Preliminary Slope Stability Analysis Proposed Residential Development Northcliff Lodge Penarth

Prepared for: Celtic Developments Penarth Limited

November 2016

Job No: 13124/1











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REPORT TITLE	:	Preliminary Slope Stability Analysis:
		Northcliff Lodge, Penarth
REPORT STATUS	:	FINAL
JOB NUMBER	:	13124/1
DATE	:	November 2016
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		1 mil
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		(Ruth Howells)
APPROVED BY	:	Chip Fole
		(Dr Gwyn C. Lake)

#### **Executive Summary**

Site Location	The site is located at the top of the Penarth Escarpment, at the eastern end of North Cliff Drive, at an approximate National Grid Reference of 318900, 172370. The site is located on three terraces. The upper, middle and lower terraces have an approximate altitude of 37m AOD, 29m AOD and 20m AOD respectively. The base of the Escarpment has an altitude of approximately 10m AOD.
Proposed Development	Celtic Developments Penarth Limited are planning a residential development of the site.
Site History	The history maps apart for the construction of Northcliff Lodge the site has remained undeveloped.
Geology & Landslip History	The Geology Report shows the site to be underlain in stratigraphical sequence by rocks of the St Mary's Well Bay Formation, Penarth Group, Blue Anchor Formation and Mercia Mudstone Formation.
	In 2006 Thomas et al published a paper titled 'Implications of urban development on escarpment instability'. The paper detailed that between 1859 and 1865 the Penarth Dock was developed and railway sidings and shunting yards, associated with the adjacent Penarth Dock, ran along the base of the escarpment.
	Historically limestone was also quarried from the escarpment. The toe of the escarpment has therefore been subject to haphazard excavation historically.
	Thomas et al (2006) record at least three previous slope failure events preceding their paper which, itself, details a fourth event in 2004. During an inspection of the slope, Thomas et al (2006) encountered morphological evidence of a large scale historical failure in the slope previously obstructed by vegetation.
	In 2013 Terra Firma Wales Ltd were engaged to assess a landslide at Penarth Marina, located immediately east of the current study site. A failure had occurred on the slope and Terra Firma Wales Ltd performed an inspection of the slope and the surrounding area. Landslide morphology was apparent and features including tree 'piston gripping' (i.e., curvature in the base of trees as they correct themselves to vertical following historical ground movement events) was noted adjacent to the slide, indicating further historical land movement to the northwest of the 2013 landslide.
Ground Conditions	Ground condition encountered comprised a stiff and very stiff gravelly clay overlying the St Mary's Well Bay Formation, over the Penarth Group over the Blue Anchor Formation over the Mercia Mudstone. Groundwater was encountered within the Blue Anchor Formation.
Slope Stability Analysis	A computer slope stability Analysis was carried out using the results of a single on site borehole enhanced by boreholes from a previous investigation with effective stress shear parameters derived from published data.
	The stability analysis has shown that all unstable factors of safety are with the shallow superficial deposits, in particular at the rear of the existing retaining wall and at the top of the escapement embankment to the north of the site.
	It was acknowledged that the analysis was based upon limited site investigation data and generic shear stress parameters derived from published data. However a sensitivity analysis undertaken using a reduction in shear strength parameters of 25% showed little change in the overall stability of the site.
	Based upon the above it was concluded that a steel pile solution socketed within the underlying competent bedrock would maintain the current stability of the site. All minor slippages encountered in the analysis would be easily dealt with using standard engineering techniques.
	It was recommended that a comprehensive site investigation including trial pits, rotary coreholes, the installation of piezometers to monitor groundwater and inclinometers to monitor ground movement, soil shear stress parameter laboratory testing and an enhanced

computer slope stability analysis should be carried out to confirm the finding of the preliminary analysis.

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#### SECTION 1 Introduction

Celtic Developments Penarth Limited are planning a residential development of a site at Northcliff Lodge, Penarth.

In December 2015, Terra Firma (Wales) Limited were commissioned to undertake a Desk Study of the site. This report (No. 13124) highlighted the past instability of the general area with regard to landslip potential.

Recommendations were made to undertake a comprehensive site investigation and computer slope stability analysis of the site to investigate the sites current stability and provide foundation recommendations to ensure its future long term stability. The proposed investigation comprised a number of rotary coreholes, trial pitting and soil instrumentation within the boreholes including inclinometers for monitoring long term slope movement and piezometers to monitor groundwater fluctuation. Samples of the various strata were also to be taken to determine soil shear stress parameters for input into the slope instability analysis.

Following completion of the above investigation a computer slope stability analysis was to be carried out in order to determine the sites current stability and to determine the slip planes with the lowest factor of safety against slope movement.

The report also recommended a tentative foundation solution of rotary installed steel piles extending through the deepest slip planes to ensure future stability of the site. With this foundation solution that can also be used on retaining walls no additional loads are placed upon shallow deposits.

Terra Firma (Wales) have been commissioned by Celtic Developments Penarth Limited to undertake a Preliminary Site Investigation and Slope Stability Analysis in order to determine the likely depth of all slip planes and hence the viability of the envisage foundation solution.

#### 1.1 Limitations and Exceptions of Investigation

Celtic Developments Penarth Limited has requested that a Preliminary Slope Stability Analysis be performed.

The preliminary slope stability analysis was conducted and this report has been prepared for the sole internal reliance of Celtic Developments Penarth Limited and its design and construction team. This report shall not be relied upon or transferred to any other parties without the express written authorisation of Terra Firma (Wales) Limited. If an unauthorised third party comes into possession of this report they rely on it at their peril and the authors owe them no duty of care and skill.

The report represents the findings and opinions of experienced geo-technical consultants. Terra Firma (Wales) Limited does not provide legal advice and the advice of lawyers may also be required.

It should be noted that only a very limited investigation could be carried out due to the presence of Northcliff Lodge and consequently the subsurface geological profiles, hydrostatic levels and plots are generalised by necessity and have been based on the information found at the locations of the exploratory holes and depths tested.

#### SECTION 2 Slope Stability Parameters

#### 2.1 Site Investigation

Only the middle tier of the site was accessible to the rotary drilling rig.

One rotary probe/core hole was subsequently sunk with the central ties of the site within the garden of Northciff lodge in order to determine the nature and depth of underlying strata.

The probe/core holes was sunk into the underlying Mercia Mudstone Bedrock using a Beretta T41 drilling rig. Open hole drilling was employed within the superficial deposits and a and highly weathered solid geology. Once encountered rock cores of the bedrock were obtained. In addition to the above Standard/Cone Penetration (SPT/CPT) tests were undertaken at regular intervals throughout extent of the borehole. Compressed air was used as the flushing medium.

The fieldworks were supervised by Terra Firma (Wales) Limited, who also logged the boreholes to the requirements of BS5930: 2015.

The rotary probe/corehole logs is presented in Annexes A.

The exploratory hole location is illustrated on **Drawing 01**.

In addition to the above rotary probeholes (BH01-BH03) sunk as part of an investigation for the redevelopment of Marine Buildings (Report No 11458 dated 2012) were abstracted for used in the analysis.

The location of the probeholes are shown in **Drawing 02**.

#### 2.2 Slope Cross Sections and Geological Profile

Slope stability analyses for a single section through the centre of the site was undertaken. The boundary between each strata has been determined from depths confirmed during drilling and estimated where required though extrapolation taking into account ground conditions in general across the site.

The section line is shown on **Drawing 01**.

This section was chosen as it contained the most precipitous slopes is are presented below.



Figure 2.1 - Profile for Slope 1

#### 2.3.1 Effective Angle of Shear Resistance and Effective Cohesion

Parameters for drained conditions have been chosen through inspection of site soils, interpretation of in-situ test results and from appropriate published data as detailed in the Notes at the foot of **Table 2.1**.

These have been allocated to ensure the most critical failure circles are considered.

Table 2.1: Angle of Effective Shear Resistance and Effective Cohesion									
Soil Sample	Angle of Shearing Resistance, ° (φ΄)	Effective Cohesion, kPa (c´)							
Made Ground	28°	0							
Stiff and very stiff gravelly Clay <sup>1</sup>	36°	0							
St Mary's Well Bay Formation <sup>2</sup>	32°	5							
Penarth Group <sup>2</sup>	35°	8							
Blue Anchor Formation <sup>2</sup>	35°	12							
Weathered Mercia mudstone <sup>3</sup>	38°	0							
Mercia Mudstone <sup>3</sup>	40°	15							

Notes:

- 1 Relationship between angle of shearing resistance and SPT N value (Peck, Hanson and Thornburn)
- 2 Engineering Geology of British Rocks and Soils Lias Group (BGS Internal Report OR/12/032)
- 3 Engineering Geology of British Rocks and Soils Mudstones of the Mercia Mudstone Group

#### 2.3.2 Pore Water Pressure

Groundwater was encountered within the Penarth Group at 17.2m depth in BH01 sunk as part of the current investigation. With regards to the boreholes sunk as part of the Marine Buildings investigation groundwater at the base of the escarpment was encountered at approximately 6 to 8m depth near the top of the Mercia Mudstone Group. Overall groundwater levels have been interpolated to link the two as shown in the computer model.

#### 2.3.3 Soil Density

A soil density of 18kN/m<sup>3</sup> has been applied to the made ground and stiff to very stiff gravelly clays.

A soil density of 20kN/m<sup>3</sup> has been applied all other soil/rock types.

#### 2.3 Computer Analytical Set-up

Computer Slope Stability Analyses were performed using the SLOPE v.19 Computer Programme by OASYS.

#### 2.4.1 Bishop Slope Failure Mechanism

Due to the thickness of the made ground relative to the height of the proposed slopes, circular slip mechanisms were considered during computer analysis. Circular slopes were assessed by the Bishop Method. Further details of this method can be found in published literature.

The analyses were performed using the grid method to specify a large number of potential rotation points for the centre of the slip circles. Grids were set up with 1.0m spacing between points. The radius of the potential slip circles was not limited.

#### 2.4.1.1 Operational Setting

Analyses were performed based on shear strength parameters. The circular slips were divided into the default number of interslice sections. Interslice forces were accommodated into the calculations via the variably inclined interslice method. All other settings were left in default mode.

#### 2.4.1.2 Factors of Safety

The programme assesses multiple failure circles rotating about centre points within the predetermined grid. The Factors of Safety presented in this report represent the most unstable failure circles.

BS 6031Section 6.5 sub section 6.5.1.2 suggests that a safety factor of between 1.3 and 1.4 should be designed for.

A factor of safety of 1.3 has, therefore, been taken as adequate. It is against this factor of safety that the results are assessed.

#### SECTION 3 Results of Stability Analysis

#### 3.1 Bishop Analysis Method

The Slope 19 Computer Programme was set up to determine the most unstable failure circle for the analysis. Any slope with a factor of safety less than 1 is considered to be unstable. The minimum acceptable factor of safety is 1.3. Those slopes with a factor of safety greater than 1.3 are considered sufficiently stable that a slip is unlikely to occur. Slips achieving a factor of safety of between 1 and 1.3 although unlikely, are considered to have the potential to occur.

The resultant Factors of Safety for the most unstable circles within these slopes are presented in **Table 3.1**.

Table 3.1. Factors of Safety for Least Stable Failure Circles								
Slope Section Analysis Method Factor of Safety								
1	Bishop	0.810						

The computer slope stability analysis is presented in Annex C.

The predicted slip surface identified is seen to pass through the existing retaining wall. Figure 3.1 shows the analysed failure planes. All failure planes with a factor of safety of less than 1.3 are located directly behind the existing retaining wall a on the surface of the escarpment face as it drops towards Marine Buildings/ Custom House.



Figure 3.1: Failure Surfaces - Bishop Method Slip Surface

#### SECTION 4 Sensitivity Analysis

#### 4.1 Introduction

Sensitivity analyses were performed upon the Bishop Method slope analysis to determine the effect of varying principle parameters upon the resultant factor of safety.

All shear strength parameters were reduced by 25% and the model re-run.

#### 4.2. Shear Strength

The shear strength parameters were reduced by 25%. The resultant Factors of Safety of presented in **Table 4.1**. The graphical output of the analysis is shown in **Figure 4.1**.

Table 4.1 Factor of Safety for Least Stable Failure Circles - 25%           Reduction in Shear Strength Parameters						
Stability Run	Factor of Safety					
Original	0.810					
-25%	0.735					



#### Figure 4.1: Failure Surfaces – 25% reduction in shear strength

Again the predicted failure planes pass through or behind the retaining wall with a lowered factor of safety. The analysis has also shown an increased area of shallow failure on the escarpment slope.

#### 4.3 **Pore Water Pressure**

In addition to the groundwater profile discussed in Section 2.3.2, an increase in groundwater levels has been modelled. The results of the analysis are presented in **Table 4.2**.

### 4.3 **Pore Water Pressure** (Continued)

It can be seen that the increase in groundwater has a negligible impact on the stability of the slope.

Table 4.2. Porewater Sensitivity Analysis									
Stability Run	Hydraulic Head within Made Ground, (m)	Factor of Safety							
Original	Within Blue Anchor Formation	0.810							
Sensitivity 1	Top of Penarth Group	0.810							
Sensitivity 2	Middle of St Mary's Well Bay Formation	0.810							

#### **SECTION 5** Conclusions

#### 5.1 Modelled Slope

In Section 2.4.1.2 it was stated that BS 6031Section 6.5 sub section 6.5.1.2 suggests that a safety factor of between 1.3 and 1.4 should be designed for.

The slope stability of the area has therefore, been analysed on the basis of a factor of safety of 1.3 guaranteeing stability for the site with the assumption that any factors of safety below 1.3 are potentially at risk.

The slope stability analysis has revealed that based upon the soil profile and generic soil shear stress parameters all significant failure plains are within the stiff and very stiff gravelly clays generally located behind the existing retaining wall with very shallow failure planes at the top of the escarpment slope. The presence of cracking in the wall would confirm this.

A 25% reduction in shear strength showed a reduced factor of safety, though the significant failure planes generally remained behind the retaining wall with slightly deeper failure planes at the top of the escarpment slope. The occurrence of the past slope instability to the east of the site confirms this.

#### SECTION 6 Further Work

The slope stability modelling has not identified an unacceptable risk of deep seated failure beneath the site. The shallow slip circles with unacceptable factors of safety identified can be engineered using common design techniques.

However, as previously stated the analysis is based upon limited data both in term of site investigation and soil parameter testing.

In order to confirm the results of the analysis the following investigation should be carried out:

- The sinking of eight rotary coreholes to a depth of typically 40m over the site area
- The installation of piezometers within the boreholes to monitor the fluctuation of ground water levels wit time
- The installation of inclinometers within the borehole to monitor ground movements before during and after construction through the full depth of the borehole
- Trial pitting to determine/confirm shallow ground conditions
- A comprehensive computer slope stability Analysis over a number of sections using the enhanced data and site specific parameters

All of the above is required to confirm that the findings of the preliminary slope stability analysis.

## However, from the preliminary analysis it appears that all lightly failure plains are shallow and confined to the superficial deposits.

The recommended foundation solution of steel piles installed into the underlying competent bedrock will not add any weight to the ground surface and will maintain the stability of the development.

This should be demonstrated by the continued monitoring of the inclinometers.

It is recommended that in the long term (before, during and after construction) the slope be monitored for signs of movement and small scale slippage. Small slips provide an indication as to whether any larger scale slips may occur.

Should any unacceptable movement of the slope be recorded that significantly increases the risk from further and greater slips, appropriate steps can be made to secure the slope as necessary.

ANNEX A Rotary Probe/Corehole Logs

<b>X</b> terra <b>firma</b>					Terra 5 Der Pentv CF23	Terra Firma (Wales) Limi 5 Deryn Court, Wharfeda Pentwyn, Cardiff CF23 7HA			Tel: 02920 735354 info@terrafirmawales.co.uk www.terrafirmawales.co.uk	Borehole No. BH01		
Project	Name:	North (	Cliff Lo	odge		Project	No.		Co-ords	:	Hole Type	4 e
Locatio	n:	Penarth	<u>ו</u>			13124	13124		Level:	Level:		
Client: Celtic Developments Penar			th Limited			Dates:	07/11/2016	Logged B	8y			
Water Strikes	Depth (m)	Type /Fl	TOD	Corin	g	Depth (m)	Level (m)	Well	Legen d	Stratum Description		
	()		ICR	SCR	RQD	2.40				Stiff light greyish brown silty CLAY. Very stiff dark greyish brown becon grey CLAY with rare white shell frag	ning dark gments.	- 1
	4.00 - 5.50	)	30	20	7	4.00				Limited recovery. Recovered as str grey LIMESTONE. Fractures are so very closely and closely spaced un smooth.	ong light ubhorizontal dulating	4
	5.50 - 7.00	)	22	0	0	5.50				Limited recovery. Recovered as ve blueish grey CLAY.	ry stiff dark	6
	7.00 - 8.50	)	34	9	0	7.00				Limited recovery. Recovered as ve extremely weak dark grey CLAY/M Fractures are subhorizontal extrem and very closely spaced planar sm	ry stiff to UDSTONE. ely closely ooth.	7
	8.50 - 10.00	0	100	68	14	8.50 8.80 9.00				Extremely weak dark grey MUDST Fractures are subhorizontal very cl planar smooth. Weak to medium strong grey and c LIMESTONE. Fractures are subho closely and closely spaced undulat Extremely weak dark grey MUDST Fractures are subhorizontal extrem closely spaced planar locally undul	ONE. osely spaced izontal very ing smooth. ONE. ely closely to ating	9
Remar	ks:											

<b>M</b> terra <b>firm</b>					ma	Terra 5 De Pent CF23	a Firma (Wa ryn Court, ' wyn, Cardi 3 7HA	ales) Lir Wharfeo ff	nited dale Roa	d Tel: 02920 735354 info@terrafirmawales.co.uk www.terrafirmawales.co.uk	Borehole No. BH01	
Project	Project Name: North Cliff Lodge				Projec	Project No.			ds:	2 of 4 Гуре		
Location: Penar			h			13124	13124			Sca 1:5	BH Scale 1:50	
Client:	Celtic [	Develo	opmen	ts Pena	rth Limited	i		Dates	07/11/2016 Logge	d By		
Water Strikes	Depth (m)	Type /FI	TCR	Corin	Ig ROD	Depth (m)	Level (m)	Well	Leger d	ر Stratum Description		
	10.00 - 11.50	0	61	33	0					smooth. 10° planar smooth fracture.	- - - - - - - - - - - - - - - - - - -	
	11.50 - 13.00	0	27	6	0	11.50				Limited recovery. Recovered as very weak light brown and dark greenish grey SILTSTONE and MUDSTONE. Non intact.	12	
	13.00 - 14.50	0	95	23	17	13.00				Very weak dark greenish grey locally dark brown MUDSTONE. Fractures are subvertical and 40-70° very closely and closely spaced planar locally undulating smooth. Fracture locally with veneer of clay. Medium strong dark grey LIMESTONE.	— 13 — 13 — 14 — 14	
	14.50 - 16.0	0	100	50	23					Weak dark grey SILTSTONE.	- - - - - - - - - - - - - - - - - - -	
	16.00 - 17.5	0	96	17	14	16.20				Extremely weak to very weak greenish grey MUDSTONE. Fractures are subvertical and 40-70° very closely and closely spaced planar locally undulating smooth. <u>Soft to firm sandy clay ban</u> d (40mm thick)	16	
	17.50 - 19.0	0	83	0	0	1				Non intact.	- - - - - - - - - - - - - - - - - - -	
	19.00 - 20.50	0	81	0	0	19.00 19.50				Very weak light greenish grey MUDSTONE. Fractures are 40-60° very closely spaced plana smooth. Won intact. Very weak greenish grey MUDSTONE.	r 19	
Remai	rks:					19.00				Fractures are 5-25° extremely closely and very	20	

# **terrafirma**

Terra Firma (Wales) Limited 5 Deryn Court, Wharfedale Road Pentwyn, Cardiff

Tel: 02920 735354 info@terrafirmawales.co.uk www.terrafirmawales.co.uk Borehole No.

						CF23	3 7HA				Sheet 3 of	4	
Project	Name:	North (	Cliff Lo	odge		Project 13124	t No.		Co-ord	s:	Hole Type BH	3	
Locatio	n:	Penarth	ו						Level:		Scale 1:50		
Client:		Celtic E	Develo	pmen	ts Pena	rth Limited	I		Dates:	07/11/2016	Logged By	у	
Water Strikes	Depth (m)	Type /FI	ТОР	Corin	Ig	Depth (m)	Level (m)	Well	Legen d	Stratum Descriptior	1		
	20.50 - 22.00	0	98	18	0	20.50 21.30 22.40				closely spaced planar smooth.         Non intact.         Very weak greenish grey MUDSTC         Fractures are 60-70° extremely cloplanar locally undulating smooth. Lintact.         Very weak dark reddish brown loca         greenish grey MUDSTONE. Fracture         30-40° closely spaced planar smooth         55° undulating smooth fracture.         Very weak light greenish grey and grey MUDSTONE. Fractures are 5         spaced planar smooth. Locally non         Non intact.         Non	INE. sely spaced ocally non Illy light res are oth. brownish 0-65° closely i intact.	21	
	23.50 - 25.00	0	97	43	37	24.10 24.40				Non intact. Locally tending to claybou and medium gravel sized mudstone li Very weak to weak light greenish g brownish grey MUDSTONE. Fractu 50-60° closely and medium spaced locally planar smooth. Subvertical undulating smooth fractur Non intact. Extremely weak light greenish grey MUDSTONE. Fractures are 60-70° closely spaced undulating smooth. Very weak to weak light greenish grey moving grey MUDSTONE Fractures and the senish grey brownish grey MUDSTONE Fractures and the senish grey MUDSTONE.	ybound tabular fine one lithorelicts. ish grey and light ractures are aced undulating acture. grey 0-70° extremely ooth. ish grey and light		
25.00 - 26.9		0	89	45	35	25.00				60-70° closely and medium spaced smooth. Extremely weak to very weak dark brown locally light greenish grey M Fractures are 50-60° closely and m spaced undulating locally planar sr Non intact.	l planar reddish UDSTONE. iedium nooth.	25	
	26.50 - 28.0	D	77	6	0	26.50 27.70				Extremely weak dark reddish brow MUDSTONE. Fractures are 20-60° closely and very closely spaced pla undulating smooth. Locally non inta Subvertical undulating smooth fractur Very weak dark reddish brown loca greenish grey MUDSTONE. Fractu	extremely anar locally act. e. illy light ires are	27 27 27	
	28.00 - 29.5	0	96	71	54	29.10				Non intact (30mm thick) Very weak locally extremely weak of brown MUDSTONE. Fractures are subhorizontal to 20° very closely to spaced planar smooth.	dark reddish medium	29	
										60° planar smooth fracture.		- 30	
Rema	rks:												

	<b>e</b> te	err	af	irı	ma	Terra 5 Der Penty CF23	Firma (Wa ryn Court, ' wyn, Cardi 3 7HA	ales) Lin Wharfeo ff	nited dale Road	Tel: 02920 735354 info@terrafirmawales.co.uk www.terrafirmawales.co.uk	Borehole N BH01	0.
Project	Name:	North (	Cliff Lo	odge		Project	No.		Co-ord	s:	Hole Type	4 e
Locatio	on:	Penartl	h			13124			Level:		Scale 1:50	
Client:		Celtic [	Develo	pmen	ts Pena	rth Limited			Dates:	07/11/2016	Logged B	у
Water Strikes	Depth (m)	Type /FI	ТСР	Corir	Ig	Depth (m)	Level (m)	Well	Legen d	Stratum Description		
	29.50 - 31.0	0	100	63	41					Extremely weak.		
	31.00 - 32.5	0	97	45	31	31.60				80° planar smooth fracture. Non intact. Locally non intact. Tending to claybou and medium gravel sized lithorelicts. Very weak dark reddish brown loca light greenish grey MUDSTONE. Fi 60° closely and medium spaced pla	Ind tabular fine	- 31 
	32.50 - 34.0	0	97	65	55	24.00						33
	34.00 - 35.5	0	96	36	23	34.00				Very weak dark reddish brown loca light greenish grey MUDSTONE. Fr subhorizontal to 30° very closely ar spaced planar smooth. 2no. 60-70° planar smooth fractures. Extremely weak dark reddish brown MUDSTONE. Non intact.	Ily spotted ractures are nd closely	- 34 
	35.50 - 37.0	0	91	0	0	36.00				50° planar smooth fracture. Vuggy. Vugs up to 10mm diam. Very stiff dark reddish brown locally greenish grey silty CLAY. 70-80° curved locally stepped smooth	/ light h fissure.	
	37.00 - 38.5	0	95	31	7	37.00 38.20				Extremely weak to very weak dark brown MUDSTONE. Fracture are 5 closely and closely spaced planar s <u>3no. 50-55° planar smooth</u> fractures. Very stiff dark reddish brown locally	reddish i-40° very smooth. / spotted	
	38.50 - 40.0	0	93	0	0	40.00				T5° undulating smooth fracture.	n	
Rema	rks:					-						

	te	rr	afirma	info ww	Tel: 02920 @terrafirma w.terrafirma	735354 wales.c wales.c	co.uk co.uk	Terra Firma (Wales) Limited 5 Deryn Court, Wharfedale Road Pentwyn, Cardiff CF23 7HA	Borehole N BH01 Sheet 1 of	lo. 5
Project Name:	North Cliff	Lodge			Project N 13124	lo:	Co-ords	5:	Hole Type BH	Э
Location	: Penarth				-1		Level:		Scale 1:50	
Client:	Celtic Deve	elopme	nts Penarth Limited				Dates:	07/11/2016 -	Logged B	у
Water	Sample	e and I	n Situ Testing	Depth	Level	Well	Legend	Stratum Description		
Ounces	Depth (m)	Туре	Results	(111)			×_^_×	Stiff light greyish brown silty CLAY.		-
	1.00	SPT	N=29 (5,4/3,4,7,15)							
	2.50	SPT	N=22 (2,3/4,4,6,8)	2.40				Very stiff dark greyish brown becoming d with rare white shell fragments.	ark grey CLAY	- 3
	4.00	SPT	N=49 (6,7/7,8,16,18)	4.00				Limited recovery. Recovered as strong lig LIMESTONE. Fractures are subhorizonta and closely spaced undulating smooth.	ght grey al very closely	4
				5.50				Limited recovery. Recovered as very stiff grey CLAY.	dark blueish	- - - - - - - - - - - - - - - - - - -
	7.00	SPT	50 (8,12/50 for 225mm)	7.00				Limited recovery. Recovered as very stiff weak dark grey CLAY/MUDSTONE. Frac subhorizontal extremely closely and very planar smooth.	to extremely tures are closely spaced	- 7 
				8.50 8.80 9.00				Extremely weak dark grey MUDSTONE. subhorizontal very closely spaced planar Weak to medium strong grey and dark gr LIMESTONE. Fractures are subhorizonta and closely spaced undulating smooth. Extremely weak dark grey MUDSTONE. subhorizontal extremely closely to closely locally undulating smooth. 10° planar smooth fracture.	Fractures are smooth. rey al very closely Fractures are y spaced planar	9
	10.00	SPT	50 (8,11/50 for 35mm)					Continued on Next Sheet		- 10
Remarks	::	1				1				

	te	rr	afirma	info	@terrafirma	vales.c	o.uk	5 Deryn Court, Wharfedale Road Pentwyn, Cardiff	BH01	
				- ~~~~	w.terranima	wales.c	JO.UK	CF23 7HA	Sheet 2 of	f 5
Project Name:	North Cliff	Lodge			Project N	lo:	Co-ords		Hole Type BH	е
Location	: Penarth				10121		Level:		Scale	
Client <sup>.</sup>	Celtic Deve	elonme	nts Penarth Limited				Dates:	07/11/2016 -	Logged B	sy
	Oomal Down				<u> </u>		Datoo.			<u> </u>
Water Strikes	Depth (m)	Type	Results	Depth (m)	Level (m)	Well	Legend	Stratum Description		
										-
										F
										-
										- 1'
										-
				11.50				Limited recovery. Recovered as very wea	k light brown	╞
								Non intact.	MUDSTONE.	-
										-
	13.00	SPT	50 (25 for 5mm/50 for	13.00				Very weak dark greenish grey locally dark	brown	
			3mm)					MUDSTONE. Fractures are subvertical ar	nd 40-70° very	-
								smooth. Fracture locally with veneer of cla	ay.	
								weaking tark grey Envicer one		
										- 14
										-
								Wook dark grov SUITSTONE		F
								Veak dark grey SILTSTONE.		- 1
	16.00	SPT	50 (25 for 10mm/50 for 5mm)	16.20						10
				10.20				Extremely weak to very weak greenish gr MUDSTONE. Fractures are subvertical ar	ey nd 40-70° very	F
								closely and closely spaced planar locally smooth.	undulating	F
								Soft to firm conductory band (10mm th	iok)	- 13
								Son to him sandy ciay band (40him th	ick)	-
								Non intact.		-
										18
								Non intact.		_
										F
	19.00	SPT	50 (25 for 135mm/50	19.00				Vanuwaak light grooniah grov MUDSTON	E Erecturee	- 19
			for 90mm)					are 40-60° very closely spaced planar sm	ooth.	F
				19.50				Very weak greenish grey MUDSTONE. Fr	actures are	ŧ
				19.85				5-25° extremely closely and very closely s smooth.	spaced planar	È
					1			Continued on Next Sheet		<u> </u>

	te	err	afirma	info www	Tel: 02920 @terrafirma w.terrafirma	735354 wales.c wales.c	o.uk o.uk	Terra Firma (Wales) Limited 5 Deryn Court, Wharfedale Road Pentwyn, Cardiff CF23 7HA	Borehole No. BH01 Sheet 3 of 5
Project Name:	North Cliff	Lodge			Project N 13124	lo:	Co-ords	5:	Hole Type BH
Location	: Penarth				1.0.2.		Level:		Scale 1:50
Client:	Celtic Dev	elopme	nts Penarth Limited				Dates:	07/11/2016 -	Logged By
Water Strikes	Sampl	e and I	n Situ Testing	Depth (m)	Level	Well	Legend	Stratum Description	
	Depth (m) 22.00	SPT	Results 50 (25 for 0mm/50 for 3mm)	20.50 21.30 22.40				Won intact.         Very weak greenish grey MUDSTONE. F         60-70° extremely closely spaced planar I         undulating smooth. Locally non intact.         Very weak dark reddish brown locally ligt         MUDSTONE. Fractures are 30-40° close         planar smooth.         65° undulating smooth fracture.         Very weak light greenish grey and brown         MUDSTONE. Fractures are 50-65° close         planar smooth. Locally non intact.         Non intact.         Non intact.         Fracture infilled with soft pinkish brow         thick).         Non intact.         Non intact.         Non intact.         Fracture infilled with soft pinkish brow         thick).         Non intact. Locally tending to claybou         and medium gravel sized mudstone li         Very weak to weak light greenish grey ar         brownish grey MUDSTONE. Fractures a         closely and medium spaced undulating lo smooth.         Subvertical undulating smooth fracture	iractures are ocally It greenish grey ly spaced ish grey ly spaced <i>n clay (20mm</i> <i>n d tabular fine</i> <i>thorelicts.</i> Id light re 50-60° cally planar <i>e.</i>
	25.00	SPT	50 (25 for 110mm/50 for 70mm)	24.10 24.40 25.00				Non intact. Extremely weak light greenish grey MUE Fractures are 60-70° extremely closely s undulating smooth. Very weak to weak light greenish grey ar brownish grey MUDSTONE. Fractures a closely and medium spaced planar smoo Extremely weak to very weak dark reddis light greenish grey MUDSTONE. Fractur closely and medium spaced undulating lo smooth. Non intact.	STONE. paced d light re 60-70° th. sh brown locally es are 50-60° ocally planar
	28.00	SPT	50 (25 for 115mm/50 for 40mm)	26.50 27.70 29.10				Extremely weak dark reddish brown MUI Fractures are 20-60° extremely closely a spaced planar locally undulating smooth intact. Subvertical undulating smooth fractur Very weak dark reddish brown locally ligi MUDSTONE. Fractures are 70-80° medi planar smooth. Non intact.	e. ht greenish grey um spaced 226 240 240 240 250 270 270 270 270 270 270 270 27
Remarks								MUDSTONE. Fractures are subhorizonta closely to medium spaced planar smooth 60° planar smooth fracture. Continued on Next Sheet	al to 20° very

	te	rr	afirma	info www	Tel: 02920 @terrafirma w.terrafirma	735354 wales.c wales.c	o.uk o.uk	Terra Firma (Wales) Limited 5 Deryn Court, Wharfedale Road Pentwyn, Cardiff CF23 7HA	Borehole No. BH01 Sheet 4 of 5
Project Name:	North Cliff	Lodge			Project N 13124	lo:	Co-ords	x	Hole Type BH
Location	: Penarth						Level:		Scale
Client:	Celtic Deve	elopme	ents Penarth Limited				Dates:	07/11/2016 -	Logged By
Water	Sample	e and I	n Situ Testing	Depth	Level	Well	legend	Stratum Description	
Strikes	Depth (m)	Туре	Results	(m)	(m)				
	31.00	SPT	50 (25 for 70mm/50 for 25mm)	31.60				-80° planar smooth fracture. Non intact. Locally non intact. Tending to claybou	nd tabular fine
								Very weak dark reddish brown locally spo greenish grey MUDSTONE. Fractures ar and medium spaced planar smooth.	otted light - 3
	34.00	SPT	50 (25 for 50mm/50 for 35mm)	34.00				Very weak dark reddish brown locally spo greenish grey MUDSTONE. Fractures ar to 30° very closely and closely spaced pl	otted light3 e subhorizontal anar smooth 
				35.00				2no. 60-70° planar smooth fractures. Extremely weak dark reddish brown MUE intact. 50° planar smooth fracture. Vuggy. Vugs up to 10mm diam.	DSTONE. Non - 3
				36.00			× × × ×	Very stiff dark reddish brown locally light silty CLAY.	greenish grey 3
	37.00	SPT	50 (25 for 5mm/50 for 5mm)	37.00			××	70-80° curved locally stepped smooth Extremely weak to very weak dark reddis MUDSTONE. Fracture are 5-40° very clo closely spaced planar smooth.	fissure3 h brown3 sely and 
								3no. 50-55° planar smooth fractures.	3
				38.20			×	Very stiff dark reddish brown locally spott greenish grey silty CLAY.	ed light
				38.50				Extremely weak dark reddish brown MUE intact. Quartz vein. 75° planar smooth fracture.	DSTONE. Non 3 3
				40.00				75° undulating smooth fracture.	

	te	rr	afirma	info( www	Tel: 02920 @terrafirma v.terrafirma	735354 wales.c wales.c	xo.uk xo.uk	Terra Firma (Wales) Limited 5 Deryn Court, Wharfedale Road Pentwyn, Cardiff CF23 7HA	Borehole N BH01	No.
Project					Proiect N	lo:			Sheet 5 of Hole Type	f 5 e
Name:	North Cliff	Lodge			13124		Co-ords	:	BH	
Location:	Penarth						Level:		Scale 1:50	
Client:	Celtic Deve	elopme	ents Penarth Limited				Dates:	07/11/2016 -	Logged B	5y
Water	Sample	e and I	n Situ Testing	Depth	Level	Well	Legend	Stratum Description		
Suikes	Depth (m) 40.00	Type SPT	Results 50 (25 for 0mm/50 for	(11)				End of Borehole at 40.000m		-
			2mm)							F
										-
										- 41
										- "
										E
										42
										E
										-
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										F
										- 50
Remarks	:	1					<u>.                                    </u>			

#### ANNEX B Site Investigation Data

te	rraf	ir	m	a			Terra Wharfe Cardiff CF23 7	Firma (Wale edale Road, F F 'HB	s) Limited Borehole No entwyn Tel: 029 20 735 354 Fax: 029 20 735 433 Email: info@terrafirmawales.co.uk Sheet 1 of 2
Projec	t Name					Pr	oject N	lo.	Hole Type
Marine	e Buildings					11	458		Co-ords: - Rotary
Locatio	on: Penart	h Mar	ina, C	Cardiff					Level: - Scale 1:50
Client:									Dates: 20/12/2011
	ater Samp	es & li	n Situ '	Testin	a	Denth			APEX&IF
VV ell Stri	ikes Depth (m)	Туре	F	Results	3	(m)	(m AOD)	Legend	Stratum Description
						1.40			Stiff CLAY (Driller's Description).
									2
						3.20			Stiff CLAY and weathered MUDSTONE (Driller's description).
						4.50			Firm to stiff, tan brown to grey, gravelly CLAY. Gravel is fine to coarse, subangular to subrounded of mudstone. Laminated in places.
						6.00			Stiff, tan brown, gravelly CLAY with occasional cobbles. Gravel is fine to coarse, subangular to subrounded of mudstone.
						7.50			Very weak MUDSTONE. Recovered as grey cobbles with red mottling and staining.
	7.50-9.00	27	5	0		0.00			(IVIIVIG) - 8
	9.00-10.50	66	40	1	+8	9.00			Very weak to moderately weak red brown MUDSTONE with light blue grey separations. Fractures are very closely spaced rough and stepped. (MMG) 45 degree smooth fracture with dark staining. 45 degree rough fracture
Dansar	ko	TCR	SCR	RQD	FI				Continued next sheet
ĸemar	KS:								AGS

HoleBASE III (Bkd 426.48) Standard Borehole Log v2 dated 27th Nov 03

+.	or	r-f		~	1			Terra I Wharfe	Firma (Wa dale Road,	es) Limited Pentwyn	Tel:	029 20 735 354	Borehole No
L	21	dl			d	1		Cardiff			Fax:	029 20 735 433	
D	o ct M	0.000.0						CF23 7	HB		Email:	info@terrafirmawales.co.uk	Sheet 2 of 2
Proj	inc P	ame uildings					Pr	UJECT IN	Ю.	Co-ords:	-		Rotary
	ation.	Donarth	Mari	ina C	ardiff			400					Scalo
LUC	allon.	Fenaru	i iviai	na, C	arum					Level:	-		1:50
Clio	nt·									Dates:	20/12	/2011	Logged By
										Dales.	20/12	72011	APEX&TF
Well	Water Strikes	F Depth (m)	Cotary	Corin SCR	<b>g</b> RQD	FI	Depth (m)	Level (m AOD)	Legend			Stratum Description	
										Remaining Deta with dark brown	il : 9.66m staining.	- 9.66m : Horizontal smooth fi	racture
							10.50				Er	nd of Borehole at 10.50 m	
													- 11
													-
													-
													-
													-12
													-
													-
													-13
													-
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													-
			TCR	SCR	RQD	FI							-
Rem	arks:								·				AGS

HoleBASE III (Bid 426.48) Standard Borehole Log v2 dated 27th Nov 03

t	er	rafi	r	na 🏓		Terra Wharfe Cardiff CF23 7	Firma (Wales edale Road, Pe f 'HB	s) Limited entwyn	Tel: Fax: Email:	029 20 735 354 029 20 735 433 info@terrafirmawales.co.uk	Borehol BHC Sheet 1	e No <b>2</b> of 2
Proj	ect N	ame			Pr	oject N	lo.				Hole T	уре
Mar	ine Bu	uildings			11	458		Co-ords:	-		Rota	ry
Loca	ation:	Penarth	n Mari	na, Cardiff				Level: - Scale 1:50			le )	
Clie	nt:							Dates:	20/12/	2011	Logged APEX8	d By TF
Well	Water Strikes	Sample Depth (m)	es & In Type	Situ Testing Results	Depth (m)	Level (m AOD)	Legend		:	Stratum Description		
					0.50			Soft to firm, tan bi coarse, subangula	rown, gra ar to subr	welly CLAY. Gravel is fine rounded of mudstone.	to	-
					1.10			coarse, subround	ed of mu	dstone.		-1
					1.20			Very stiff, tan brow	wn, CLAY	with lithorelicts of mudst	one.	
					0.70			angular of mudstc	one with I	ithorelicts.	coarse,	-2
					2.70			Very stiff, tan brov	wn, CLAY	vith lithorelicts of mudst	one.	-3
					4.20							-4
					5 70			No recovery.				
					5.70 5.90			Fine to coarse, an	ngular to	subangular GRAVEL of m	udstone and	
	$\square$				7 20			Very stiff, tan brov angular of mudsto	wn, grave one.	Ily CLAY. Gravel is fine to	coarse,	-7
					1.20			Weak MUDSTON fine to coarse, any	IE. Recov gular to s	vered as grey and occasic ubangular GRAVEL of mu	nally red, clayey, udstone.	
					8.70			Weak MUDSTON GRAVEL of muds	IE. Recov stone.	vered as medium to coars	e, angular, red,	
					9.50			Weak MUDSTON of mudstone. Red	IE. Recov I staining	vered as fine to coarse, ar and mineralisation.	ngular, red, GRAV	EL
			Туре	Results						Continued next sheet	1	-
Rem	arks:											
											Α	GS

ter	rafi	r	m	а			Terra Wharf Cardif	Firma (Wa edale Road,	es) Limited Pentwyn Tel: 029 20 735 354 Fax: 029 20 735 433	Borehole No BH02
			-				CF23	7HB	Email: info@terrafirmawales.co.uk	Sheet 2 of 2
Project N Marine E	Name Buildings					Pr 11	oject N 458	NO.	Co-ords: -	Hole Type Rotary
Location	: Penarth	Mari	ina, C	ardiff					Level: -	Scale 1:50
Client:									Dates: 20/12/2011	
w.u Wate		es & Ir	n Situ	Testin	a	Depth	Level			APEXAIF
Strike	s Depth (m)	Туре	F	Results	3	(m)	(m AOD	) Legend	Stratum Description Weak MUDSTONE. Recovered as fine to coarse, angular	r, red, GRAVEL
				1	1	10.50			of mudstone. Red staining and mineralisation.	-
									grey, GRAVEL of mudstone. Red staining and mineralisa	tion.
	10.50-12.00	66	10	15						-11
										-
						12 00				12
						10.40			Weak MUDSTONE. Recovered as red, fine to coarse, an gravel. 45 degree smooth red brown stained fracture	gular,
	12 00 13 50	00	12	20	+15	12.40			Weak to moderately weak, red and grey banded MUDST( 75 degree smooth fracture with red brown staining	ONE.
	12.00-13.00	90		20	+13				Closely spaced horizontal stepped fractures.	-13
						10 -0			45 dama and the discuss states of feature	-
						13.50			45 degree smooth red brown stained fracture. Weak MUDSTONE. Recovered as fine to coarse, angula	r, red, GRAVEL
						13.90			of mudstone. Red staining and mineralisation and calcifie gypsum.	ed14
	13.50-15.00	73	27	16					Weak to moderately weak, red and grey banded MUDST( Horizontal red brown stained fracture	
									45 degree smooth red brown stained fracture.	-
					-	15.00			End of Borehole at 15.00 m	
										-
										- 16
										-
										- 17 -
										- 18 - -
										-
										- - 19 V
										dated 271th
										hole Loo v2
		TCP	SUB	ROD	-					, indard Bore
Remarks	:		001				1			
										AGS

te		rafi	irı	ma 🏓	Pr	Terra Firma (Wald Wharfedale Road, F Cardiff CF23 7HB Oject No.	es) Limited Pentwyn Tel: 029 20 735 354 Fax: 029 20 735 433 Email: info@terrafirmawales.co.uk	Borehole No BH03 Sheet 1 of 1 Hole Type
Mar	ine Bu	uildings			11	458	Co-ords: -	RO
Loca	ation:	Penarth	n Mari	na, Cardiff			Level: -	Scale 1:50
Clier	nt:						Dates: 20/12/2011	Logged By APEX
Well	Water Strikes	Sample Depth (m)	es & Ir Type	Results	Depth (m)	Level (m AOD) Legend	Stratum Description	
		1.20	СРТ	N=13 N=13 (3,3,3,2,4,4)	1.20		Backfill (Drillers Description) Clay and Gravel (Drillers Description)	-1
		3.00	СРТ	N=6 N=6 (3,3,2,1,2,1)	3.30		Alluvium (Drillers Description)	-3
		4.50	СРТ	N=3 N=3 (1,0,1,0,1,1)				
					5.80			-
		6.00	CPT	N=41 N=41 (7,6,8,10,10,13)	6.00		Weathered Mudstone and Clay (Drillers Description)	
		7.50	CPT	N=12 N=12 (2,3,3,2,3,4)	7.30		Clay (Drillers Description)	-7
		9.00	CPT	N=15 N=15 (3,3,2,2,4,7)	8.80		Weathered Mudstone and Clay (Drillers Description)	-9
			Туре	Results			End of Borehole at 10.00 m	
Rem	arks:	No grour	nd wa	ter encountered.				AGS



