



Contractor



Forth Crossing Bridge Constructors

HOCHTIEF Solutions
American Bridge International
DRAGADOS
Morrison Construction

Project **FORTH REPLACEMENT CROSSING**

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VIBRATION MONITORING REPORT
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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 April 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

April 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})
Butlaw Fisheries	0	0	0	0
Clufflat Brae	11	3	0	1
Dundas Home Farm	0	0	1	6
Echline	0	0	0	0
Inchgarvie Lodge	0	0	0	0
Linn Mill	10	7	0	1
Scotstoun	0	0	0	0
Springfield	0	0	0	0
Tigh-Na-Grian	1	5	12	20
Whinnyhill	3	1	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 VDV 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 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 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 April 2013
M1	Whinny Hill	Network	Loading of rock at Whinny Hill N.B. No evening, night time or Sunday daytime construction in vicinity.
M3	Tigh-Na-Grian	Crossing	Works within Central Tower cofferdam North Tower caisson excavation North Tower airlifting preparation works
M7	Butlaw Fisheries	Crossing	Works within Central Tower cofferdam South Tower excavation Pier S1 caisson excavation Pier S4 airlifting Pier S5 airlifting & concrete works Drilling of de-stressing wells at pier S6 Construction of access causeway between piers S6 and S5
M10	Inchgarvie Lodge	Crossing	South Tower excavation Pier S1 caisson excavation Pier S4 airlifting Pier S5 airlifting & concrete works Drilling of de-stressing wells at pier S6 Construction of access causeway between piers S6 and S5 Excavation of launch South Abutment works Works on launch foundations including fixing steel, erecting formwork and concreting
M11	Linn Mill	Network	Excavation of launch South Abutment works Works on launch foundations including fixing steel, erecting formwork and concreting N.B. No evening, night time or Sunday daytime construction in vicinity.
M13	Clufflat Brae	Crossing	Excavation of launch South Abutment works Works on launch foundations including fixing steel, erecting formwork and concreting

M14	Springfield	Network	Excavation of launch South Abutment works Works on launch foundations including fixing steel, erecting formwork and concreting Structure works at gyratory N.B. No evening, night time or Sunday daytime construction in vicinity.
M15	Echline Field	Network	Excavation of launch Works on launch foundations including fixing steel, erecting formwork and concreting Structure works at gyratory Drainage works at A904/U221 U221 topsoil batters N.B. No evening, night time or Sunday daytime construction in vicinity.
M16	Scotstoun	Network	Drainage works Placing rock/clay for embankment N.B. No evening, night time or Sunday daytime construction in vicinity.
M17	Dundas Home Farm	Network	Utilities works Fill using clay for road network 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 April 2013.

Table 3: PCNV Predicted PPV & VDV Levels

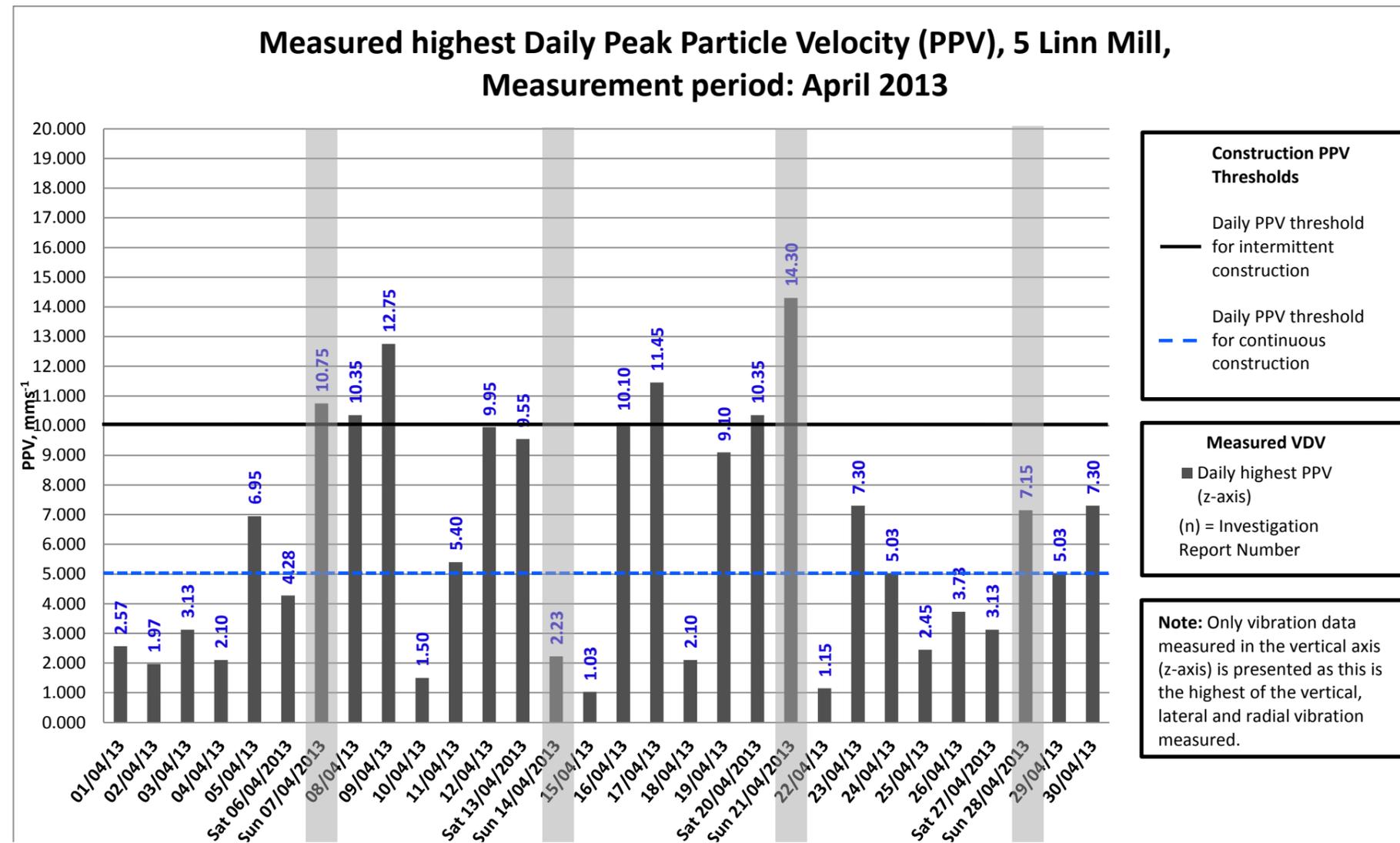
Monitor	Minimum distance from work areas (m)		Type of vibration emitting plant/activity operated at nearest work areas	Worst case predicted vibration levels	
	Day (07:00-19:00)	Night (19:00-07:00)		PPV (mm/s)	eVDV (m.s ^{-1.75})
Butlaw Fisheries	150	230	Roller/Whacker	0.39	0.23
Clufflat Brae	40	350	Roller/Whacker	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	250	Roller/Whacker	1.77	0.33
Linn Mill	60	500	Roller/Whacker	1.36	0.33
Scotstoun	50	2000	Roller/Whacker	1.77	0.33
Springfield	50	600	Roller/Whacker	1.77	0.33
Tigh-Na-Grian	200	200	N/A	-	-
Whinny Hill	270	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

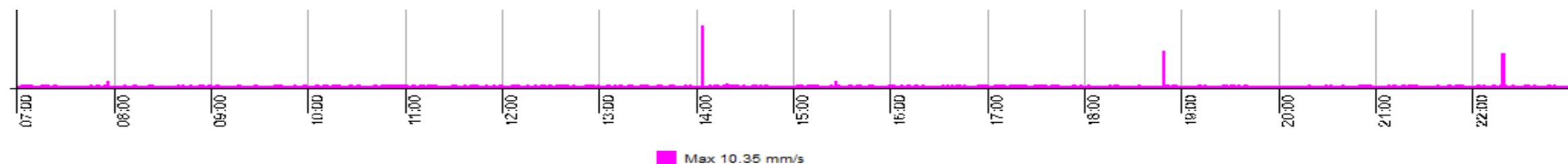
- All plant used during construction activities has been assessed with respect to vibration. The only plant utilised over the period in question considered to generate appreciable levels of vibration was a vibratory roller and a whacker plate (NOTE: Hydraulic rock breakers which typically generate 4.5mm/s @ 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 80m of any occupied sensitive receptors & were not operated within 25m 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 4 hours a minimum 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.

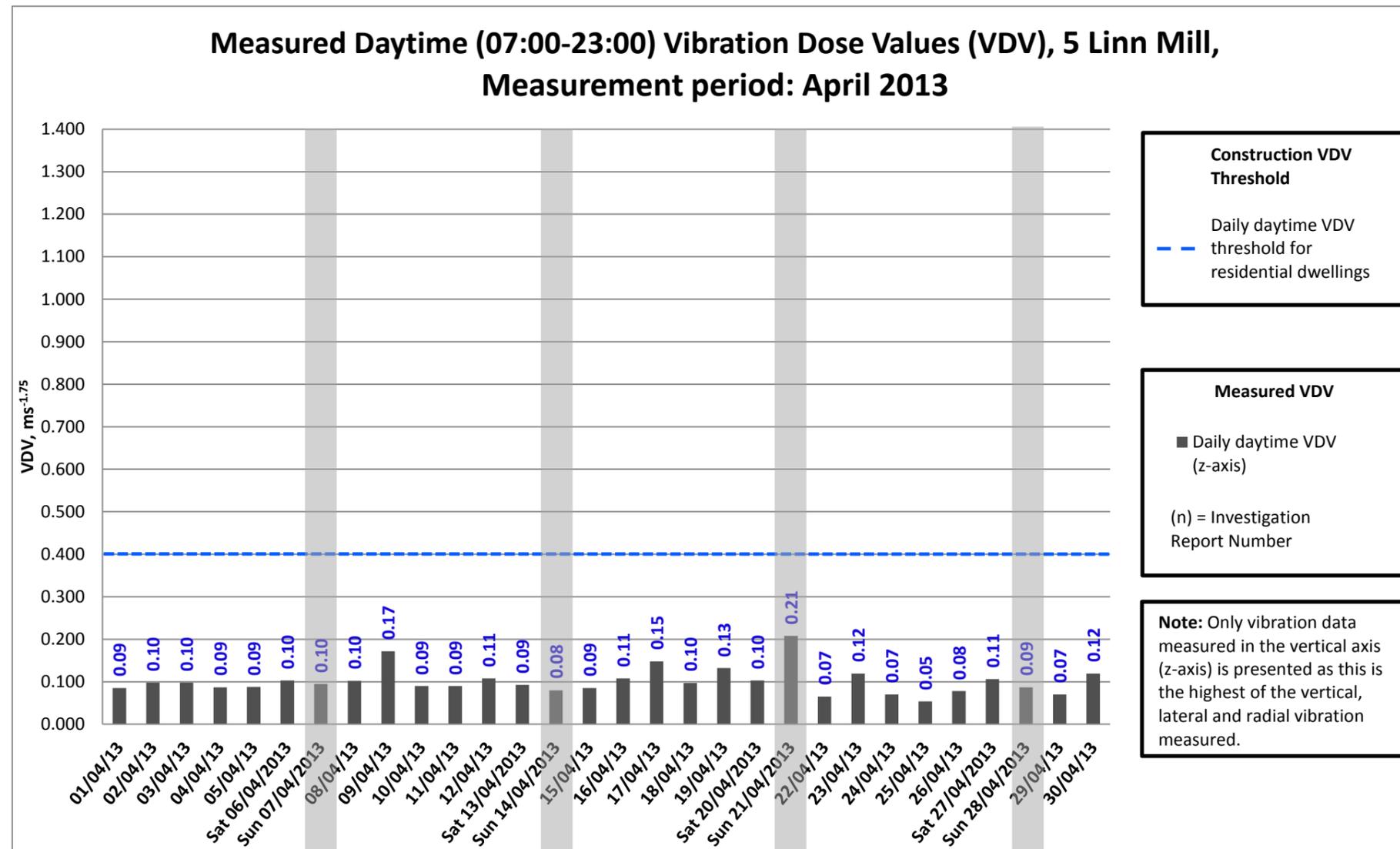
APPENDIX B – VIBRATION GRAPHS



Notes:

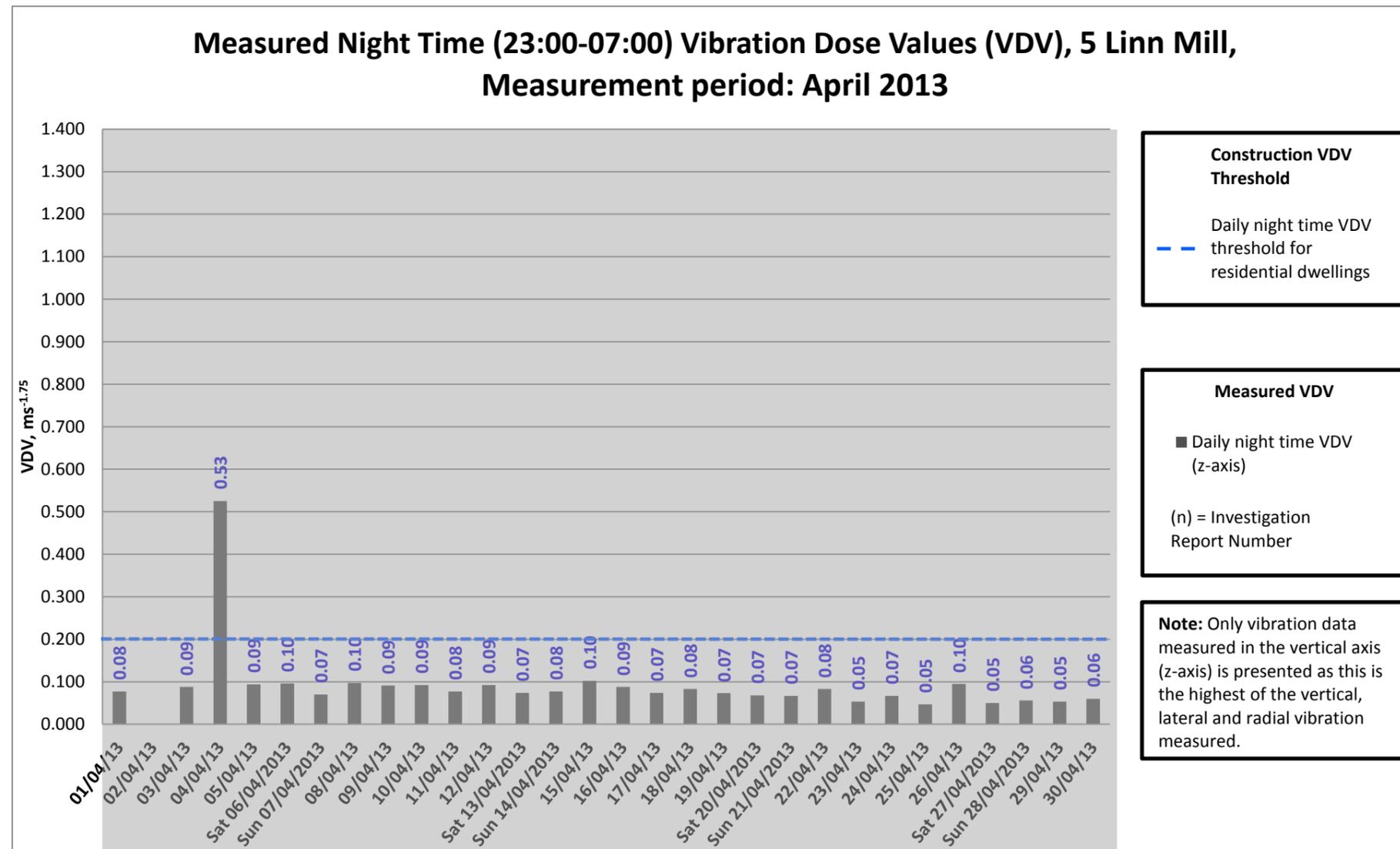
- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.
- The PPV values on 05/04/13, 08/04/13, 09/04/13, 11/04/13, 12/04/13, 13/04/13, 16/04/13, 17/04/13, 19/04/13, 20/04/13, 23/04/13, 24/04/13, 29/04/13 & 30/04/13 have all been investigated, and have been seen to be individual, isolated events within each period (see Vibrock PPV graph below from 08/04/13), the majority of which are within the intermittent threshold of 10mm/s. Furthermore, these particular levels cannot have been generated as a result of FCBC construction, as the only works to be conducted on these dates in the vicinity of the monitor, were excavation works at the launch area and blinding, reinforcement & formwork at South Abutment, which did not involve any vibration inducing plant or equipment.





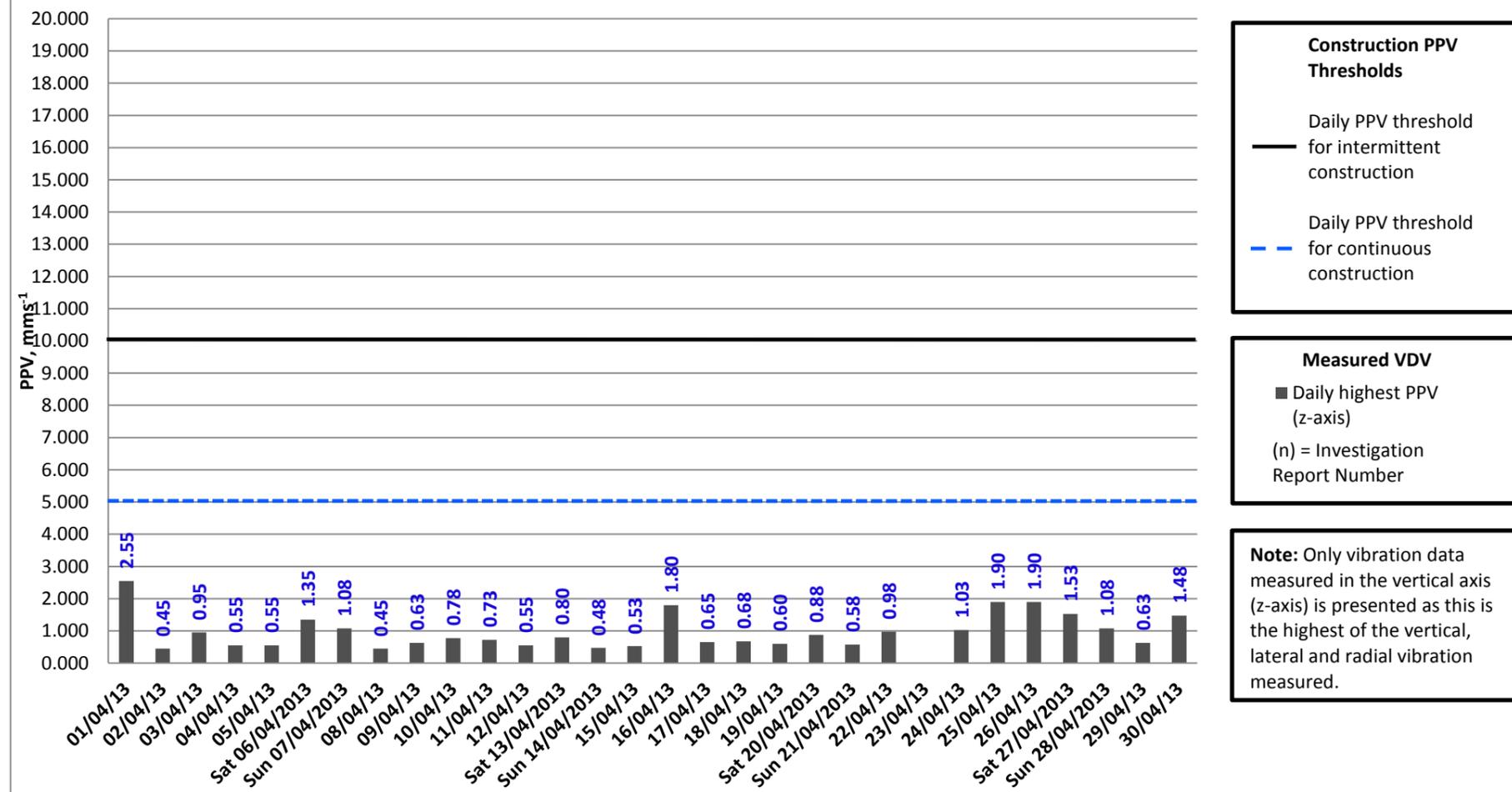
Notes:

- 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 April 2013. This graph is included for illustrative purposes only.

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



Construction PPV Thresholds

- Daily PPV threshold for intermittent construction
- Daily PPV threshold for continuous construction

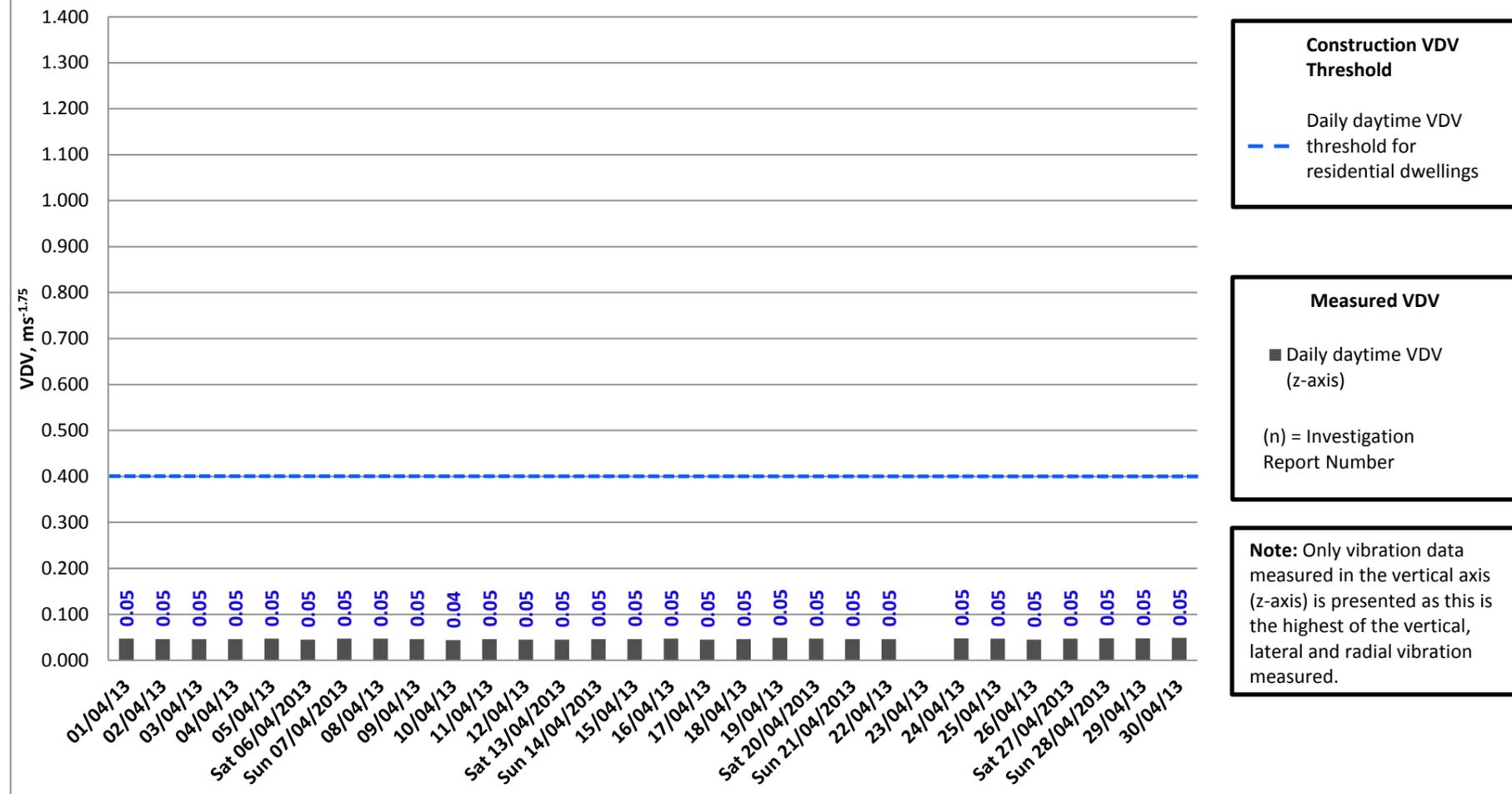
Measured VDV

- Daily highest PPV (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.

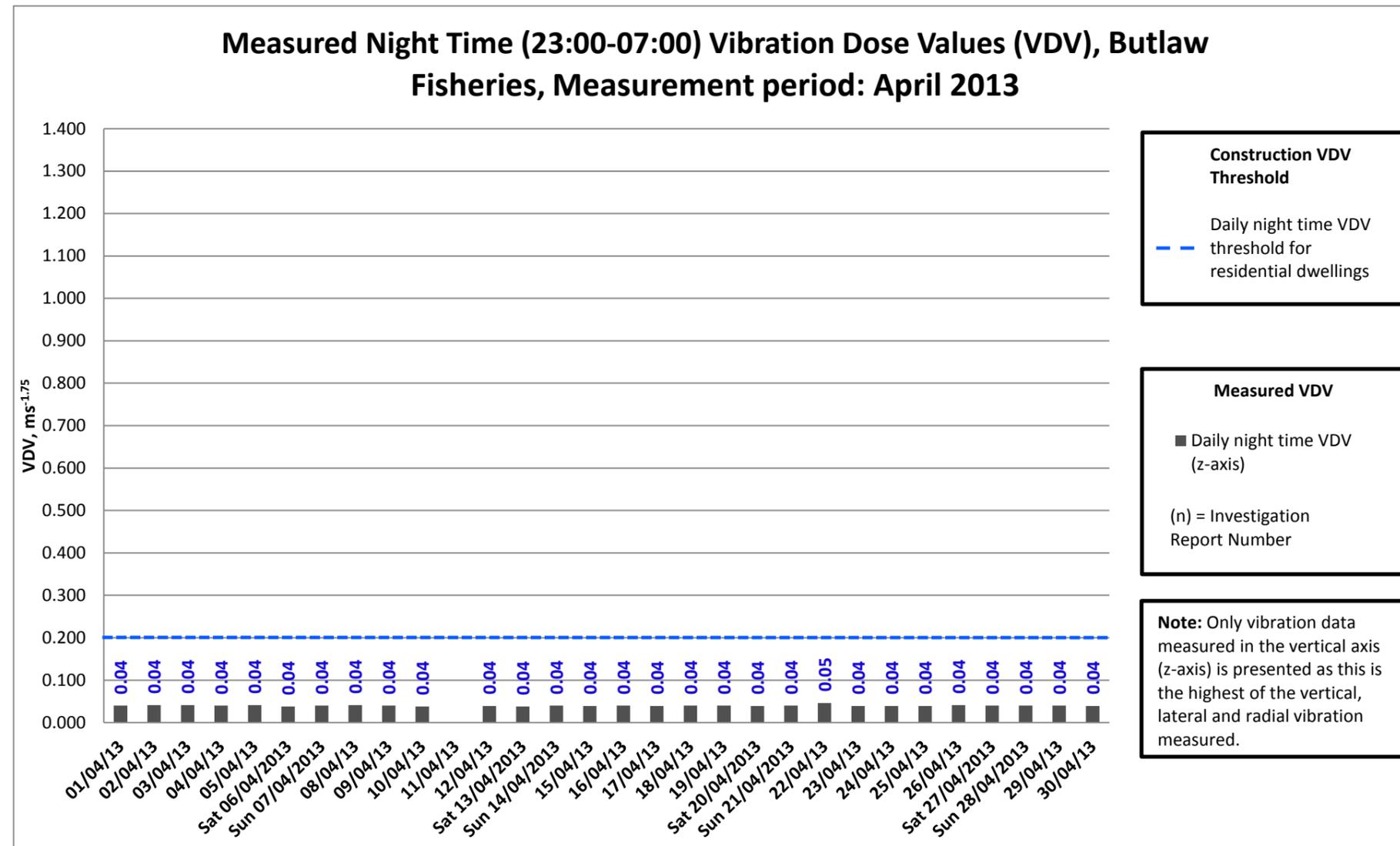
- Notes:**
- Data is missing from 23/04/13 due to device error.

Measured Daytime (07:00-23:00) Vibration Dose Values (VDV), Butlaw Fisheries, Measurement period: April 2013



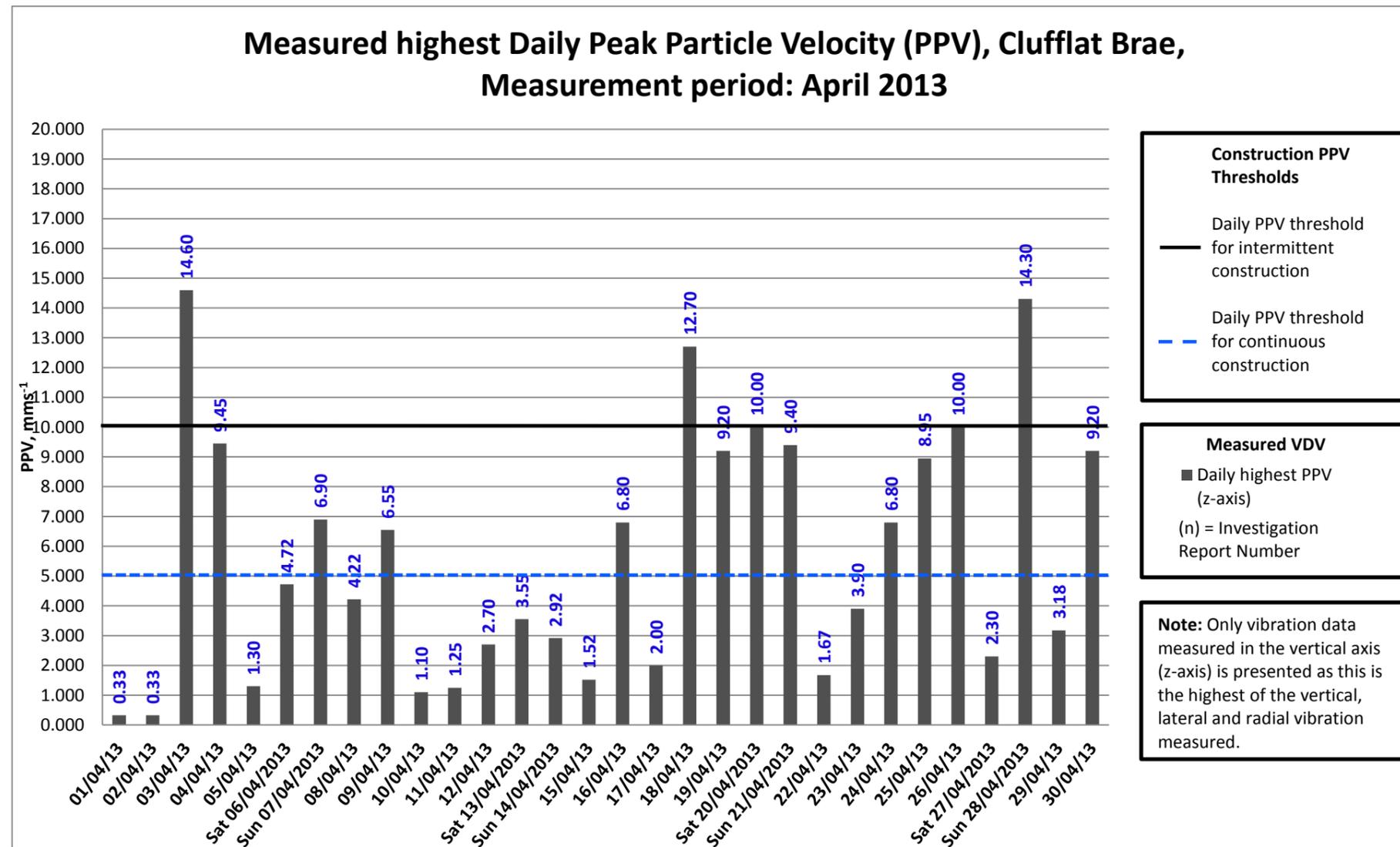
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- Data is missing from 23/04/13 due to device error.



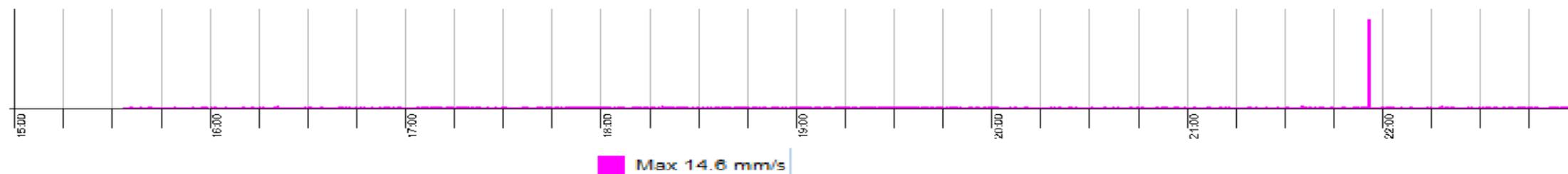
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- Data is missing from 10/04/13 due to device error.

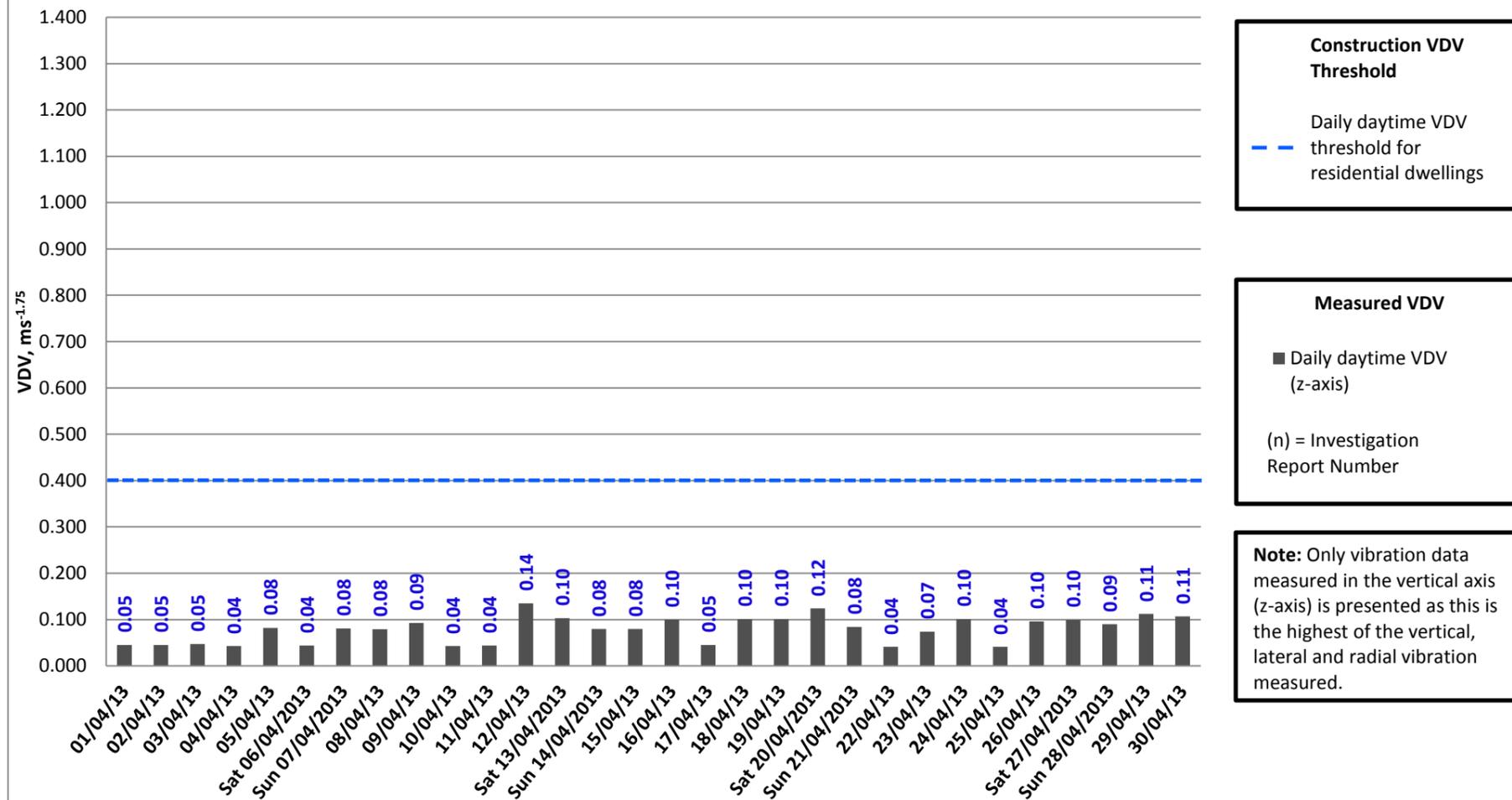


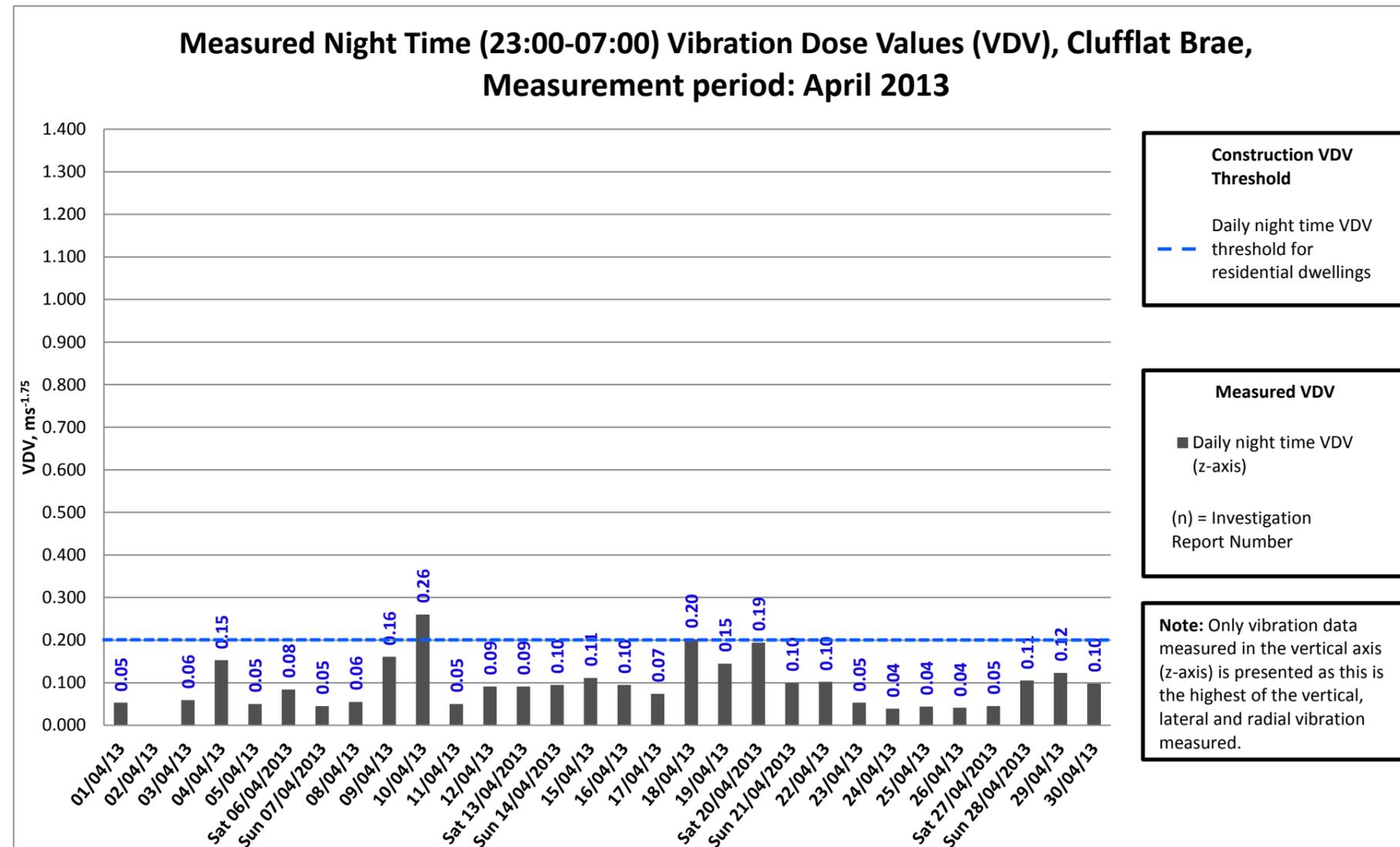
Notes:

- The PPV values on 03/04/13, 04/04/13, 07/04/13, 09/04/13, 16/04/13, 18/04/13, 19/04/13, 20/04/13, 19/04/13, 20/04/13, 21/04/13, 24/04/13, 25/04/13, 26/04/13, 28/04/13 & 30/04/13 have been investigated, and have been seen to be individual, isolated events within each period (see Vibrock PPV graph below from 03/04/13), the majority of which are within the intermittent threshold of 10mm/s. Furthermore, these particular levels cannot have been generated as a result of FCBC construction, as the only works to be conducted on these dates in the vicinity of the monitor, were excavation works at the launch area and blinding, reinforcement & formwork at South Abutment, which did not involve any vibration inducing plant or equipment.



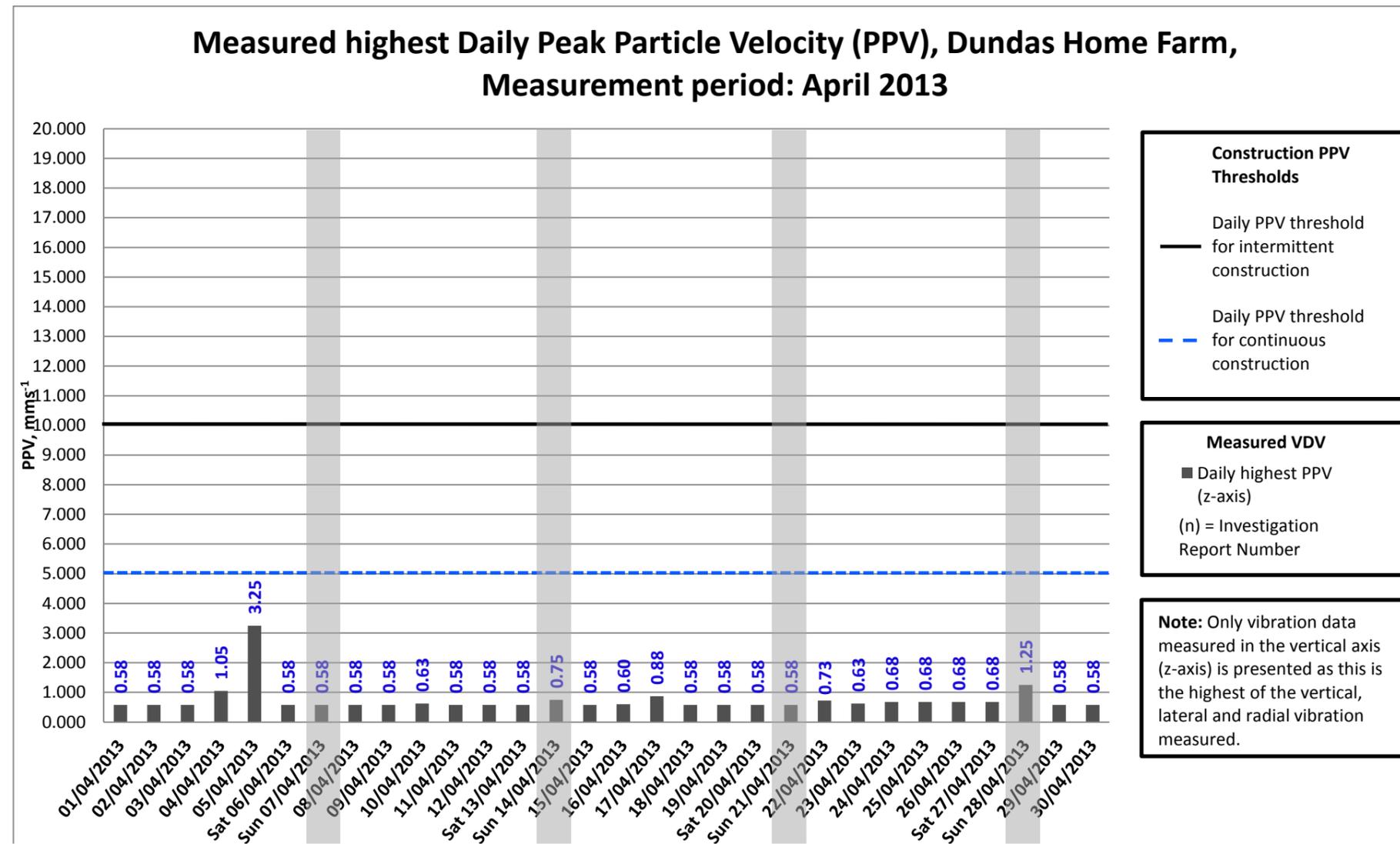
**Measured Daytime (07:00-23:00) Vibration Dose Values (VDV), Clufflat Brae,
 Measurement period: April 2013**





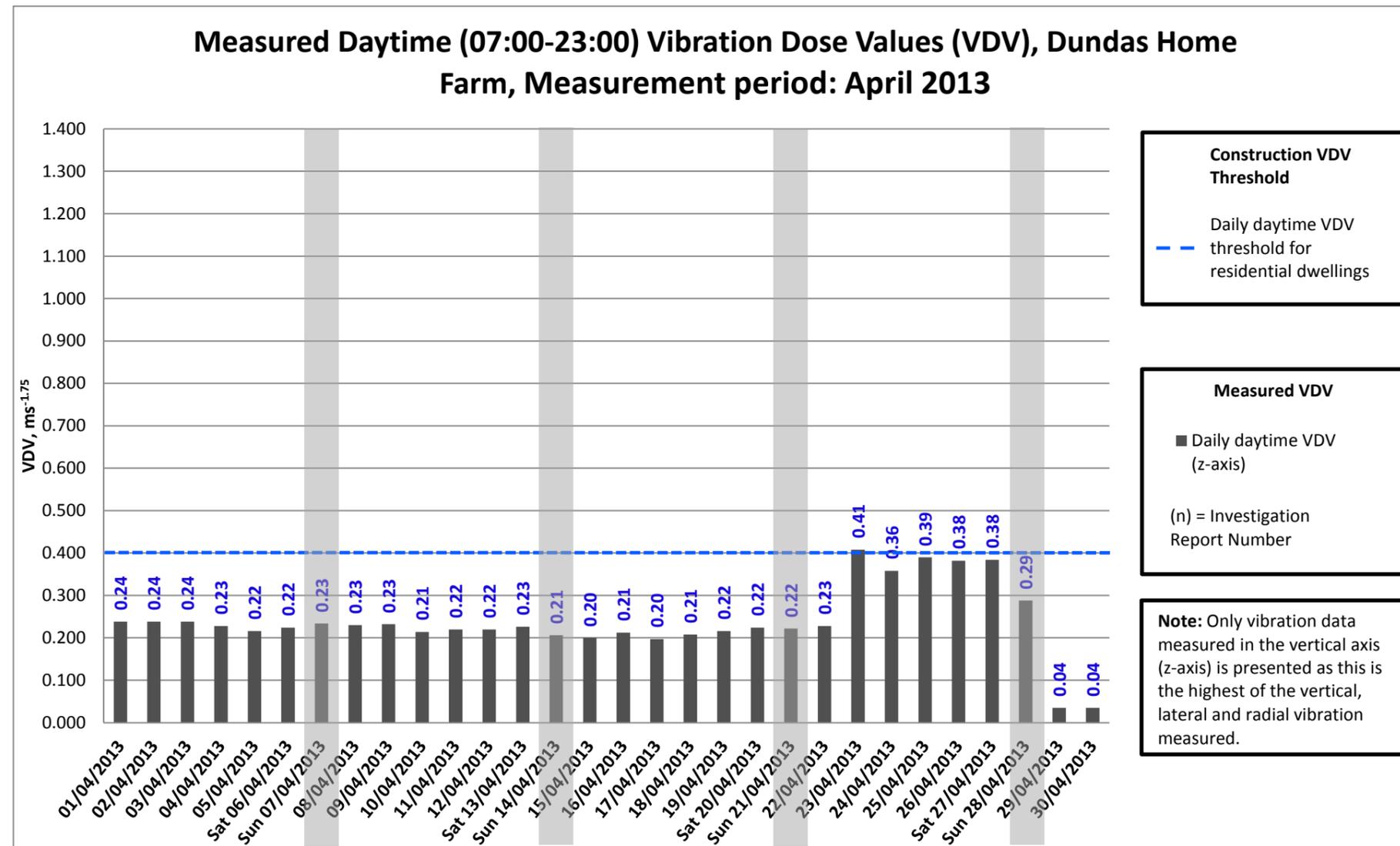
Notes:

- The VDV value on 10/04/13 has been investigated, and cannot have been generated as a result of FCBC construction, as the only works to be conducted during this night time period in question were caisson excavation works at Pier S1 and the South Tower, which are over 500m from the monitor and did not involve the use of any vibration inducing plant or equipment.
- Data is missing from 02/04/13 due to device error.



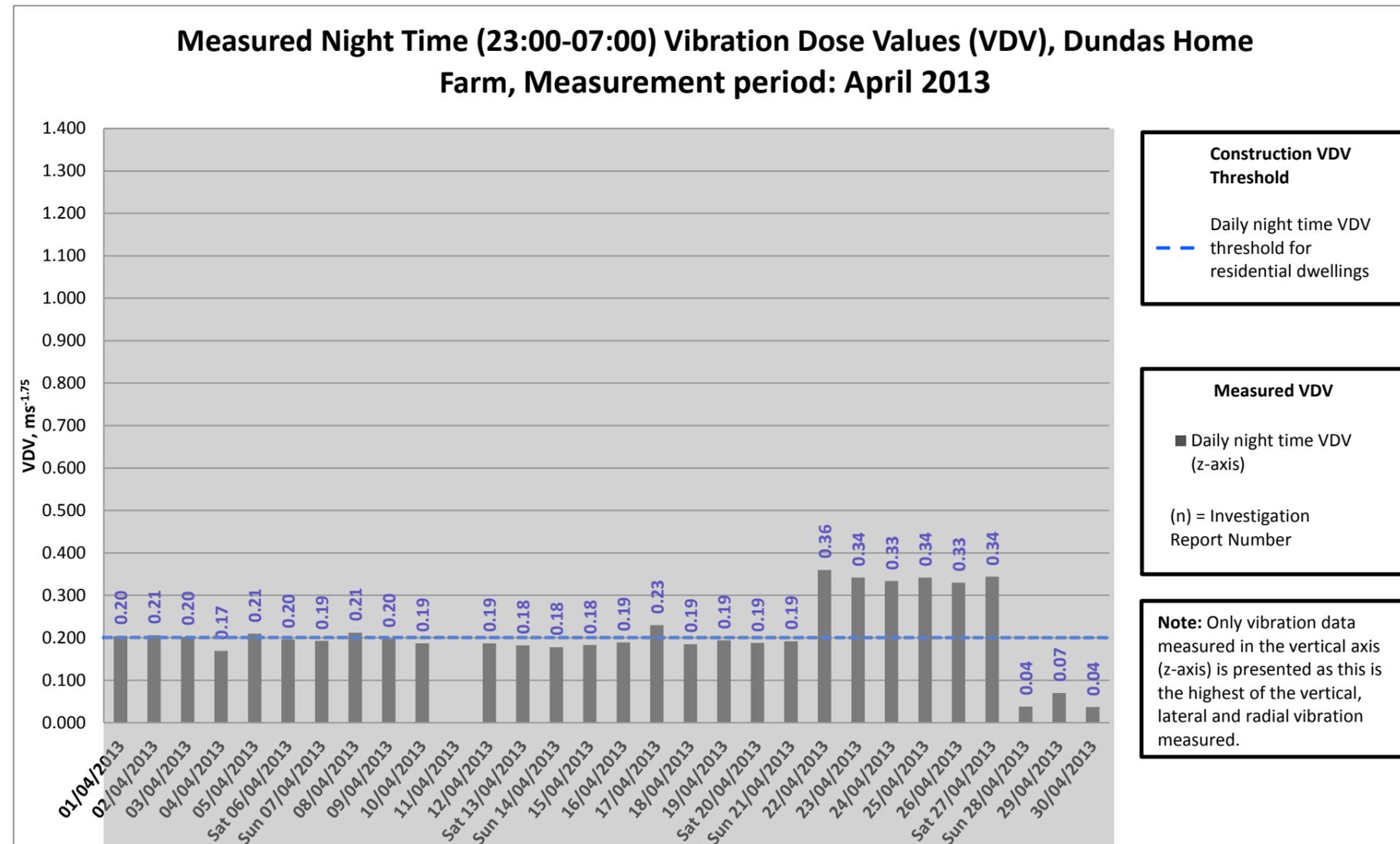
Notes:

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



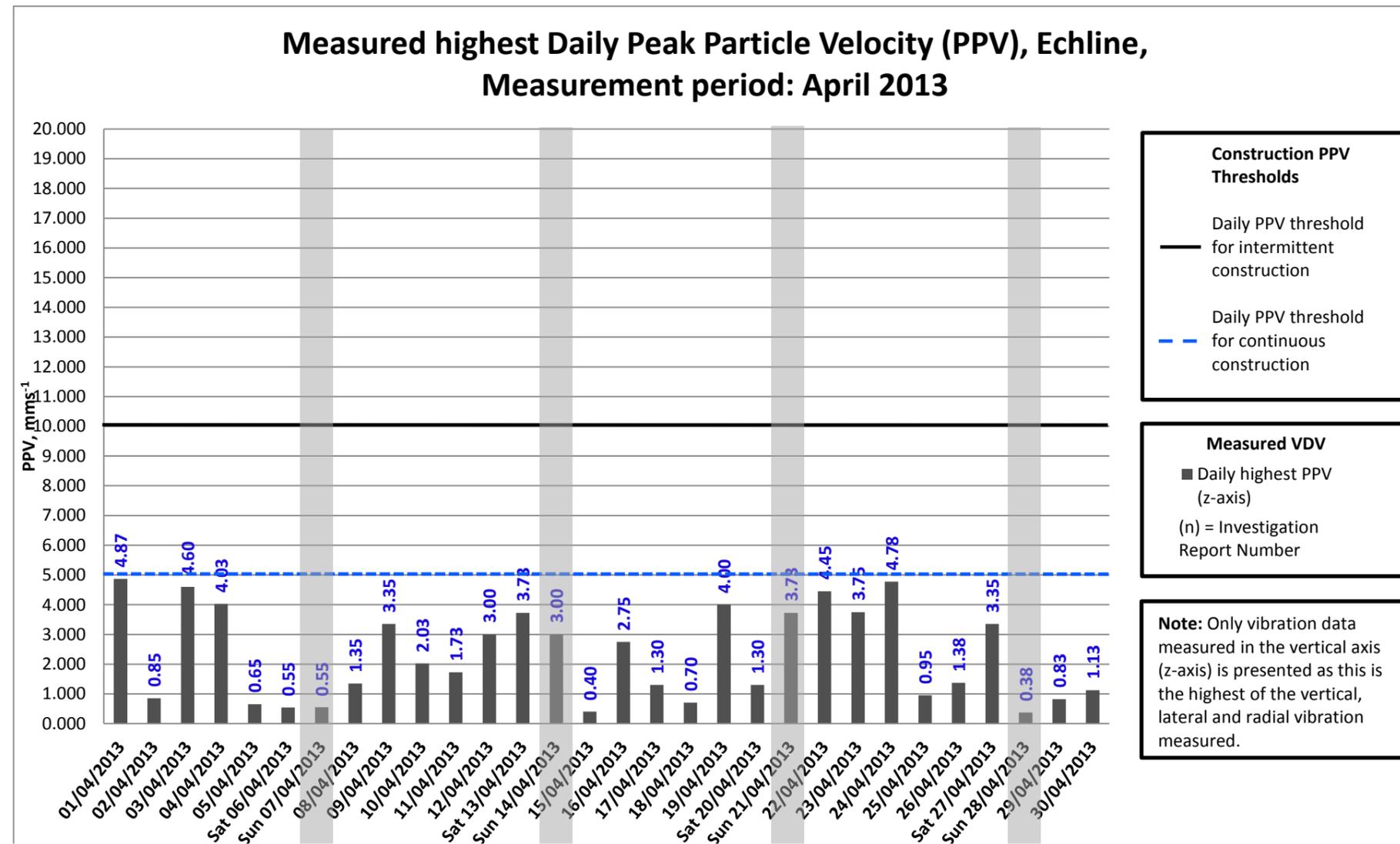
Notes:

- 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 23/04/13 (and the 5 days following) has been investigated, and cannot have been generated as a result of FCBC construction, as the only works to be conducted in the vicinity of the monitor during this period were back filling works, which did not involve the use of any vibration inducing plant or equipment. Examination of the monitor's night time results for the same period (which can be viewed overleaf), further underlines that these levels cannot have resulted from FCBC construction, as the nearest FCBC night time works were conducted a distance of ~1.9km away.



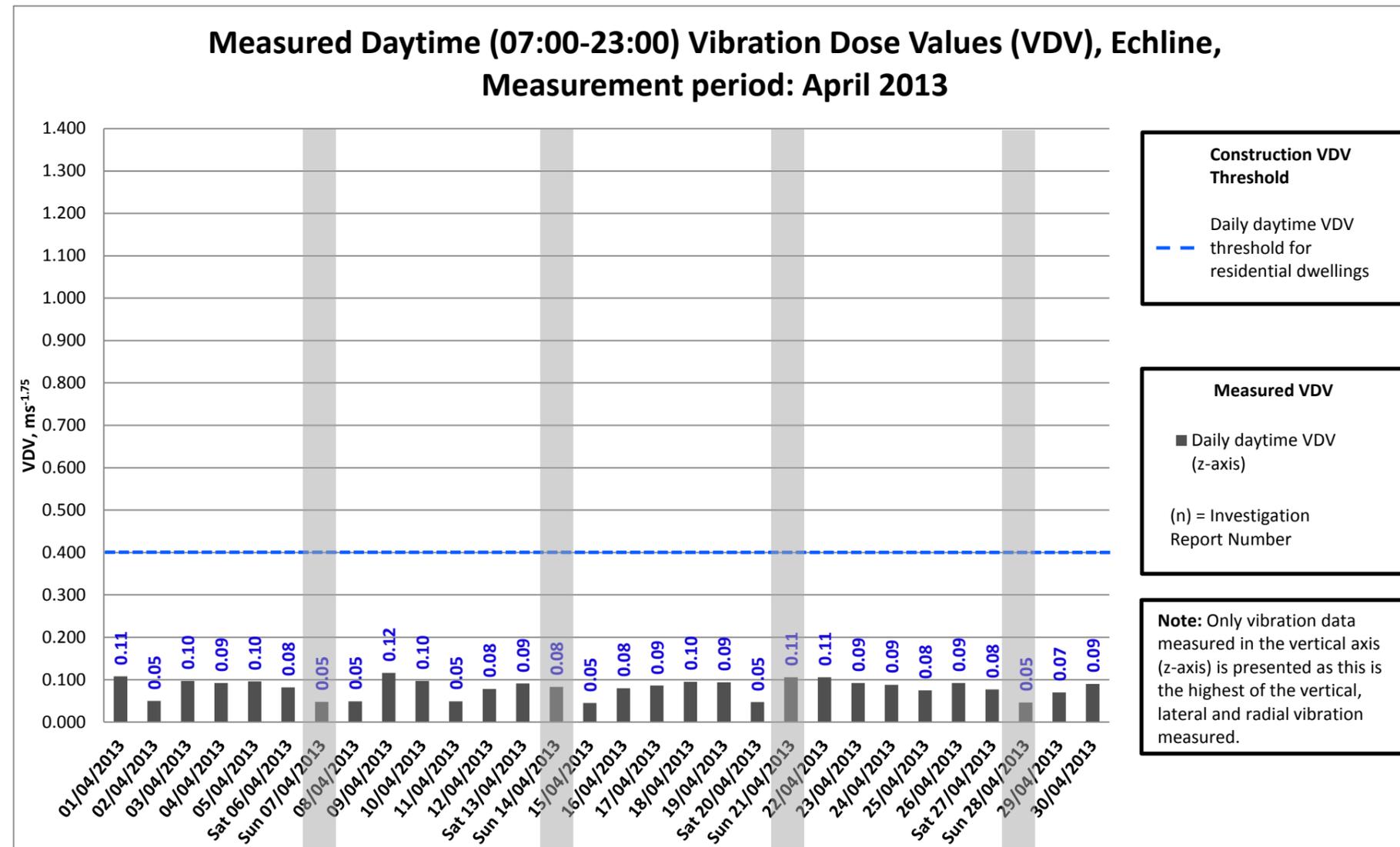
Notes:

- 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 vibration monitor throughout the month of April 2013. This graph is included for illustrative purposes only.



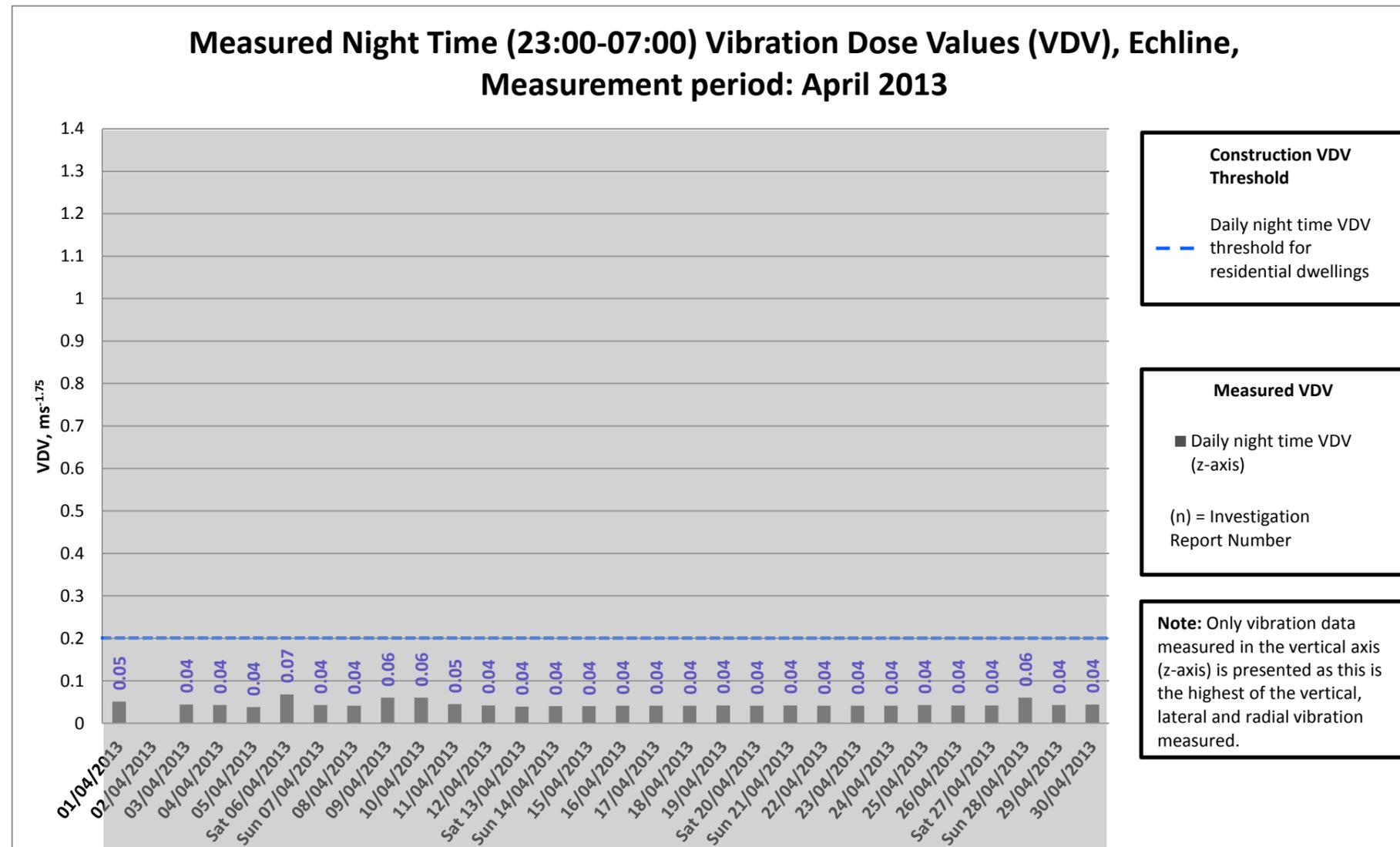
Notes:

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Notes:

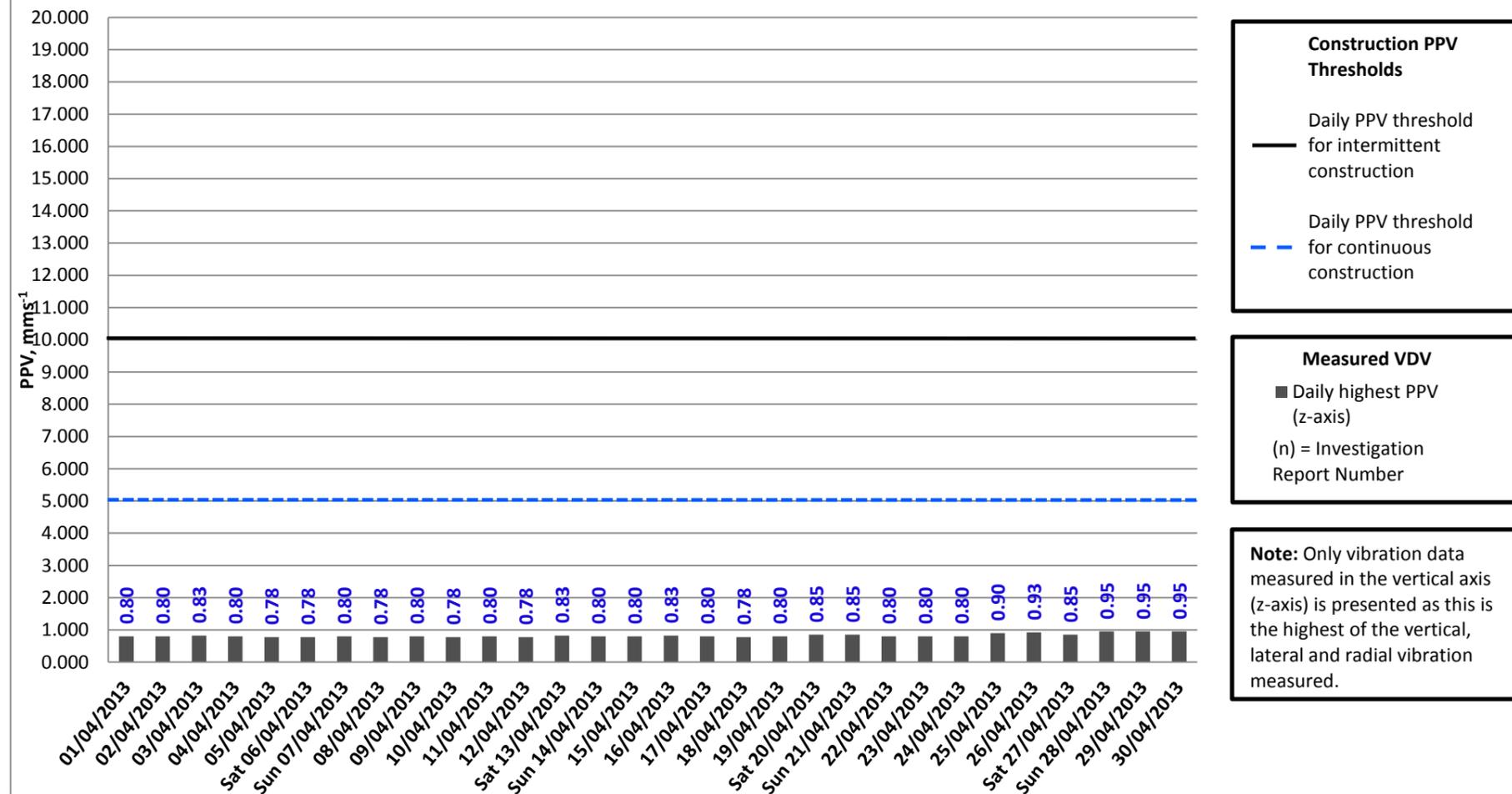
- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sunday.



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 Echline vibration monitor throughout the month of April 2013. This graph is included for illustrative purposes only.

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



Construction PPV Thresholds

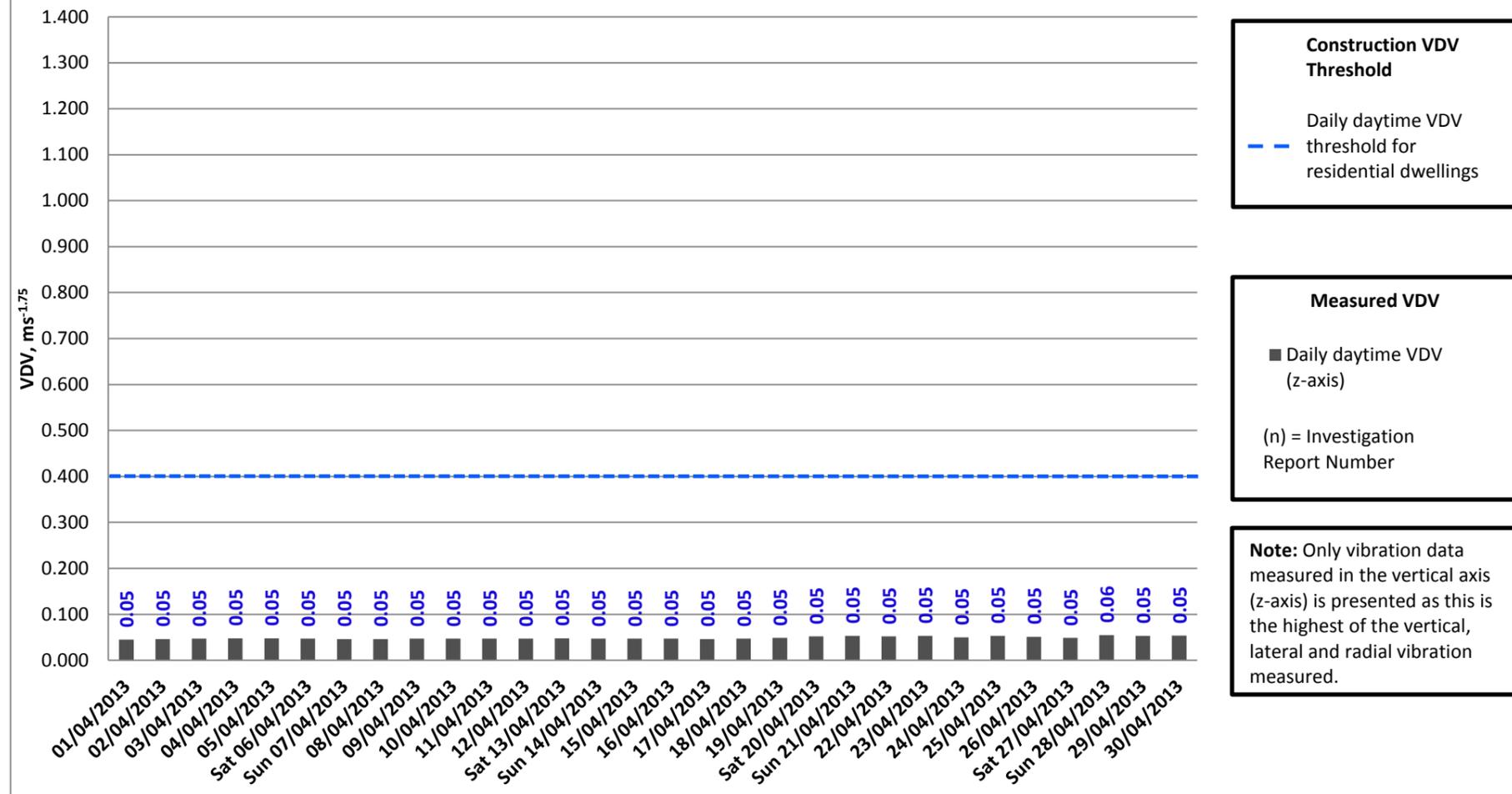
- Daily PPV threshold for intermittent construction
- Daily PPV threshold for continuous construction

Measured VDV

- Daily highest PPV (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 Daytime (07:00-23:00) Vibration Dose Values (VDV), Inchgarvie Lodge,
 Measurement period: April 2013**



Construction VDV Threshold

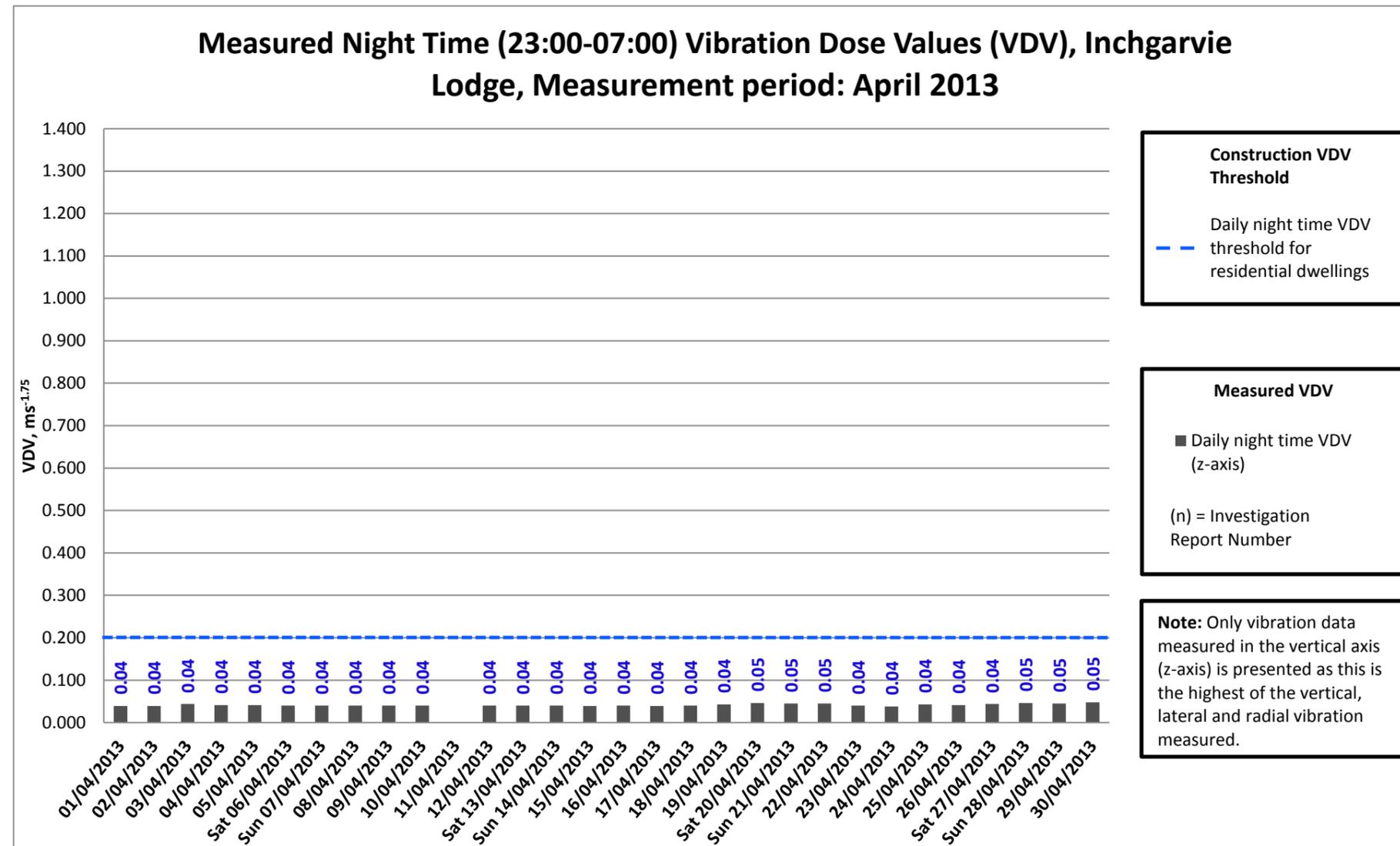
— Daily daytime VDV threshold for residential dwellings

Measured VDV

■ Daily daytime VDV (z-axis)

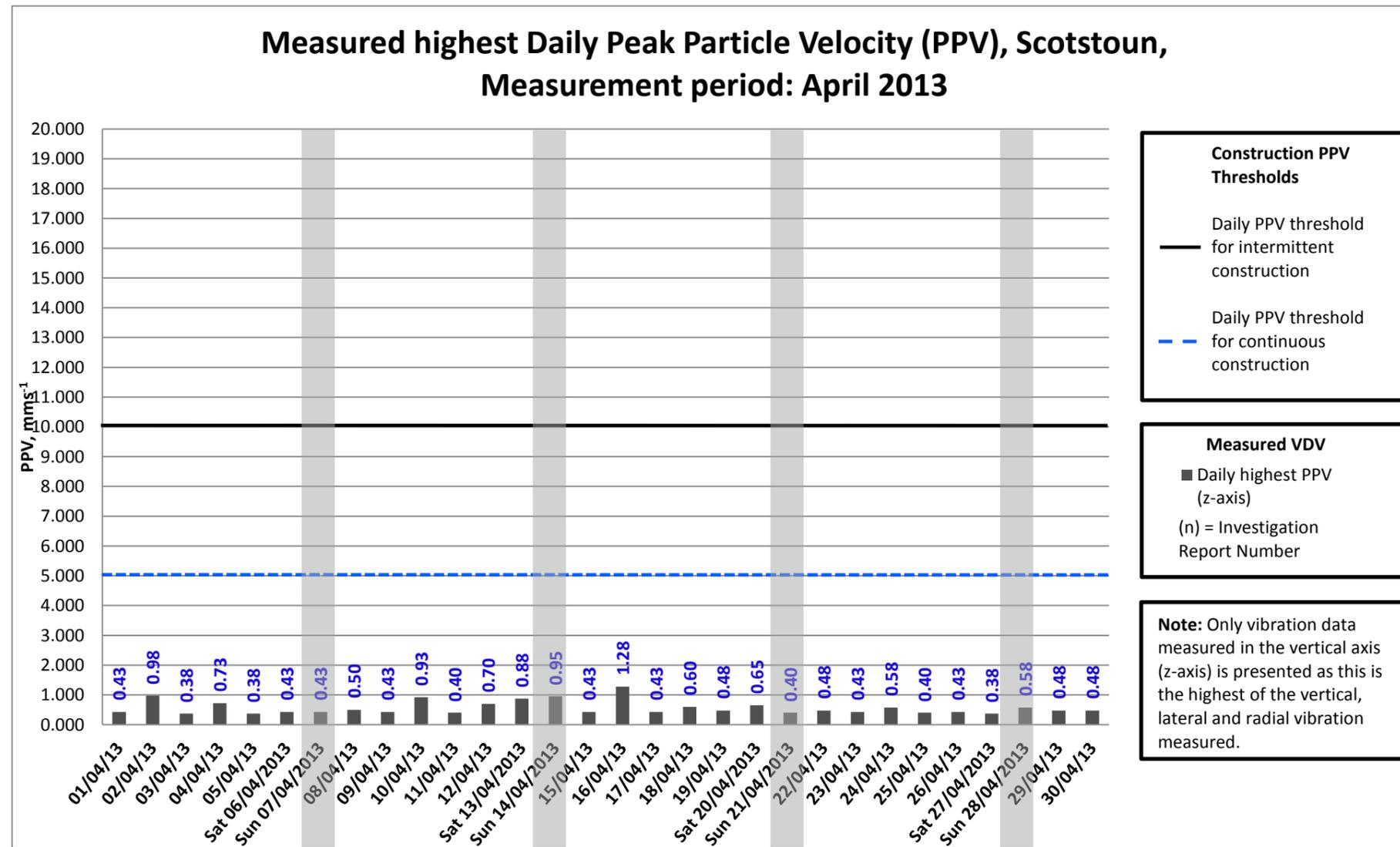
(n) = Investigation Report Number

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.



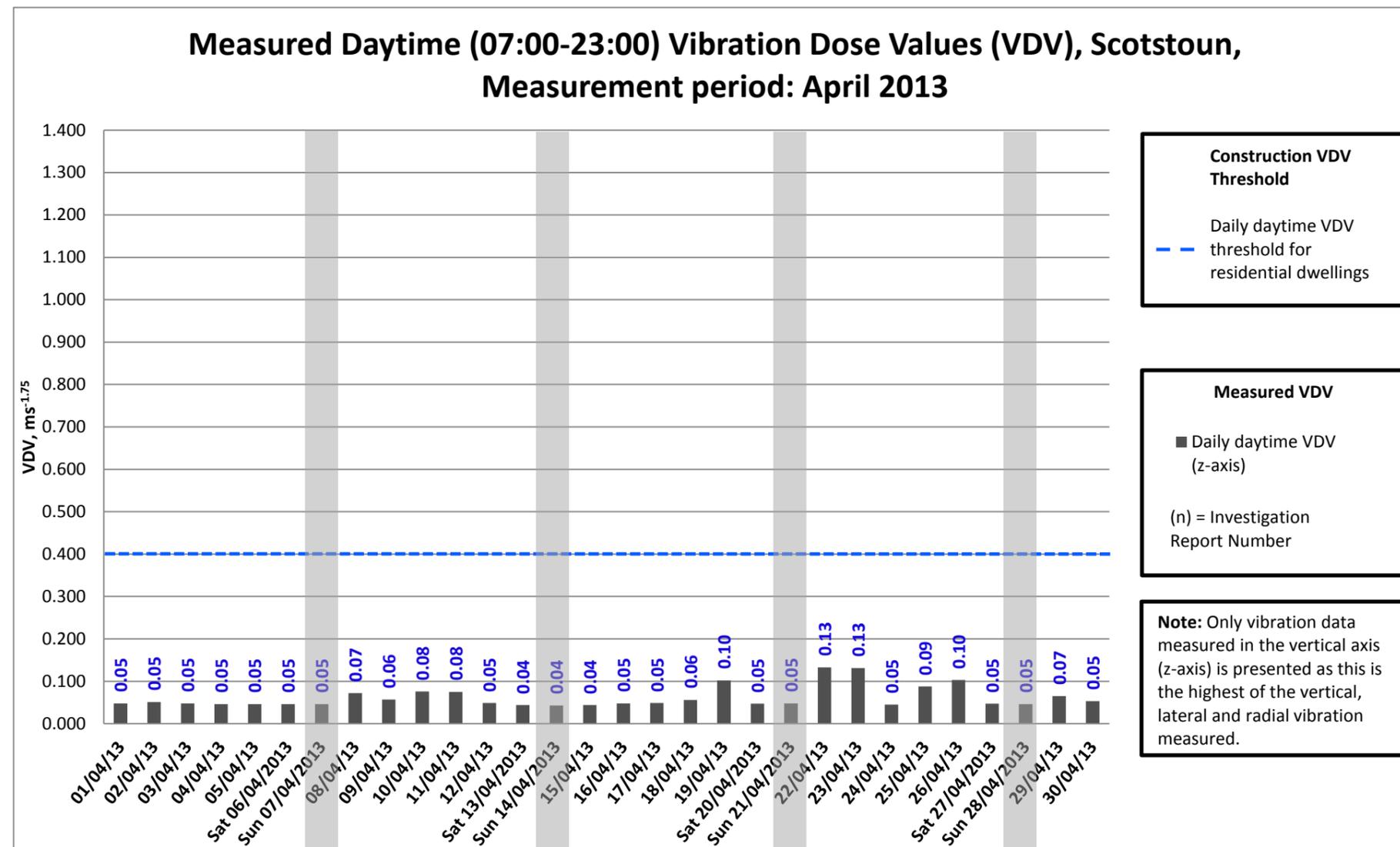
Notes:

- Data is missing from 11/04/13 due to device error.



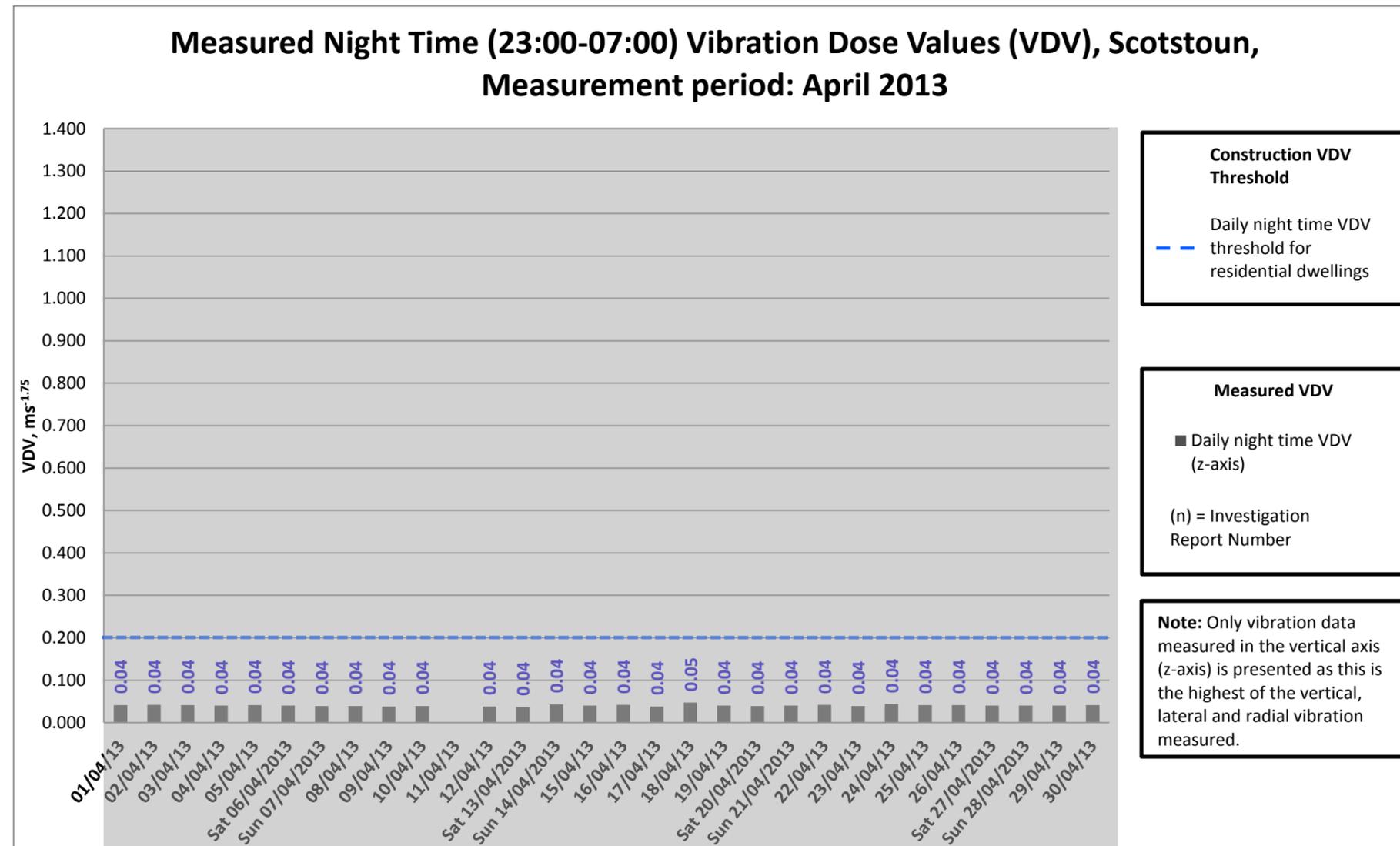
Notes:

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



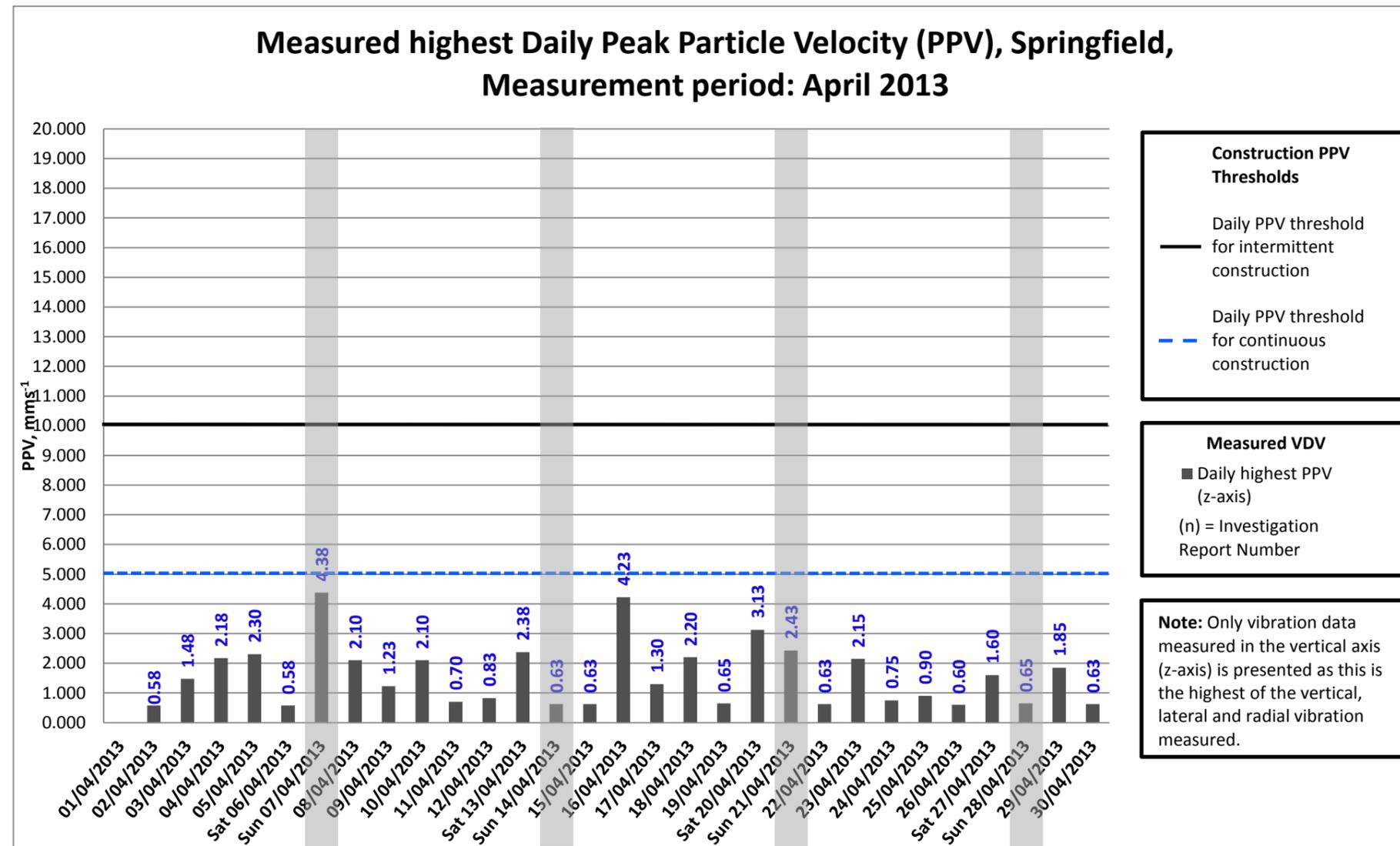
Notes:

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



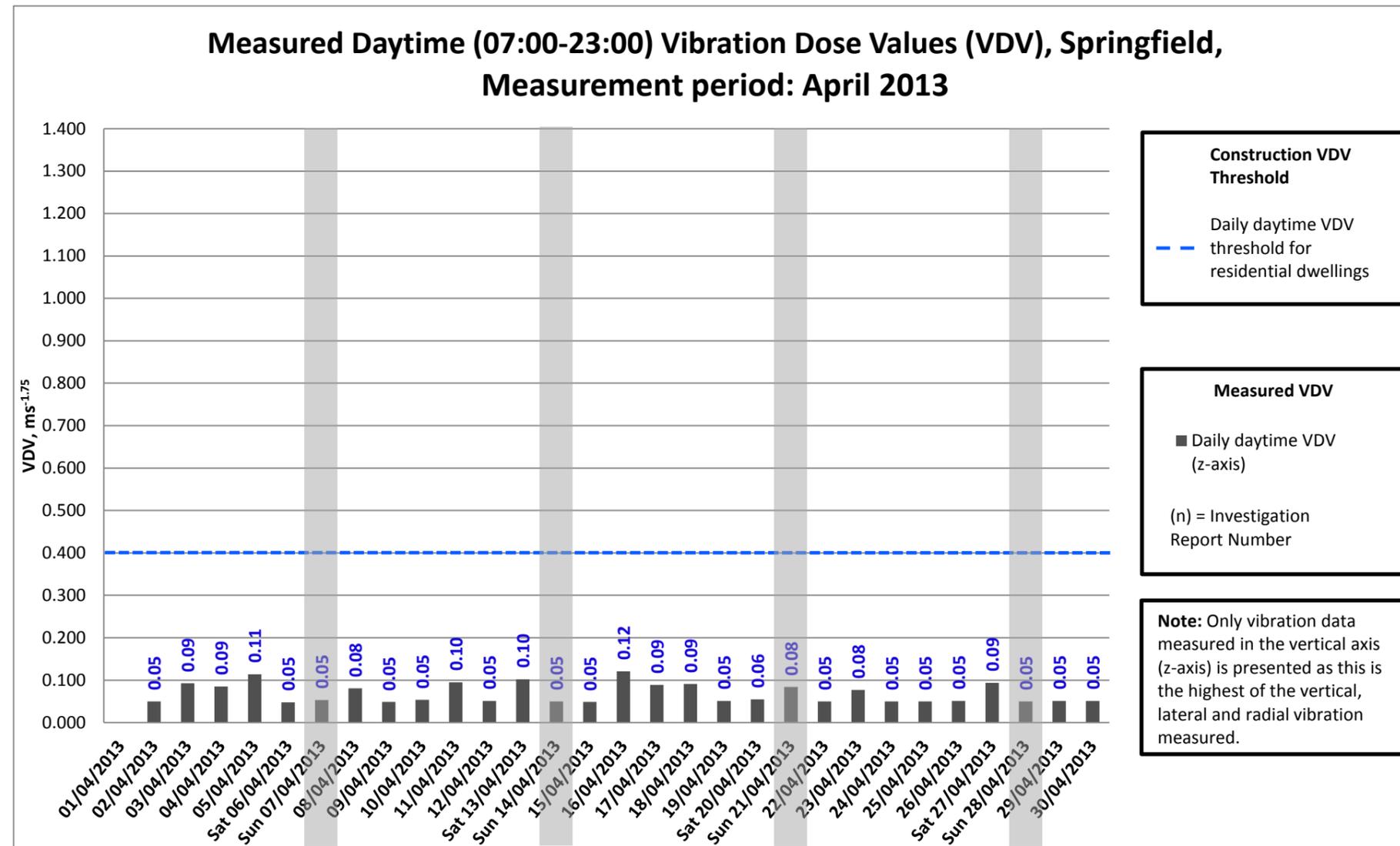
Notes:

- 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 April 2013. This graph is included for illustrative purposes only.



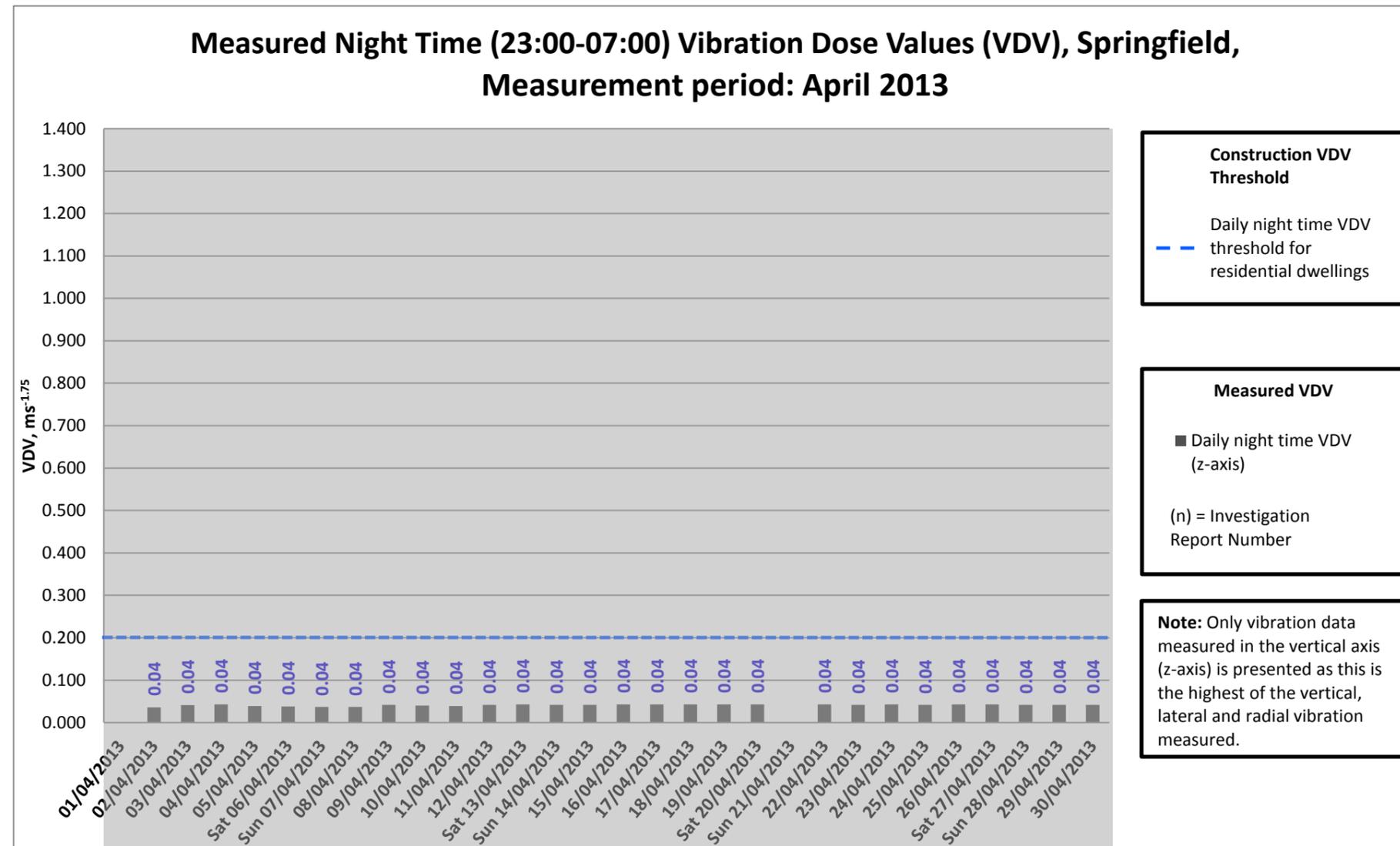
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.
- Data is missing from 01/04/13 due to device error.



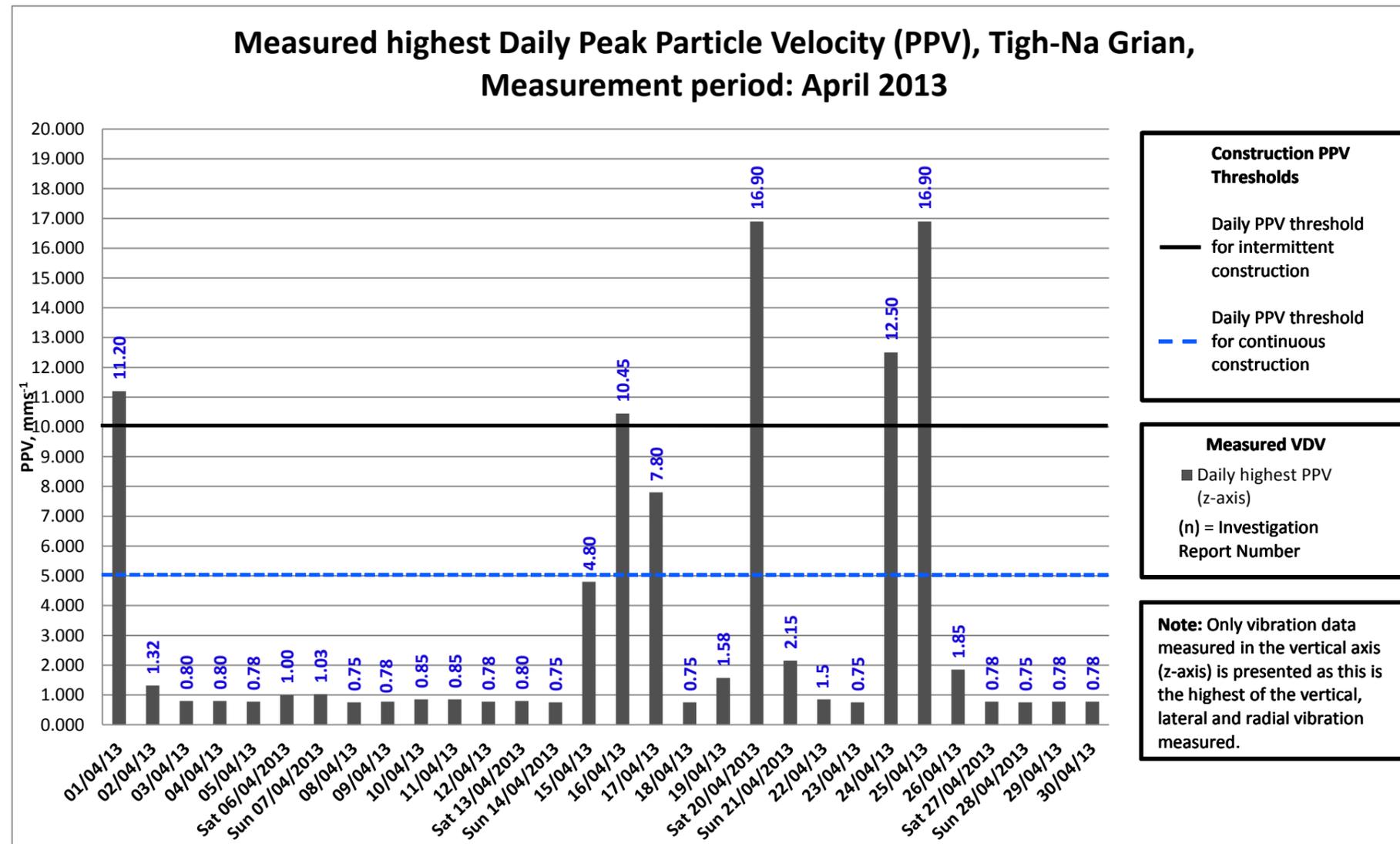
Notes:

- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sunday.
- Data is missing from 01/04/13 due to device error.

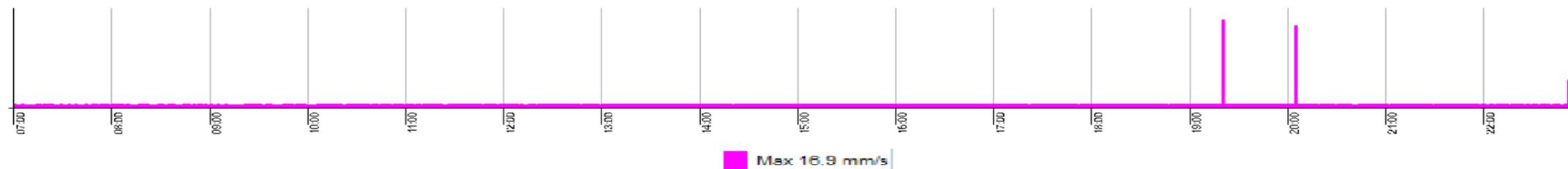


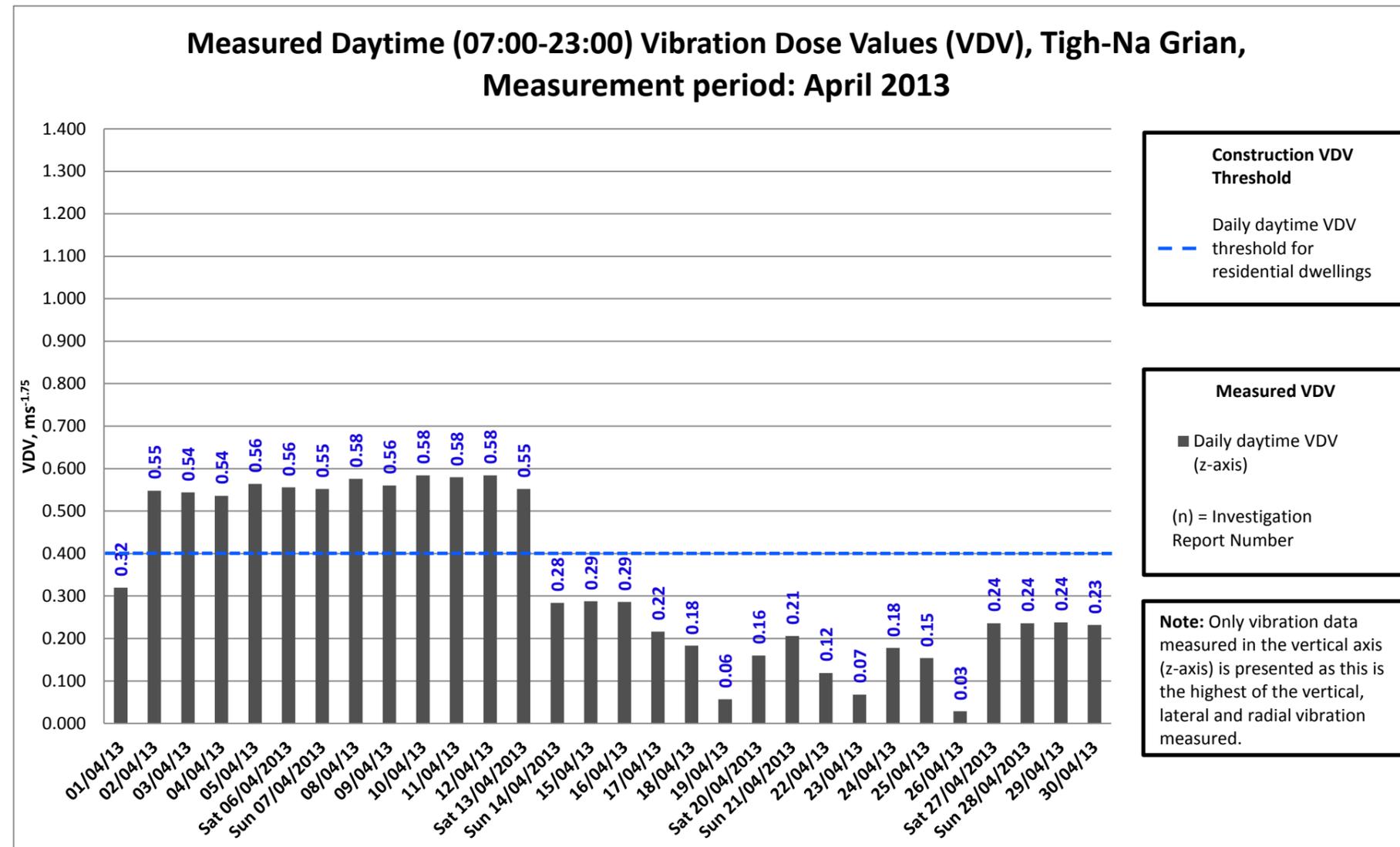
Notes:

- 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 April 2013. This graph is included for illustrative purposes only.

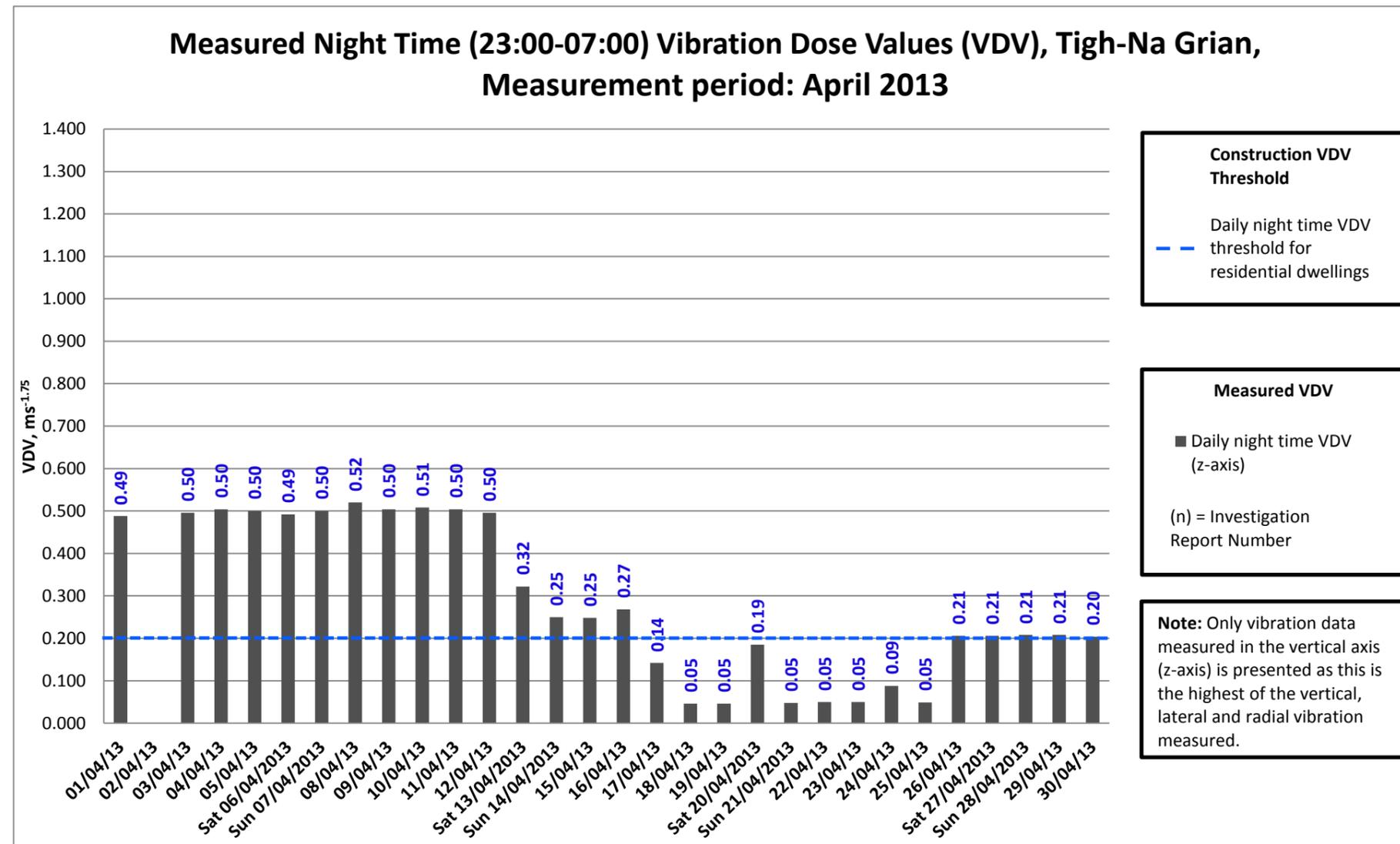


- Notes:**
- The PPV values on 01/04/13, 16/04/13, 17/04/13, 20/04/13, 24/04/13 & 25/04/13 have been investigated, and have been seen to be individual, isolated events within each period (see Vibrock PPV graph below from 20/04/13). Furthermore, these particular levels cannot have been generated as a result of FCBC construction, as the only the works to be conducted throughout the month of April in vicinity of the monitor, were caisson excavation and airlifting preparation works at the North Tower, which is over 250m from the monitor, and did not involve the use of any vibration inducing plant or equipment.



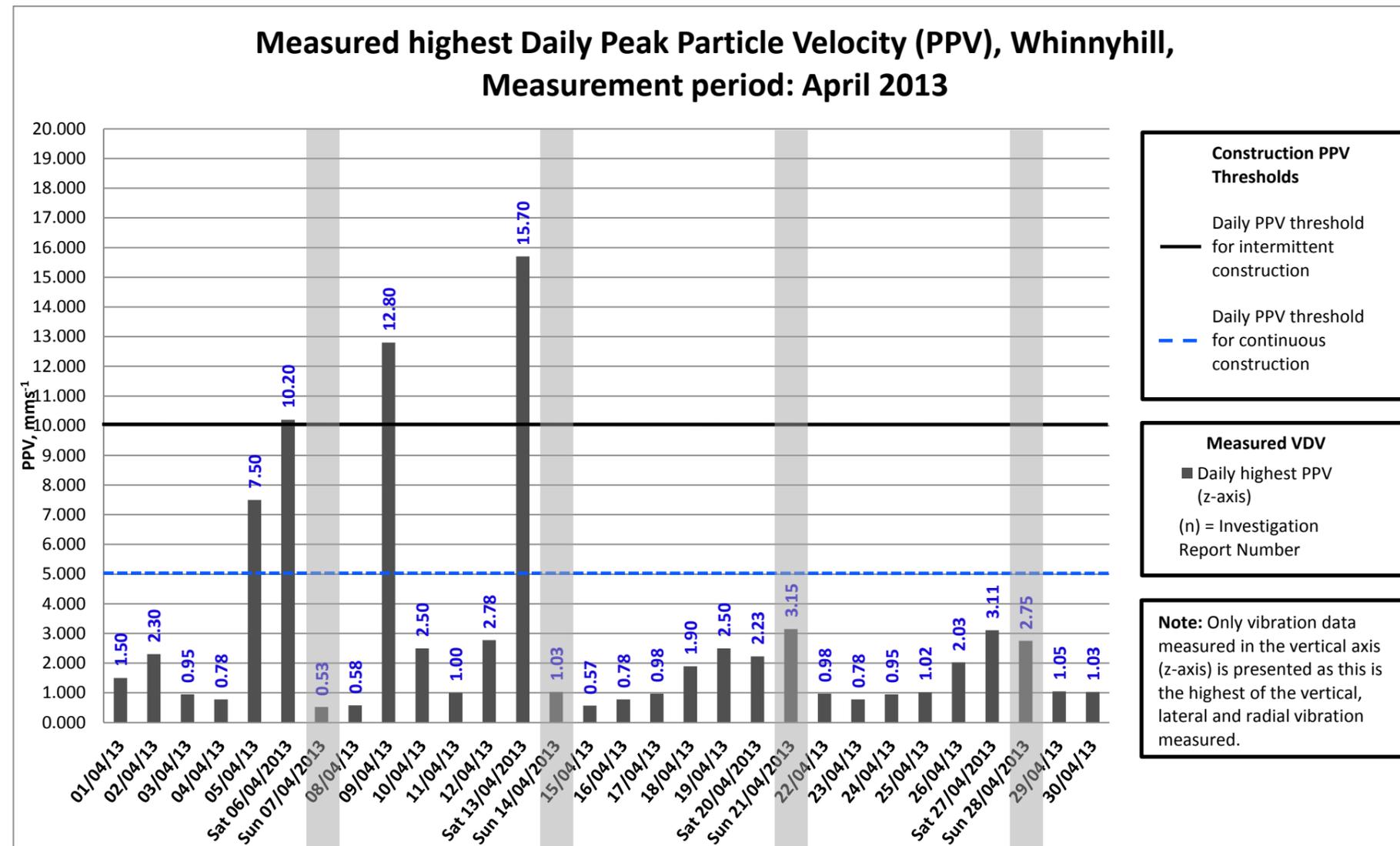


- The VDV exceedances recorded between 02/04/13 & 13/04/13 have been investigated, and cannot have been generated as a result of FCBC construction, as the only the works to be conducted throughout the month of April in vicinity of the monitor, were caisson excavation and airlifting preparation works at the North Tower, which is over 250m from the monitor, and did not involve the use of any vibration inducing plant or equipment.



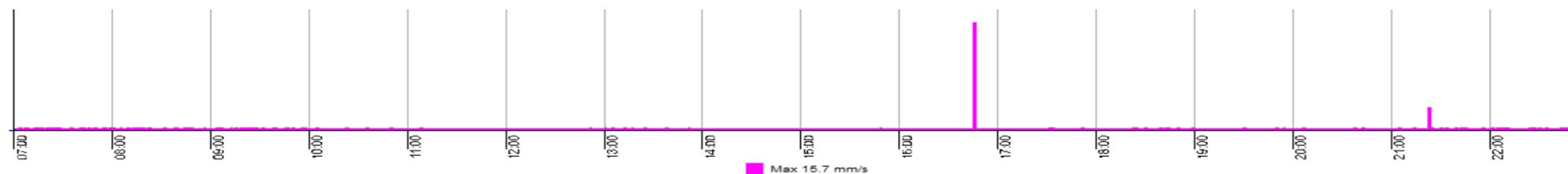
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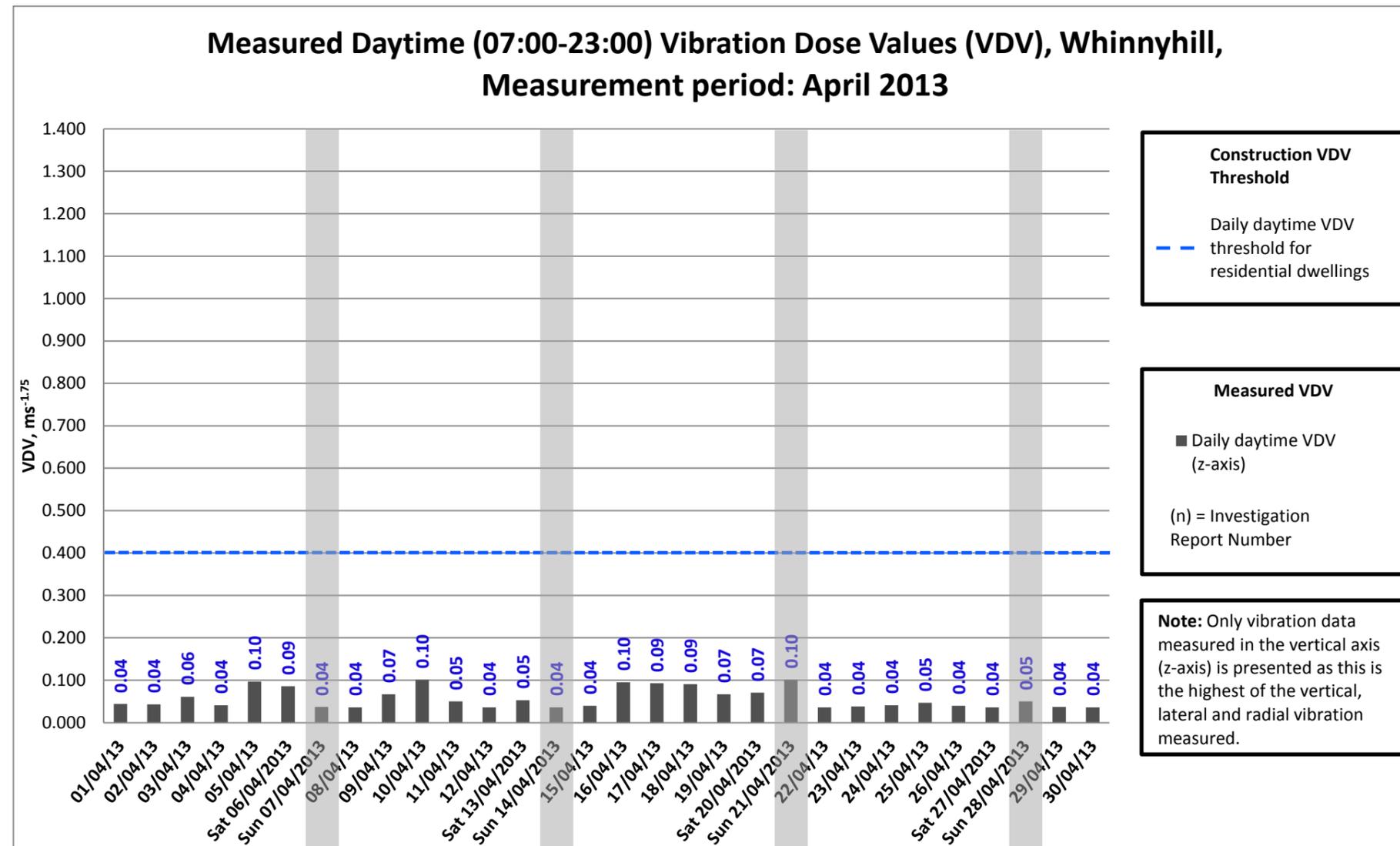
- The VDV exceedances recorded during April 2013 have been investigated, and cannot have been generated as a result of FCBC construction, as the only the works to be conducted throughout the month of April in vicinity of the monitor, were caisson excavation and airlifting preparation works at the North Tower, which is over 250m from the monitor, and did not involve the use of any vibration inducing plant or equipment.



Notes:

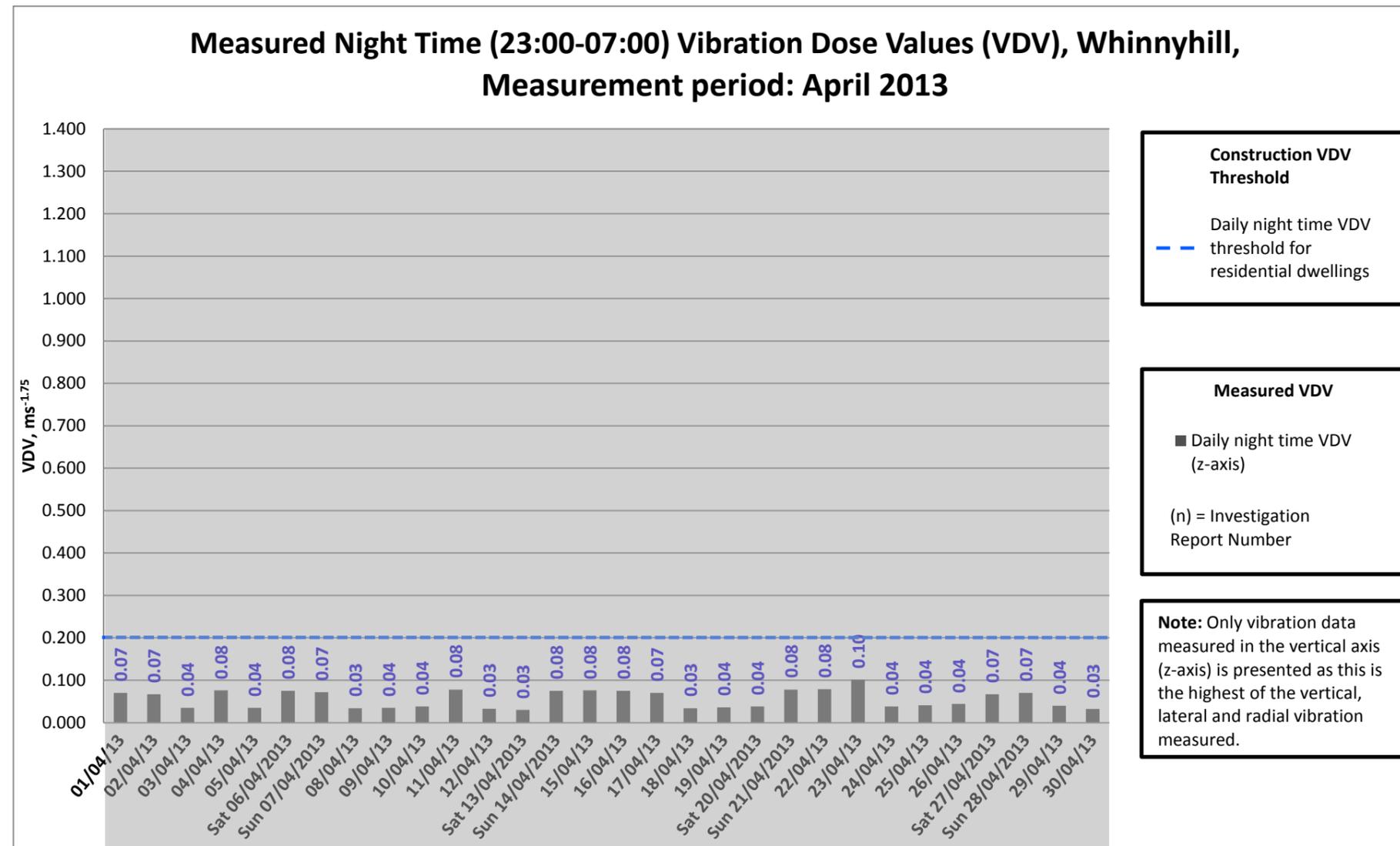
- The grey areas of the chart represent the days on which no construction works were undertaken; no works were conducted on Sundays.
- The PPV values on 05/04/13, 06/04/13, 09/04/13 & 13/04/13 have been investigated, and have been seen to be individual, isolated events within each period (see Vibrock PPV graph below from 13/04/13). Furthermore, these particular levels cannot have been generated as a result of FCBC construction, as the only work to be conducted throughout the month of April in the vicinity of the monitor, was the loading of broken rock at Whinny Hill, which is over 270m from the monitor, and did not involve the use of any vibration inducing plant or equipment.





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 April 2013. This graph is included for illustrative purposes only.