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WHOLE BODY VIBRATION EXPOSURE TO CRANE OPERATOR'S

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by

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Abstract

Whole body vibration (WBV) has been linked to lower back disorders (LBD's). The purpose of this study is to determine whether crane operators are exposed to whole body vibration (WBV). If exposure exists then, do they exceed a current consensus standard. This information will be used to determine whether WBV should become a larger discussion item when purchasing cranes and or rebuilding. This information can also be used to make the case for seat replacement or at the very least a qualification to consider when purchasing replacement seats.

While many studies exist relating WBV to LBD, I could not find information regarding the quantification of the vibration. Is there little vibration? Does it exceed a consensus standard? If it does exceed a consensus standard then it warrants greater attention when rebuilding cranes including their seats as well as purchasing new ones.

Eight different cranes were tested in this study. A variety of manufacturers were tested.

Manufacturer of crane	# of Samples
Link Belt	6
Grove	3
Manitowac	2

Two primary types of cranes were tested, lattice boom crawler type and rough terrain hydraulic.

Style of Crane	# of Samples Collected
Hydraulic, Rough Terrain	5
Lattice Boom, Crawler	6

As a result of this study we find crane operators are exposed to WBV during operations. Two of the Rough terrain cranes and one of the crawler cranes readings exceeded the Action Level set by ISO 2631.1 of 9.1 m/s^2 but none exceed the Exposure Limit Value of 21 m/s^2. Furthermore, When analyzing the vibration data with the exception of one lattice boom crane, the Manitowoc 16000, the Rough terrain hydraulic cranes were significantly higher almost double for the x and y axis than the lattice boom crawler style cranes. The Manitowac may be an anomaly and with such a small data set perhaps more testing should be done to see if it is a crane specific anomaly. All data is presented in Appendices A and B.

Keywords: ergonomics, whole body vibration, WBV, cranes, crane operators

Dedication

I wish to thank my loving wife for supporting me through all my endeavors. Without her support I would not be who I am today.

Acknowledgements

I would like to thank all of the crane operators who put up with a device between their legs or at their feet and accommodating the interruptions'. Also, many thanks to Dillon, one of my summer interns, for collecting many of the vibration readings.

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Whole Body Vibration Exposure to Crane Operators Report

1. Introduction

Operators of heavy equipment are subject to lower back disorders, (LBD's). These LBD's have been linked to whole body vibration (WBV) exposure (Tokisol, 1993). Are vibration levels the same for all equipment operators? At the company studied, there are 26 cranes and 18 operators. All of our crane operators with over ten years' experience, 10 out of 18 state they have or have had a LBD. Also there have been two LBD workers compensation claims in the last four years by crane operators. Could there be a possible link between whole body vibration (WBV) and LBD's? Some studies believe so (Bongers, 1988). In Bongers retrospective 10 year study, crane operators with at least 5 years experience had a risk ratio of three for compared to the control group for disability due to disease of the intervertebral disc. In another study it was found that career vibration exposures was related to low back ,neck and shoulder pain (Pope, 1998).

This study will identify whether or not crane operators are exposed to WBV and if so the magnitude of that vibration. It will also identify which cranes may be of concern. Based on the data collected, the company can then identify whether WBV should be of consideration when updating or purchasing the fleet of cranes it owns.

2. Problem Statement

While many experts agree that equipment operators are subject to lower back disorders, it is unclear the exact cause. As a matter of fact, there can be many causes; some include whole body vibration, awkward postures, static sitting and poor seat design (Kittusamy, 2001). While not listed as a cause in the study aforementioned, many crane operators assist in setting up and assembling their own cranes. Set up can include the use of heavy dunnage used to set crane booms and also used to level the cranes. These tasks in themselves subject an operator to many opportunities for back injury outside of the direct operation as they handle the heavy and bulky equipment and support materials. There are approximately 540,000 operating engineers in the U.S. of which about 10% are crane operators (Kittusamy, 2001). It is generally agreed upon that these operators are subject to WBV and therefore there may be a correlation as indicated in 15 different studies (Paschold, 2011). The problem resides in the fact that while it is agreed that crane operators are subject to WBV, through an extensive lit review, a study was not found to quantify exposure dose and the incidence of LBP among crane operations. Hence, the purpose of this study is to quantify the vibration exposure to operators of cranes. By quantifying the vibration exposure, we can better ascertain whether WBV should be a primary consideration when purchasing, repairing and or maintaining cranes.

As the company purchases new cranes, rebuilds the old ones and replace components like seats, there are many ergonomic based criteria to consider but one in particular is the operators’ exposure to WBV. The question I seek to answer in this project is; are crane operators being subject to WBV at levels of significance and therefore need to play a major factor in purchase of new cranes and the remodeling of old?

3. Background

Equipment Operators have a high rate of low back disorders. There are many known causes to these injuries, like jarring as studied by National Institute of Occupational Safety and Health (NIOSH) in the mines of West Virginia. Many of these operators with lower back disorders are also exposed to whole body vibration. Therefore WBV is suspected by many to be a culprit to LBD's (Paschold, 2011). ANSI S3 indicates that frequencies between 0.5 and 80 Hz are of consequence to WBV (ANSI, 2002). WBV is measured as a certain distance from zero in a period of time. As vibration goes back and forth, approximately the same distance a raw measurement would average out to zero. As such, vibration is measured as the root-mean-square (RMS) of the vibration acceleration (m/s2) and is found by calculating the square root of the arithmetic mean of the squares of the individual vibration wave values (Paschold, 2011). Another measurement utilized in the ANSI standard is vibration dose value ,VDV. This measurement takes into account the RMS over some period of time. It also weights the highs and lows to reflect jarring motions that can have been shown to cause injury (Helmut Paschold, 2011) (ANSI, 2002).

While many studies have been performed linking WBV to LBD's and a portion of those studies have measured the WBV for operators, none found involved the actual measurement of crane operators.

Our company in particular has had two workers compensation cases in the last four years by crane operators with lower back disorders. Also, ten out of the eighteen crane operators say they have experienced some form of LBD. The purpose of this study is to find out whether or not crane operators are subject to WBV. If so, at what level? Lastly, this information can then be used to determine the importance vibration should play as a risk factor when determining ergonmomic assessments for cranes and their operators.

4. Literature Review

What is known about Whole Body Vibration, WBV, can perhaps be broken into three cate categories. WBV's links to low back disorders, the vibration frequency of concern for WBV and the relationship of WBV regarding crane operators.

Lower Back Disorders

WBV has been linked to LBD by many studies; fifteen to be exact according to one NIOSH review (Paschold, 2011). These studies have covered many industries to include heavy construction, forklift operations, vehicle operators, professional drivers, farmers and mining operators. They have also have taken place around the world in countries; Belgium, Germany, Netherlands, France, Canada and Australia. These studies all support a strong correlation between WBV and lower back disorders. While a dose response relationship has not yet been established, ample evidence that WBV is a contributor to LBP, exists.

Frequency

The frequency of concern for whole body vibration is 0.5 to 80 Hz (ANSI, 2002). Depending on the part of the body we are concerned with the range of frequency can be a subset of the overall range. As an example the range of frequency of concern for hand-arm vibration (HAV) is 5 to 1500 Hz (Paschold, 2011). The lower back appears to be most sensitive to the range of 2 – 10 Hz according to one study (Limerick, 2015).

In this study we will look for vibration throughout the range of concern but we will give more relevance to ranges between the 2-10 Hz range. These ranges are illustrated in the chart following, Chart 1.

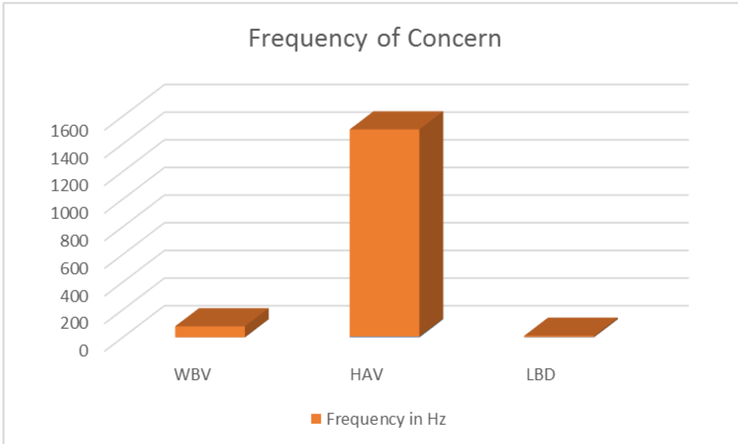


Chart 1: Frequency Ranges of Concern by Body Part

WBV for Crane Operators

While a number of studies regarding equipment operators exist, a study identifying the vibration measurements of cranes was not found. As mentioned before, approximately 10% of the operators in the US are crane operators (Kittusamy, 2001). Among operators the most frequent musculoskeletal symptom was low back pain, 60%. It was also the most cited cause of a physician's visit at 25% (Kittusamy, 2001). The particular group at greatest risk appears to be the earthwork workers (Kittusamy, 2001). Having read a number of these studies one might conclude that they are exposed to a great deal of jarring during their operation and therefore at greater risk (Chambers, 2001). This study will determine if crane operators are exposed to vibration at ranges of concern.

5. Research Design and Methods

In order to ascertain whether crane operators are being exposed to WBV at frequencies of concern, we decided to test them. We first needed to decide on the instrument of choice and then secondly on the cranes to be tested.

Instrument of Measurement

A number of instruments are currently available to measure vibration. These include the more traditional devices like the CEL-960 Human Vibration Dosimeter by Casella and the HVM100 Human Vibration Meter by Larson Davis. However, more recently the University of Queensland received a grant funded by the Australian Coal Association research Program. This grant funded the development of an application for smart phones to measure whole body vibration. The app, WBV, can be downloaded from the Apple App Store for free. In particular the intent is to develop an app for measuring mining equipment for vibration exposure for operators as part of a whole body vibration management plan (Limerick, 2015). Currently OSHA does not have a standard and the ISO standard is one referenced for use by ACGIH as a TLV, in particular ISO 2631 "Evaluation of Human Exposure to Whole Body Vibration" (ACGIH, 2001). The smartphone app, WBV, is built to collect data and compare it against the ISO 2631.1 standard (Limerick, 2015). The Whole Body Vibration app , WBV, is still in testing mode but has shown 95% accuracy when compared to "gold" standard (Limerick, 2015). The test comparison data has been provided as an attachment, Attachment 1 Technical Manual for WBV, for reference.

It was agreed that we would collect as many samples as we could without too much interference. The WBV application installed on an I-phone 5 based on the ISO 2631.1 standard was utilized in accordance with the directions as attached in Attachment 2 User's Manual. The floor tests were done at the base of the seats of the cranes. The I-phone was placed per figure 1, on the floor at the base of the center of the seat. Seat tests were conducted between the operator's legs while seated in the crane, in alignment with figure 1 alignment. The collection of data was primarily done with cranes working on a wind farm site over the course of a month. All of the cranes at the wind site were sitting on earthen crane pads. In most cases this consisted of blasted rock. The rough terrain hydraulic cranes were all supported by the outriggers in the fully extended position. The outriggers rested on outrigger pads on the ground. The two Linkbelt 418 and 518 cranes were tested at a bridge construction site. Both cranes were crawler type and sitting directly on wood mats set atop a temporary trestle.

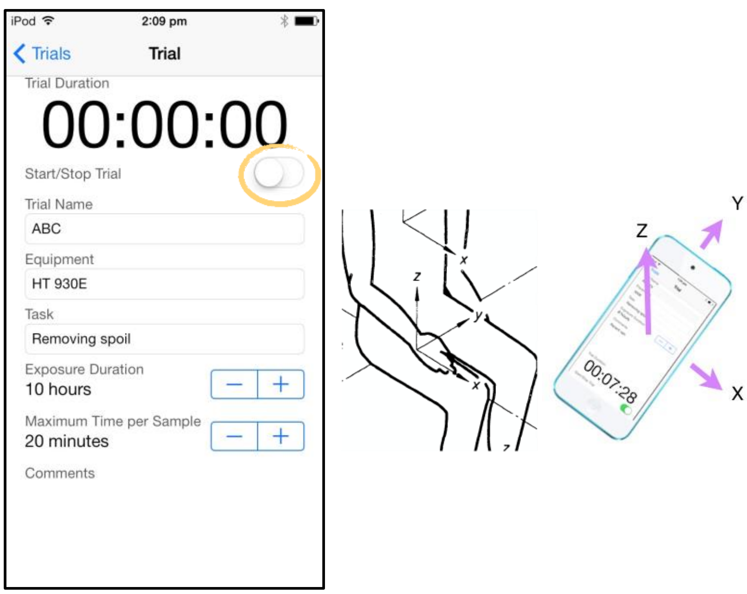


Figure 1: x, y and z axis and proper alignment for testing

Eight floor samples were collected; one from each crane and three seat samples were collected. Five of the floor samples were collected from lattice boom cranes that sit on crawler type chassis similar to Picture 1.These chassis sit directly on the ground. One seat sample was also collected from a lattice boom crawler style crane. Three floor samples were collected from rough terrain hydraulic style cranes similar to Picture 2. These cranes were tested while the cranes were leveled with outriggers and sitting on outrigger pads but no dunnage. Two seat samples were also collected on rough terrain hydraulic style cranes. Crane identification, sample collection dates and sample times are reflected in Table 1 below.

Picture 1: Manitowac 16000 (Manitowac, 2015)

Picture 2: Linkbelt RTC 8050 (LinkBelt Cranes, 2015)

Table 1

Trial name, Crane, Owner, Location	Trial Start	Trial Duration
Grove 890, Irving Deep South	7/14/2015 9:37	0h 38m 16s
Grove 890, Irving, South	6/17/2015 15:49	0h 29m 48s
Link Belt 8050, Irving, East	6/12/2015 10:23	0h 39m 46s
Manitowac 2250, Irving Cr253, South	6/17/2015 16:46	0h 37m 14s
Link Belt 138, Irving, North	6/17/2015 7:45	0h 54m 55s
Link Belt 418,Reed, Howland	7/13/2015 10:33	0h 25m 33s
Link Belt LS 518, Reed, Howland	7/13/2015 13:17	0h 40m 34s
Manitowac 16000, Lomma, East	6/11/2015 7:25	0h 40m 2s
Link Belt 138, Irving, North	6/17/2015 8:43	0h 31m 29s
Grove 890, Irving, South	6/17/2015 16:20	0h 21m 57s
Link Belt 8050, Irving,East	6/12/2015 11:03	0h 45m 25s

6. Results

Measurements taken to ascertain whether crane operators are exposed to WBV are varied. Eight different cranes were tested in this study. Mostly, the levels are within the safe range when utilizing the smart phone app, WBV as based on the ISO 2631.1 standard. There are a couple results that are in the caution zone. However none were in the danger zone when looking at the RMS and VDV data when compared to ISO 2631.1. Raw data of those tests are provided in Appendix A and full results are provided in Attachment 3. A compilation of the graphs is shown in Appendix B.

Sample times ranged from 21 minutes 57 seconds to 54 minutes 55 seconds with the average sample time being 33 minutes 32seconds.

Root mean squared (RMS) values for the x axis ranged from .01 to .13 on the floor for rough terrain cranes and .01 to .10 for lattice boom crawler style cranes. RMS values for the y axis ranged from .02 to .14 on the floor for rough terrain cranes and .01 to .10 for lattice boom crawler style cranes. Root mean squared (RMS) values for the z axis ranged from .05 m/s^2 to .16 m/s^2 on the floor for rough terrain cranes and .03 m/s^2 to .17m/s^2 for lattice boom crawler style cranes. None of these values exceed the Action Level of 0.5 m/s^2 let alone the Exposure Limit Value of 1.15 m/s^2 as set by the ISO2631.1 or AS2670.1. See Figure 1 below for reference to the axis of measurement.

Vibration dose values (VDV) weighted for an 8 hour average are as follows. VDV values for the x axis ranged from 0.84 $m/s^{1.75}$ to 9.48 $m/s^{1.75}$ for the floor measurements on the rough terrain cranes and 0.28 to 7.24 $m/s^{1.75}$ for lattice boom crawler style cranes. VDV values for the y axis ranged from 2.68 to 9.27 $m/s^{1.75}$ for the floor measurements on the rough terrain cranes and 0.21 to 7.58 $m/s^{1.75}$ for lattice boom crawler style cranes. VDV values for the z axis ranged from

8.82 to 10.84 m/s$^{1.75}$ for the floor measurements on the rough terrain cranes and 1.51 to 16.44 m/s$^{1.75}$ for lattice boom crawler style cranes. Two of the Rough terrain cranes and one of the crawler cranes readings exceeded the Action Level set by ISO 2631.1 of 9.1 m/s^2 but none exceed the Exposure Limit Value of 21 m/s^2.

Only one seat for a lattice boom crawler style crane was measured. Seat readings were similar to floor readings for this crane. The RMS value for the x axis was .01, y axis was .01 and the z axis was .12 m/s^2. Two rough terrain hydraulic crane seat readings were taken. On the Grove 890 rough terrain hydraulic style crane we saw the x and z RMS values for the seat dampened when compared to floor measurements. These tests were taken one following the other and not at the same time however the same task was being performed. The Link belt 8050 saw measurements in the other direction where the seat measurements were slightly amplified from the floor measurements. VDV levels therefore are reflective of those results.

When analyzing the data with the exception of one lattice boom crane, the Manitowoc 16000 the Rough terrain hydraulic cranes were significantly higher almost double for the x and y axis than the lattice boom crawler style cranes. The Manitowac may be an anomaly and with such a small data set perhaps more testing should be done to see if it is a crane specific anomaly. All data is presented in Appendices A and B.

7. Discussion, Conclusion, Recommendations for Further research

7.1. Discussion

An I-phone 5 was used in this study with a WBV app. It is possible that different phones and different models may have different results. Also as accelerator technology changes in smart phones their effectiveness of measurement may change.

Also all of the cranes measured were performing heavy timely picks rather than shorter duration light load lifts. This could influence vibration measurements.

7.2. Conclusion

Crane operators are exposed to WBV during operations. However, while some level exceeded the Action level as set by the ANSI standard regarding vibration none exceeded the Exposure Limit Values, ELV's.

Based on this information, WBV should be considered in the crane management program. In particular, WBV needs to be considered when replacing seats and identifying the specifications of new cranes.

7.3. Recommendations

Further research is needed for activities where jarring or greater impacts may be felt. I suspect these would occur during pile driving and demolition operations where the use of hammers and drop ball type attachments are used. Also, no tests were conducted while cranes were traveling. Typically the crawler type cranes rarely move, however the rough terrain style cranes may move numerous times on projects. Travel path conditions and duration of travel may place an operator at some level of risk to WBV. As presented, all measurements done as a result of this research were done during normal lifting operations while the crane remained stationary. Also, more seat tests need to be conducted as it is possible that seats may amplify vibration.

8. References

ANSI S3.18:2002. (2002). *Guide for the evaluation of human exposure to whole body vibration.* New York: ANSI.

Bongers, B. H. (1988). *National Institute of Health.* Retrieved from Back Disorders in crane operators exposed to whole body vibration: http://www.ncbi.nih.gov/pubmed/2964414

Chambers, D. K. (2001). *Whole Body Vibration and Low Back Pain.* British Columbia: Workers Compensation Board of British Columbia.

Paschold, H, & Mayton, A.G. (2011, April). Whole Body Vibration, Building Awareness in SH&E. *Professional Safety*, pp. 30-35.

Limerick, R. B. (2015, August 12). *UQ Ergonomics*. Retrieved from University of Queensland Ergonomics: http://ergonomics.uq.edu.au/

Kittusamy, N. Kumar B. B. (2001). *Whole-body vibration and postural stress among operators of construction equipment.* Spokane, WA and Lowell, MA: NIOSH and Construction Occupational Health Project.

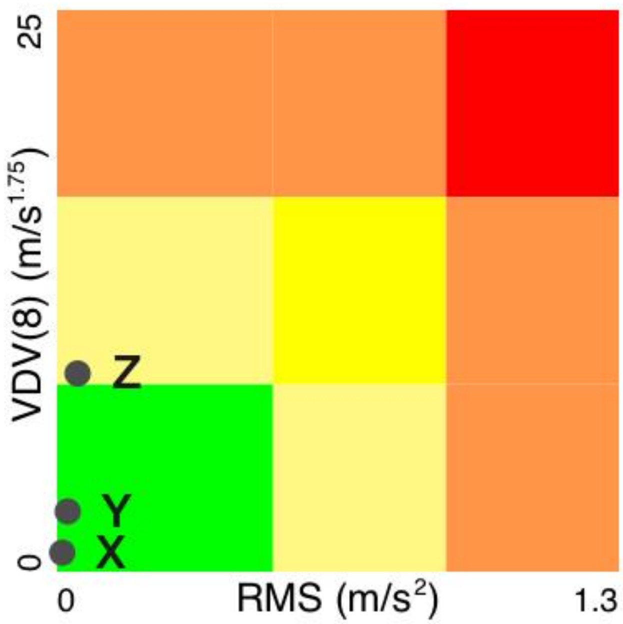
Tokisol, A. H. (1993, September). *National Institute of Health.* Retrieved from The effect of whole body vibration: an unrecognized medical probelm: http://www.ncbi.nlm.nih.gov/pubmed/8311700

Appendix A: Spreadsheet of Raw Data

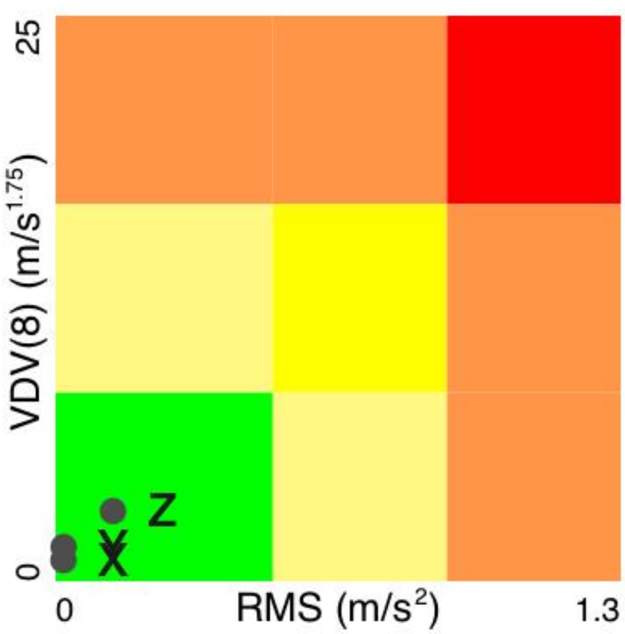
Trial name, Crane, Owner, Location	RMS X	RMS Y	RMS Z	VDV X	VDV Y	VDV Z	VDV(h) X	VDV(h) Y	VDV(h) Z	Equipment	Sample Location
Grove 890, Irving Deep South	0.01	0.02	0.05	0.45	1.42	4.68	0.84	2.68	8.82	Rough Terrain Hydraulic Crane	Floor
Link Belt LS 518, Reed, Howland	0.02	0.02	0.13	0.5	0.81	1.67	0.93	1.51	3.1	Lattice Boom Crawler Crane	Floor
Link Belt 418,Reed, Howland	0.02	0.01	0.11	0.27	0.68	1.75	0.57	1.42	3.66	Lattice Boom Crawler Crane	Floor
Grove 890, Irving, South	0.11	0.11	0.16	3.44	4.04	5.4	6.91	8.11	10.84	Rough Terrain Hydraulic Crane	Floor
Link Belt 138, Irving, North	0.02	0.01	0.03	1.05	0.46	1.49	1.8	0.79	2.56	Lattice Boom Crawler Crane	Floor
Link Belt 138, Irving, North	0.01	0.01	0.12	0.19	0.09	1.01	0.37	0.18	2	Lattice Boom Crawler Crane	Seat
Manitowac 2250, Irving Cr253, South	0.01	0.01	0.03	0.15	0.11	0.79	0.28	0.21	1.51	Lattice Boom Crawler Crane	Floor
Grove 890, Irving, South	0.02	0.02	0.11	0.13	0.15	0.8	0.27	0.33	1.75	Rough Terrain Hydraulic Crane	Seat
Link Belt 8050, Irving, East	0.13	0.14	0.14	5.08	4.97	5.37	9.48	9.27	10.04	Rough Terrain Hydraulic Crane	Floor
Link Belt 8050, Irving,East	0.16	0.11	0.19	6.76	5.04	8.89	12.22	9.1	16.06	Rough Terrain Hydraulic Crane	Seat
Manitowac 16000, Lomma, East	0.1	0.1	0.17	3.88	4.07	8.82	7.24	7.58	16.44	Lattice Boom Crawler Crane	Floor

Appendix B: Graphs of Vibration Analysis

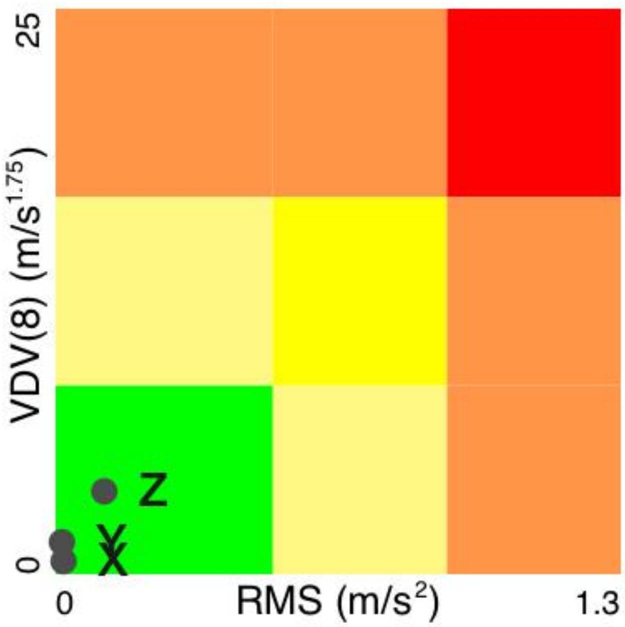
Grove 890, Irving, Deep South



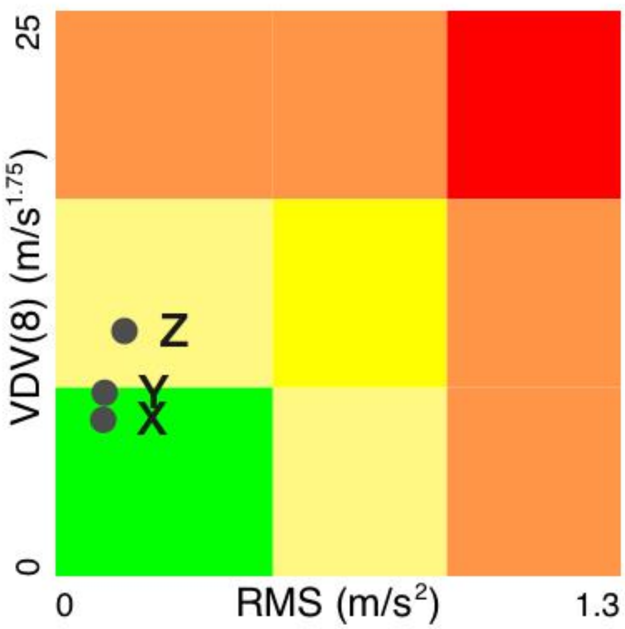
Link Belt LS 518, Reed, Howland



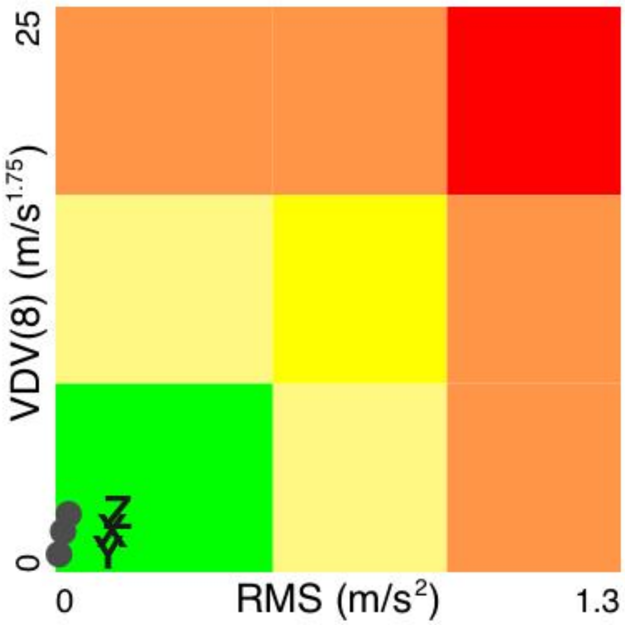
Link Belt 418, Reed, Howland



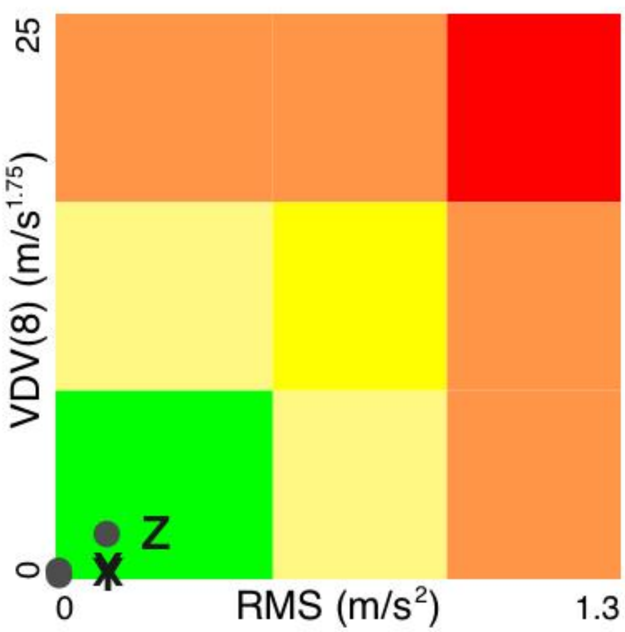
Grove 890 Irving, South



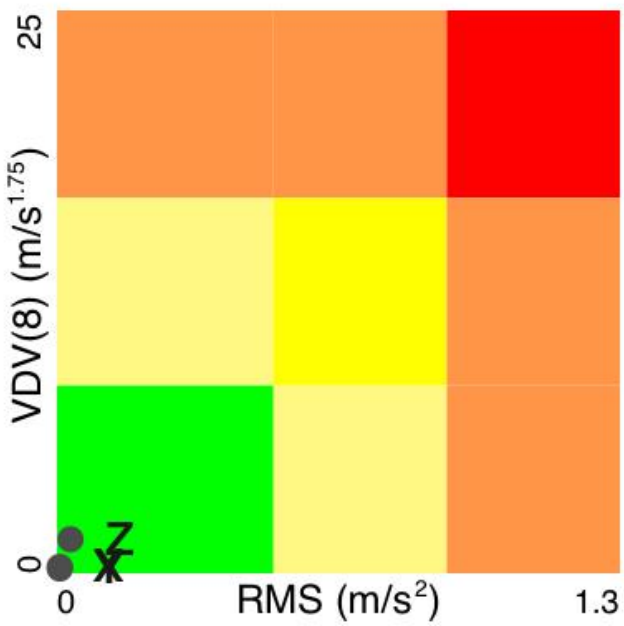
Linkbelt 138 Irving, North



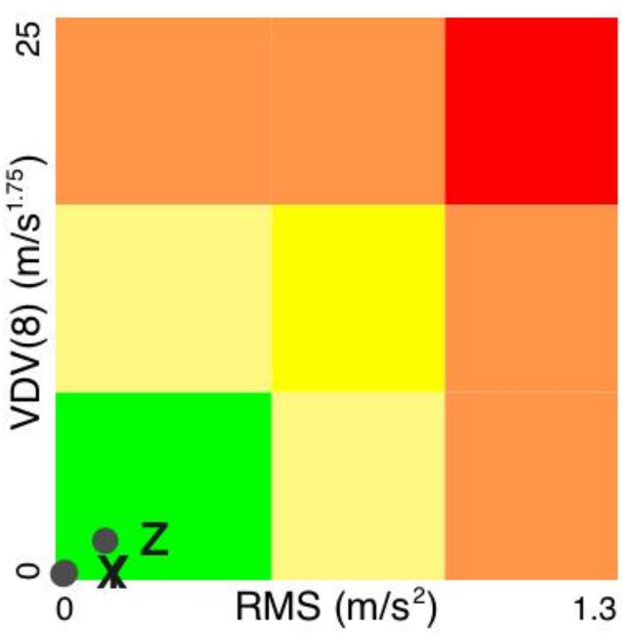
Linkbelt 138, Irving, North



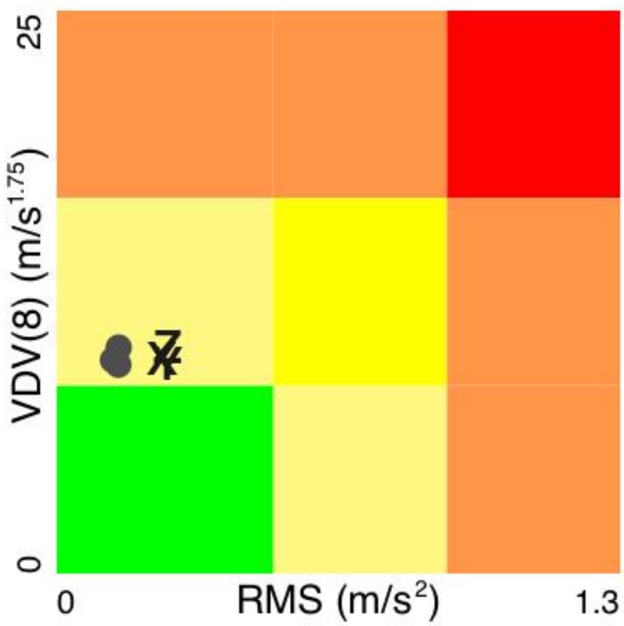
Manitowac 2250, Irving, South



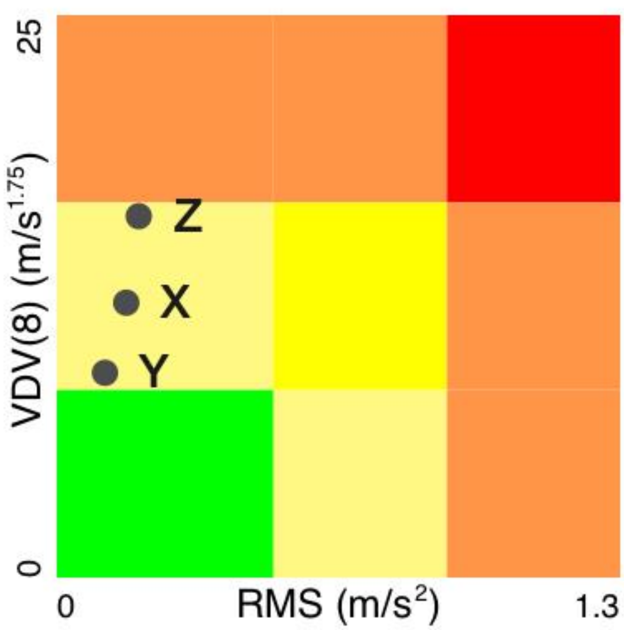
Grove 890 Irving South, Seat



Linkbelt 8050, Irving, East



Linkbelt 8050 Irving, East



Manitowac 16000, Lomma, East, Floor