Contractor

Forth Crossing Bridge Constructors

HOCHTIEF Solutions
American Bridge International
DRAGADOS
Morrison Construction

Project

FORTH REPLACEMENT CROSSING

Document title

VIBRATION MONITORING REPORT

NOVEMBER 2013

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Contents

Appendices:

INTRODUCTION

1.1. Monitoring of construction vibration is being undertaken by FCBC during the construction of the new Forth Crossing and associated road network. This report covers the month of November 2013. The objective of this report is to detail the vibration monitoring that has been undertaken across the site during this period, which has been done so in accordance with the Code of Construction Practice (CoCP), and Noise and Vibration Management Plan (NVMP).

1.2. FCBC have risk assessed noise & vibration resulting from all construction activities through the production of Plans for Control of Noise & Vibration (PCNVs). During the preparation of the PCNVs, the assessment/prediction of vibration levels has illustrated that no construction plant, equipment or methodology to be utilised by FCBC during the period in question, was envisaged to induce any levels of vibration at receptors that would exceed the vibration threshold levels stated in the CoCP. These assessments/predictions have been validated by means of the vibration monitoring results displayed in this report.

2. MONITORING SUMMARY

2.1. Due to the location and sensitivity of vibration monitoring equipment, the exceedances presented in the graphs included in the appendices of this report do not represent levels generated by construction, but rather show local interference around the monitoring equipment. This can include, for example, doors being slammed, or indeed any significant movements occurring close to the monitoring equipment.

2.2. According to the BS5228-2 (2009) there is minimal documented proof of actual damage to structures or their finishes resulting from construction, and damage resulting solely from well-controlled construction and demolition vibrations is rare. There are many other mechanisms which cause damage, especially in decorative finishes, and it is often incorrectly concluded that vibrations from construction and demolition sites are to blame. In many cases it is not possible to ascertain the exact source of vibration, though it is possible to rule out construction as a source on an activity basis.

2.3. The works carried out in each of the various construction work areas as well as the related vibration assessments are summarised in Appendix A.

2.4. Considering the distances between the various construction work areas and sensitive receptors as well as working methods utilised, the risk of any damage to structures or nuisance to residents occurring as a result FCBC construction related vibration is highly unlikely.

2.5. The number of threshold exceedances at the various vibration monitoring stations during the period in question are shown in Table 1 below.

Table 1: Exceedances of thresholds set out in the CoCP

November 2013

Location	PPV Exceedance		VDV Exceedance	
	Continuous (5 mm.s^{-1})	***Intermittent (10 mm.s^{-1})***	***Day (0.4 m.s$^{-1.75}$)***	***Night (0.2 m.s$^{-1.75}$)***
Linn Mill	0	0	0	17
Butlaw Fisheries	0	0	0	0
Clufflat Brae	5	1	0	0
Dundas Home Farm	0	0	1	1
Echline	3	1	0	0
Inchgarvie Lodge	0	0	0	0
Scotstoun	0	0	0	0
Springfield	2	3	0	0
Tigh-Na-Grian	7	4	1	2
Whinnyhill	3	4	0	0

2.6. Peak Particle Velocity (PPV) is used to measure vibration through a solid surface. When a vibration is measured, the point at which the measurement takes place can be considered to have a particle velocity. This particle vibration will take place in three dimensions (x, y and z).

2.7. The Peak Particle Velocity is the highest velocity that is recorded during a particular event, and as such is appropriate for the measurement of activities such as blasting and piling. The thresholds for the Forth Replacement Crossing are 5 mm.s^{-1} for continuous construction (e.g. piling), and 10 mm.s^{-1} for intermittent construction (e.g. blasting).

2.8. These thresholds are set to protect against building damage. For this monitoring period, all the exceedances have been investigated thoroughly and appear to have been generated as a result of standalone, instantaneous events arising from local interferences, the exact source of which remains unknown.

2.9. Vibration Dose Value (VDV) is a metric used in vibration monitoring. It is calculated by taking the fourth root of the integral of the fourth power of acceleration after it has been frequency-weighted. The frequency-weighted acceleration is measured in $m.s^{-2}$ and the time period over which the VDV is measured is in seconds. This yields VDVs in $m.s^{-1.75}$.

2.10. The vibration dose value (VDV), a cumulative measurement of the vibration level received over an 8-hour or 16-hour period, is recommended in BS 6472 as the appropriate measure to evaluate human exposure to vibration in buildings in residential and other uses.

2.11. During the monitoring period, vibratory rollers, crushers and whacker plates were used intermittently at several locations around the site. Due to the distances between the work areas and any sensitive receptors, none of the exceedances in VDV levels can be associated with the use of vibratory rollers, crushers or whacker plates.

2.12. In addition, detailed investigation of all exceedances (i.e. review of PPV levels over 30 seconds periods) has shown that each resulted from isolated, non-construction related events, which likely occurred close to the monitoring station.

2.13. Within the Appendix B, there are short gaps of missing data in the PPV and VDV graphs. These occurred as a result of monitoring device errors.

3. CONCLUSION

3.1. Considering the distance between FCBC construction works and sensitive receptors, and the methods of working utilised, the risk of damage to structures or nuisance to residents resulting from vibration is highly unlikely.

3.2. Due to the location and sensitivity of vibration monitoring equipment, the exceedances presented in the graphs included in the appendices of this report do not represent levels generated by construction, but rather show local interference around the monitoring equipment.

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APPENDIX A – MONITORING LOCATIONS & VIBRATION ASSESSMENTS FROM RELEVANT PCNVs

Table 2: Monitoring Locations

Ref.	Monitoring Location	Crossing or Network	Main Construction Activities During November 2013
M1	Whinny Hill	Network	- King Malcolm Drive embankment landscaping N.B. No evening, night time or Sunday daytime construction in vicinity.
M3	Tigh-Na-Grian	Crossing	- Central Tower rebar, formwork & concreting works - North Tower rebar, formwork & concreting works - North Tower crane platform piling - Pier N1 de-stressing wells & trestle bridge foundation works
M7	Butlaw Fisheries	Crossing	- Central Tower rebar, formwork & concreting works - South Tower rebar, formwork & concreting works - Pier S1 de-stressing wells preparatory works - Pier S3 cofferdam construction - Pier S5 rebar, formwork & concreting works - Pier S6 backfilling for crane pad - Society Road works
M10	Inchgarvie Lodge	Crossing	- Central Tower rebar, formwork & concreting works - South Tower rebar, formwork & concreting works - Pier S1 de-stressing wells preparatory works - Pier S3 cofferdam construction - Pier S5 rebar, formwork & concreting works - Launch – delivery and assembly of steel sections - South abutment – preparatory works for the launch of west section - Placing segments/rebar, concreting, waterproofing and installation of tie beams at S7/S8 - Society Road works
M11	Linn Mill	Network	- Launch – delivery and assembly of steel sections - South abutment – preparatory works

			for the launch of west section - Placing segments/rebar, concreting, waterproofing and installation of tie beams at S7/S8 - Society Road works N.B. No evening, night time or Sunday daytime construction in vicinity.
M13	Clufflat Brae	Network	- Launch – delivery and assembly of steel sections - South abutment – preparatory works for the launch of west section - Placing segments/rebar, concreting, waterproofing and installation of tie beams at S7/S8 - Society Road works N.B. No evening, night time or Sunday daytime construction in vicinity.
M14	Springfield	Network	- Launch – delivery and assembly of steel sections - South abutment – preparatory works for the launch of west section - Placing segments/rebar, concreting, waterproofing and installation of tie beams at S7/S8 - Society Road works - Echline cut – ripping rock and crushing N.B. No evening, night time or Sunday daytime construction in vicinity.
M15	Echline Field	Network	- Launch – delivery and assembly of steel sections - South abutment – preparatory works for the launch of west section - Echline cut – ripping rock and crushing - Gyratory – installation of beams - A904 tie in road works, including drainage works N.B. No evening, night time or Sunday daytime construction in vicinity.
M16	Scotstoun	Network	- Utilities works - Structure works N.B. No evening, night time or Sunday daytime construction in vicinity.

M17	Dundas Home Farm	Network	- Utility works - Mainline works N.B. No evening, night time or Sunday daytime construction in vicinity.

Table 2 lists the main construction activities undertaken in the locality of each of the vibration monitors during the period of November 2013.

Table 3: PCNV Predicted PPV & VDV Levels

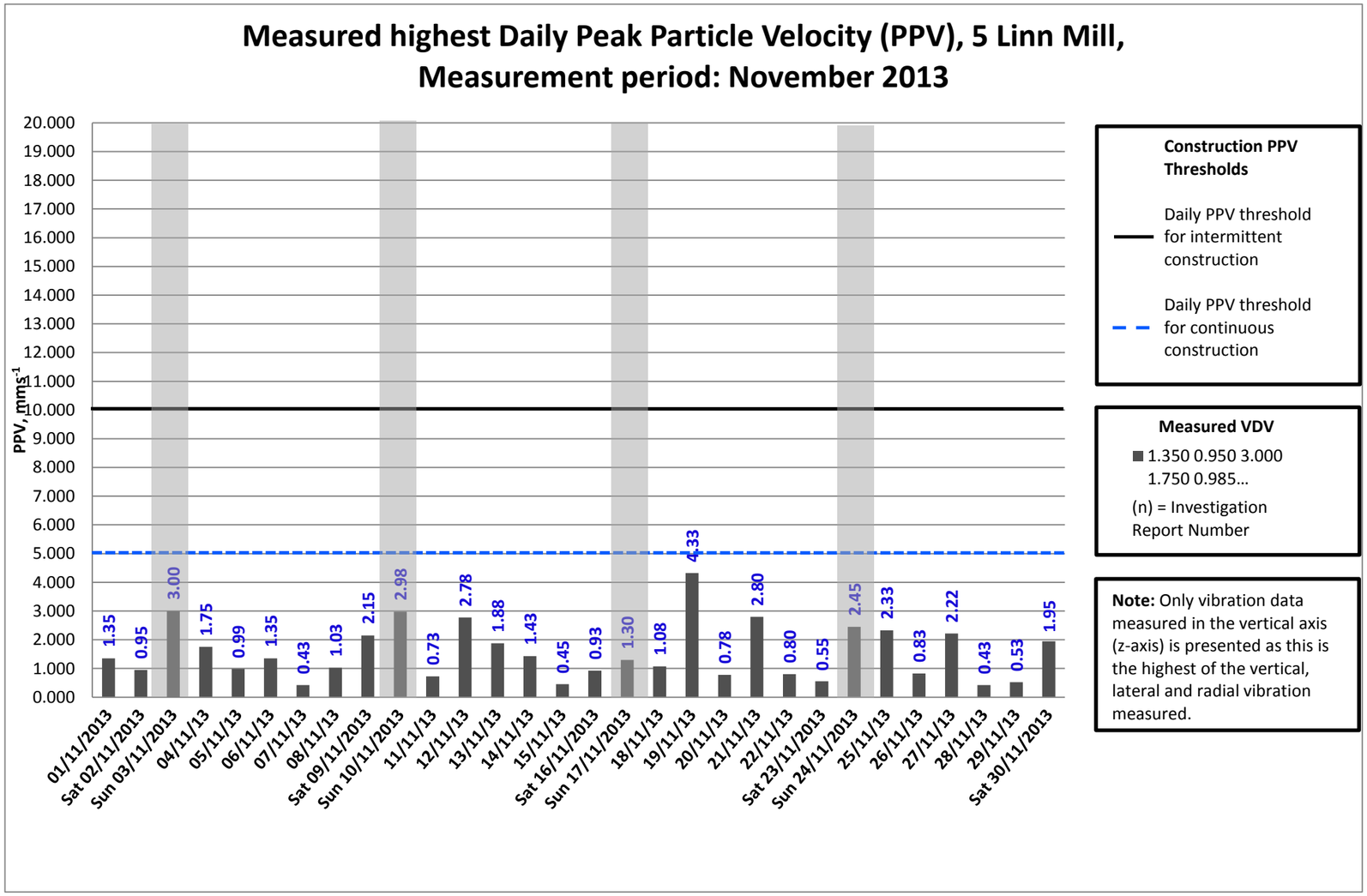
Monitor	Minimum distance from work areas (m)		Type of vibration emitting plant/activity operated at nearest work areas	Worst case predicted vibration levels	
	Day (07:00-19:00)	Night (19:00-07:00)		PPV (mm/s)	eVDV ($m.s^{-1.75}$)
Butlaw Fisheries	130	160	Roller/Whacker	0.44	0.23
Clufflat Brae	40	90	Roller/Whacker	2.44	0.37
Dundas	75	2000	Roller/Whacker	0.98	0.33
Echline	40	1000	Roller/Whacker	2.44	0.37
Inchgarvie Lodge	50	40	Roller/Whacker	1.77	0.33
Linn Mill	60	250	Roller/Whacker	1.36	0.33
Scotstoun	40	2000	Roller/Whacker	2.44	0.37
Springfield	50	300	Roller/Whacker	1.77	0.33
Tigh-Na-Grian	200	200	N/A	-	-
Whinny Hill	180	1800	N/A	-	-

Table 3 lists the distances from vibration monitors to the closest work areas for both day and night time periods. It also lists worst case PPV and eVDV calculations exhibited at the vibration monitors, resulting from the maximum vibration inducing plant operated at the nearest work areas.

Notes on Table 3

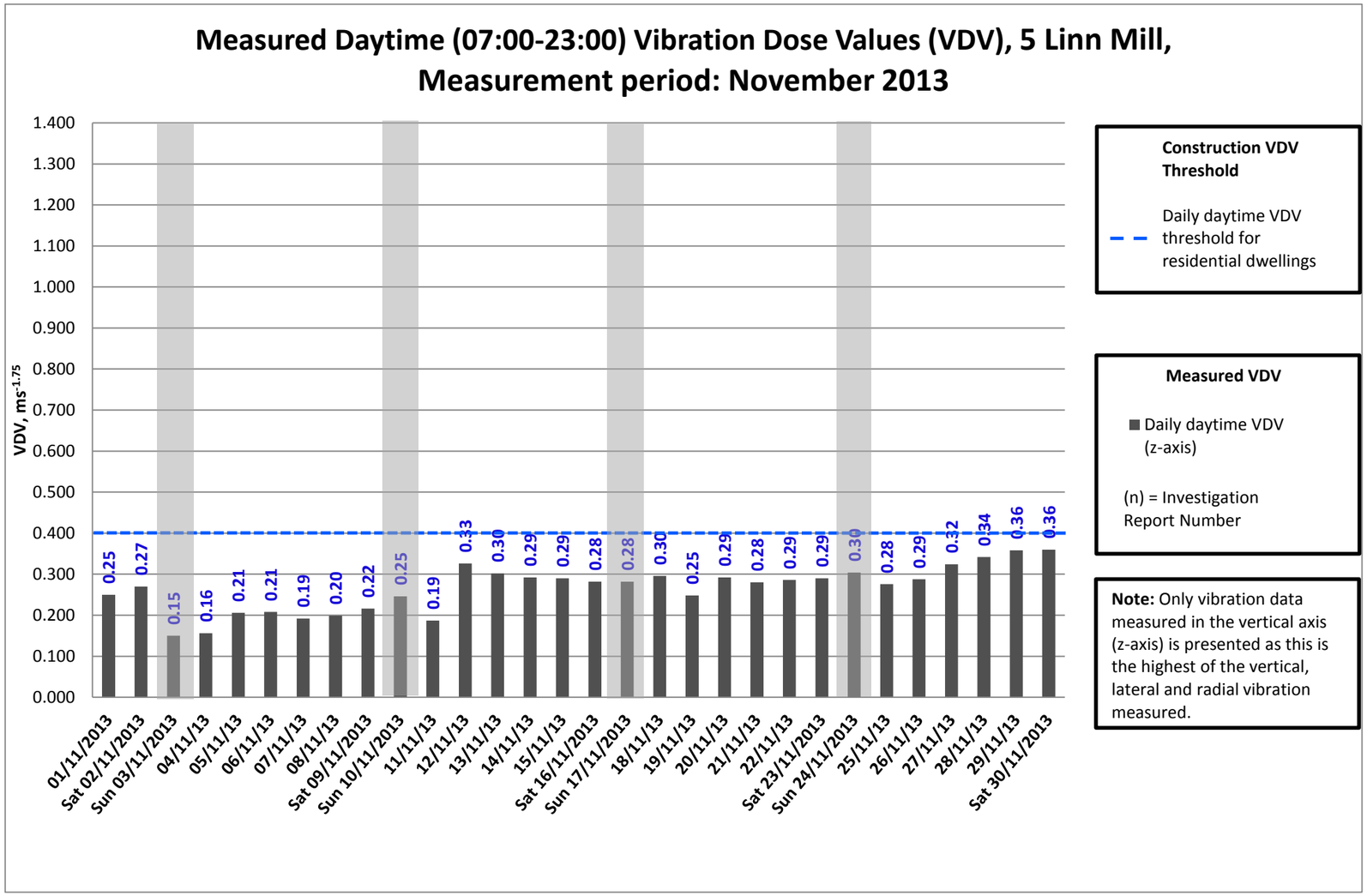
- All plant used during construction activities has been assessed with respect to vibration. The only plant utilised over the period in question considered to generate appreciable levels of vibration was a vibratory roller and a whacker plate (NOTE: Hydraulic rock breakers which typically generate 4.5mm/s @ 5m, 0.4mm/s @ 20m, 0.1mm/s @ 50m have been discounted due to the distances of use from the closest receptors).
- Vibratory rollers were not operated within 20m of any sensitive receptor.
- Whacker plates were not utilised within 40m of any occupied sensitive receptor.
- All roller eVDV values in the table above are based on the worst case scenario of a vibratory roller remaining in continuous operation for 2 hours an average distance (100m) from the nearest occupied receptors.
- All whacker plate eVDV values in the table above are based on the worst case scenario of a whacker plate remaining in continuous operation for 2 hours a minimum distance from the nearest receptor.

APPENDIX B – VIBRATION GRAPHS



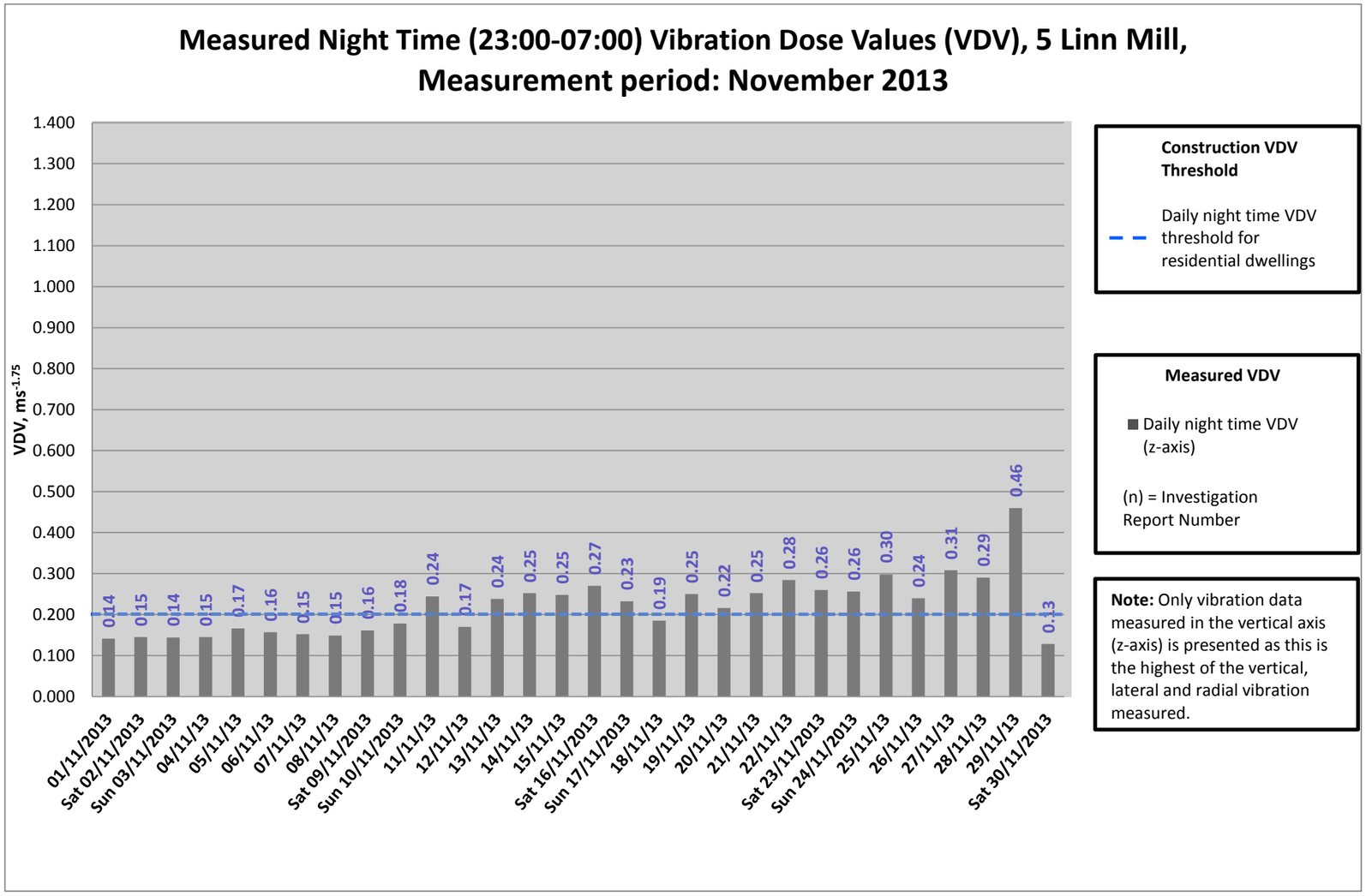
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.



Notes:

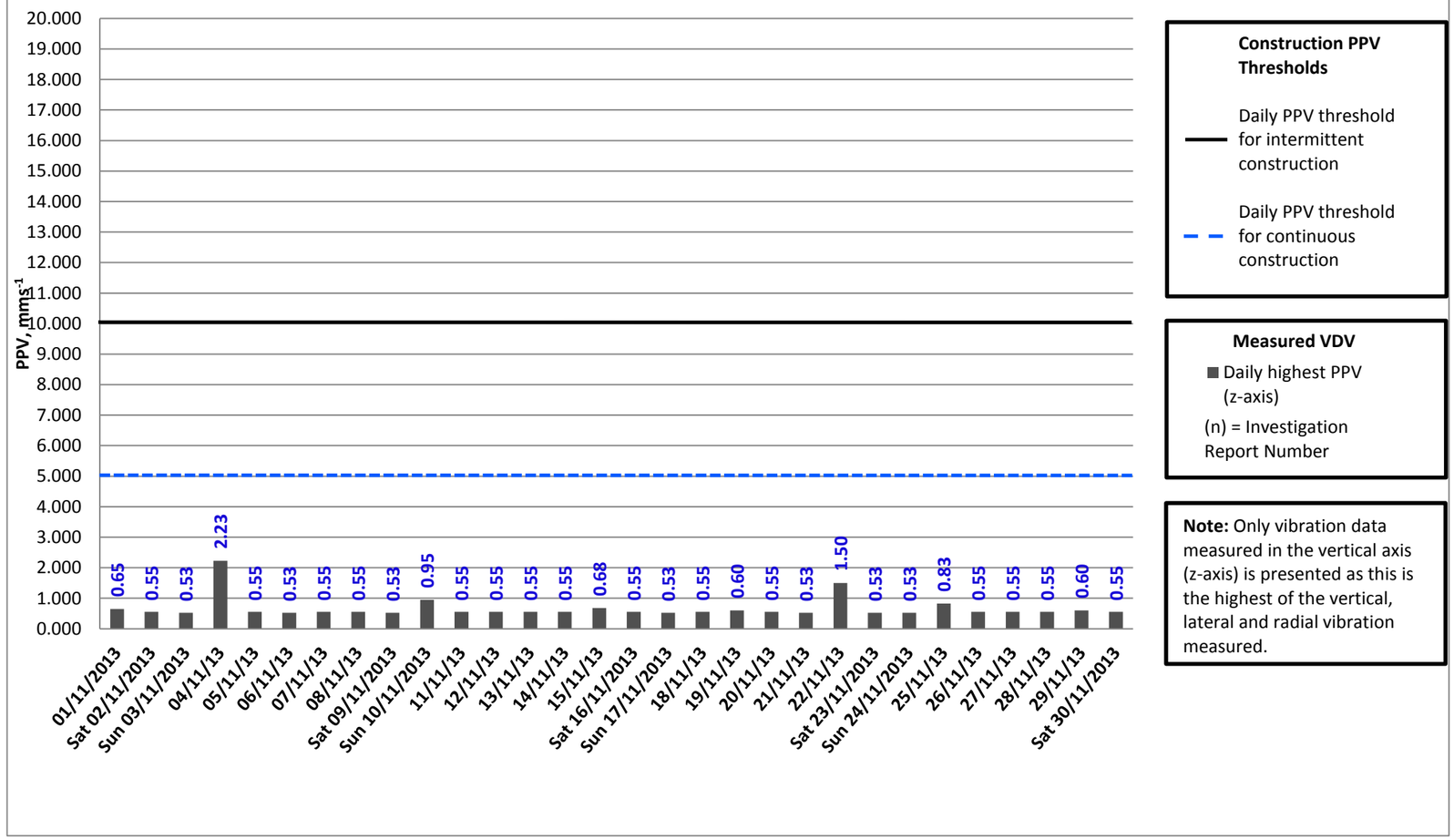
- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.

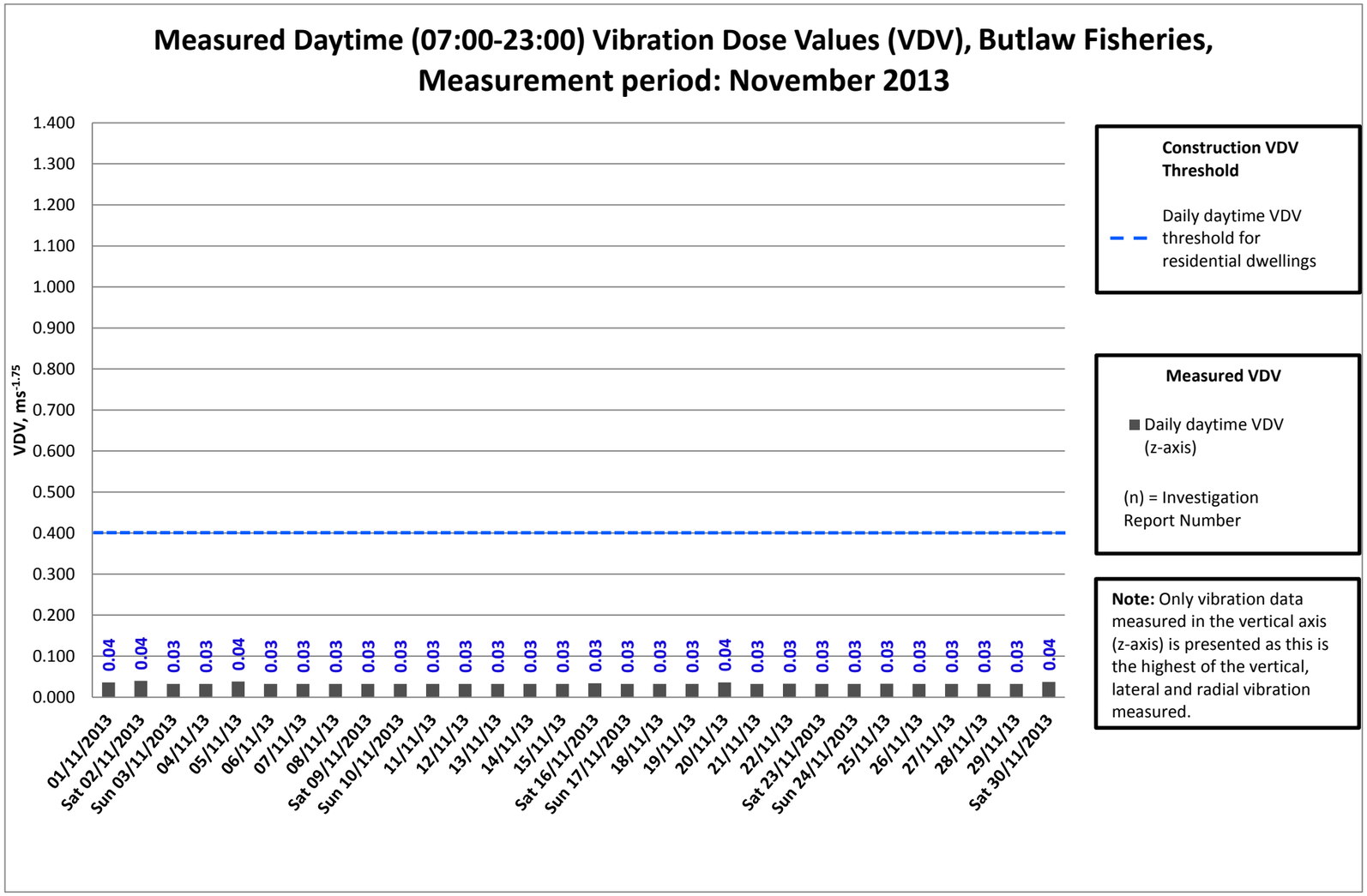


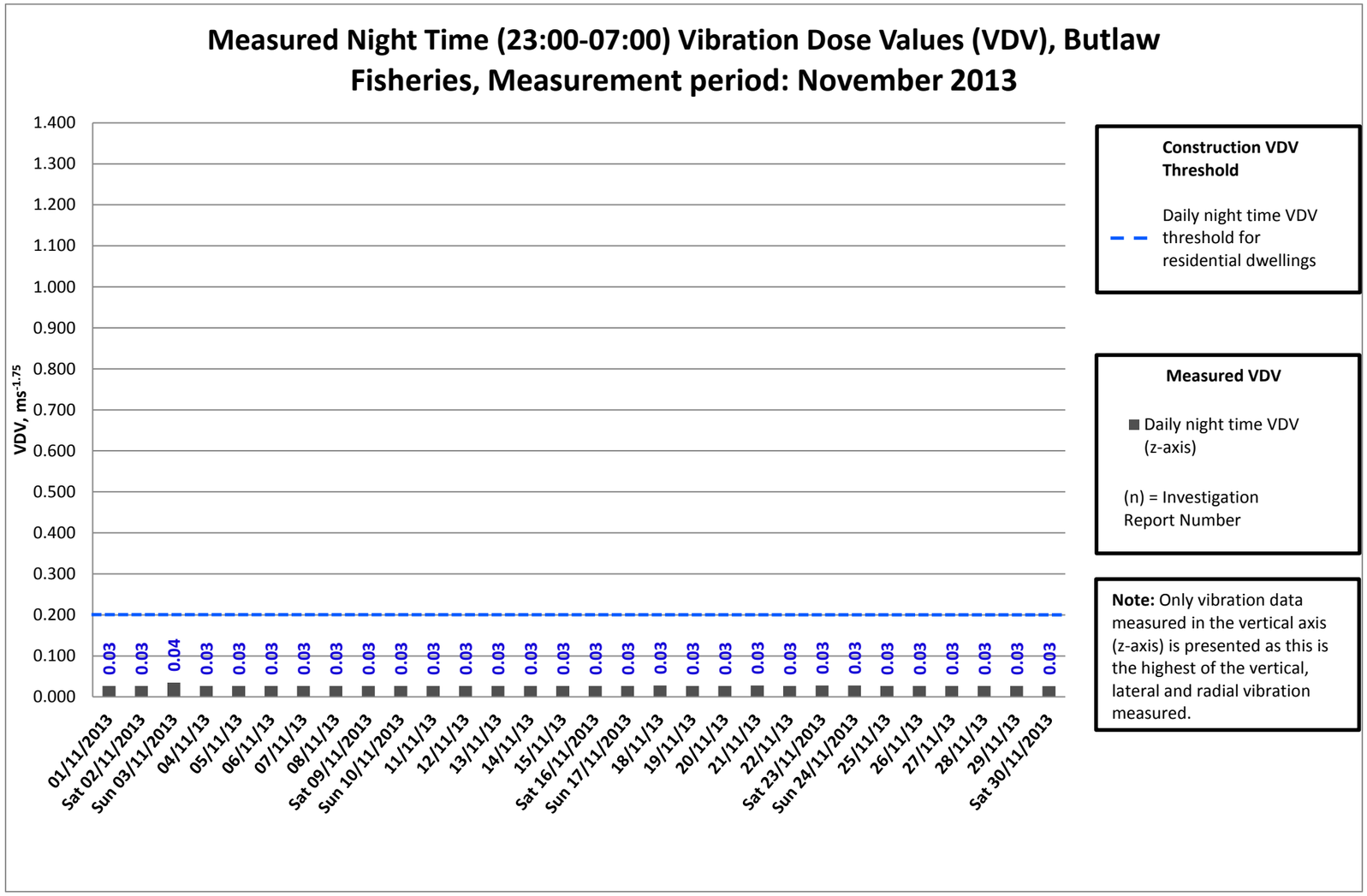
Notes:

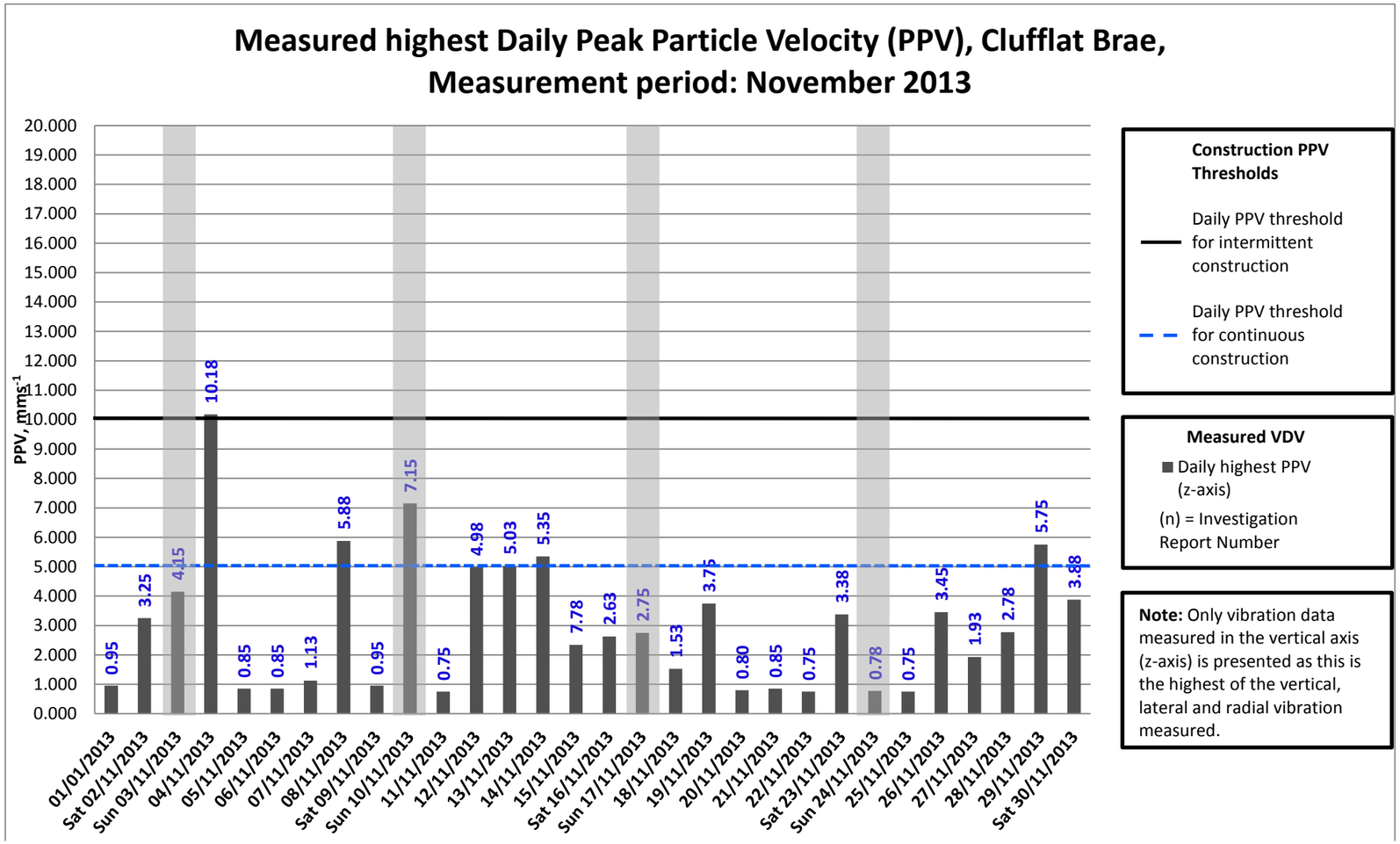
- The grey areas of the chart represent the days on which no construction works were undertaken; no night time works were conducted in the vicinity of the Linn Mill vibration monitor throughout the month of November 2013. This graph is included for illustrative purposes only.

Measured highest Daily Peak Particle Velocity (PPV), Butlaw Fisheries, Measurement period: November 2013



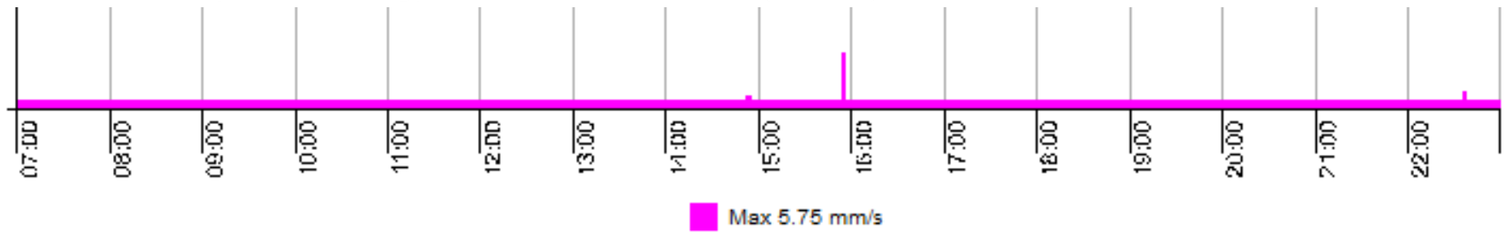

Measured Daytime (07:00-23:00) Vibration Dose Values (VDV), Butlaw Fisheries,
Measurement period: November 2013
VDV, ms-1.75
1.400
1.300
1.200
1.100
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.04 0.04 0.03 0.03 0.04 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04
01/11/2013
Sat 02/11/2013
Sun 03/11/2013
04/11/13
05/11/13
06/11/13
07/11/13
08/11/13
Sat 09/11/2013
Sun 10/11/2013
11/11/13
12/11/13
13/11/13
14/11/13
15/11/13
Sat 16/11/2013
Sun 17/11/2013
18/11/13
19/11/13
20/11/13
21/11/13
22/11/13
Sat 23/11/2013
Sun 24/11/2013
25/11/13
26/11/13
27/11/13
28/11/13
29/11/13
Sat 30/11/2013
Construction VDV Threshold
Daily daytime VDV threshold for residential dwellings
Measured VDV
Daily daytime VDV (z-axis)
(n) = Investigation Report Number
Note: Only vibration data measured in the vertical axis (z-axis) is presented as this is the highest of the vertical, lateral and radial vibration measured.

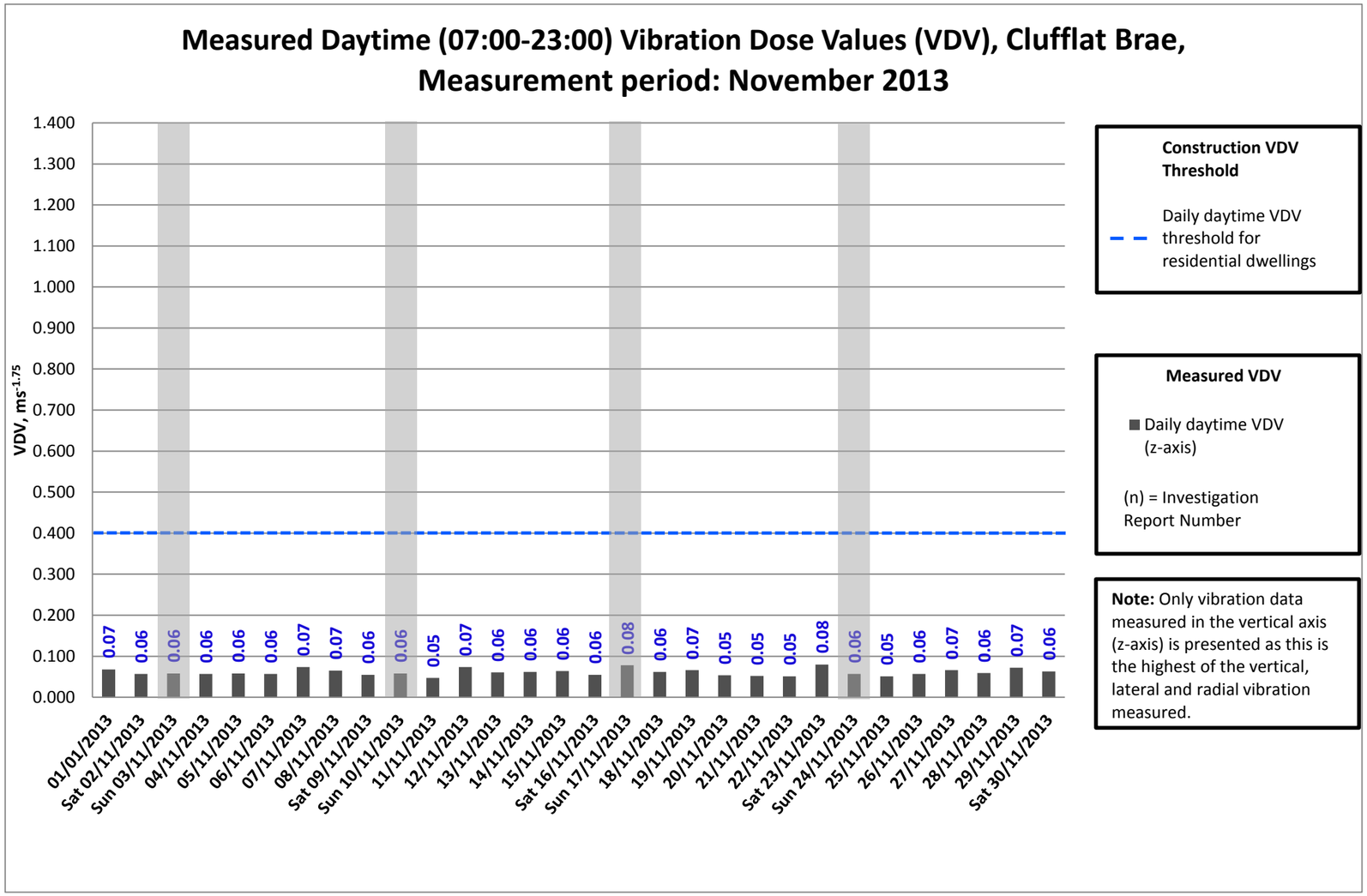

Measured Night Time (23:00-07:00) Vibration Dose Values (VDV), Butlaw Fisheries, Measurement period: November 2013
VDV, ms-1.75
1.400
1.300
1.200
1.100
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.03 0.03 0.04 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
01/11/2013
Sat 02/11/2013
Sun 03/11/2013
04/11/13
05/11/13
06/11/13
07/11/13
08/11/13
Sat 09/11/2013
Sun 10/11/2013
11/11/13
12/11/13
13/11/13
14/11/13
15/11/13
Sat 16/11/2013
Sun 17/11/2013
18/11/13
19/11/13
20/11/13
21/11/13
22/11/13
Sat 23/11/2013
Sun 24/11/2013
25/11/13
26/11/13
27/11/13
28/11/13
29/11/13
Sat 30/11/2013
Construction VDV Threshold
Daily night time VDV threshold for residential dwellings
Measured VDV
Daily night time VDV (z-axis)
(n) = Investigation Report Number
Note: Only vibration data measured in the vertical axis (z-axis) is presented as this is the highest of the vertical, lateral and radial vibration measured.



Notes:

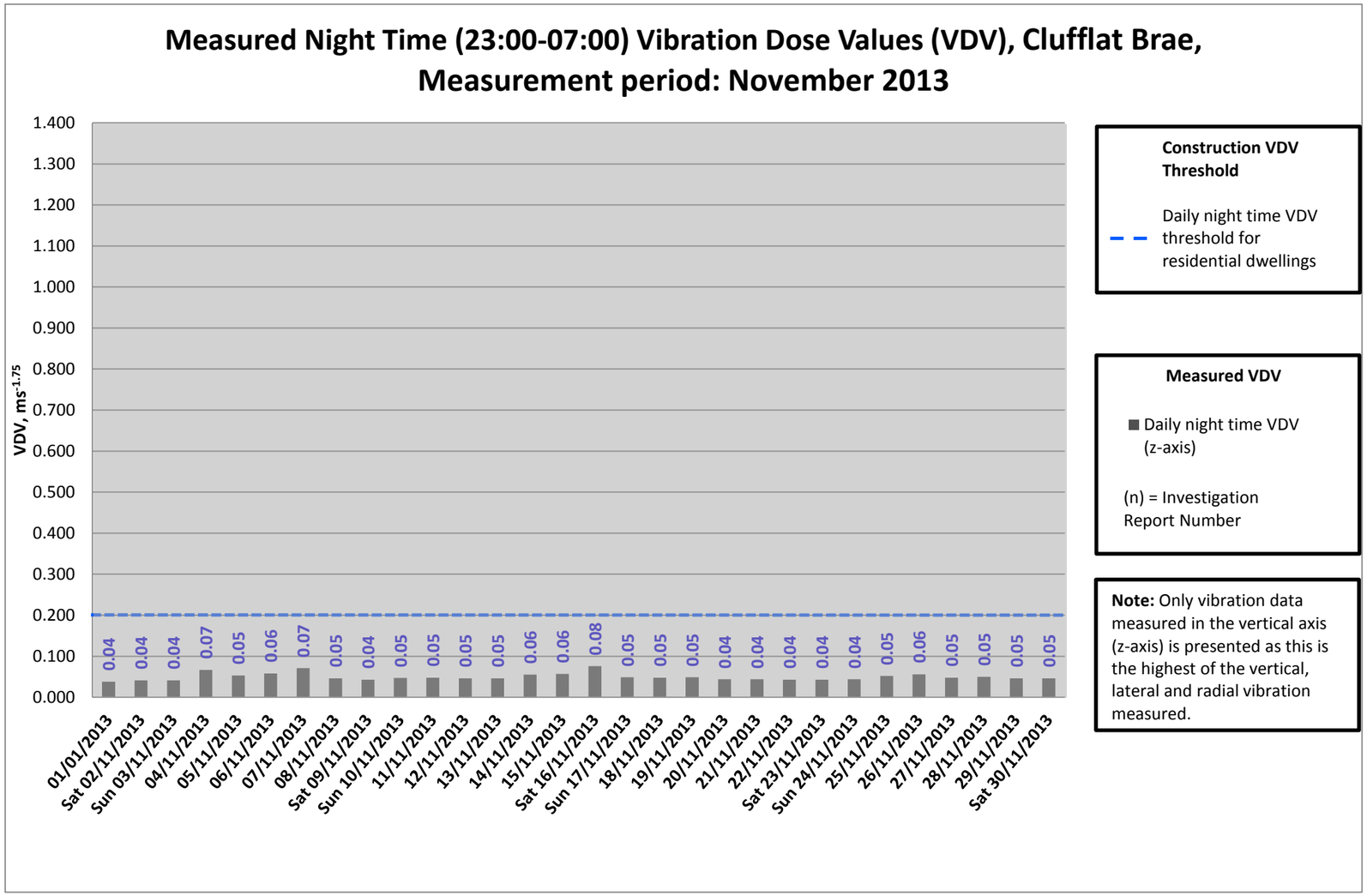
- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.
- The PPV values on 08/11/13, 13/11/13, 14/11/13 & 29/11/13 have been investigated, and have been seen to be individual, isolated events within each period (see Vibrock PPV graph below from 29/11/13), the majority of which are within the intermittent threshold of 10mm/s. The PPV value on 04/11/13 has been investigated; it is extremely unlikely that this particular level was generated as a result of FCBC construction, as the only works to be conducted in the vicinity of the monitor on this date were preparatory works for the launch of west bridge section at the South Abutment and placing segments/rebar, concreting, waterproofing and installation of tie beams at Piers S7 & S8. None of these works involved the use of any vibration inducing plant and were a minimum of 160m (worst case) from the monitor.





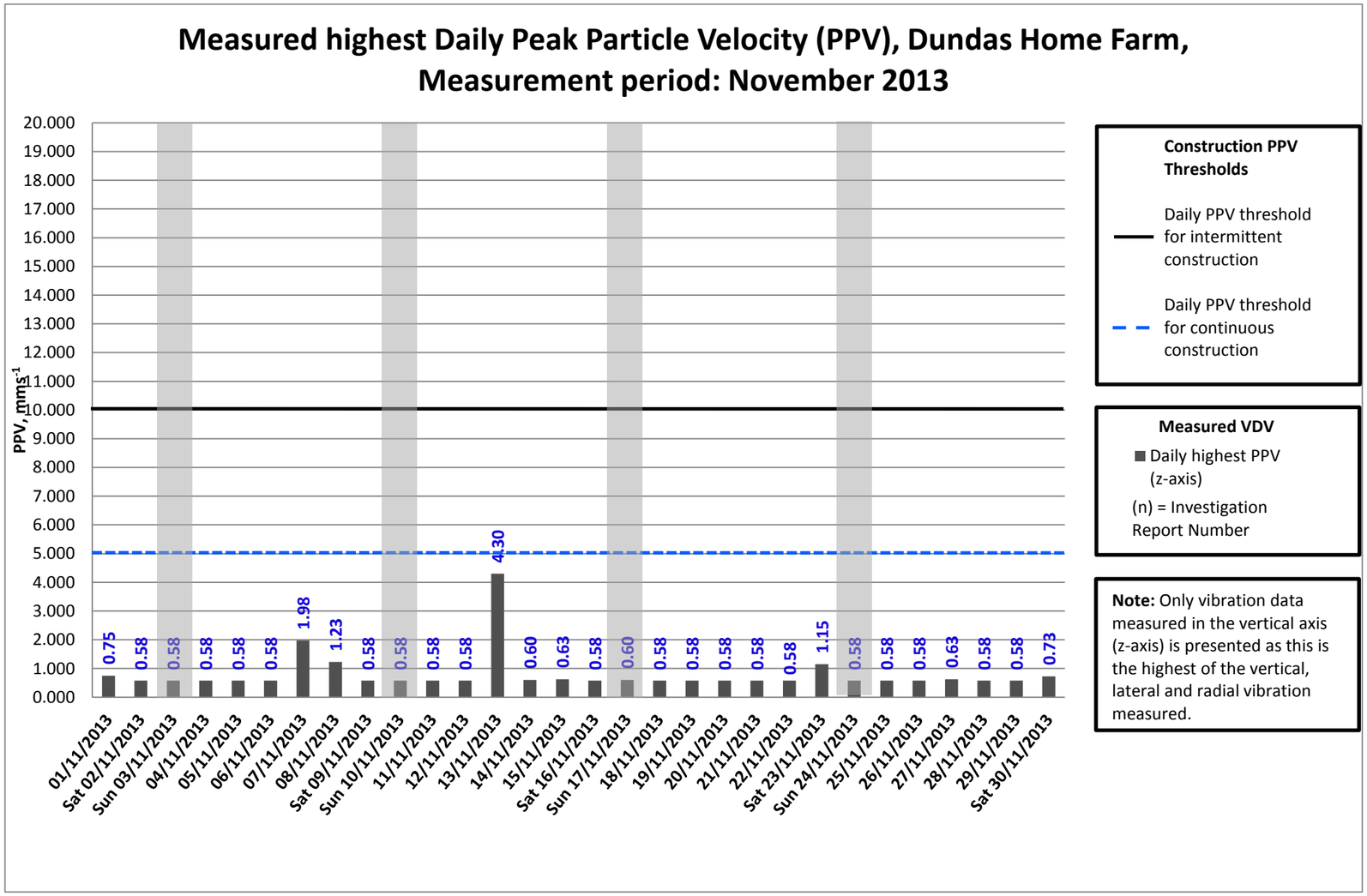
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.



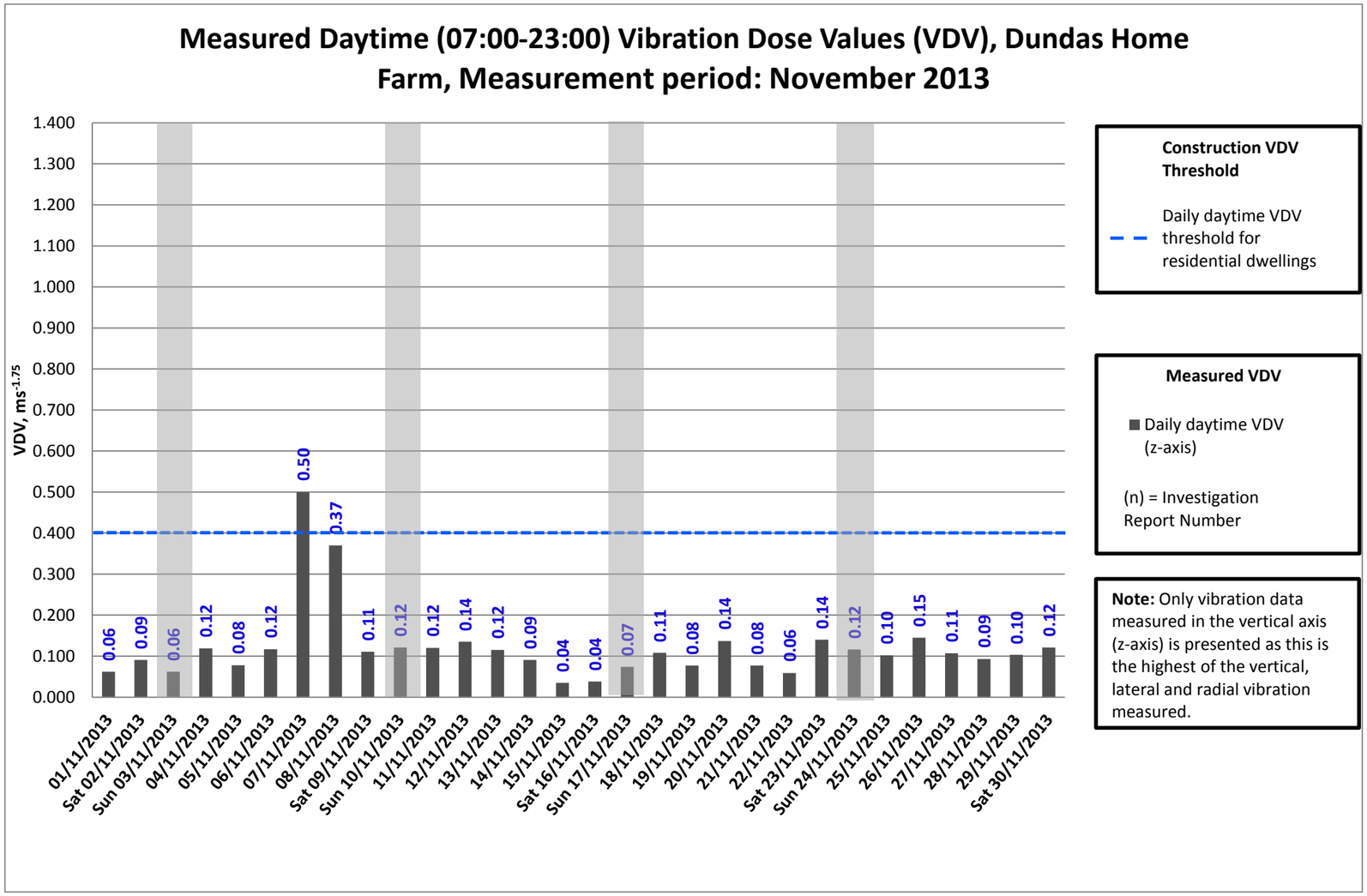
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no night time works were conducted in the vicinity of the Clufflat Brae vibration monitor throughout the month of November 2013. This graph is included for illustrative purposes only.



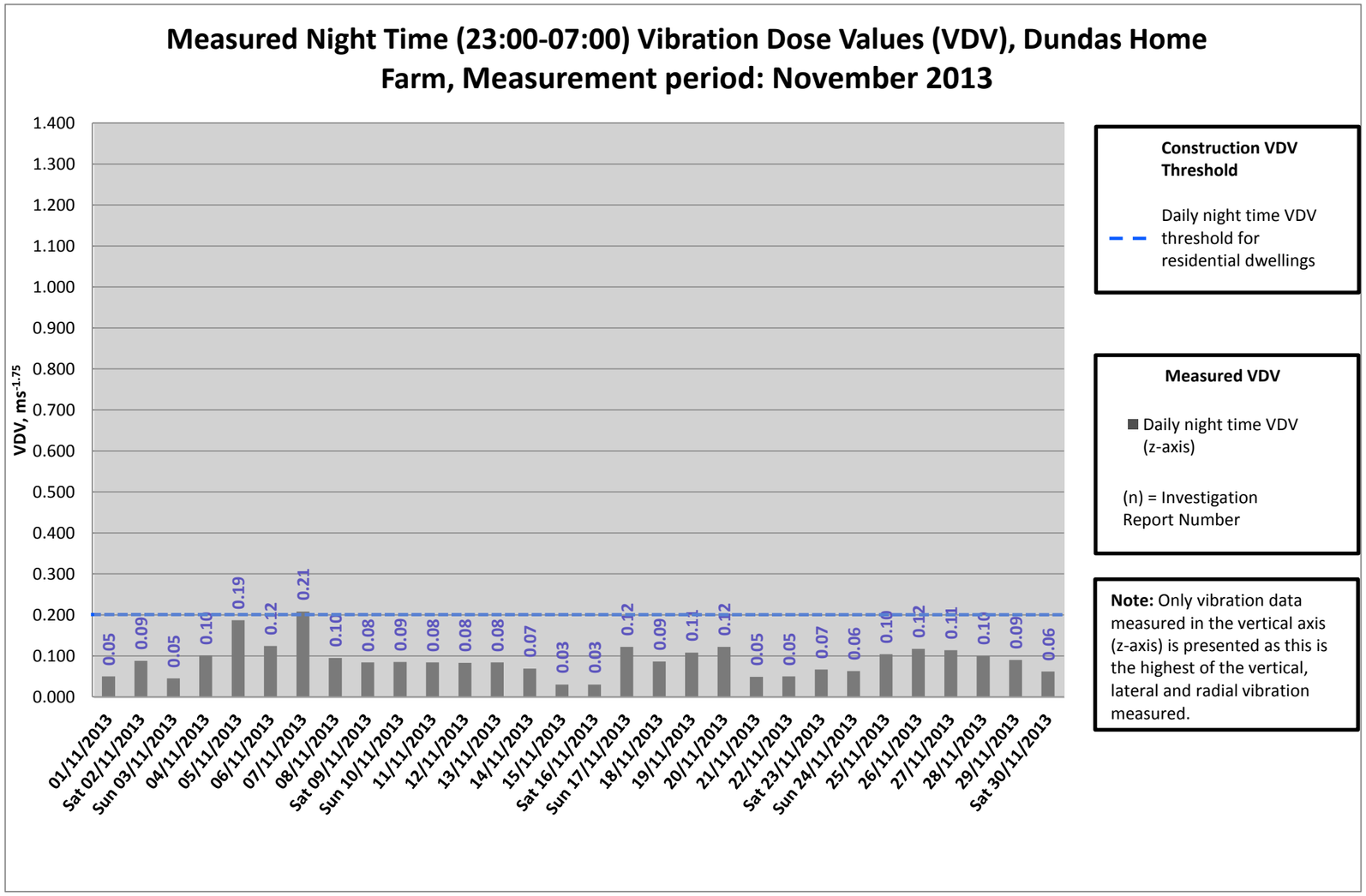
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.



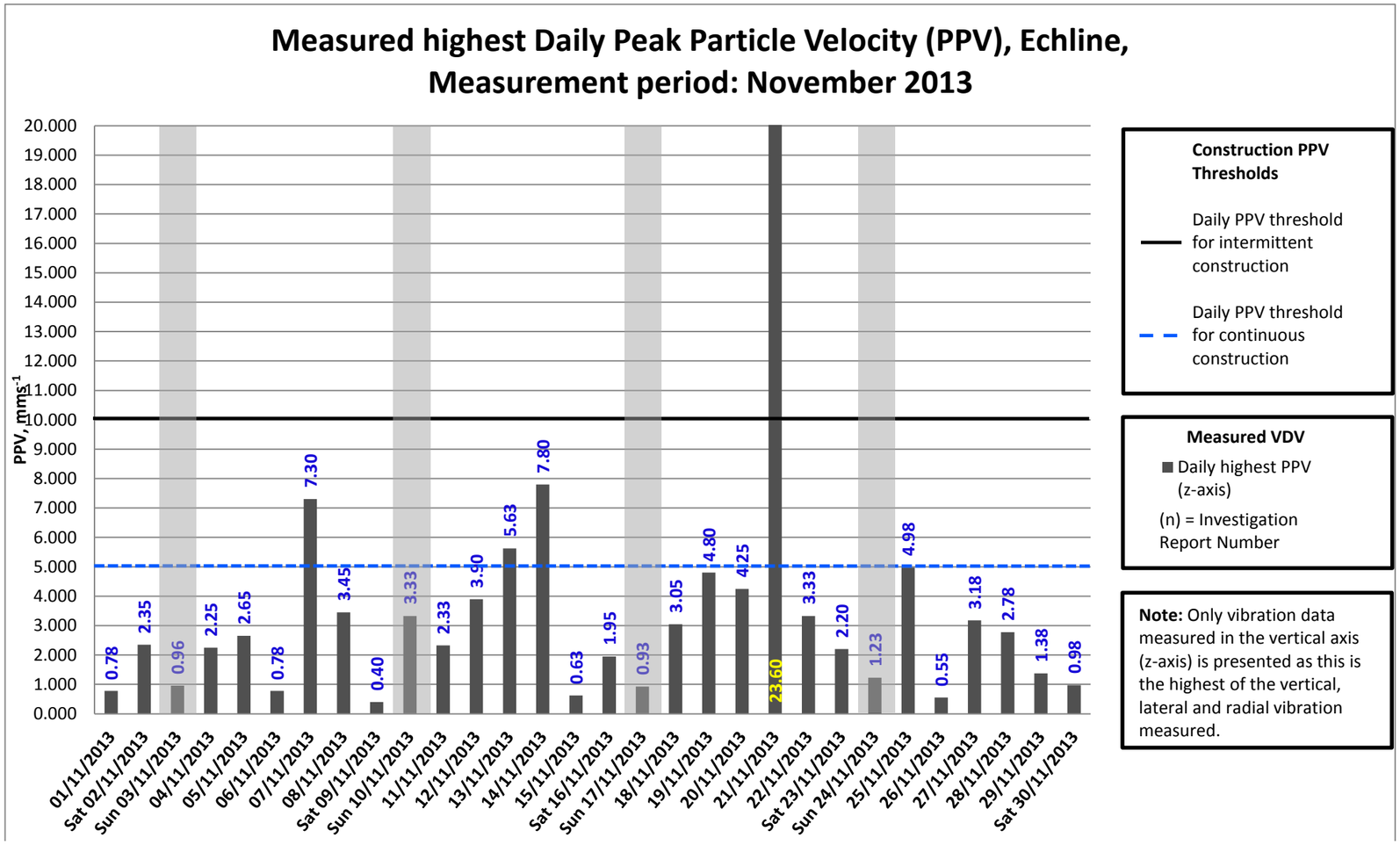
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.
- The VDV on 07/11/13 has been investigated. It is extremely unlikely that this particular level was generated as a result of FCBC construction, as the only works to be conducted in the vicinity of the monitor on this date were utility works, which did not involve the use of any vibration inducing plant and were a minimum of 75m (worst case) from the monitor.



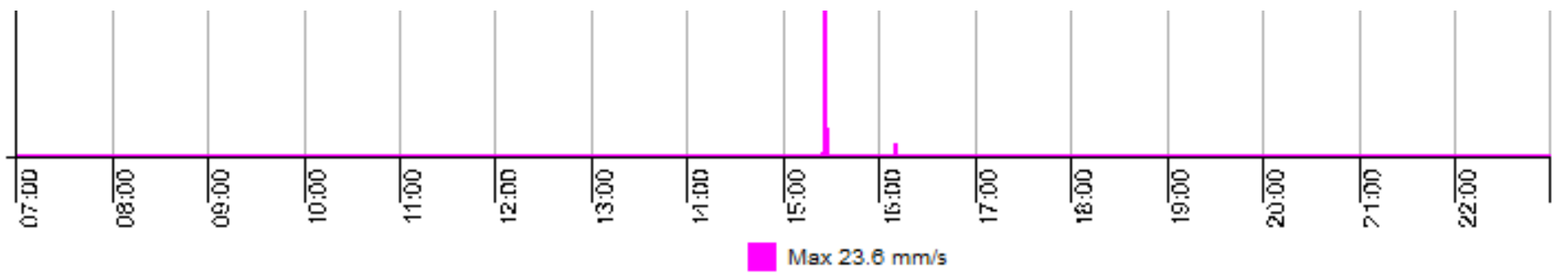
Notes:

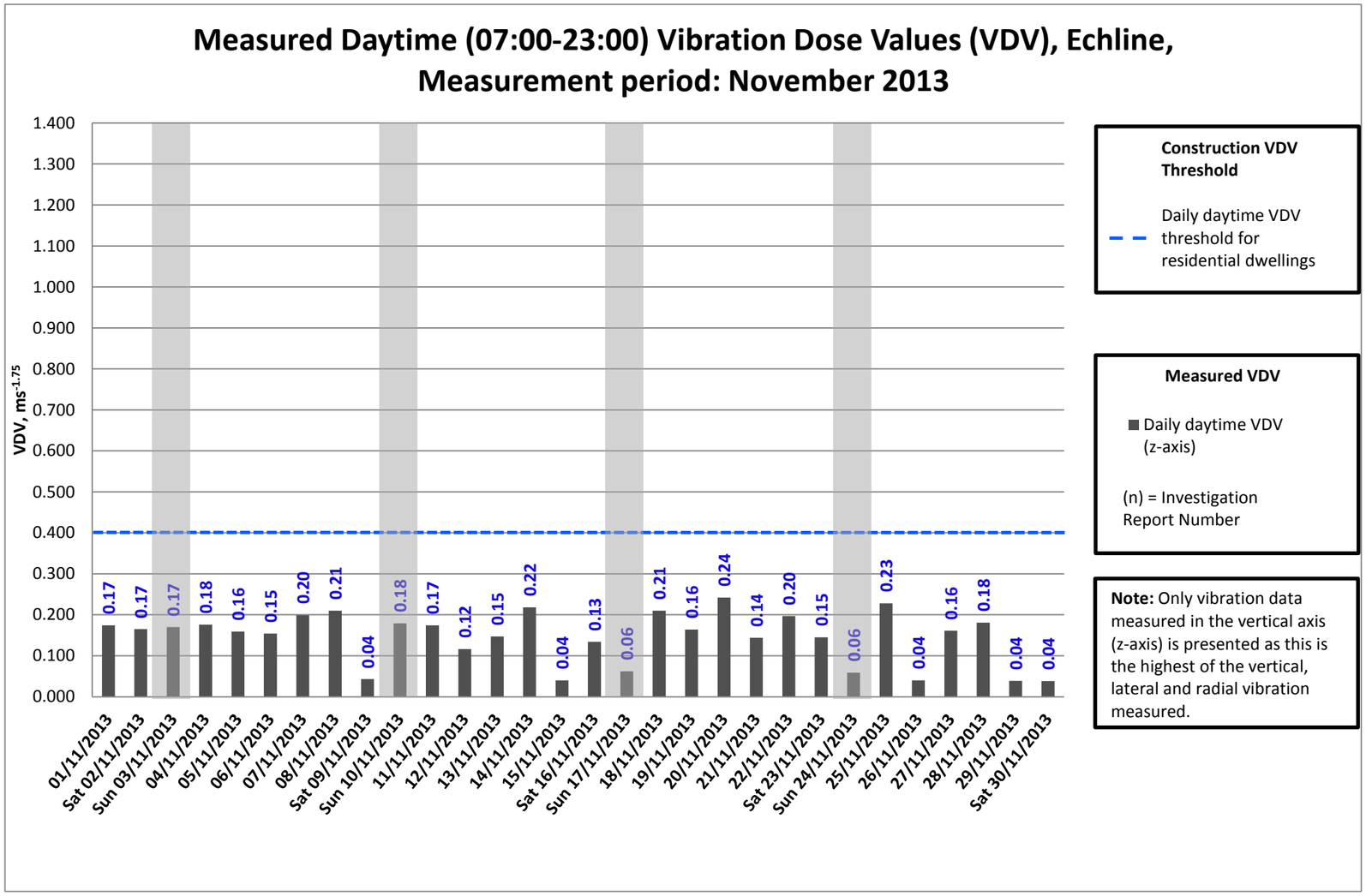
- The grey areas of the chart represent the days on which no construction works were undertaken; no night time works were conducted in the vicinity of the Dundas Home Farm vibration monitor throughout the month of November 2013. This graph is included for illustrative purposes only.



Notes

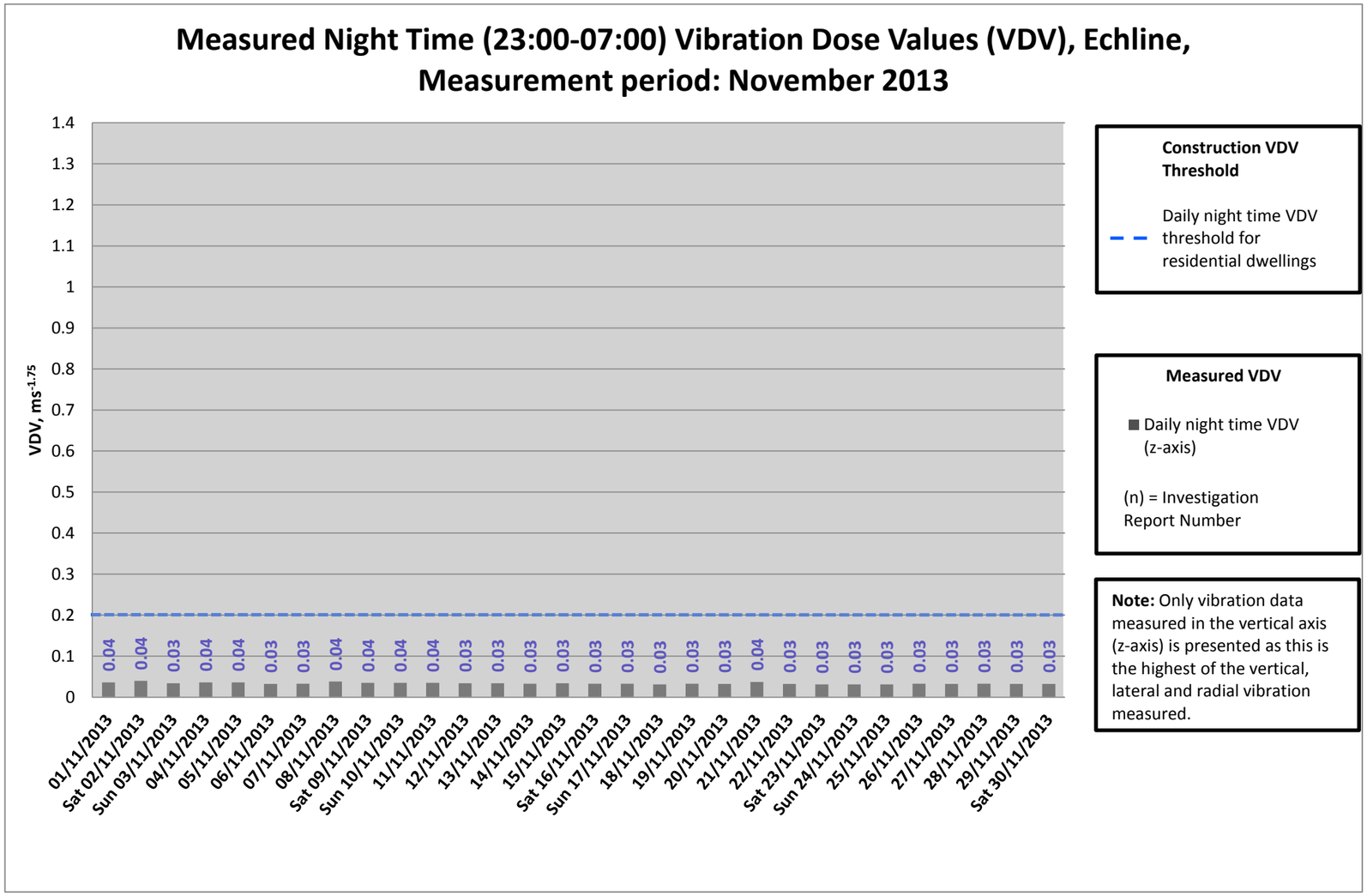
- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.
- The PPV values on 07/11/13, 13/11/13, 14/11/13 & 21/11/13 have been investigated, and have been seen to be individual, isolated events within each period (see Vibrock PPV graph below from 21/11/13), all but one of which are within the intermittent threshold. Furthermore, it is extremely unlikely that these particular levels were generated as a result of FCBC construction, as the only works to be conducted in the vicinity of the monitor on any of these dates in question, were rock ripping & crushing works within the Echline cut and structural works at the Queensferry Gyratory. None of these works involved the use of any vibration inducing plant and were a minimum of 70m (worst case) from the monitor.





Notes:

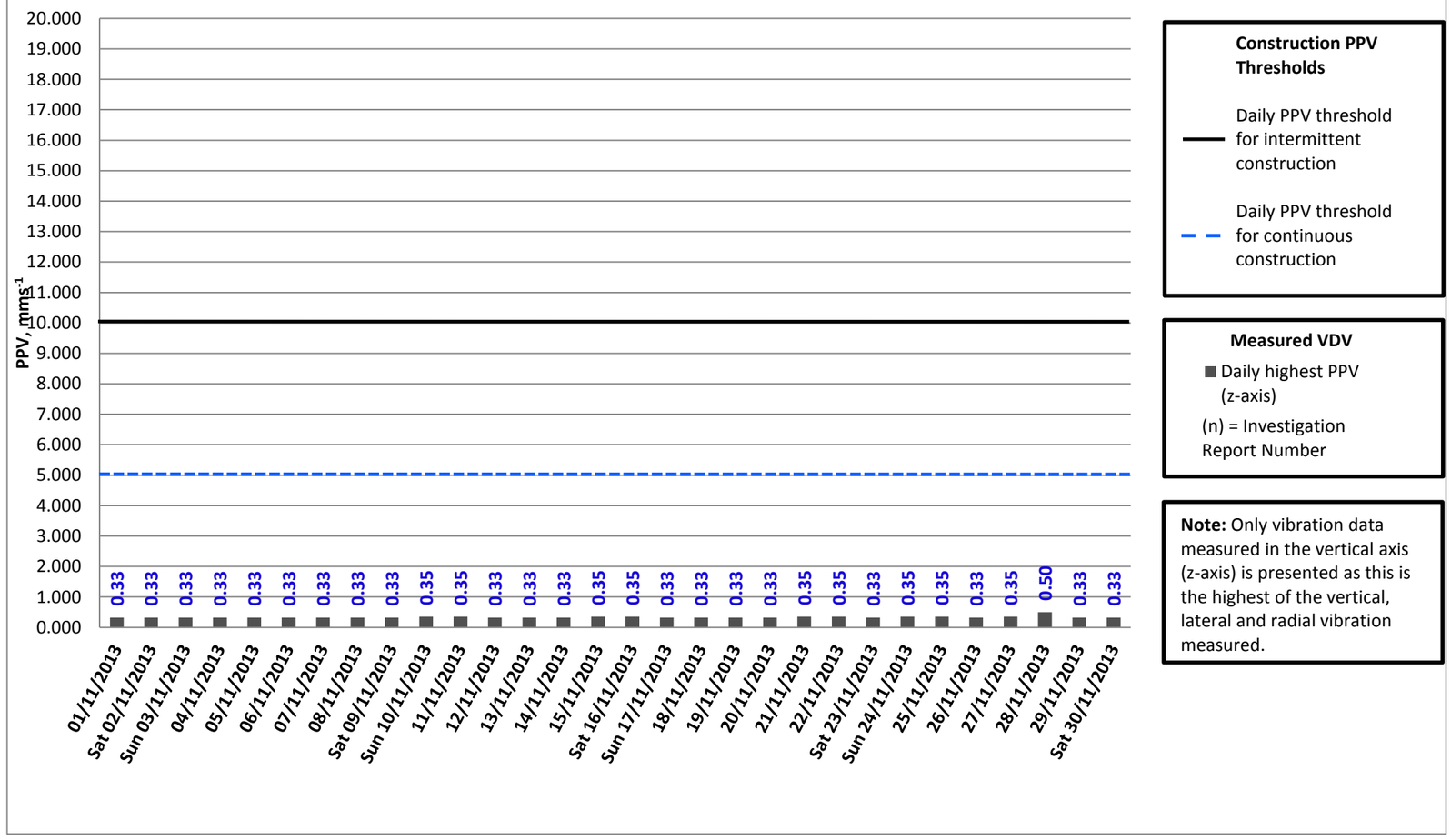
- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.

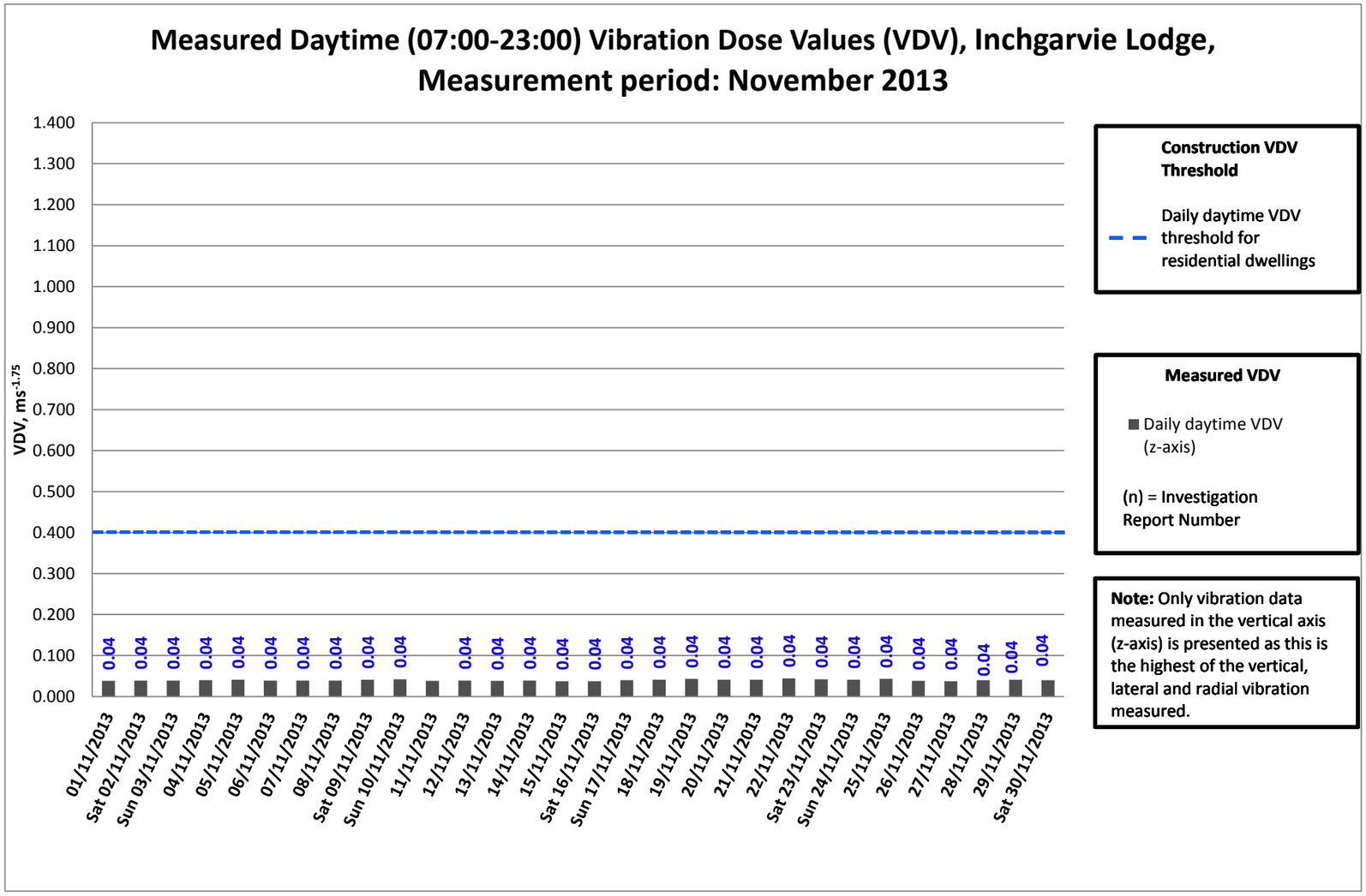


Notes:

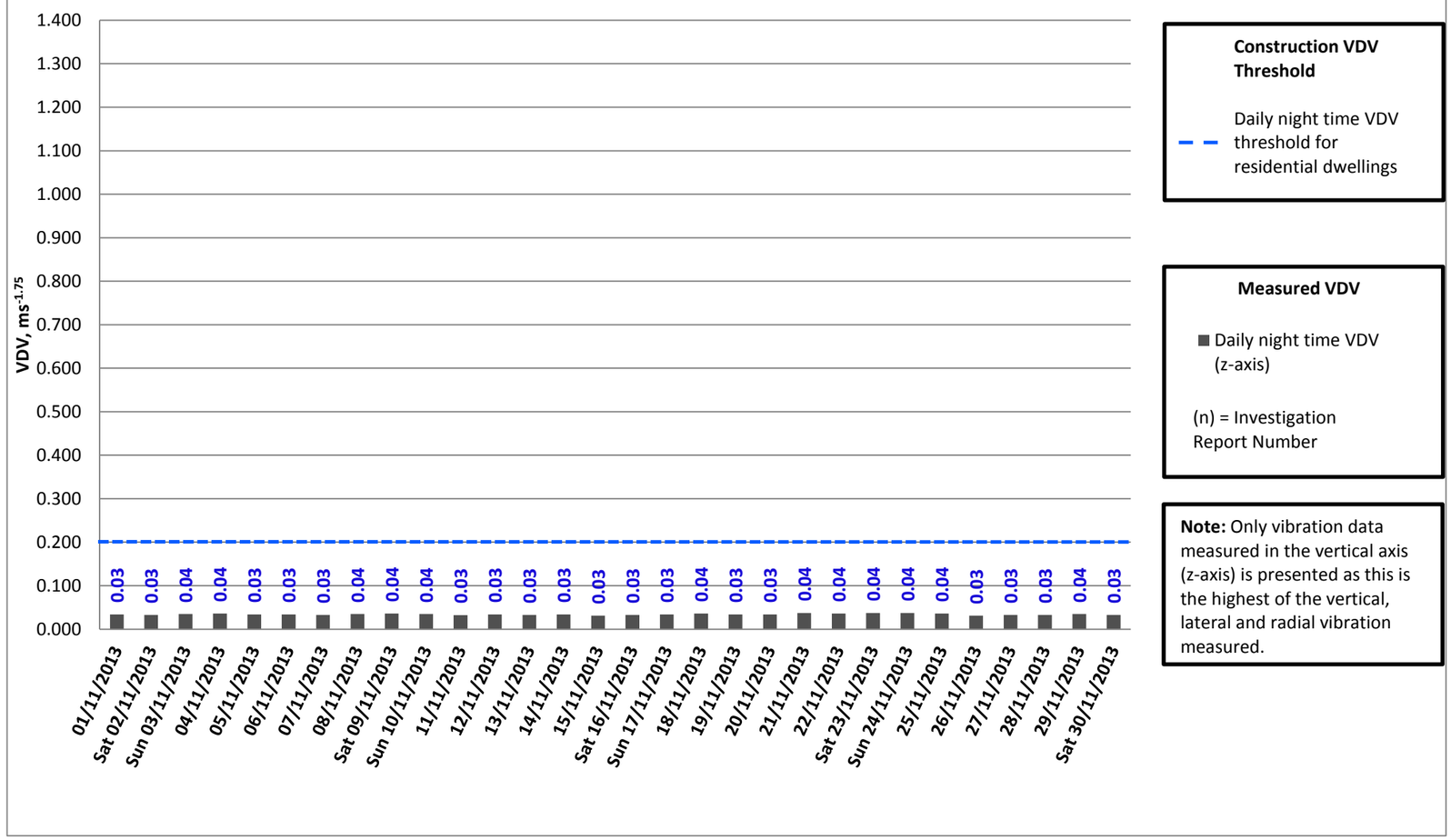
- The grey areas of the chart represent the days on which no construction works were undertaken; no night time works were conducted in the vicinity of the Echline vibration monitor throughout the month of November 2013. This graph is included for illustrative purposes only.

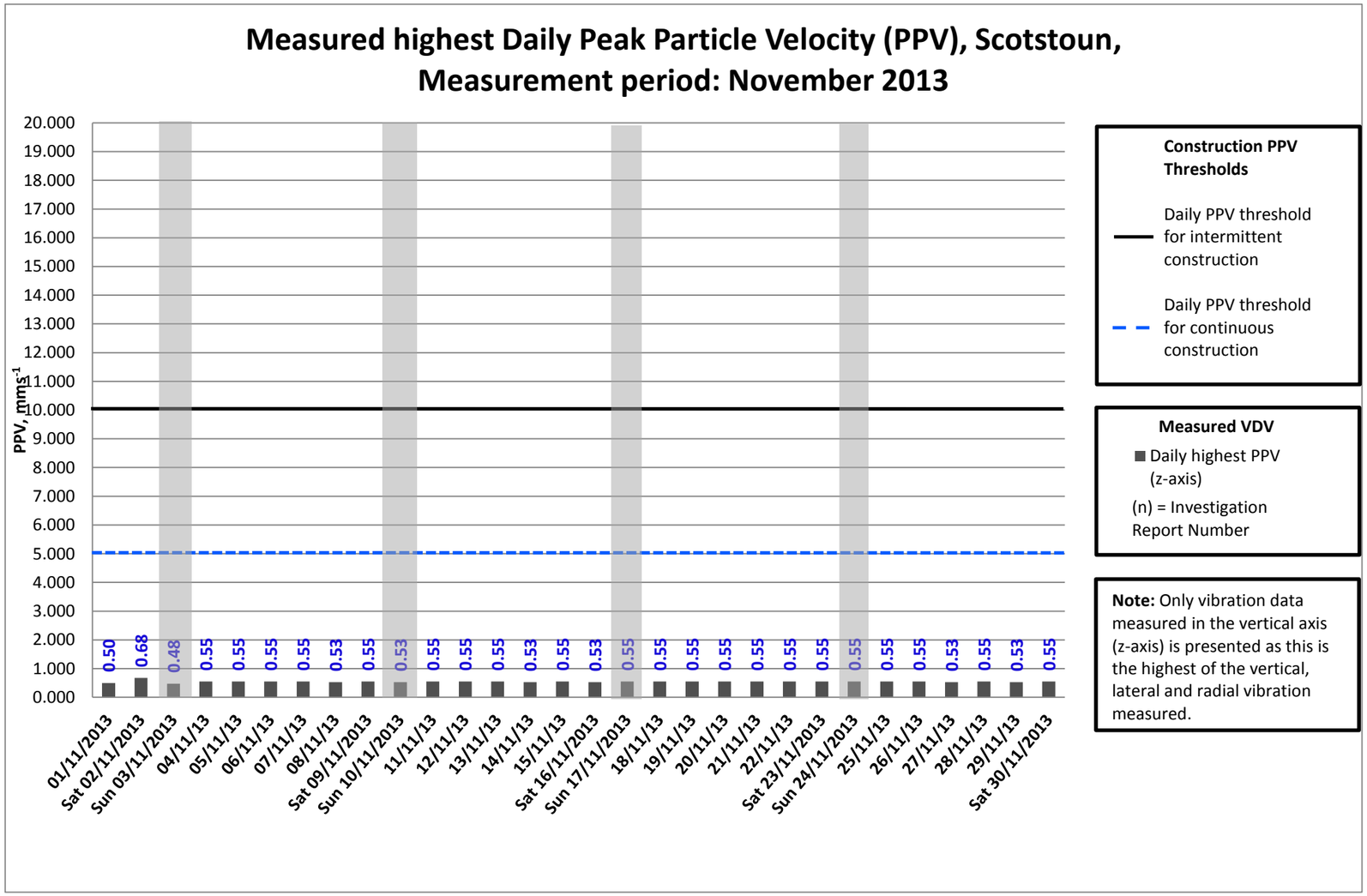
Measured highest Daily Peak Particle Velocity (PPV), Inchgarvie Lodge, Measurement period: November 2013




Measured Daytime (07:00-23:00) Vibration Dose Values (VDV), Inchgarvie Lodge,
Measurement period: November 2013
VDV, ms-1.75
1.400
1.300
1.200
1.100
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.04
01/11/2013
Sat 02/11/2013
Sun 03/11/2013
04/11/2013
05/11/2013
06/11/2013
07/11/2013
08/11/2013
Sat 09/11/2013
Sun 10/11/2013
11/11/2013
12/11/2013
13/11/2013
14/11/2013
15/11/2013
Sat 16/11/2013
Sun 17/11/2013
18/11/2013
19/11/2013
20/11/2013
21/11/2013
22/11/2013
Sat 23/11/2013
Sun 24/11/2013
25/11/2013
26/11/2013
27/11/2013
28/11/2013
29/11/2013
Sat 30/11/2013
Construction VDV Threshold
Daily daytime VDV threshold for residential dwellings
Measured VDV
Daily daytime VDV (z-axis)
(n) = Investigation Report Number
Note: Only vibration data measured in the vertical axis (z-axis) is presented as this is the highest of the vertical, lateral and radial vibration measured.

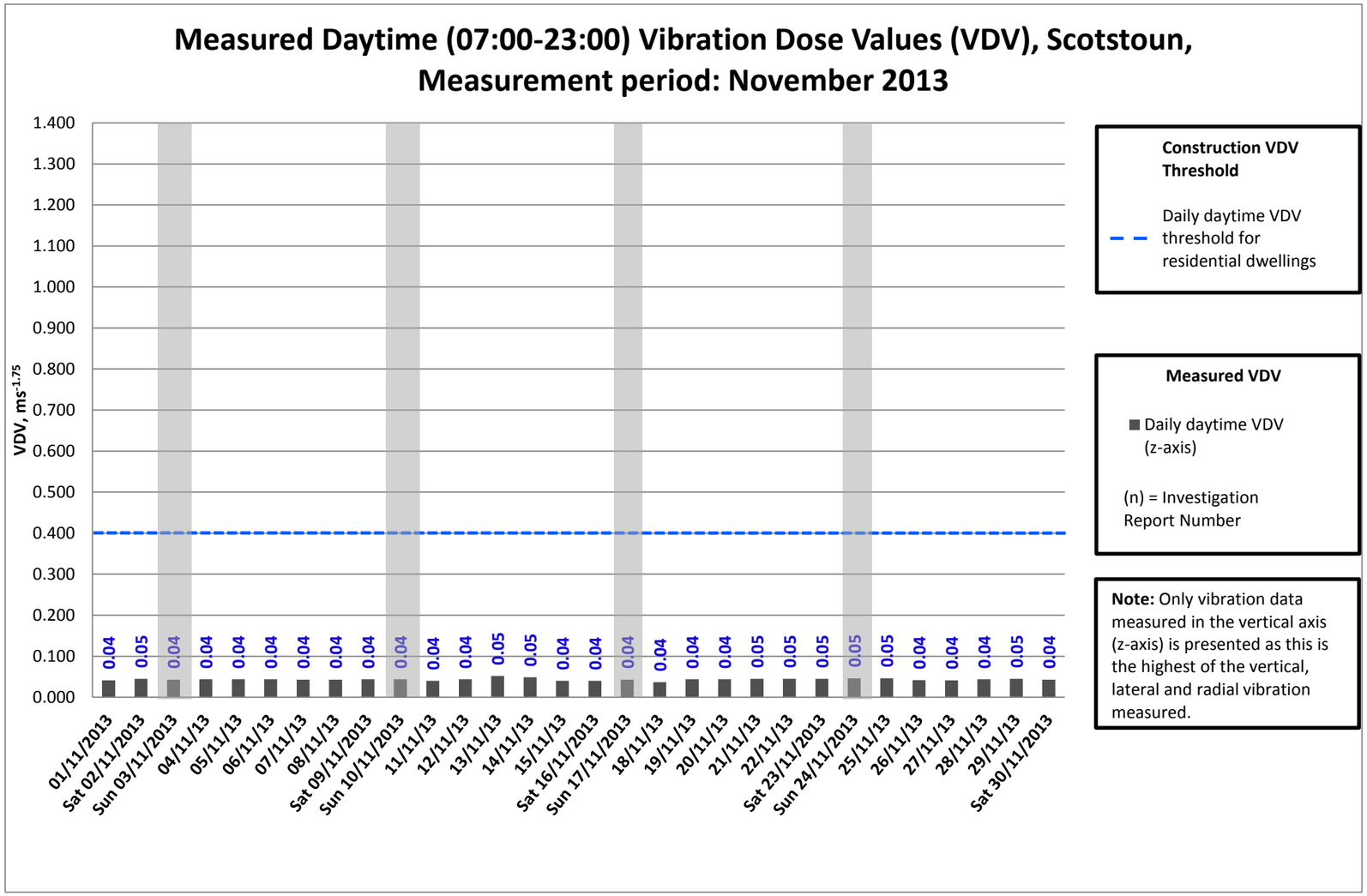
Measured Night Time (23:00-07:00) Vibration Dose Values (VDV), Inchgarvie Lodge, Measurement period: November 2013





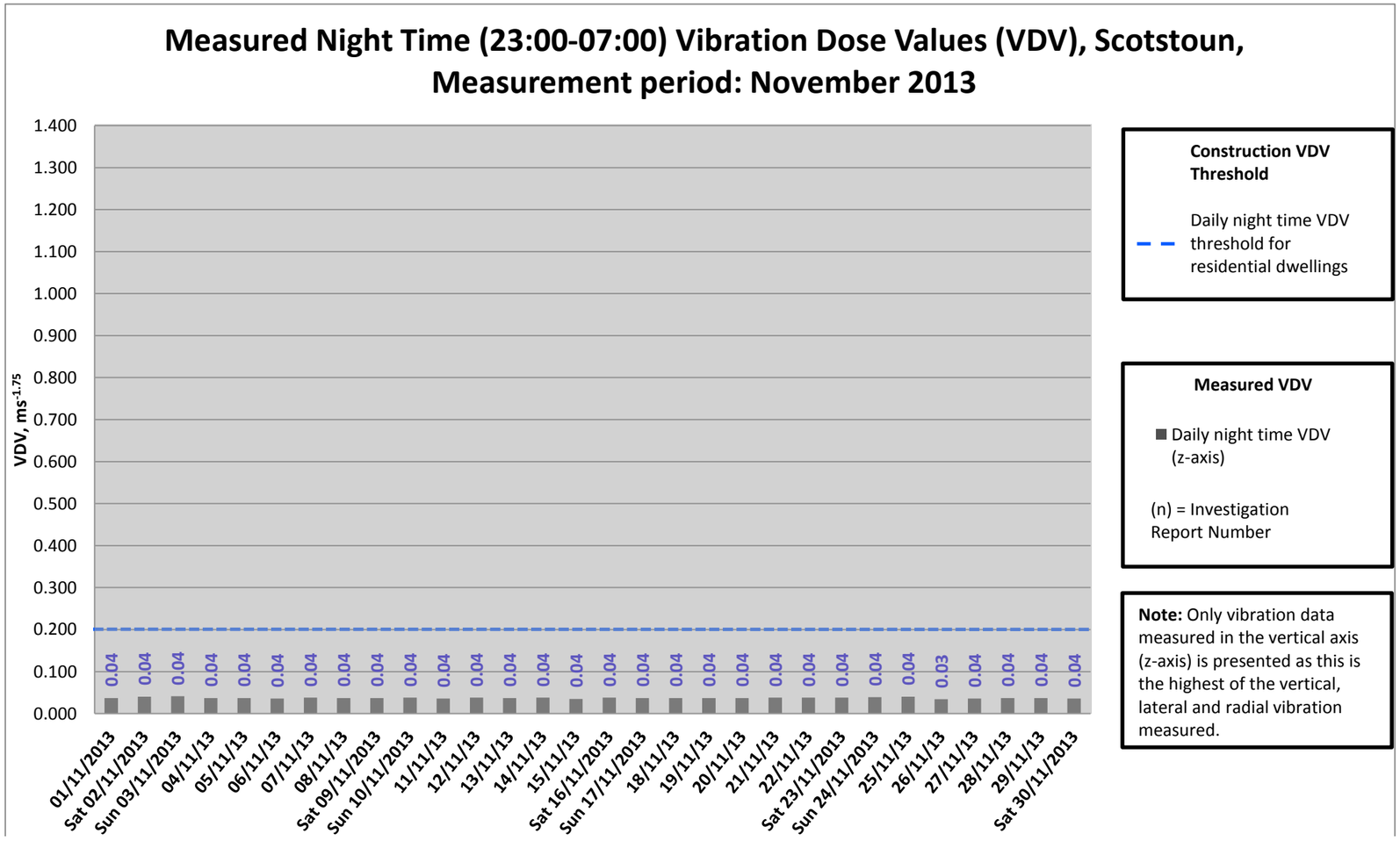
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.



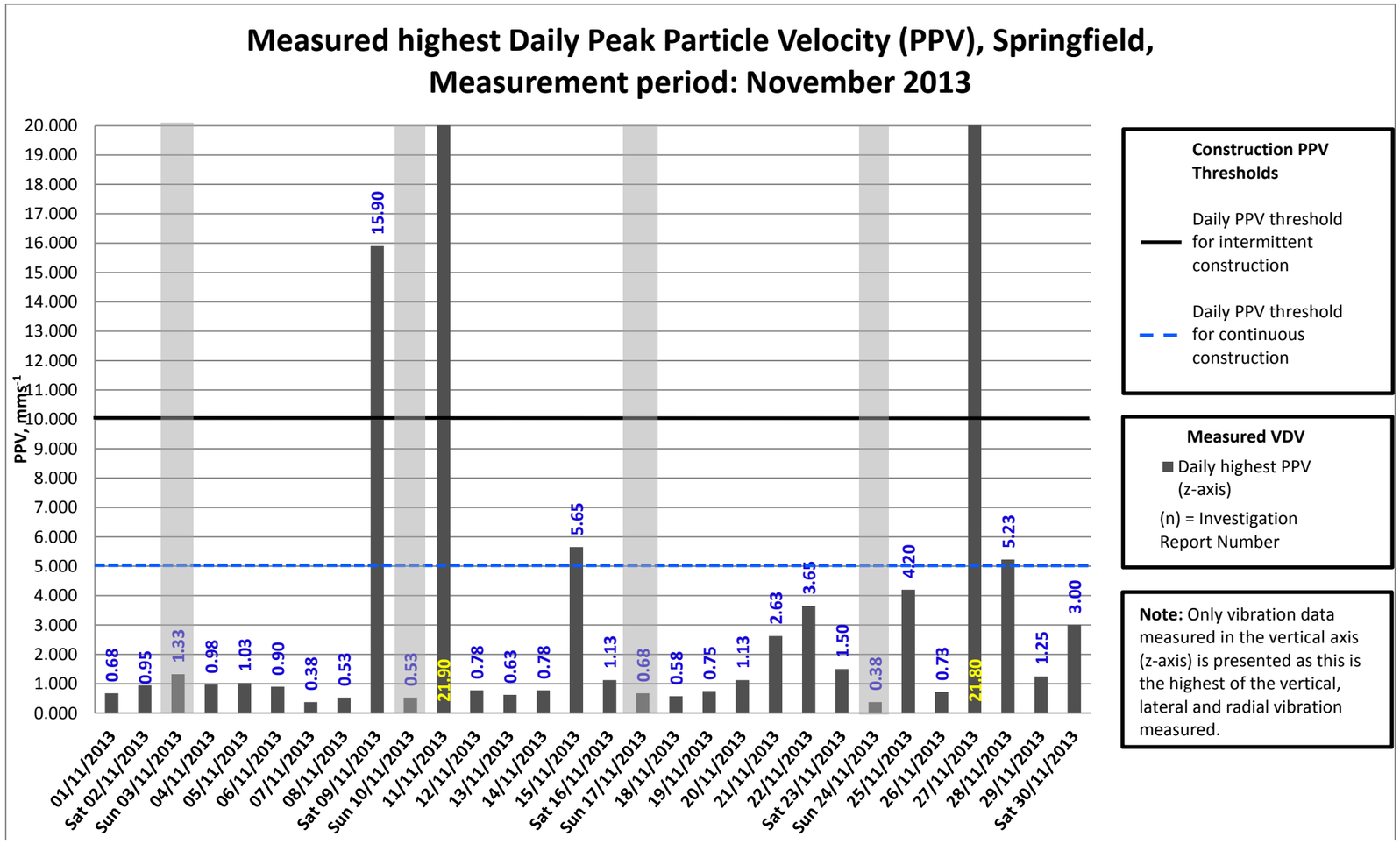
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.



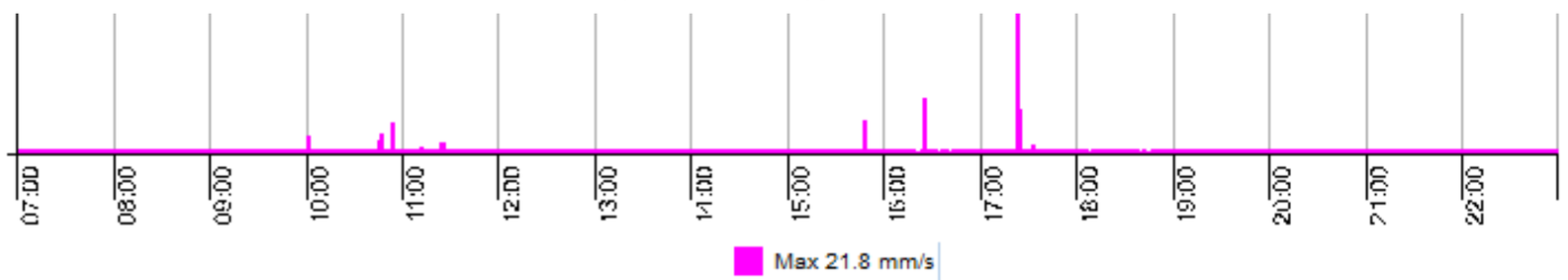
Notes:

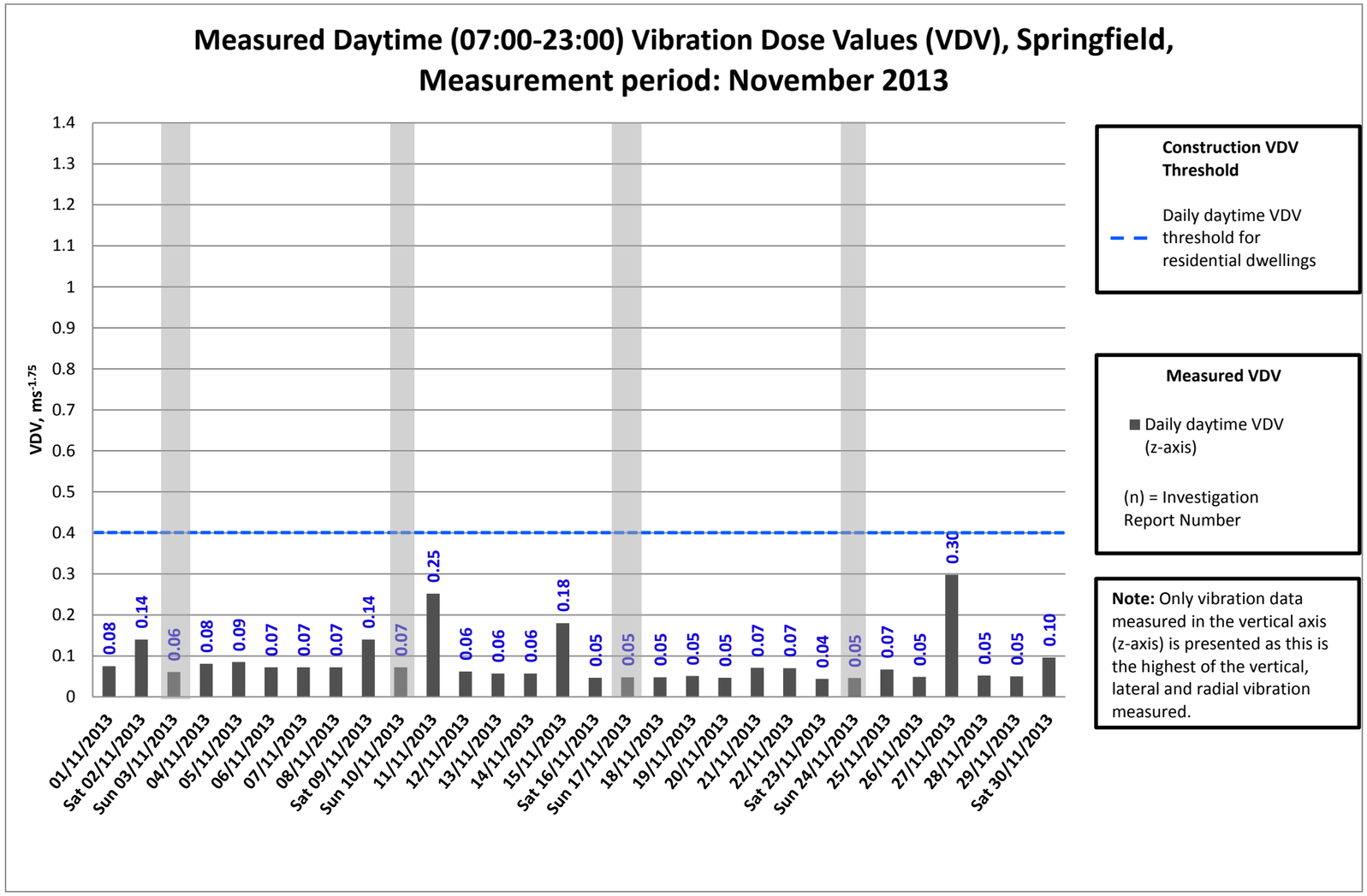
- The grey areas of the chart represent the days on which no construction works were undertaken; no night time works were conducted in the vicinity of the Scotstoun vibration monitor throughout the month of November 2013. This graph is included for illustrative purposes only.



Notes:

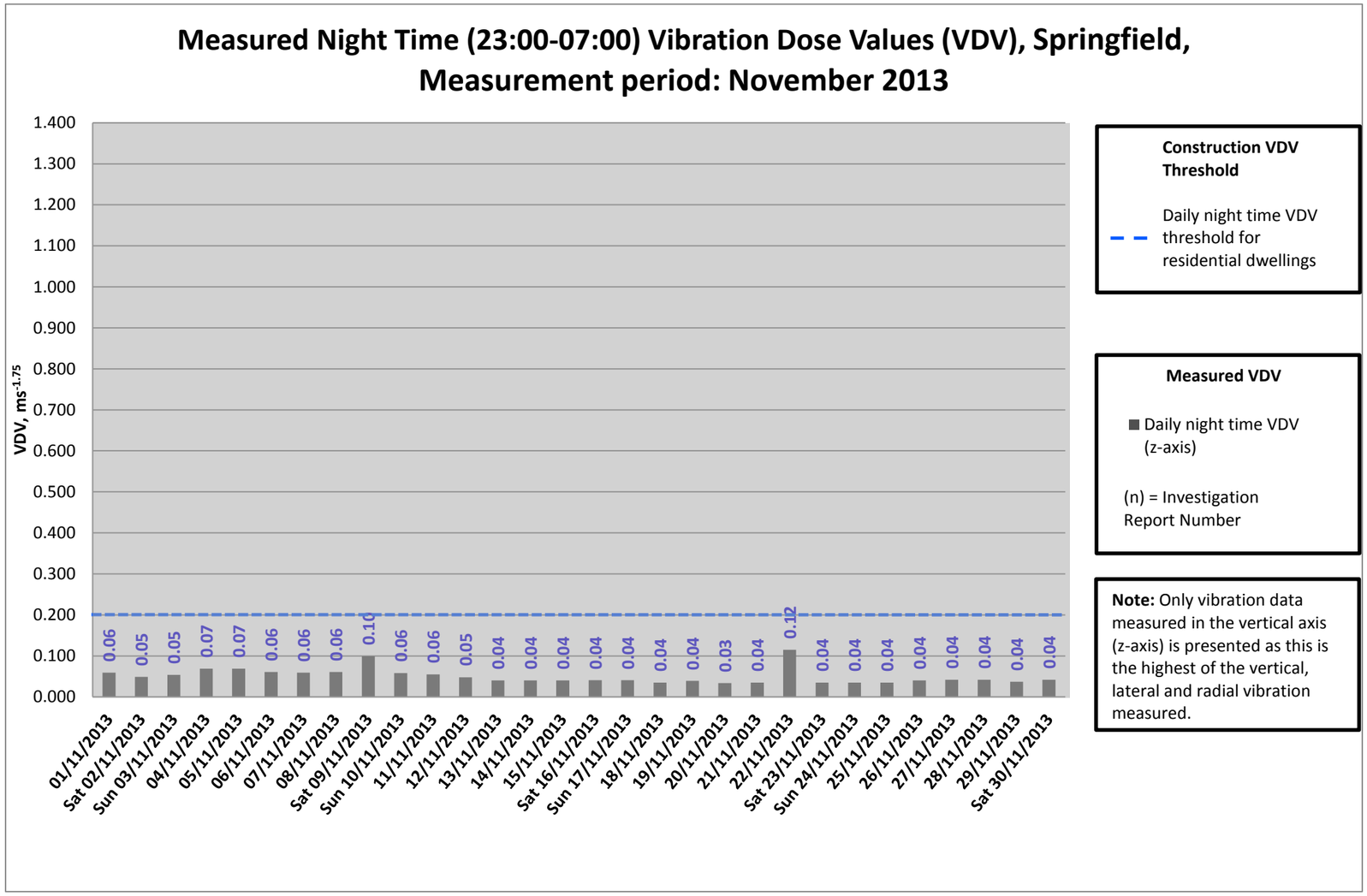
- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.
- The PPV values on 09/11/13, 11/11/13, 15/11/13, 27/11/13 & 28/11/13 have all been investigated, and have been seen to be individual, isolated events within the period (see Vibrock PPV graph below from 27/11/13), two of which are within the intermittent threshold of 10mm/s. Furthermore, it is extremely unlikely that these particular levels were generated as a result of FCBC construction, as the only works to be conducted in the vicinity of the monitor on the dates in question were preparatory works for the launch of west bridge section at the South Abutment, placing segments/rebar, concreting, waterproofing and installation of tie beams at Piers S7 & S8 and were rock ripping & crushing works within the Echline cut. None of these works involved the use of any vibration inducing plant and were a minimum of 180m (worst case) from the monitor.





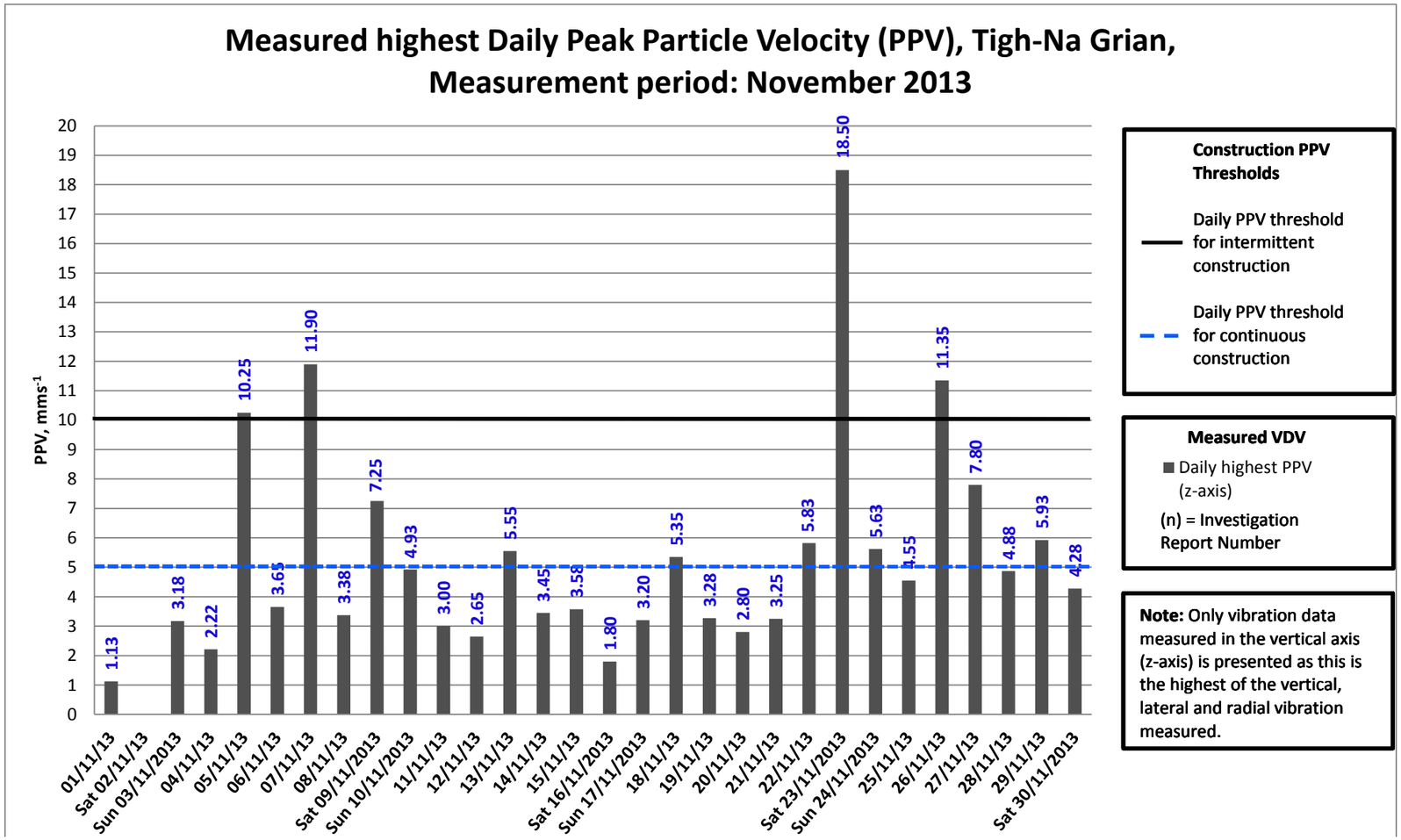
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sunday.



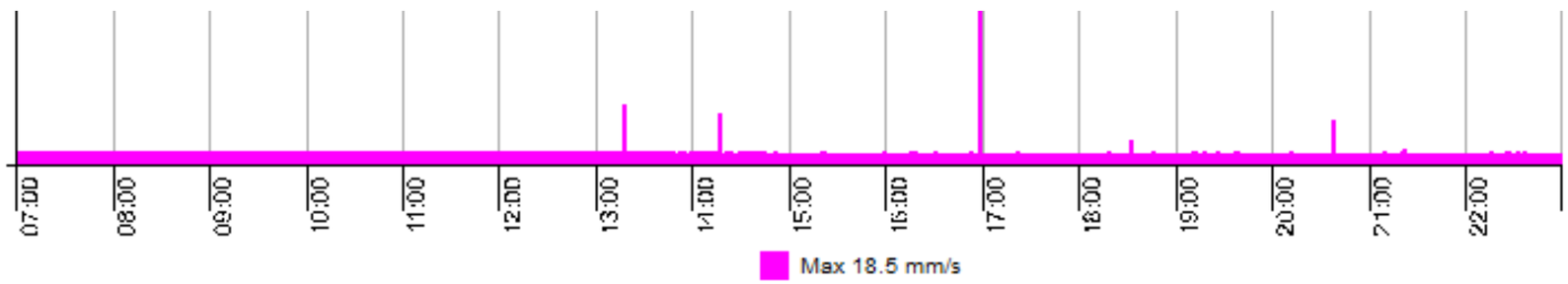
Notes:

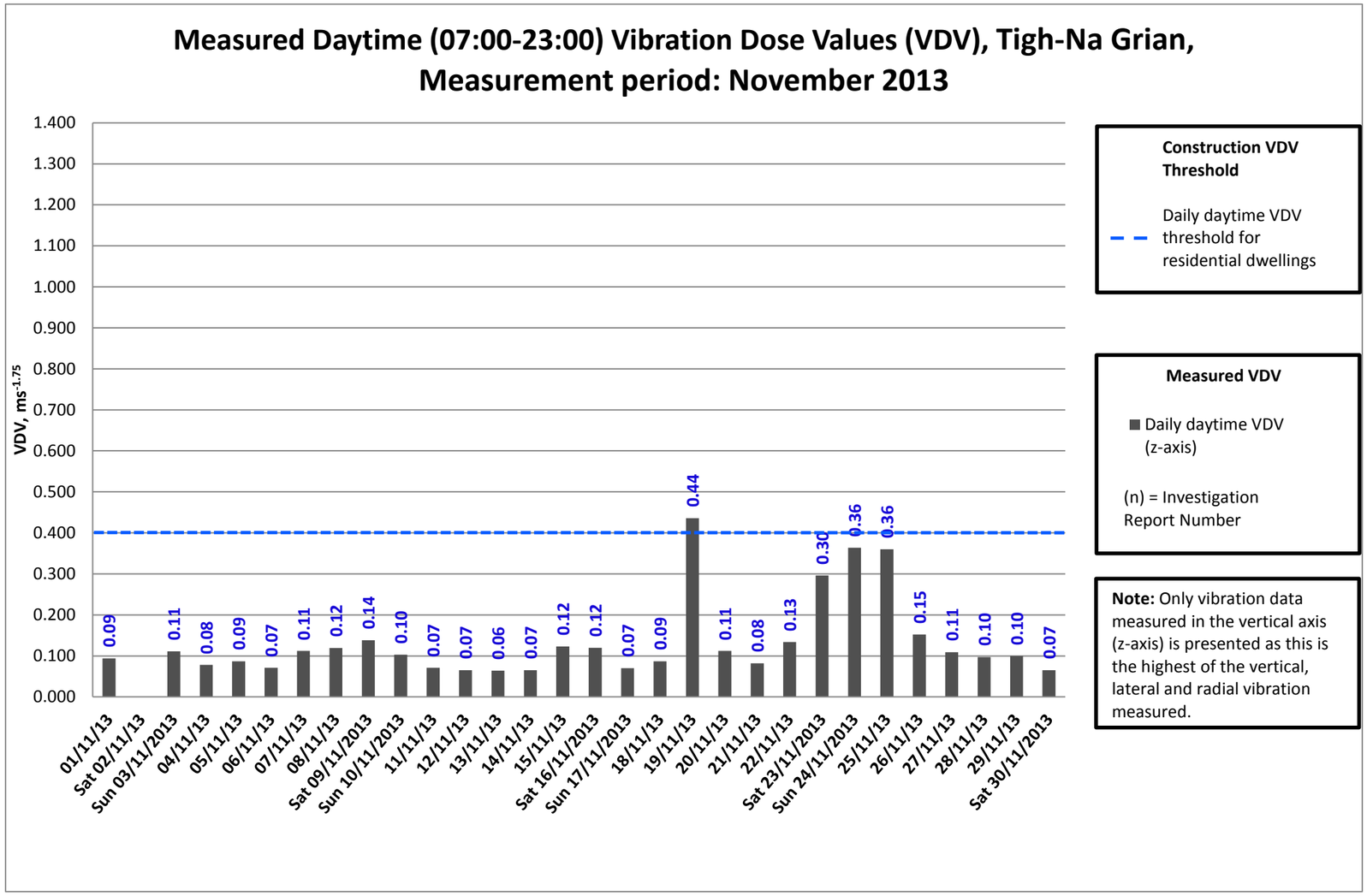
- The grey areas of the chart represent the days on which no construction works were undertaken; no night time works were conducted in the vicinity of the Springfield vibration monitor throughout the month of November 2013. This graph is included for illustrative purposes only.



Notes:

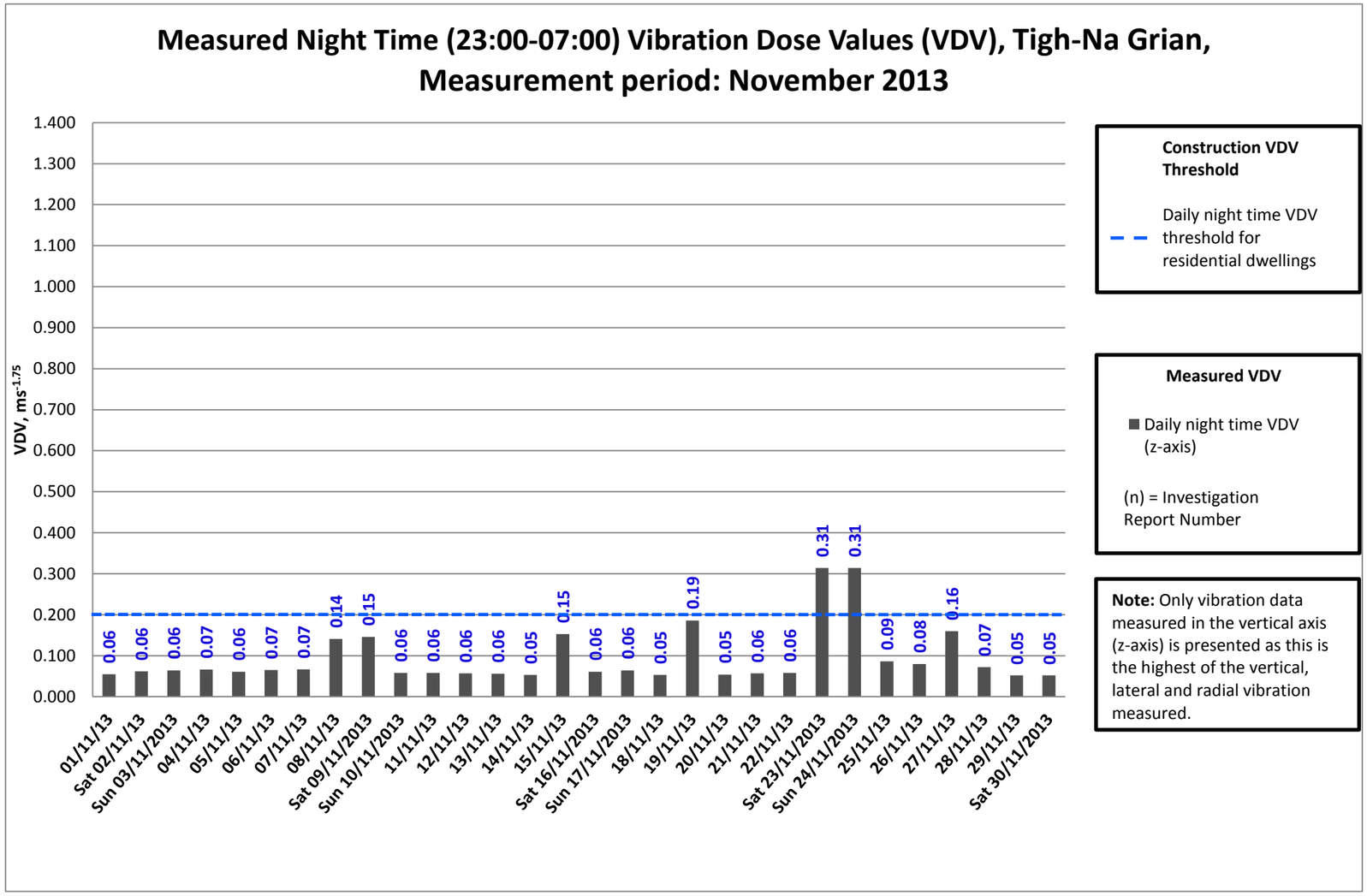
- Data is missing from 02/11/13 due to device error.
- The PPV values on 05/11/13, 07/11/13, 09/11/13, 13/11/13, 18/11/13, 22/11/13, 23/11/13, 24/11/13, 26/11/13, 27/11/13 & 29/11/13 have all been investigated, and have been seen to be individual, isolated events within the period (see Vibrock PPV graph below from 23/11/13), the majority of which are within the intermittent threshold of 10mm/s. Furthermore, it is extremely unlikely that these particular levels were generated as a result of FCBC construction, as the only works to be conducted in the vicinity of the monitor on the dates in question were rebar, formwork & concreting works at the North Tower and drilling for de-stressing wells at Pier N1. None of these works involved the use of any vibration inducing plant and were a minimum of 180m (worst case) from the monitor.





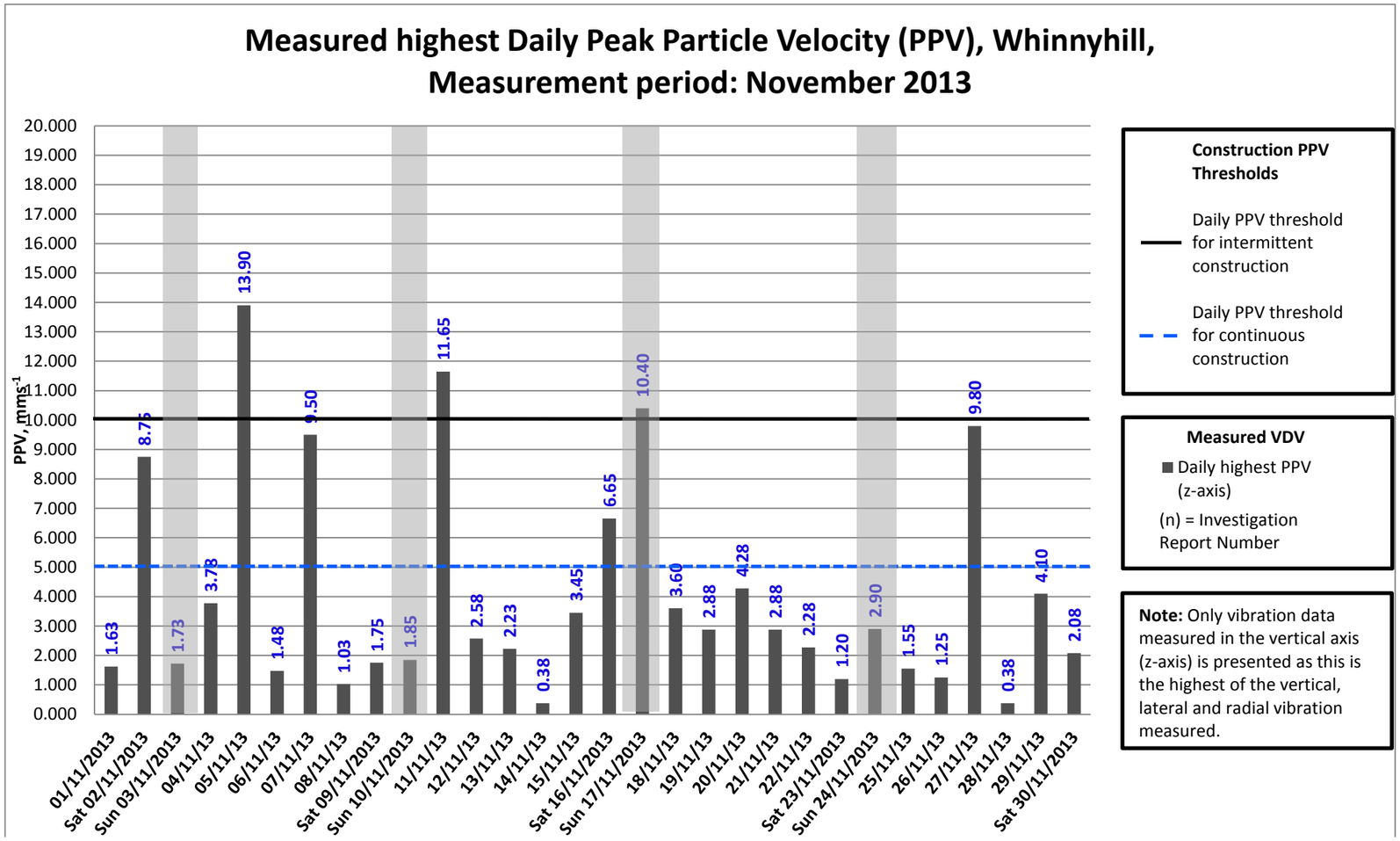
Notes:

- The VDV on 19/11/13 have both been investigated. It is extremely unlikely that these particular levels were generated as a result of FCBC construction, as the only works to be conducted in the vicinity of the monitor on the dates in question were rebar, formwork & concreting works at the North Tower and drilling for de-stressing wells at Pier N1. None of these works involved the use of any vibration inducing plant and were a minimum of 180m (worst case) from the monitor.



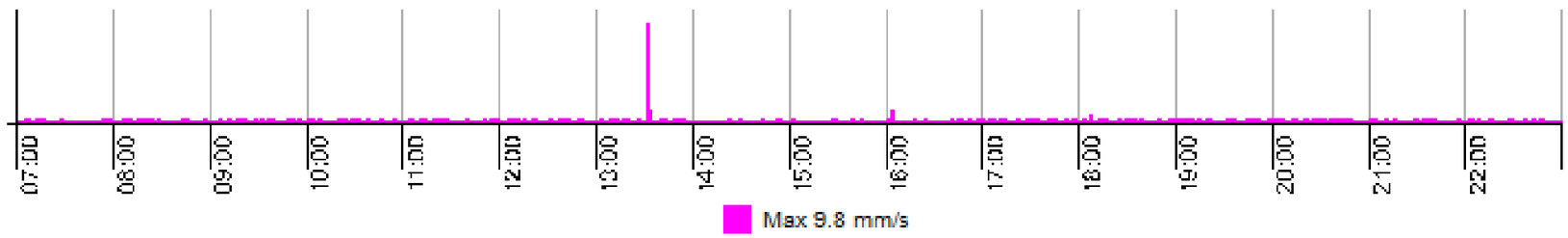
Notes:

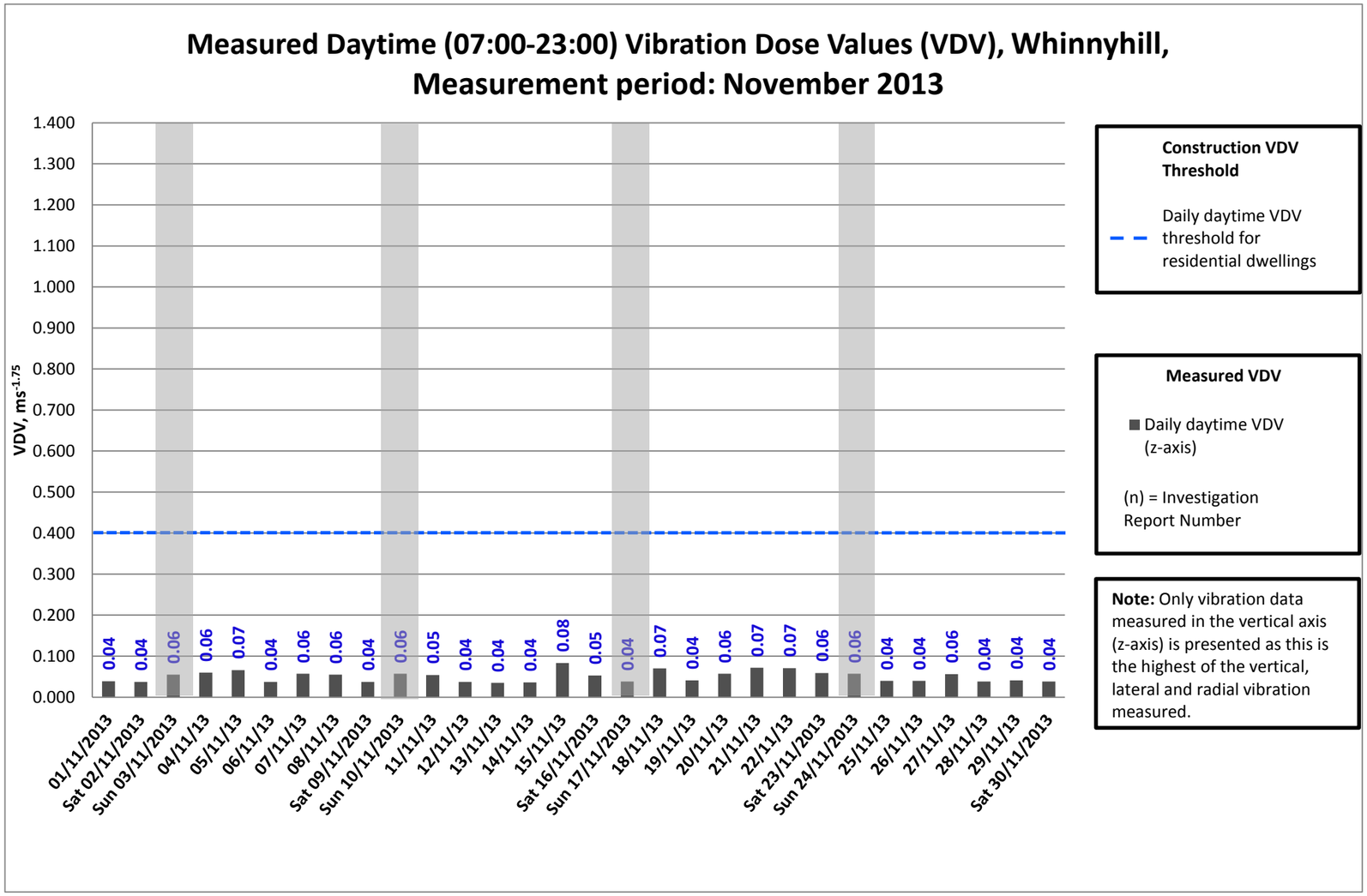
- The VDVs on 23/11/13 & 24/11/13 have both been investigated. It is extremely unlikely that these particular levels were generated as a result of FCBC construction, as the only works to be conducted in the vicinity of the monitor on the dates in question were rebar, formwork & concreting works at the North Tower and drilling for de-stressing wells at Pier N1. None of these works involved the use of any vibration inducing plant and were a minimum of 180m (worst case) from the monitor.



Notes:

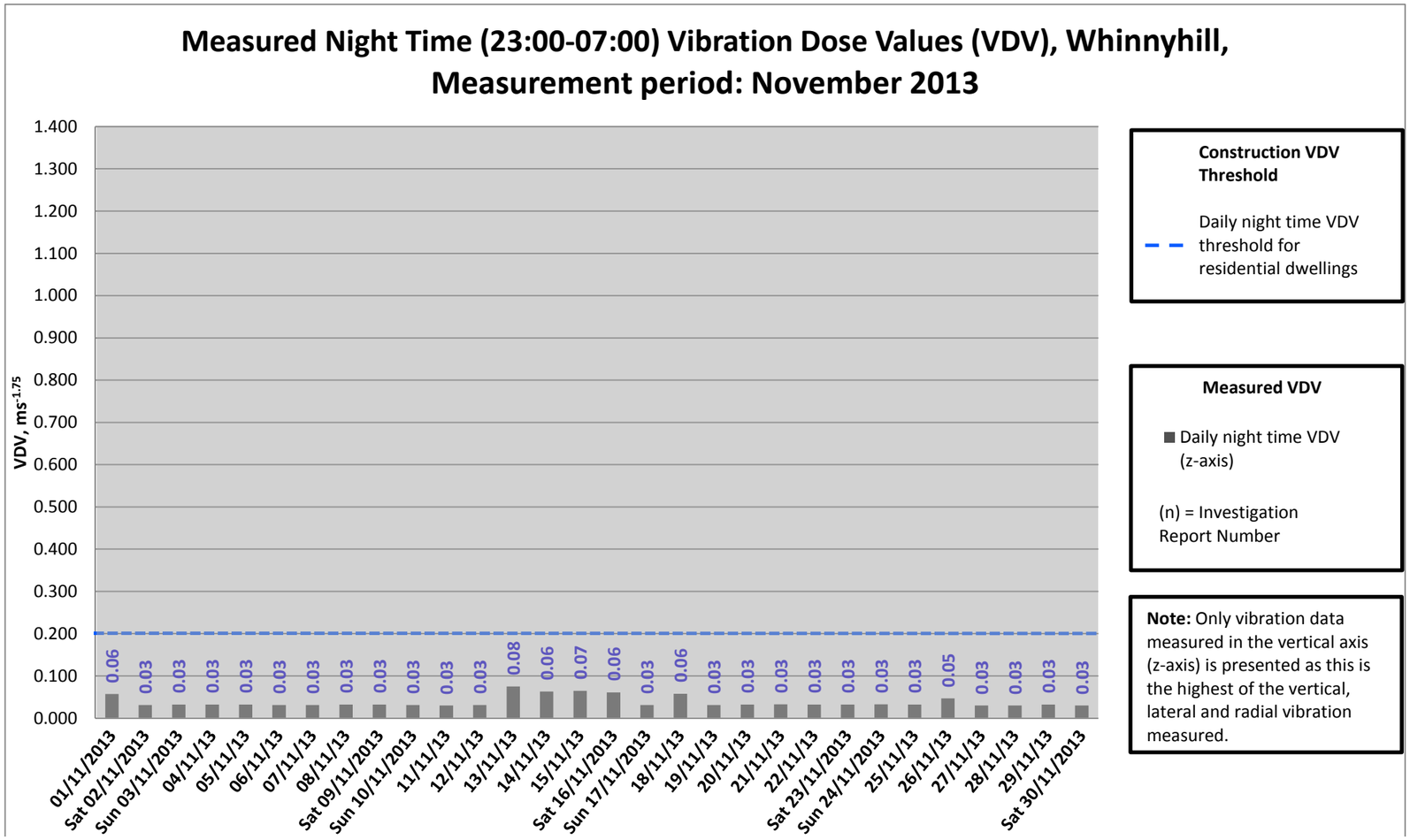
- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.
- The PPV values on 02/11/13, 05/11/13, 07/11/13, 11/11/13, 16/11/13, 26/11/13 & 27/11/13 have been investigated, and have been seen to be individual, isolated events within each period (see Vibrock PPV graph below from 27/11/13), many of which are within the intermittent threshold of 10mm/s. Furthermore, it is extremely unlikely that these particular levels were generated as a result of FCBC construction, as the only works to be conducted in the vicinity of the monitor on the dates in question were landscaping works at the King Malcolm Drive embankment. These works did not involve the use of any vibration inducing plant and were a minimum of 180m (worst case) from the monitor.





Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.



Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no night time works were conducted in the vicinity of the Whinnyhill vibration monitor throughout the month of November 2013. This graph is included for illustrative purposes only.