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REPORT 49215/G/6

TESTING OF

PORTLAND LIMESTONE

BROADCROFT WHITBED

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TESTING OF

PORTLAND LIMESTONE

BROADCROFT WHITBED

Portland Stone Firms Limited
99 Easton Street
Portland
Dorset
DT5 1BP

This report comprises
6 pages of text
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For the attention of Mr Neil Fuller

29 April 2014

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TESTING OF

PORTLAND LIMESTONE

BROADCROFT WHITBED

Reference: Instructions from Mr Neil Fuller of Portland Stone Firms Limited.
Purchase Order no. : M0454 dated 8 July 2013.

1. INTRODUCTION

We were instructed to undertake testing of natural stone, advised to be Portland limestone Broadcroft Whitbed, in order to establish physical characteristics.

2. SAMPLES

Test specimens prepared ready for test were received from Portland Stone Firms Limited at Sandberg laboratories on 29 January 2014, as follows.

Sandberg Reference	Specimen Size	Test
	Portland limestone Broadcroft Whitbed	
G40124	6 no. 50 x 50 x 50mm	Density & porosity
G40125	6 no. 50 x 50 x 50mm	Water absorption at atmospheric pressure
G40126	6 no. 70 x 70 x 70mm	Water abs. coeff. by capillarity [BS EN 772-11]
G40127	10 no. 50 x 50 x 50mm	Compressive strength [BS EN 772-1]
G40128	10 no. 300 x 100 x 50mm	Flexural strength (4-point)
G40129	13 no. 300 x 50 x 50mm	Frost resistance Identification Test (Test B) (56 cycles) - visual inspection - dynamic modulus of elasticity - apparent volume
G40130	6 no. 200 x 200 x 30mm	Slip resistance

3. TEST METHODS AND RESULTS

3.1 Density and porosity

Specimens were tested in accordance with BS EN 1936 : 2006.

Detailed test results are given in Table 1 of this report and are summarised as follows:

Sandberg Reference	Apparent Density (kg/m^3)		Open Porosity (%)	
	Range	Mean	Range	Mean
G40124	2230 - 2240	2230	16.5 - 17.2	16.9

3.2 Water Absorption at atmospheric pressure

Specimens were tested in accordance with BS EN 13755 : 2008.

Detailed test results are given in Table 2 of this report and are summarised as follows:

Sandberg Reference	Water Absorption (%)	
	Range	Mean
G40125	5.9 - 6.9	6.6

3.3 Water absorption coefficient by capillarity

Specimens were tested in accordance with BS EN 772-11 : 2011.

Detailed test results are given in Table 3 of this report and are summarised as follows:

Sandberg Reference	Water absorption coefficient by capillarity ($g/m^2.sec^{-2}$)
G40126	29.9

3.4 Compressive strength

Specimens were tested in accordance with the method given in BS EN 772-1 : 2011.

Tests were carried out with the load applied in a perpendicular to bedding orientation and in an oven dried condition.

The detailed test results are given in Table 4 of this report and may be summarised as follows:

Sandberg Reference	Orientation / Condition	Compressive Strength (MPa) Range	Mean
G40127	Perpendicular - dry	56.57 - 73.81	64 *

* To nearest 1.0 MPa

3.5 **Flexural strength (4-point) under constant moment**

Specimens were tested in accordance with the method given in BS EN 13161 : 2008.

Tests were carried out with the load applied in a perpendicular to bedding orientation and in an oven dried condition.

The detailed test results are given in Table 5 of this report and may be summarised as follows.

Sandberg Reference	Orientation / Condition	Flexural Strength (3-pt) (MPa) Range	Mean
G40128	Perpendicular - dry	5.0 - 8.3	6.9

Statistical evaluation of the test results in accordance with the methods in BS EN 13161 : 2008 Annex A (normative) produced the following:-

	Lowest Expected Value (MPa)
Perpendicular - dry	5.1

3.6 **Frost resistance Identification Test (Test B)**

Specimens were prepared and tested in accordance with BS EN 12371 : 2010 Identification Test (Test B).

It was instructed to continue the test to 56 cycles.

Specimens were visually inspected and tested for dynamic modulus of elasticity (fundamental resonance frequency) in an unknown bedding orientation and change in apparent volume in accordance with BS EN 14156 : 2004 at specified intervals (0, 14 and 56 cycles).

The detailed test results are given in Table 6 of this report and may be summarised as follows:

Sandberg Reference	Visual inspection score at 56 cycles (Nc)	Decrease in dynamic elastic modulus at 56 cycles (%)	Change in apparent volume at 56 cycles (%)
G40129 a	0	0.90	0.24
G40129 b	0	0.26	0.12
G40129 c	0	0.00	0.24
G40129 d	0	0.54	0.12
G40129 e	0	0.31	0.12
G40129 f	0	0.26	0.12
G40129 g	0	0.93	0.12
G40129 h	0	0.00	0.12
G40129 j	0	0.20	0.24
G40129 k	0	1.83	0.36
G40129 l	0	0.00	0.36
G40129 m	0	0.61	0.24

Note : A test set is defined as having failed when two or more samples show a visual score of 3 and/or a decrease in dynamic elastice modulus of 30%.

3.7 **Slip resistance**

Specimens with an as received surface finish were tested for slip resistance in accordance with BS EN 14231 : 2003 using a portable skid resistance tester (pendulum tester).

Testing was carried out in dry and wet conditions.

Surface roughness measurements were also carried out using a Surtronic Duo R_z roughness meter whilst the slip resistance measurements were being made.

Detailed results of the slip resistance test are given in Table 7 and are summarised below.

Sandberg Reference		Average Slip Resistance Value (SRV) (55 rubber)	
		Dry	Wet
G40130	**55 slider** - as received	64	53

The TRL pendulum tester has a range of readings from 0 to 150, high values indicate good slip resistance. Guidance on the interpretation of results is suggested by the UK Slip Resistance Group[1] . These are generally accepted limits and are given below.

Pendulum Test Value	**Slip Potential**
0 - 24	High
25 - 35	Moderate
36+	Low

The surface roughness measurements are a guide to slip resistance particularly in borderline regions. It is recognised that increased roughness of the floor surface can give an improvement in slip resistance in wet conditions.

Surfaces contaminated with pure water generally require a surface roughness of at least 10µm R_z to provide a moderate level of slip resistance and at least 20µm R_z to indicate low slip potential. More viscous contaminants require higher surface roughness[2].

The slip resistance results relate to the samples in their as-received condition. It should be noted that the slip resistance of surfaces in service can be altered by various factors such as abrasion, polishing and contamination. Overall assessment of the potential for slip should take into account conditions of use and the environment, in addition to test results.

1 The assessment of Floor Slip Resistance. The UK Slip Resistance Group, Issue 4, 2011.

2 Roughness measurements should not be solely relied upon to evaluate the potential slip resistance of a floor.

4. **REMARKS**

These results conclude the requested programme of testing. Please do not hesitate to contact us if we can be of any further assistance in this matter.

Portland Stone Firms Limited
99 Easton Street
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for Sandberg LLP

For the attention of Mr Neil Fuller

D J Ellis
Partner

DJE/Geoman/ws

29 April 2014

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Table
1

APPARENT DENSITY AND OPEN POROSITY

BS EN 1936 : 2006

Rock Name	Broadcroft Whitbed			Test By/Date	MB / 06.02.14	
Rock Type	Portland limestone			Checked/Date	LN / 06.02.14	
Sandberg Sample Ref.	Oven Dried Mass in Air (g)	Density of Water (kg/m³)	Vacuum Saturated Mass in Air (g)	Vacuum Saturated Mass in Water (g)	Open Porosity (%)	Apparent Density (kg/m³)
G40124 a	287.72	998	309.51	180.99	17.0	2230
G40124 b	286.87	998	307.95	180.32	16.5	2240
G40124 c	283.04	998	304.47	178.01	17.0	2230
G40124 d	286.62	998	307.96	180.39	16.7	2240
G40124 e	284.92	998	306.49	179.16	16.9	2230
G40124 f	279.66	998	301.26	176.00	17.2	2230
Mean					16.9	2230

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Table
2

WATER ABSORPTION AT ATMOSPHERIC PRESSURE

BS EN 13755 : 2008

Rock Name	Broadcroft Whitbed	Test By / Date	MB / 13.02.14
Rock Type	Portland limestone	Checked / Date	LN / 13.02.14

Sandberg Sample Ref.	Oven Dried Mass (g)	Saturated Surface Dried Mass (g)	Water Absorption (%)
G40125 a	284.49	304.05	6.9
G40125 b	283.67	302.81	6.8
G40125 c	289.68	306.66	5.9
G40125 d	281.16	300.56	6.9
G40125 e	286.38	304.88	6.5
G40125 f	283.63	302.43	6.6
Average			6.6

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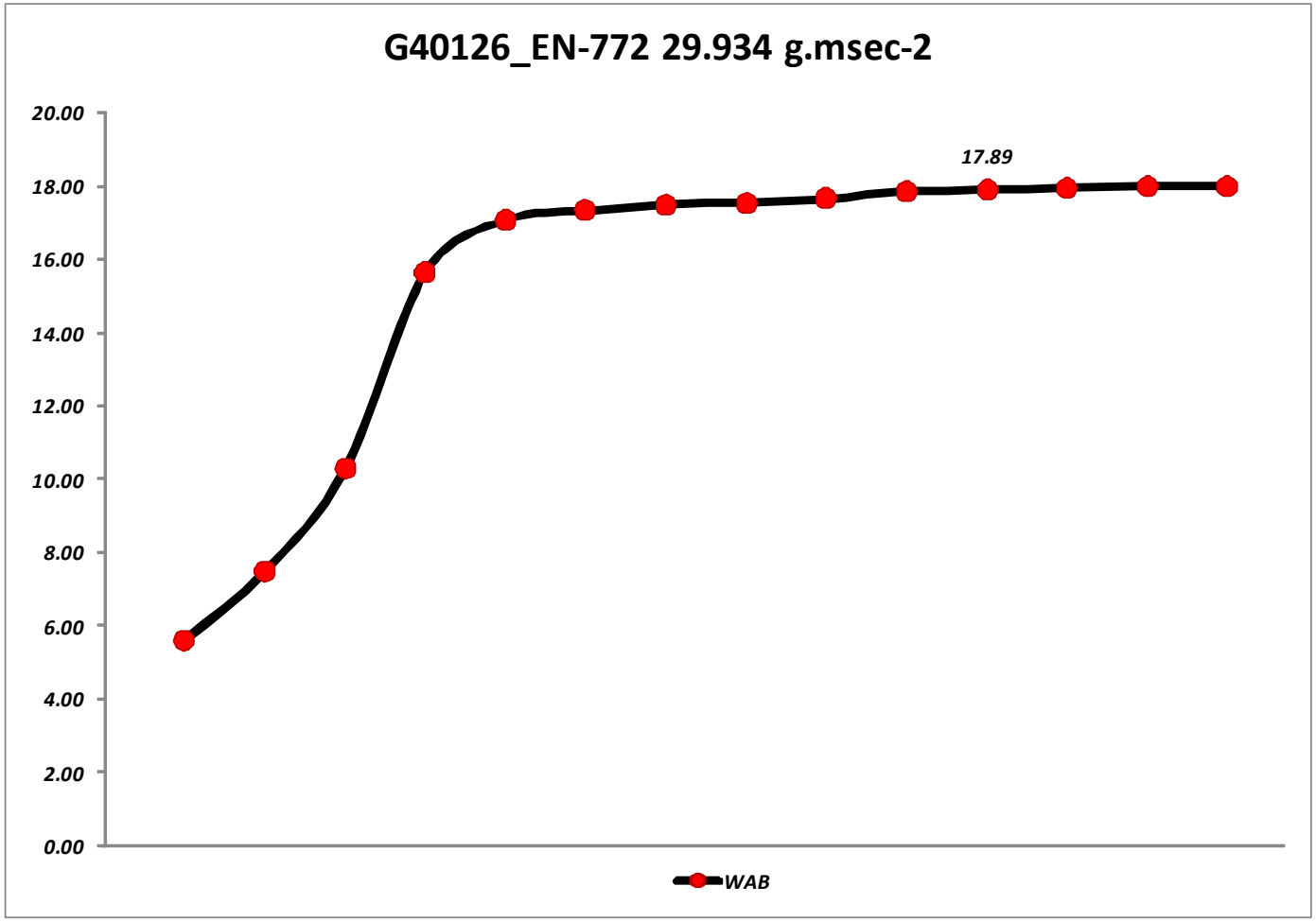

Coefficient of water absorption by capillarity: **29.93** **g/m^2.Sec^{-2}**

DETERMINATION OF WATER ABSORPTION COEFFICIENT BY CAPILLARITY

BS EN 772-11:2011

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Table
4

COMPRESSIVE STRENGTH

BS EN 772-1 : 2011

Load Orientation[1] : Perpendicular
Test Condition : Oven dried

Rock Name	Broadcroft Whitbed				Test By/Date	MB / 06.02.14	
Rock Type	Portland limestone				Checked/Date	HO / 06.02.14	
Sandberg Sample Reference	Breaking Load (N)	Specimen Height (mm)	Mean Lateral Dimension (mm)	Mean Lateral Dimension (mm)	Cross Section Area (mm^2)	Compressive Strength [a] (MPa)	Observations
G40127 a	153900	50.2	50.6	50.3	2545	60.47	Normal failure
G40127 b	186000	50.4	50.3	50.1	2520	73.81	Normal failure
G40127 c	143400	50.2	50.3	50.4	2535	56.57	Normal failure
G40127 d	161100	50.2	50.6	50.3	2545	63.30	Normal failure
G40127 e	167000	50.0	50.4	50.2	2530	66.01	Normal failure
G40127 f	168500	50.5	50.3	50.2	2525	66.73	Normal failure
G40127 g	157600	50.5	50.3	50.2	2525	62.42	Normal failure
G40127 h	167900	50.2	50.4	50.3	2535	66.23	Normal failure
G40127 j	147500	50.2	50.2	50.0	2510	58.76	Normal failure
G40127 k	153000	50.1	50.2	50.2	2520	60.71	Normal failure
Mean						64 *	
Std. Dev.						5 *	
Var. Coef.						0.1	

[1] Relative to bedding

* To nearest 1.0 MPa

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Table
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FLEXURAL STRENGTH (UNDER CONSTANT MOMENT)

BS EN 13161 : 2008

Load Orientation[1] : Perpendicular
Finish : Sawn
Test Condition : Oven dried

Rock Name	Broadcroft Whitbed			Test By/Date	MB / 07.02.14	
Rock Type	Portland limestone			Checked/Date	LN / 10.02.14	
Sandberg Sample Reference	Breaking Load (N)	Specimen Span (mm)	Specimen Width (mm)	Specimen Thickness (mm)	Flexural Strength (MPa)	Observations
G40128 a	6860	250	100.4	50.3	6.8	Normal Failure
G40128 b	6840	250	100.1	50.3	6.8	Normal Failure
G40128 c	6330	250	100.5	50.4	6.2	Normal Failure
G40128 d	7210	250	100.4	50.7	7.0	Normal Failure
G40128 e	5080	250	100.4	50.5	5.0	Normal Failure
G40128 f	7390	250	100.4	50.6	7.2	Normal Failure
G40128 g	7610	250	100.5	50.4	7.5	Normal Failure
G40128 h	7630	250	100.0	50.2	7.6	Normal Failure
G40128 j	8490	250	100.6	50.4	8.3	Normal Failure
G40128 k	6290	250	100.4	50.3	6.2	Normal Failure
Mean					6.9	
Std. Dev.					0.9	
Var. Coef.					0.1	

[1] With respect to bedding

Lowest Expected Value (MPa) : 5.1

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FROST RESISTANCE

BS EN 12371 : 2010
Identification test (Test B)

Rock Name	Broadcroft Whitbed											Test by/Date		HO / 18.03.14			
Rock Type	Portland limestone											Checked by/ Date		MB / 18.03.14			
Sandberg Sample Ref.	Visual inspection score						Dynamic elastic modulus (% decrease)										
	0	**14**	**56**	**84**	**140**	**168**	**0** (MPa)	**14** (MPa)	**14** (%)	**56** (MPa)	**56** (%)	**84** (MPa)	**84** (%)	**140** (MPa)	**140** (%)	**168** (MPa)	**168** (%)
G40129 a	0	0	0	-	-	-	54004	53848	0.29	53517	0.90	-	-	-	-	-	-
G40129 b	0	0	0	-	-	-	52280	52281	0.00	52144	0.26	-	-	-	-	-	-
G40129 c	0	0	0	-	-	-	51788	51887	0.00	51887	0.00	-	-	-	-	-	-
G40129 d	0	0	0	-	-	-	53060	52736	0.61	52773	0.54	-	-	-	-	-	-
G40129 e	0	0	0	-	-	-	53909	53652	0.48	53740	0.31	-	-	-	-	-	-
G40129 f	0	0	0	-	-	-	50667	49999	1.32	50533	0.26	-	-	-	-	-	-
G40129 g	0	0	0	-	-	-	53101	52846	0.48	52609	0.93	-	-	-	-	-	-
G40129 h	0	0	0	-	-	-	54284	54153	0.24	54296	0.00	-	-	-	-	-	-
G40129 j	0	0	0	-	-	-	54629	54621	0.02	54519	0.20	-	-	-	-	-	-
G40129 k	0	0	0	-	-	-	54428	54127	0.55	53434	1.83	-	-	-	-	-	-
G40129 l	0	0	0	-	-	-	53444	53329	0.22	53622	0.00	-	-	-	-	-	-
G40129 m	0	0	0	-	-	-	53873	53467	0.75	53543	0.61	-	-	-	-	-	-

Bedding direction : Unknown
Surface finish : Sawn

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FROST RESISTANCE

BS EN 12371 : 2010
Identification test (Test B)

Note : Failure is defined in BS EN 12371 : 2010 clause 7.3.2.5 as when two or more specimens show either ; - a visual inspection score of 3
- decrease in dynamic elastic modulus of 30%

Visual inspection score :

0	Specimen intact
1	Very minor damage (minor rounding of corners and edges) which does not compromise the integrity of the specimen
2	One or several minor cracks (≤0.1mm width) or detachment of small fragments (≤10mm² per fragment)
3	One or several cracks, holes or detachment of fragments larger than those defined for the ‘2' rating, or alteration of material in veins.
4	Specimen broken in two or with major cracks.
5	Specimen in pieces or disintegrated.

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FROST RESISTANCE

BS EN 12371 : 2010
Identification test (Test B)

Rock Name	Broadcroft Whitbed					Test by/Date	HO / 18.03.14		
Rock Type	Portland limestone					Checked by/ Date	MB / 18.03.14		
Sandberg Sample Ref.	Measurement of apparent volume (% decrease)								
	Initial dry mass (g)	Initial saturated mass (g)	Apparent mass in water (g)	Dry mass at **56** cycles (g)	Saturated mass at **56** cycles (g)	Apparent mass at **56** cycles (g)	Initial apparent volume (ml)	Apparent volume at **56** cycles (ml)	Change in apparent volume **56** cycles (%)
G40129 a	1719	1823	986	1720	1821	986	837	835	0.24
G40129 b	1700	1803	970	1700	1802	970	833	832	0.12
G40129 c	1707	1814	978	1707	1812	978	836	834	0.24
G40129 d	1707	1811	981	1707	1810	981	830	829	0.12
G40129 e	1708	1812	982	1709	1811	982	830	829	0.12
G40129 f	1695	1802	969	1695	1801	969	833	832	0.12
G40129 g	1731	1835	992	1730	1834	992	843	842	0.12
G40129 h	1716	1817	985	1715	1816	985	832	831	0.12
G40129 j	1712	1814	983	1712	1812	983	831	829	0.24
G40129 k	1732	1838	993	1732	1835	993	845	842	0.36
G40129 l	1711	1813	980	1710	1811	981	833	830	0.36
G40129 m	1711	1813	981	1710	1810	980	832	830	0.24

Nc : Maximum number of cycles (56) or number of cycles completed to failure

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Sandberg Reference	Material	Surface Finish	Orientation	Surface Roughness[1] R_z,µm	Temperature °C		Slip Resistance Value (SRV)			
							Dry		Wet	
					Surface	Ambient	Mean [5 readings]	Mean	Mean [5 readings]	Mean
G40130 a	Broadcroft Whitbed	As received	A	26.3	21	21	63	62	58	57
			180° to A	-	21	21	60		55	
G40130 b	Broadcroft Whitbed	As received	A	22.6	21	21	65	65	55	55
			180° to A	-	21	21	64		54	
G40130 c	Broadcroft Whitbed	As received	A	33.8	21	21	64	65	52	53
			180° to A	-	21	21	65		53	
G40130 d	Broadcroft Whitbed	As received	A	24.2	21	21	62	64	45	49
			180° to A	-	21	21	65		53	
G40130 e	Broadcroft Whitbed	As received	A	21.2	21	21	64	64	52	52
			180° to A	-	21	21	64		52	
G40130 f	Broadcroft Whitbed	As received	A	19.5	21	21	65	64	46	49
			180° to A	-	21	21	63		52	

SRV dry (6 no. specimens) : 64
SRV wet (6 no. specimens) : 53

SLIP RESISTANCE TESTING - RUBBER SLIDER TYPE : 55
BS EN 14231 : 2003

Test by / Date	Table	Job No.
SF / 19.02.14	7	49215/G/6

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