785
	138.326	1959.423	361.918
	146.238	1977.55	380.045
	153.601	1993.713	396.208

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160
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140
120
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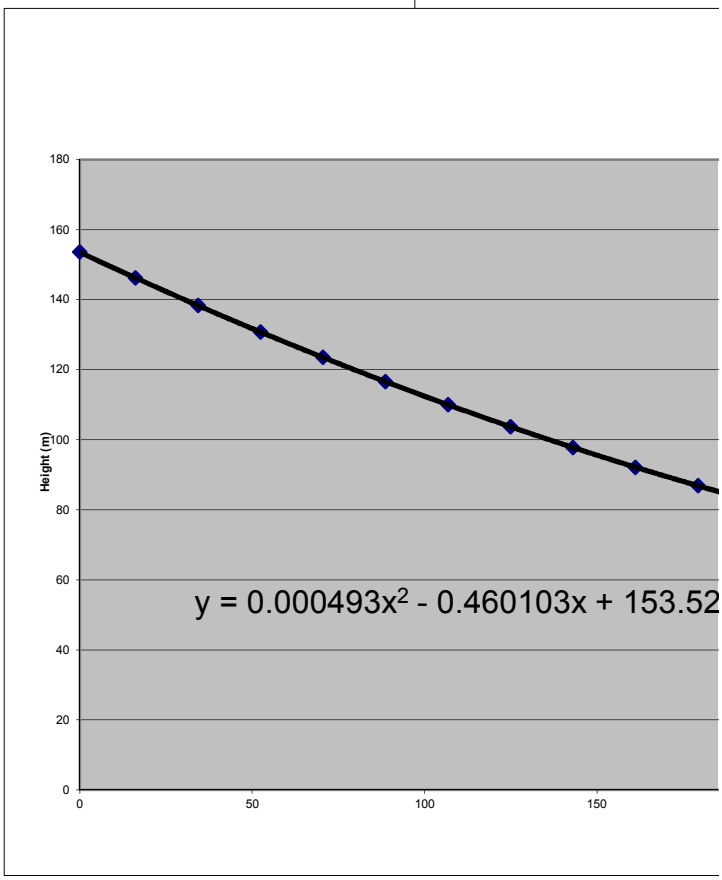
80
60
40
20
0
0
50


180
160
140
120
Height (m)
100
80
60
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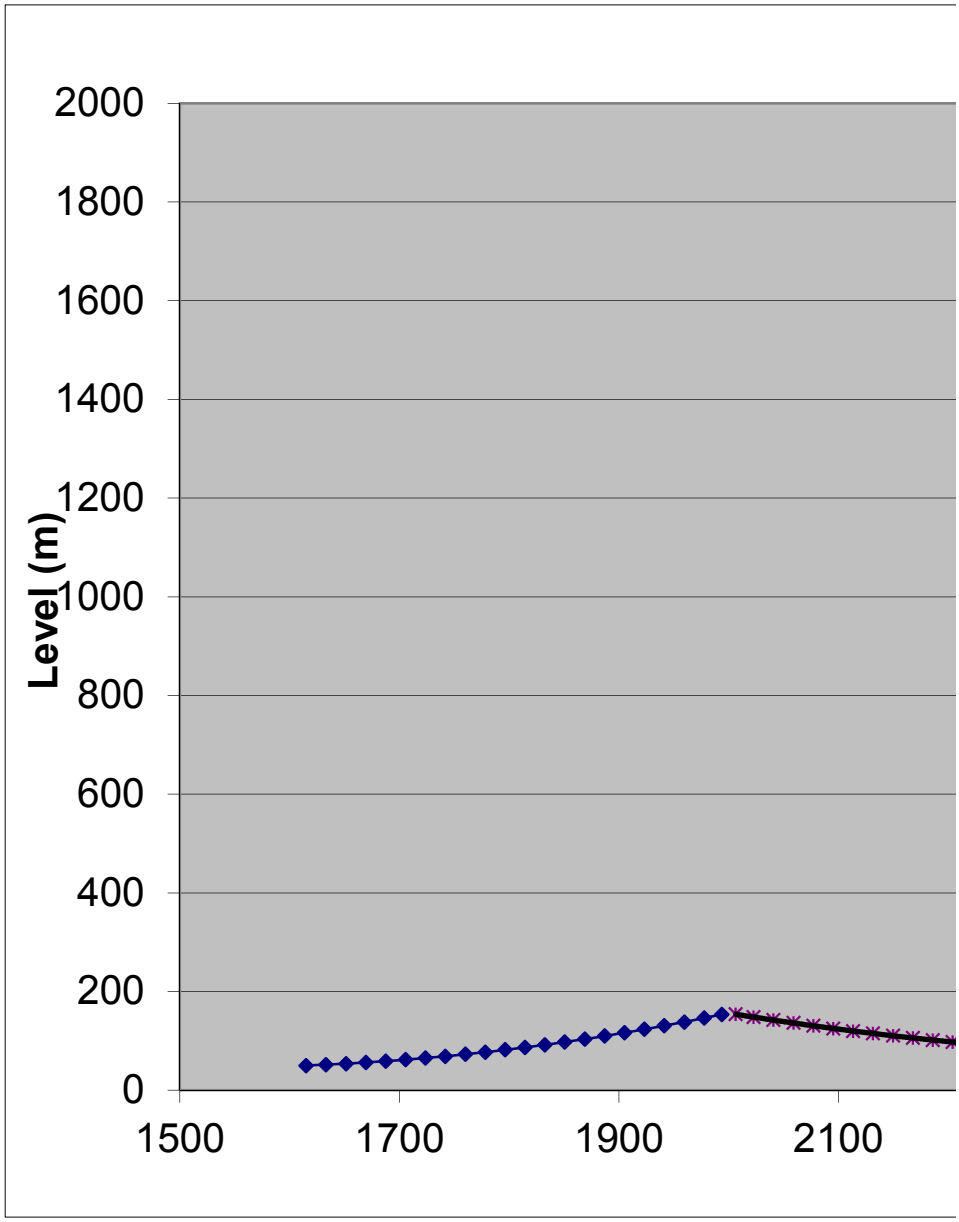
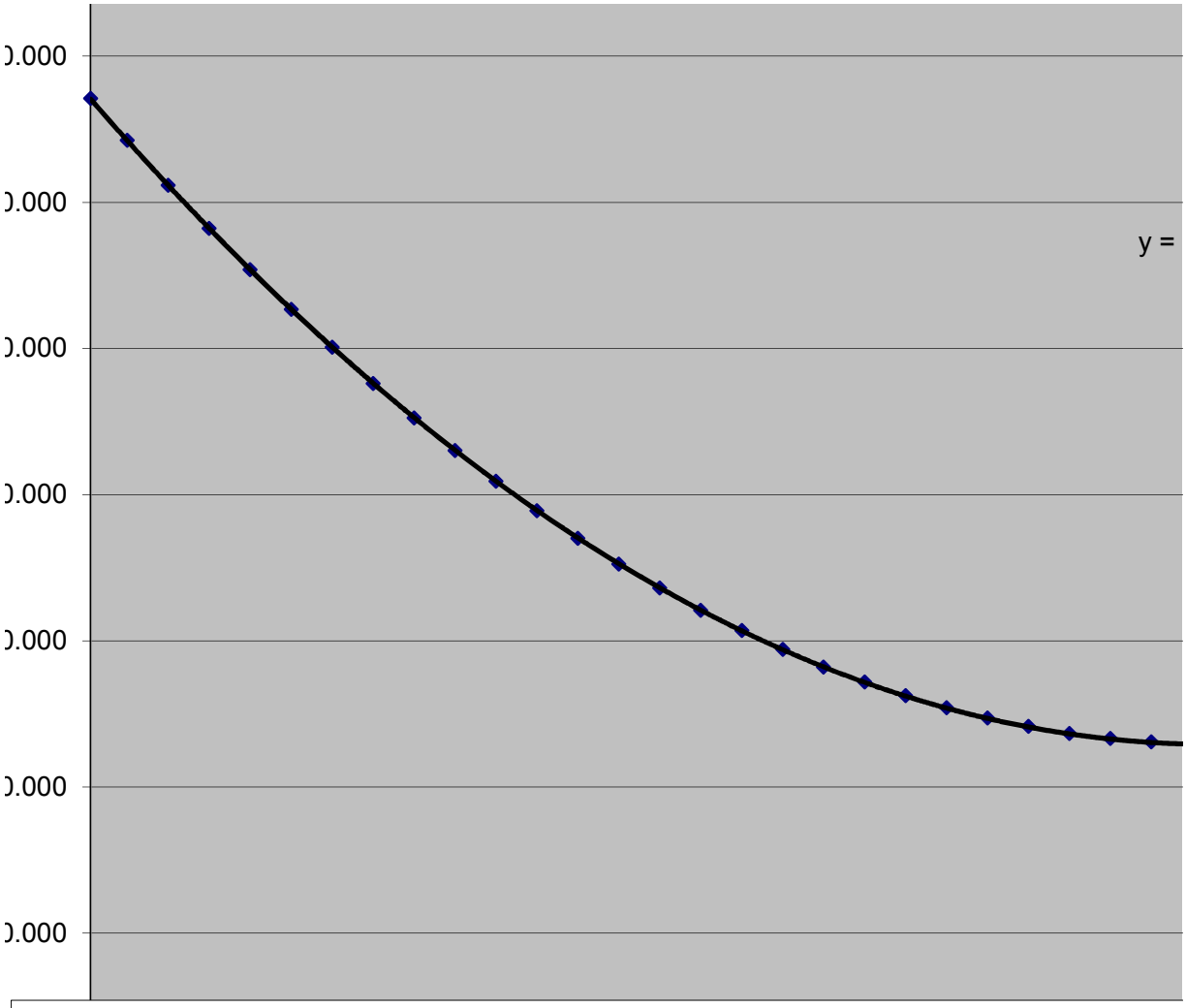
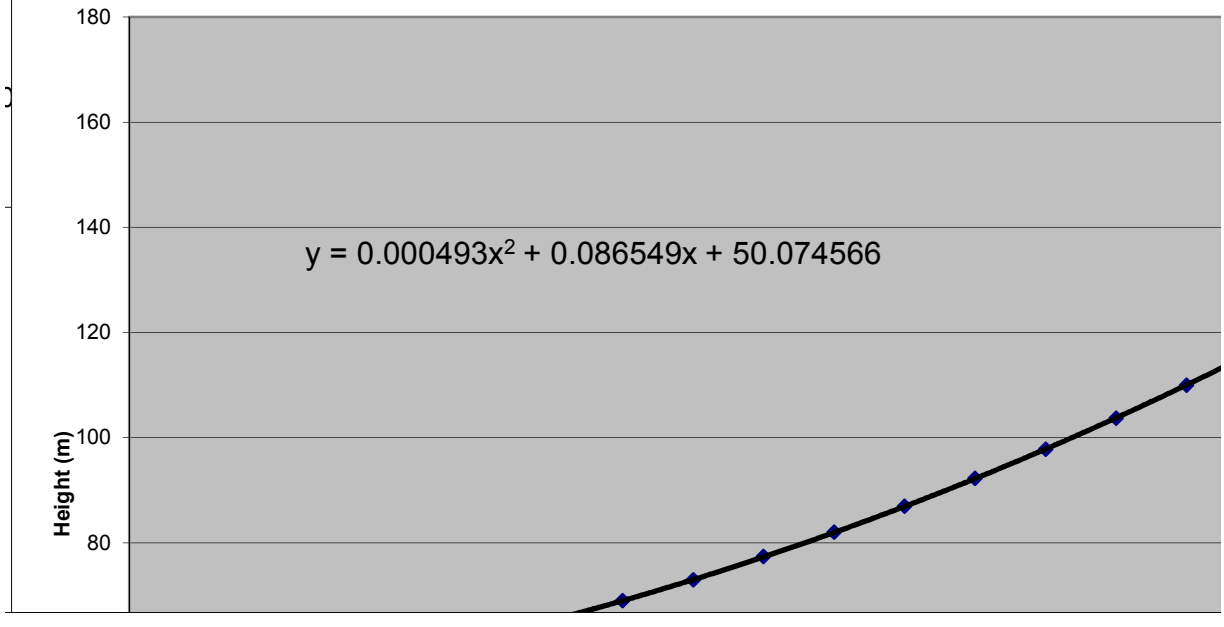
40
20
0
0
50
100
150


2000
1800
1600
1400
1200
1000
800
600
400
200
0
Level (m)
1500
1700
1900
2100

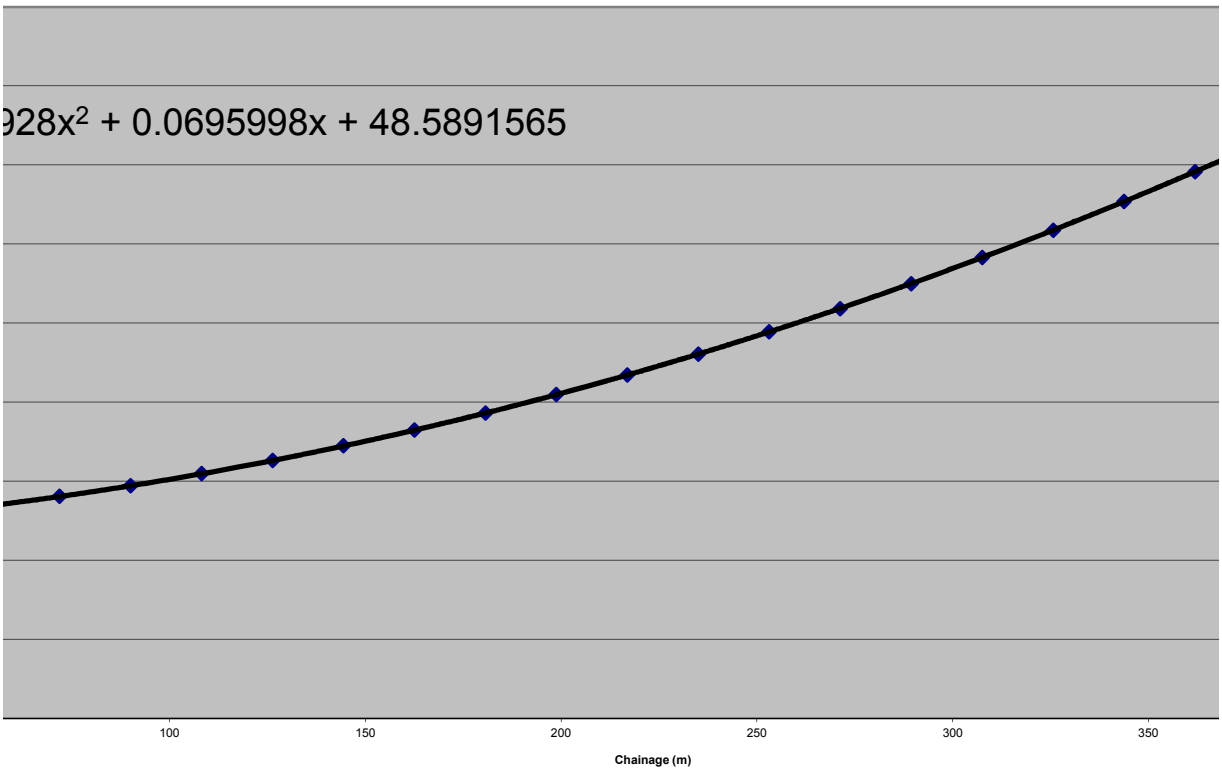

0.000

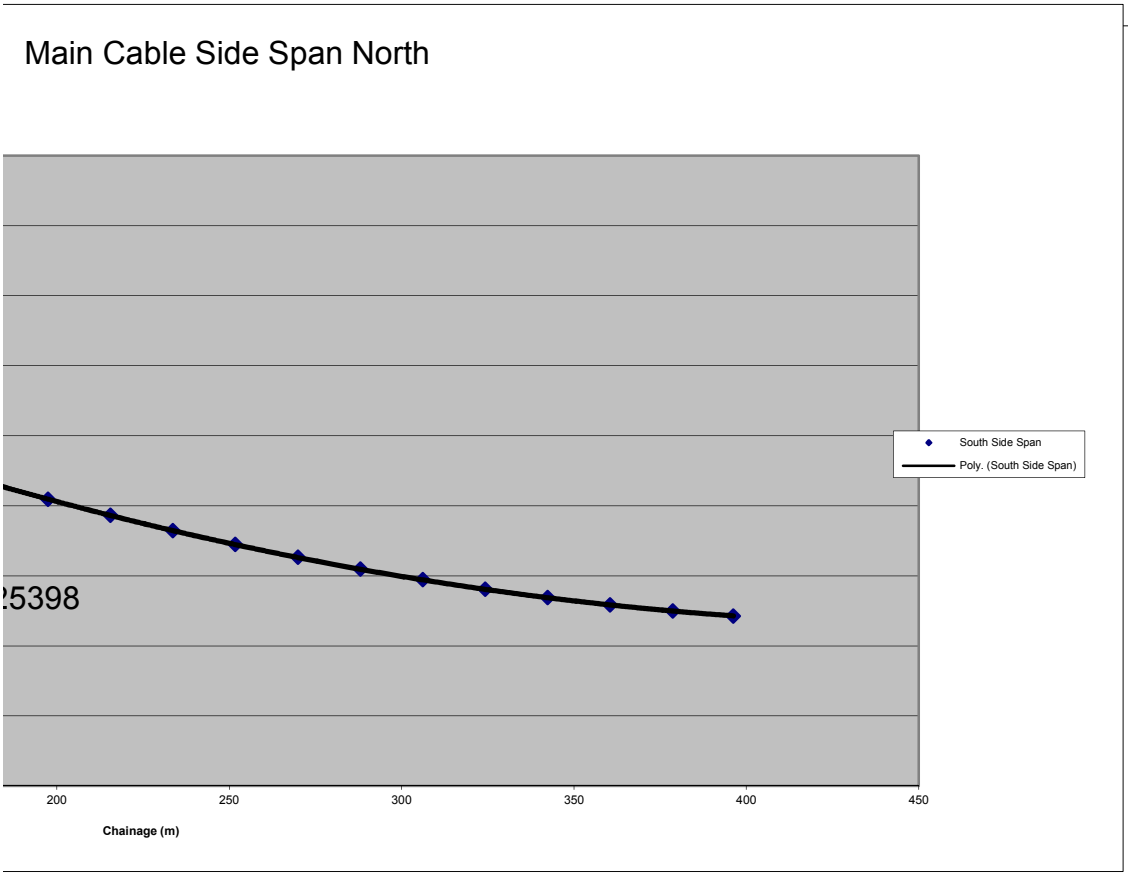


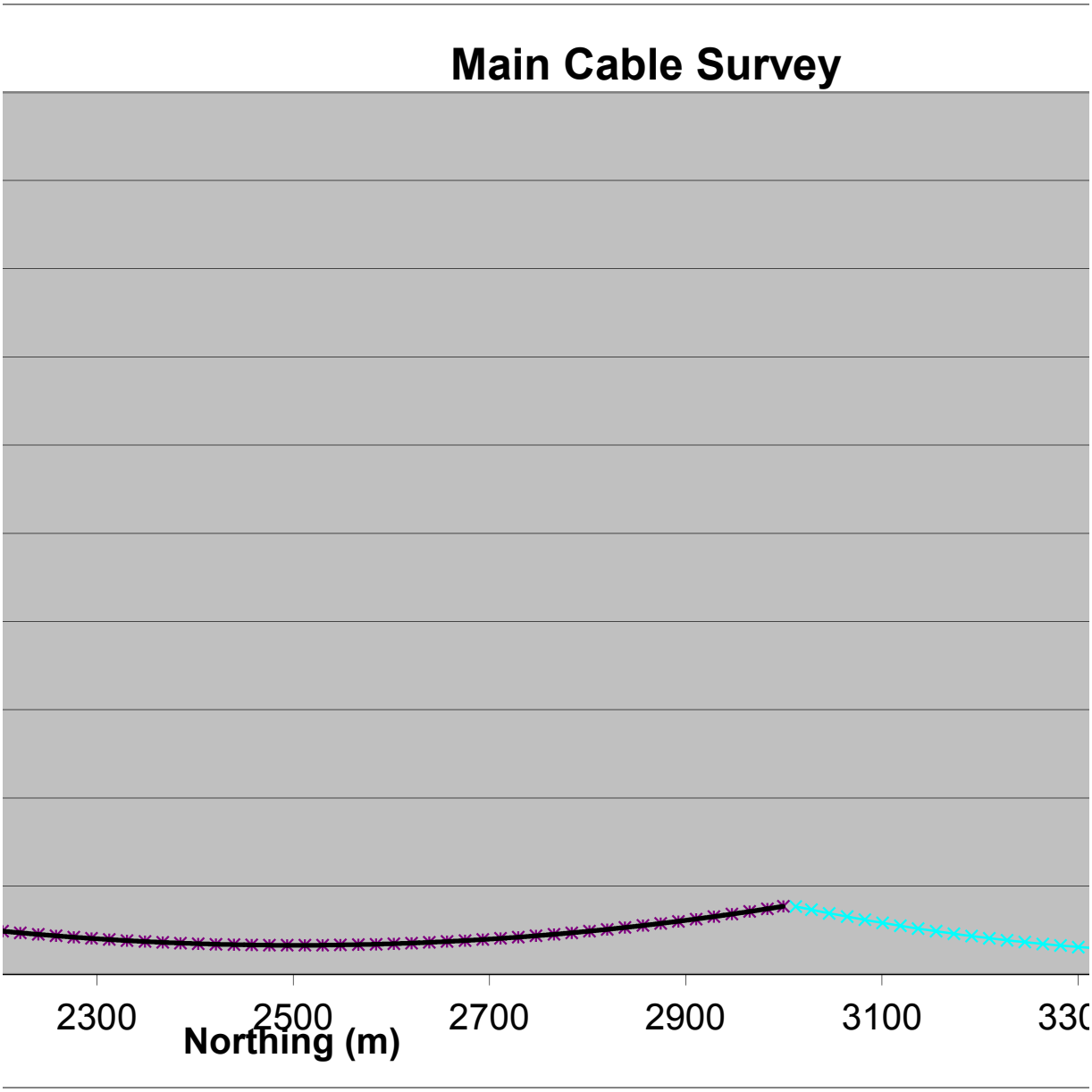
Main Cable Side Span South

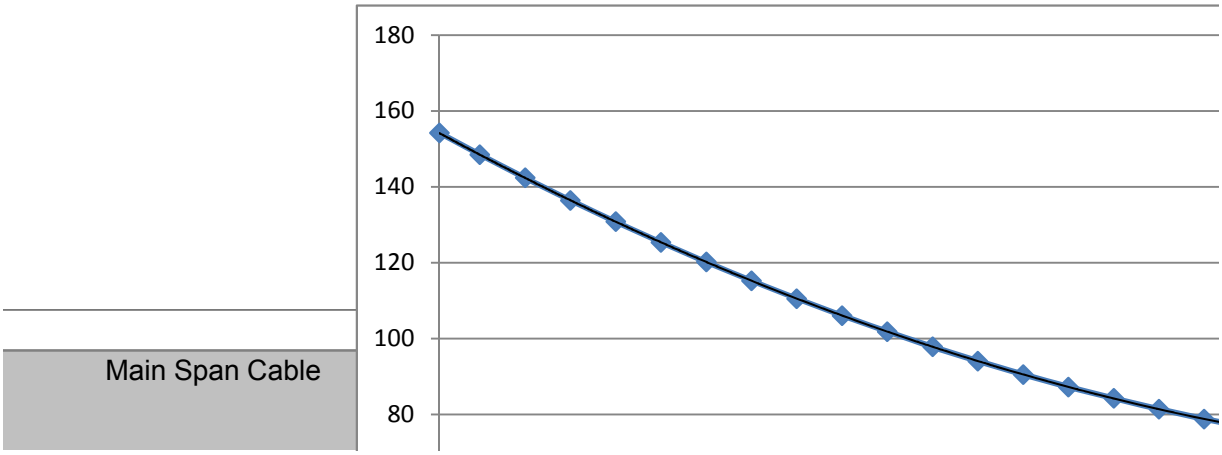


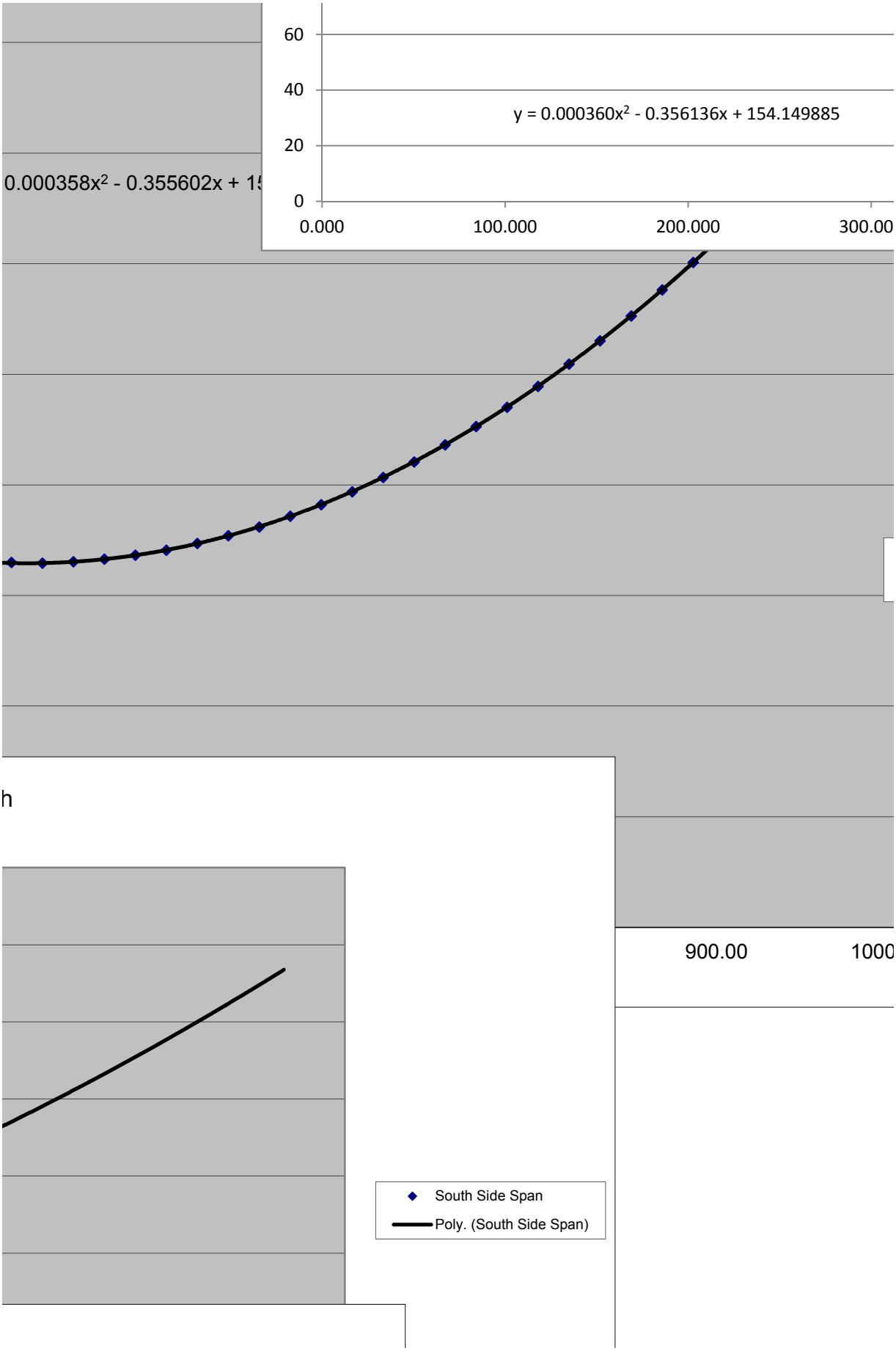
Main Cable Side Span North


928x² + 0.0695998x + 48.5891565
100
150
200
250
300
350
Chainage (m)


Main Cable Side Span North
25398
South Side Span
Poly. (South Side Span)
200
250
300
350
400
450
Chainage (m)


Main Cable Survey
2300
2500
2700
2900
3100
330
Northing (m)


180
160
140
120
100
80
Main Span Cable


60
40
20
0
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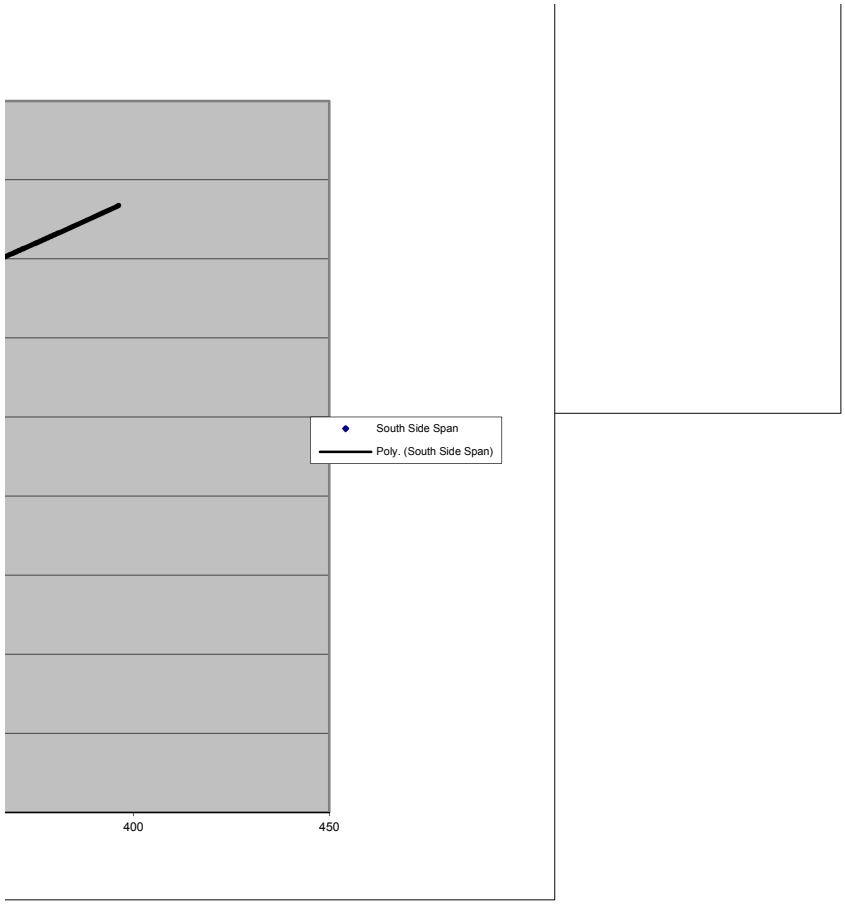
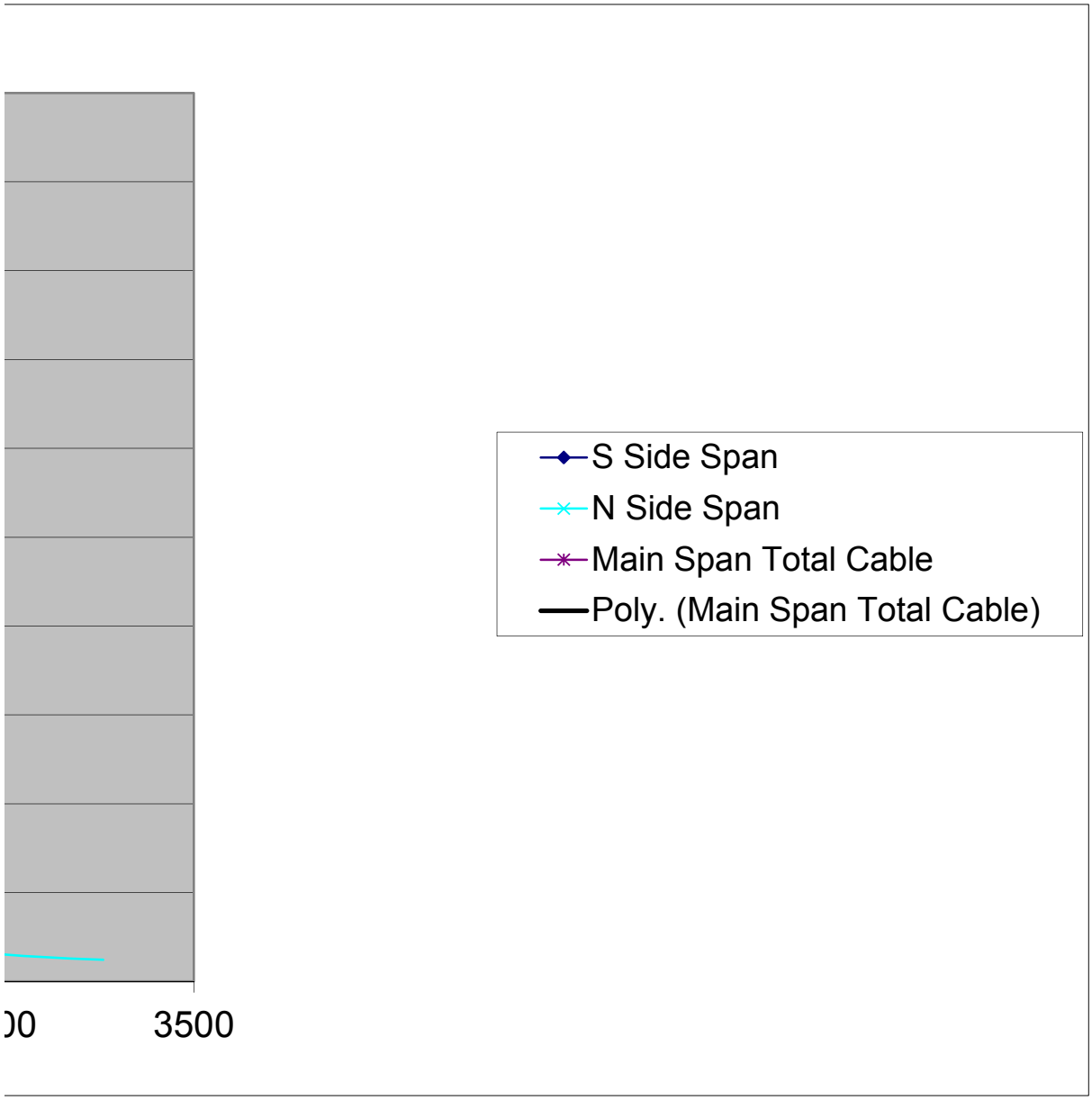
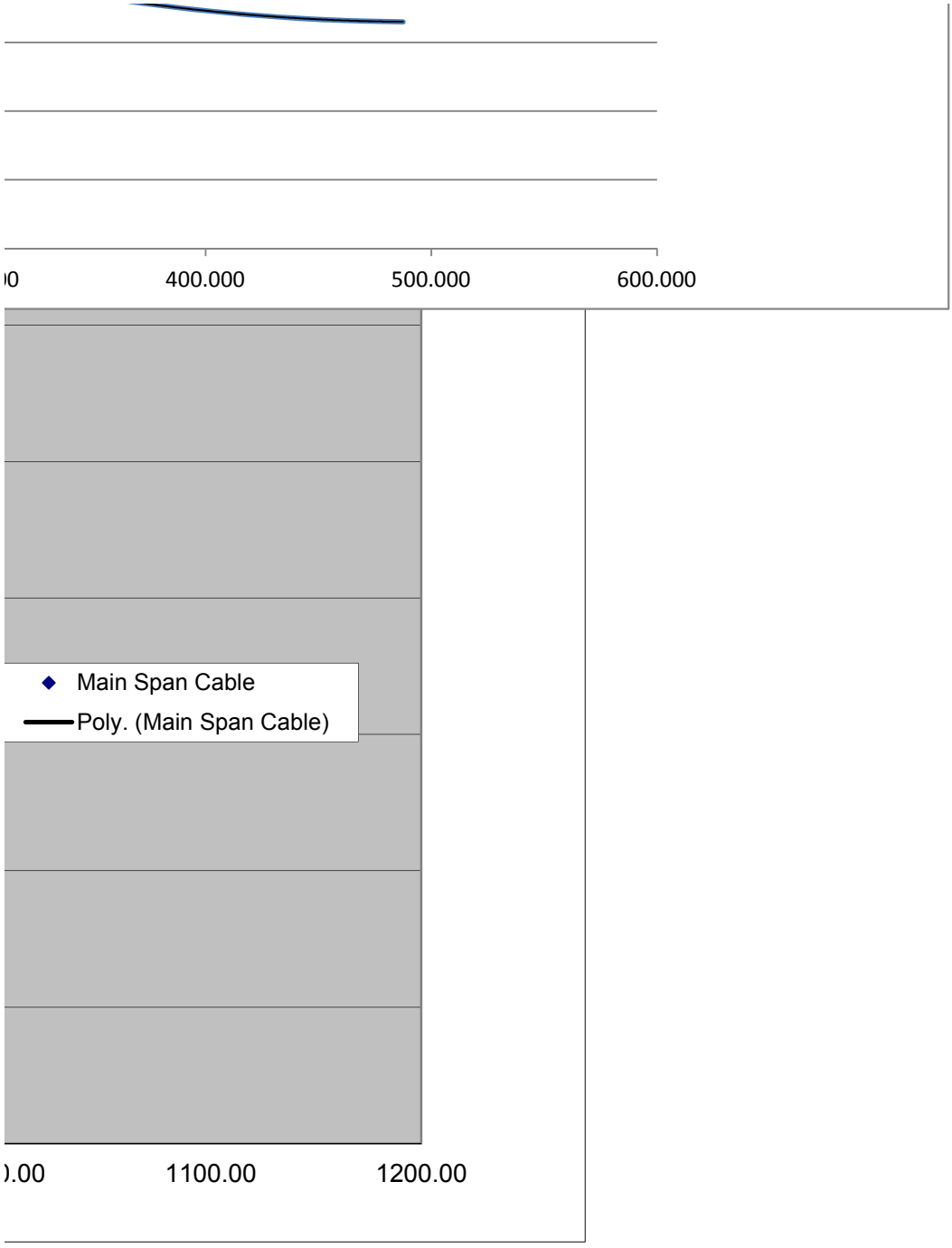
0.000
100.000
200.000
300.00
0.000358x² - 0.355602x + 15
h
900.00
1000
South Side Span
Poly. (South Side Span)


South Side Span
Poly. (South Side Span)
400
450


S Side Span
N Side Span
Main Span Total Cable
Poly. (Main Span Total Cable)
)0
3500


Series1
Poly. (Series1)


0
400.000
500.000
600.000
Main Span Cable
Poly. (Main Span Cable)
.00
1100.00
1200.00

Survey of Main cable and Deck - West Side

Point	Date	Level	Northing		
10	840520	46.538	1588.048		
11	840520	40.833	1572.077	cable	
12	840520	35.15	1556.322	S Back Stay	
13	840520	29.543	1540.496		
14	840520	23.974	1524.642		
15	840520	18.457	1508.794		
31	840520	50.071	1615.068		
32	840520	51.791	1633.184		
33	840520	53.834	1651.32		
35	840520	56.267	1669.422		South Tower Northing =
36	840520	58.901	1687.569		North Tower Northing =
37	840520	61.937	1705.69		
38	840520	65.351	1723.791		
39	840520	68.969	1741.932		
40	840520	72.967	1760.065		
41	840520	77.402	1778.138	cable	
42	840520	82.032	1796.269	S side Span	
43	840520	86.963	1814.396		
44	840520	92.235	1832.527		
45	840520	97.779	1850.673		
46	840520	103.708	1868.806		
47	840520	109.969	1886.939		
48	840520	116.578	1905.06		
49	840520	123.501	1923.197		
50	840520	130.75	1941.323		
51	840520	138.336	1959.45		
52	840520	146.251	1977.574		
53	840520	153.6	1993.714		
70	840520	65.967	2493.859		
71	840520	66.179	2475.739		
72	840520	66.663	2457.62		
73	840520	67.339	2439.504		
74	840520	68.303	2421.39		
75	840520	69.468	2403.265		
76	840520	70.854	2385.143		
77	840520	72.493	2367.017		
78	840520	74.369	2348.894		
79	840520	76.435	2330.755		
80	840520	78.825	2312.649		
81	840520	81.405	2294.526	cable	
82	840520	84.186	2276.387	S half Main Span	
83	840520	87.242	2258.261		
84	840520	90.501	2240.137		
85	840520	94.045	2222.006		
86	840520	97.82	2203.882		
87	840520	101.83	2185.762		
88	840520	106.043	2167.63		
89	840520	110.502	2149.497		
90	840520	115.218	2131.353		
91	840520	120.174	2113.234		

92	840520	125.358	2095.089	
93	840520	130.776	2076.947	
94	840520	136.439	2058.811	
95	840520	142.349	2040.679	
96	840520	148.486	2022.54	
97	840520	154.204	2006.305	
300	840715	46.569	3417.774	
301	840715	40.79	3433.734	
302	840715	35.171	3449.477	cable
303	840715	29.559	3465.246	N back Stay
304	840715	24.011	3481.029	
305	840715	18.504	3496.832	
306	840715	13.022	3512.788	
330	840715	48.566	3408.3	
331	840715	49.968	3390.73	
332	840715	51.701	3372.613	
333	840715	53.747	3354.482	
334	840715	56.123	3336.375	
335	840715	58.83	3318.264	
336	840715	61.816	3300.099	
337	840715	65.195	3281.997	
338	840715	68.919	3263.9	
339	840715	72.961	3245.772	
340	840715	77.25	3227.652	cable
341	840715	81.811	3209.5	N side span
342	840715	86.804	3191.374	
343	840715	92.121	3173.261	
344	840715	97.762	3155.145	
345	840715	103.711	3137.018	
346	840715	109.98	3118.87	
347	840715	116.591	3100.763	
348	840715	123.531	3082.634	
349	840715	130.789	3064.509	
350	840715	138.374	3046.383	
351	840715	146.315	3028.234	
352	840715	153.646	3012.14	
362	840715	65.828	2511.975	
363	840715	66.097	2530.099	
364	840715	66.584	2548.219	
365	840715	67.294	2566.333	
366	840715	68.197	2584.461	
367	840715	69.394	2602.585	
368	840715	70.804	2620.7	
369	840715	72.403	2638.832	
370	840715	74.349	2656.951	
371	840715	76.42	2675.089	
372	840715	78.749	2693.209	
373	840715	81.342	2711.328	
374	840715	84.157	2729.452	
375	840715	87.253	2747.568	cable
376	840715	90.531	2765.7	N half of Main span
377	840715	94.044	2783.833	
378	840715	97.817	2801.966	

379	840715	101.837	2820.095	
380	840715	106.053	2838.237	
381	840715	110.528	2856.365	
382	840715	115.256	2874.503	
383	840715	120.206	2892.627	
384	840715	125.398	2910.747	
385	840715	130.819	2928.88	
386	840715	136.484	2947.022	
387	840715	142.384	2965.151	
388	840715	148.515	2983.279	
389	840715	154.234	2999.514	
1000	840715			
1001	840715			
1002	840715			
1003	840715			
1004	840715			
1005	840715			
1006	840715			
1007	840715			
1008	840715			
1009	840715			
1010	840715			deck S side Span
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1022	840715	58.156		
1023	840715	58.479		
1024	840715	58.79		
1025	840715	59.098		
1026	840715	59.398		
1027	840715	59.676		
1028	840715	59.966		
1029	840715	60.237		
1030	840715	60.507		
1031	840715	60.749		
1032	840715	61.003		
1033	840715	61.231		
1034	840715	61.447		
1035	840715	61.647		
1036	840715	61.843		
1037	840715	62.03		
1038	840715	62.19		
1039	840715	62.323		
1040	840715	62.473		
1041	840715	62.597		
1042	840715	62.703		

1043	840715	62.799
1044	840715	62.883
1045	840715	62.963
1046	840715	62.975
1047	840715	63.041
1048	840715	63.063
1049	840715	63.064
1050	840715	63.053
1051	840715	63.053
1052	840715	63.044
1053	840715	62.997
1054	840715	62.959
1055	840715	62.892
1056	840715	62.82
1057	840715	62.707
1058	840715	62.592
1059	840715	62.494
1060	840715	62.36
1061	840715	62.194
1062	840715	62.018
1063	840715	61.84
1064	840715	61.639
1065	840715	61.428
1066	840715	61.217
1067	840715	60.975
1068	840715	60.713
1069	840715	60.44
1070	840715	60.18
1071	840715	59.891
1072	840715	59.574
1073	840715	59.259
1074	840715	58.931
1075	840715	58.583
1076	840715	58.214
1077	840715	58.214
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2006.305
2999.514

Main Cable Transposed Values Main Span					
Point	Date	Level		Northing	Chainage
97.000	840520.000	154.204	154.204	2006.305	0.000
96.000	840520.000	148.486	148.486	2022.540	16.235
95.000	840520.000	142.349	142.349	2040.679	34.374
94.000	840520.000	136.439	136.439	2058.811	52.506
93.000	840520.000	130.776	130.776	2076.947	70.642
92.000	840520.000	125.358	125.358	2095.089	88.784
91.000	840520.000	120.174	120.174	2113.234	106.929
90.000	840520.000	115.218	115.218	2131.353	125.048
89.000	840520.000	110.502	110.502	2149.497	143.192
88.000	840520.000	106.043	106.043	2167.630	161.325
87.000	840520.000	101.830	101.830	2185.762	179.457
86.000	840520.000	97.820	97.820	2203.882	197.577
85.000	840520.000	94.045	94.045	2222.006	215.701
84.000	840520.000	90.501	90.501	2240.137	233.832
83.000	840520.000	87.242	87.242	2258.261	251.956
82.000	840520.000	84.186	84.186	2276.387	270.082
81.000	840520.000	81.405	81.405	2294.526	288.221
80.000	840520.000	78.825	78.825	2312.649	306.344
79.000	840520.000	76.435	76.435	2330.755	324.450
78.000	840520.000	74.369	74.369	2348.894	342.589
77.000	840520.000	72.493	72.493	2367.017	360.712
76.000	840520.000	70.854	70.854	2385.143	378.838
75.000	840520.000	69.468	69.468	2403.265	396.960
74.000	840520.000	68.303	68.303	2421.390	415.085
73.000	840520.000	67.339	67.339	2439.504	433.199
72.000	840520.000	66.663	66.663	2457.620	451.315

Main Cable
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Main Cable
Point

71.000	840520.000	66.179	66.179	2475.739	469.434	352
70.000	840520.000	65.967	65.967	2493.859	487.554	351
362.000	840715.000	65.828	65.828	2511.975	505.670	350
363.000	840715.000	66.097	66.097	2530.099	523.794	349
364.000	840715.000	66.584	66.584	2548.219	541.914	348
365.000	840715.000	67.294	67.294	2566.333	560.028	347
366.000	840715.000	68.197	68.197	2584.461	578.156	346
367.000	840715.000	69.394	69.394	2602.585	596.280	345
368.000	840715.000	70.804	70.804	2620.700	614.395	344
369.000	840715.000	72.403	72.403	2638.832	632.527	343
370.000	840715.000	74.349	74.349	2656.951	650.646	342
371.000	840715.000	76.420	76.420	2675.089	668.784	341
372.000	840715.000	78.749	78.749	2693.209	686.904	340
373.000	840715.000	81.342	81.342	2711.328	705.023	339
374.000	840715.000	84.157	84.157	2729.452	723.147	338
375.000	840715.000	87.253	87.253	2747.568	741.263	337
376.000	840715.000	90.531	90.531	2765.700	759.395	336
377.000	840715.000	94.044	94.044	2783.833	777.528	335
378.000	840715.000	97.817	97.817	2801.966	795.661	334
379.000	840715.000	101.837	101.837	2820.095	813.790	333
380.000	840715.000	106.053	106.053	2838.237	831.932	332
381.000	840715.000	110.528	110.528	2856.365	850.060	331
382.000	840715.000	115.256	115.256	2874.503	868.198	330
383.000	840715.000	120.206	120.206	2892.627	886.322	
384.000	840715.000	125.398	125.398	2910.747	904.442	
385.000	840715.000	130.819	130.819	2928.880	922.575	
386.000	840715.000	136.484	136.484	2947.022	940.717	
387.000	840715.000	142.384	142.384	2965.151	958.846	
388.000	840715.000	148.515	148.515	2983.279	976.974	
389.000	840715.000	154.234	154.234	2999.514	993.209	

Transposed Values South Side Span			
Date	Level	Northing	Chainage
840520	50.071	1615.068	0
840520	51.791	1633.184	18.116
840520	53.834	1651.32	36.252
840520	56.267	1669.422	54.354
840520	58.901	1687.569	72.501
840520	61.937	1705.69	90.622
840520	65.351	1723.791	108.723
840520	68.969	1741.932	126.864
840520	72.967	1760.065	144.997
840520	77.402	1778.138	163.07
840520	82.032	1796.269	181.201
840520	86.963	1814.396	199.328
840520	92.235	1832.527	217.459
840520	97.779	1850.673	235.605
840520	103.708	1868.806	253.738
840520	109.969	1886.939	271.871
840520	116.578	1905.06	289.992
840520	123.501	1923.197	308.129
840520	130.75	1941.323	326.255
840520	138.336	1959.45	344.382
840520	146.251	1977.574	362.506
840520	153.6	1993.714	378.646

Transposed Values North Side Span			
Date	Level	Northing	Chainage

840715	153.646	3012.14	0
840715	146.315	3028.234	16.094
840715	138.374	3046.383	34.243
840715	130.789	3064.509	52.369
840715	123.531	3082.634	70.494
840715	116.591	3100.763	88.623
840715	109.98	3118.87	106.73
840715	103.711	3137.018	124.878
840715	97.762	3155.145	143.005
840715	92.121	3173.261	161.121
840715	86.804	3191.374	179.234
840715	81.811	3209.5	197.36
840715	77.25	3227.652	215.512
840715	72.961	3245.772	233.632
840715	68.919	3263.9	251.76
840715	65.195	3281.997	269.857
840715	61.816	3300.099	287.959
840715	58.83	3318.264	306.124
840715	56.123	3336.375	324.235
840715	53.747	3354.482	342.342
840715	51.701	3372.613	360.473
840715	49.968	3390.73	378.59
840715	48.566	3408.3	396.16

444.875
0

Appendix B

Nominal axial loads in the hangers

	PP	Dead Load	Superimposed Dead Load	HA Loads + Footway (BD 37/01)
Side Span	2	1.31	0.33	0.92
	4	1.29	0.28	0.54
	6	1.32	0.29	0.55
	8	1.23	0.27	0.53
	10	1.27	0.28	0.54
	12	1.28	0.28	0.55
	14	1.3	0.28	0.57
	16	1.28	0.27	0.58
	18	1.27	0.27	0.6
	20	1.28	0.27	0.6
	22	1.27	0.27	0.6
	24	1.3	0.27	0.6
	26	1.3	0.27	0.6
	28	1.27	0.27	0.6
	30	1.28	0.27	0.6
	32	1.31	0.28	0.59
	34	1.27	0.28	0.57
	36	1.29	0.28	0.54
	38	1.31	0.29	0.53
	40	1.37	0.28	0.5
	42	1.52	0.24	0.41

Table 2 - Hanger Loads - Side Span

	PP	Dead Load	Superimposed Dead Load	HA Loads + Footway (BD 37/01)
	48	1.11	0.1	0.16
	50	0.92	0.22	0.39
	52	0.85	0.26	0.48
	54	0.81	0.27	0.53
	56	0.83	0.27	0.56
	58	0.84	0.27	0.58
	60	0.81	0.27	0.6
	62	0.81	0.27	0.6
	64	0.84	0.28	0.62
	66	0.83	0.27	0.62

Side Span	68	0.81	0.27	0.6
	70	0.84	0.27	0.6
	72	0.81	0.27	0.6
	74	0.83	0.27	0.59
	76	0.85	0.27	0.6
	78	0.8	0.27	0.6
	80	0.83	0.27	0.6
	82	0.83	0.27	0.61
	84	0.83	0.27	0.6
	86	0.83	0.27	0.61
	88	0.79	0.27	0.6
	90	0.83	0.27	0.61
	92	0.83	0.27	0.61
	94	0.79	0.27	0.62
	96	0.83	0.27	0.62
	98	0.83	0.27	0.62
	100	0.79	0.27	0.61

Table 3- Hanger Loads - Main Span

Nominal Axial load in the hangers - Fx (MN)		
BSALL (2006) + Footway (BD 37/01)	Dead + Superimposed + HA Loads + Footway (BD 37/01)	Dead + Superimposed + BSALL (2006) + Footway (BD 37/01)
0.54	2.56	2.18
0.35	2.11	1.92
0.36	2.16	1.97
0.35	2.03	1.85
0.35	2.09	1.9
0.37	2.11	1.93
0.38	2.15	1.96
0.38	2.13	1.93
0.4	2.14	1.94
0.39	2.15	1.94
0.39	2.14	1.93
0.39	2.17	1.96
0.4	2.17	1.97
0.4	2.14	1.94
0.4	2.15	1.95
0.39	2.18	1.98
0.38	2.12	1.93
0.37	2.11	1.94
0.35	2.13	1.95
0.33	2.15	1.98
0.26	2.17	2.02

Nominal Axial load in the hangers - Fx (MN)		
BSALL (2006) + Footway (BD 37/01)	Dead + Superimposed + HA Loads + Footway (BD 37/01)	Dead + Superimposed + BSALL (2006) + Footway (BD 37/01)
0.1	1.37	1.31
0.25	1.53	1.39
0.31	1.59	1.42
0.34	1.61	1.42
0.36	1.66	1.46
0.37	1.69	1.48
0.39	1.68	1.47
0.39	1.68	1.47
0.4	1.74	1.52
0.4	1.72	1.5

0.39	1.68	1.47
0.39	1.71	1.5
0.39	1.68	1.47
0.38	1.69	1.48
0.39	1.72	1.51
0.39	1.67	1.46
0.39	1.7	1.49
0.4	1.71	1.5
0.390	1.7	1.49
0.400	1.71	1.5
0.390	1.66	1.45
0.400	1.71	1.5
0.400	1.71	1.5
0.410	1.68	1.47
0.410	1.72	1.51
0.400	1.72	1.5
0.400	1.67	1.460

1.47037037

1.955714