

EXTRACTING MORE INFORMATION FROM FIELD DATA

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Example of ASTM d4169-14 Truck Level 2, amplitude vs. frequency vs. cycle, spreadsheet format

	A	B	C	D	E	F	G	H	I	J	K	L	M
▼ 20	Edges (G):	Upper Frequency (hz):	3	5	7	9	11	13	15	17	19	21	23
21		Lower Frequency (hz):	1	3	5	7	9	11	13	15	17	19	21
60	-1.2		0	0	0	0	0	0	0	0	0	0	0
61	-1.1		0	0	0	0	0	0	0	0	0	0	22
62	-1		0	0	0	0	0	0	0	0	0	22	44
63	-0.9		0	0	0	0	0	0	0	0	0	22	87
64	-0.8		0	0	0	22	0	11	33	120	273	382	447
65	-0.700		0	0	22	131	218	174	523	730	1188	1548	1635
66	-0.600		0	22	218	436	1112	1591	1951	2660	4044	5123	6278
67	-0.500		0	153	1341	2529	3848	5548	6823	9102	11325	13145	15042
68	-0.4		0	1472	4970	7892	11020	14137	16699	20383	24307	28057	29931
69	-0.3		0	6584	12829	16644	20928	25026	28918	32929	36537	40984	44821
70	-0.2		523	13843	15805	20198	24536	27392	31392	33964	36439	38641	41769
71	-0.1		0	0	0	0	0	0	0	0	0	0	0
72	0		0	0	0	0	0	0	0	0	0	0	0
73	0.1		567	13723	16459	20067	24078	27010	31457	33670	36591	38248	42586
74	0.2		0	6431	12317	16775	21353	25430	28929	32973	37180	41780	44439
75	0.3		0	1493	5123	7804	10747	14235	16470	20361	23849	28089	29703
76	0.4		0	174	1330	2507	3728	5396	7183	9254	11260	12906	15216
77	0.5		0	11	251	545	1090	1537	1875	2871	4207	5101	6202
78	0.6		0	0	0	87	240	196	512	709	1123	1591	1679
79	0.7		0	0	11	22	0	11	44	120	273	360	469
80	0.8		0	0	0	0	0	0	0	0	11	55	87
81	0.9		0	0	0	0	0	0	0	0	0	22	65
82	1		0	0	0	0	0	0	0	0	0	0	11
83	1.1		0	0	0	0	0	0	0	0	0	0	0
84	1.2		0	0	0	0	0	0	0	0	0	0	0

Figure 1.

Sine Vibration, 1G zero to peak, 10 Hz, 360 seconds

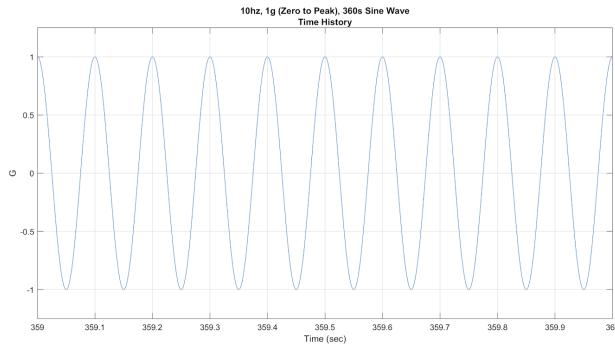


Figure 2.

Now that the methodology is described, we can focus on its application in field vibration data. In 2.1, we discussed how traditional PSD plots remove valuable information from real-world time history data. To put it in simple terms, when we look at sine vibration, two signals are considered equivalent if:

- They have the same zero to peak amplitude.
- They have the same period.
- They have the same number of cycles.
- Their individual cycles are aligned.

These basic metrics enable us to extract valuable information about the actual transportation environments, using real-world data, which was previously difficult with traditional methods. Here are some key takeaways:

Key Takeaways	Significance
1. ASTM d4169-14, field data vs. shaker table profile	Very similar
2. Air ride suspension vs. steel leaf suspension	Significant difference
3. Comparing air ride suspension in different region of the US	Significant difference
4. Comparing locations within the same vehicle with air ride suspension	Notable difference
5. Visualizing “Over-testing” and “Under-testing”	Significant difference
6. Visualizing cycles of vibration over time	Unavailable from past method

Table 1.

Takeaway #1: ASTM d4169-14 (steel leaf suspension), field data vs. shaker table profile

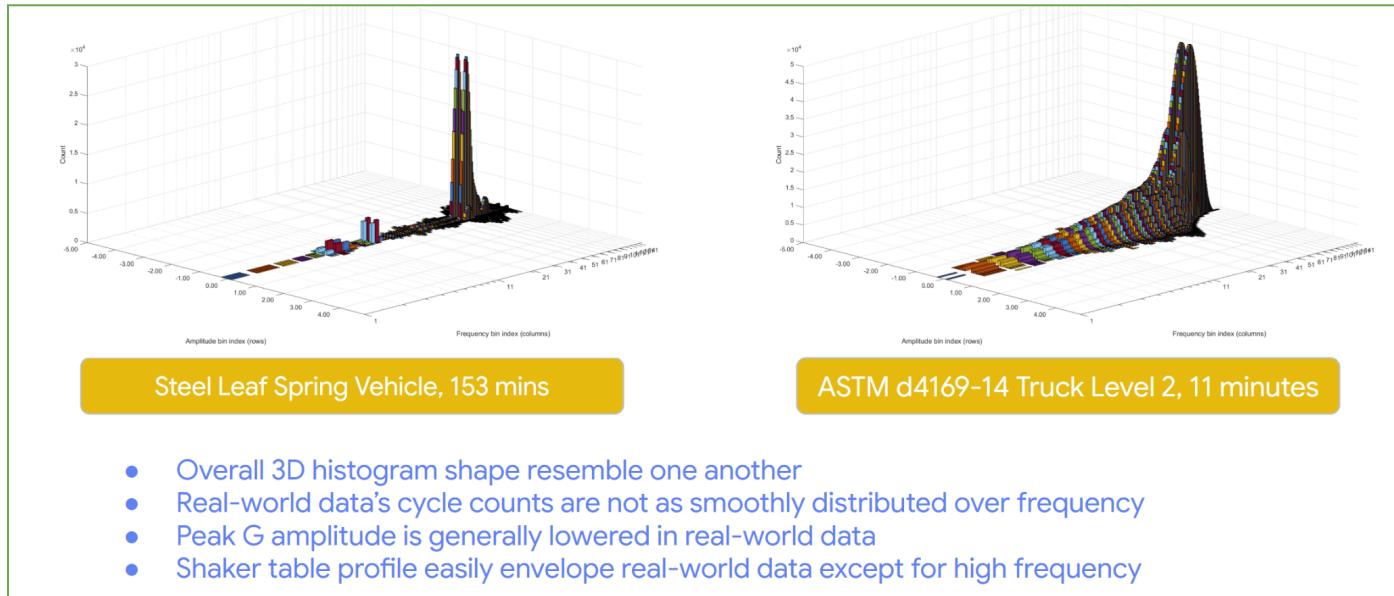


Figure 3.

ASTM's d4169-14 truck profile, level 2, generally represents real-world data really well. Factors that contribute toward such alignment might include shorter transit duration, smaller vehicle sizes, and most importantly, consistent road conditions. In our experiences, vehicles with such profile are primarily used for transits within local areas (15 to 30 mins), which greatly eliminates variability in road conditions. Such consistency is not observed when examining data from vehicles represented by ASTM's d4169-16 truck profile (air ride).

Takeaway #2: Air ride suspension (field data) vs. steel leaf suspension (ASTM d4169-14 truck profile)

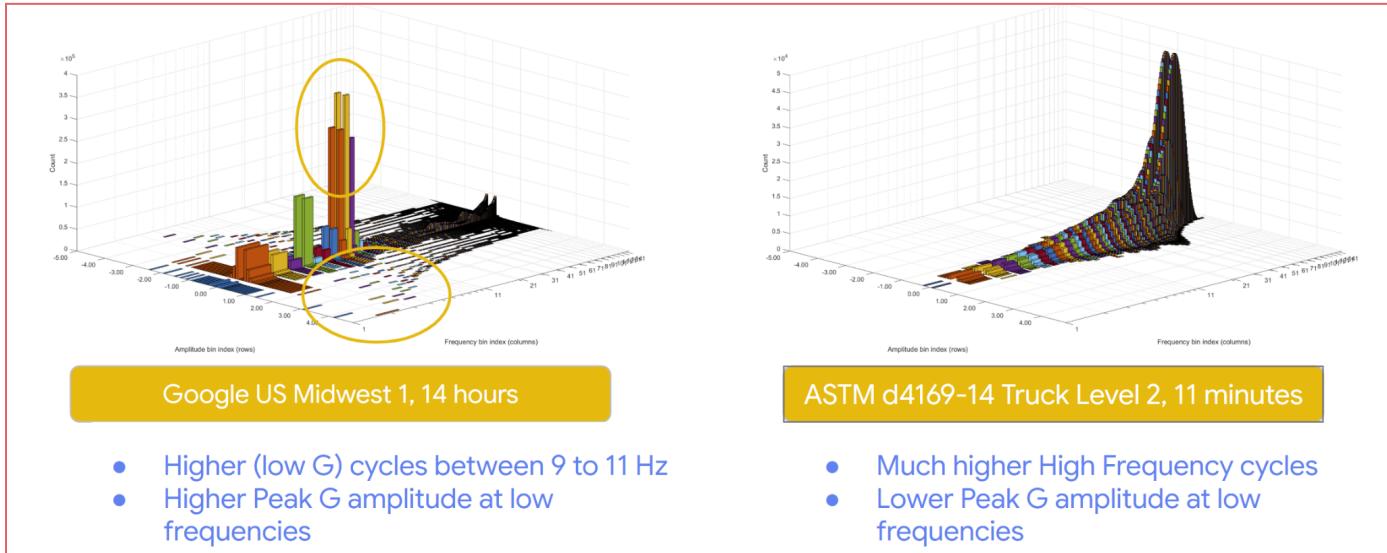


Figure 4.

As shown in 2.1, real-world data of vehicles with air ride suspension looks very different from vehicles with steel leaf suspension (represented here with ASTM d4169-14 truck profile). The locations of high cycle are very different, along with locations of high G amplitude. The ASTM truck profile was changed for 2016 with good reason. Still, it is difficult for shaker table profiles to accurately replicate the overall shape seen in real-word data, with correct cycle counts for specific frequencies.

We will capture shaker table data of the 2016 profile in the near future to understand what differences there are, if any, between real-world data and shaker table profile.

Takeaway #3: Comparing air ride suspension in different region of the US

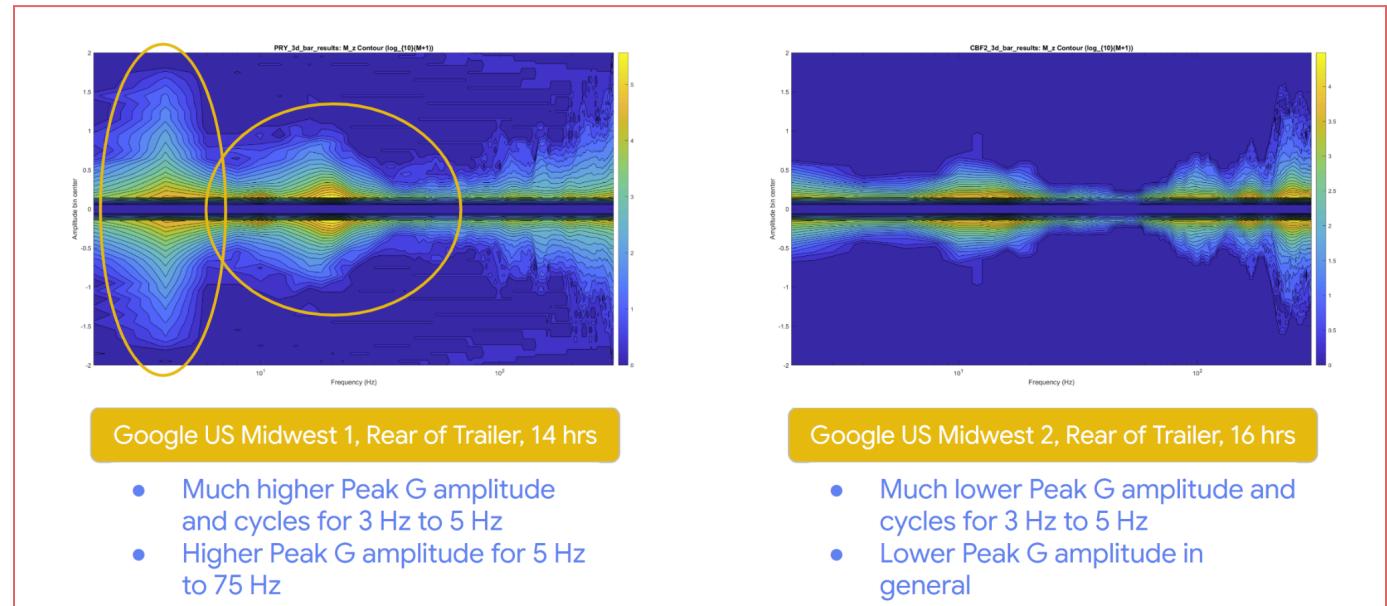


Figure 5.

Another way to look at the data is by creating heatmaps like figure 5. Cycle count is represented with color mapping, and the two dimensional view allows us to focus our attention on the relationship between frequency (2 to 300 Hz) and amplitude (-2.0 to 2.0 G).

Such visualization really allows us to appreciate the difference between two sets of data. In this example, the two data sets are supposed to be the same because they are both from vehicles with air ride suspension. But as we can see, they look very different because the vehicles traveled in different regions within the US Midwest. Feedback from people who live in Midwest 1 says road conditions there are much worse, which explains the higher amplitudes at low frequencies. Worse roads make the vehicle bounce more, which leads to more vibration.

Takeaway #4: Comparing locations within the same vehicle with air ride suspension

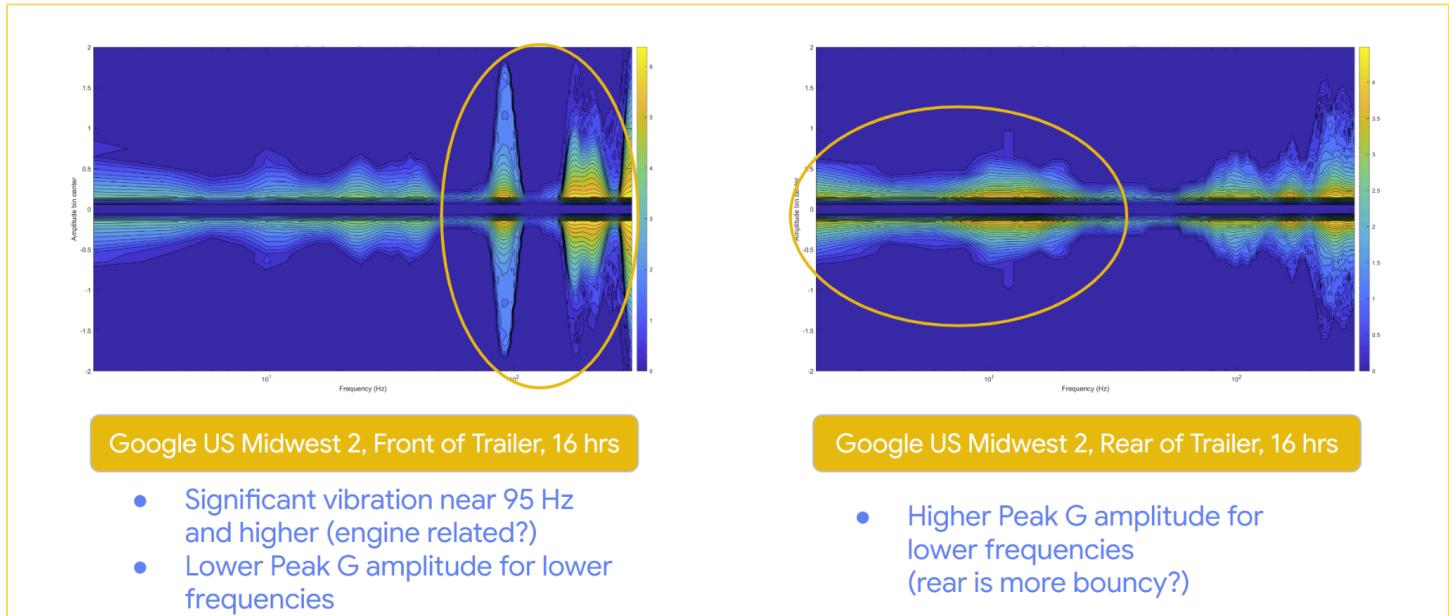


Figure 6.

Another interesting finding came from the same vehicle traveling in Google US Midwest 2. Sensors were placed near the front of the trailer (left figure) and the rear of the trailer (right figure), and their data distributions were compared and shown in figure 6. There are notable differences between the two plots - 1.) cycle counts for low frequencies (<50 Hz) are noticeably higher for the rear of the trailer, and 2.) amplitude for high frequencies (>90 Hz) are significantly higher for the front of the trailer.

One explanation might be that the rear of the trailer consists of a long, heavy load platform on soft suspension and long wheelbase, which leads to large vertical displacements at low frequencies, while the front is picking up high frequency vibration from combustion pulses, gear-mesh tones, turbo whine, and universal-joint imbalance from the tractor unit.

Takeaway #5: Visualizing “Over-testing” and “Under-testing”

3D histograms allow us to compare real-world data with shaker table profiles, and visually identify areas of “Over-testing” (cycles of shaker table vibration that exceed real-world data) and “Under-testing” (cycles that fall short of real-world data). For example, when we take the difference between US Midwest 1 and ASTM d4169-14 (scaled to 2 hours), we generate the following 3D histogram, which shows area of “Over-testing” in red and “Under-testing” in blue:

Visualizing “Over-testing” and “Under-testing” between US Midwest 1 and ASTM d4169-14 Truck Profile

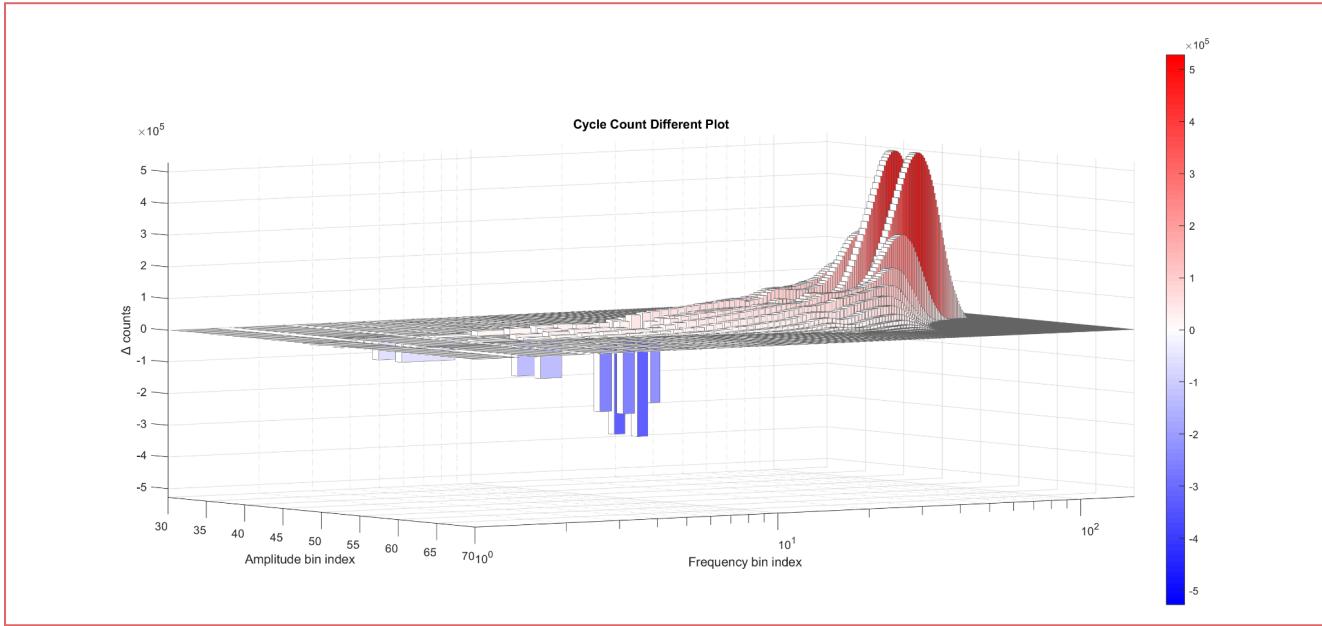


Figure 7.

Alternatively, this can be examined in a spreadsheet, where the exact difference of cycle count is calculated and shown in each cell. Orange/red colors representing “Over-testing”, blue/purple representing “Under-testing”.

Visualizing “Over-testing” and “Under-testing” in Spreadsheet

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
48	-2.6		0	-1	0	0	0	0	0	0	0	0	-1	-1	-1	-1	0	
49	-2.4		-1	0	0	0	0	0	-1	-1	-1	0	0	0	-1	-1	-1	
50	-2.3		0	-1	0	0	0	0	0	0	-1	-1	0	0	0	-1	-1	
51	-2.2		0	0	0	0	0	-1	0	0	0	0	0	-1	-1	0	0	
52	-2.1		0	0	-1	0	0	0	-1	0	0	0	0	0	0	-1	-1	
53	-2		0	-1	0	0	0	0	0	-1	0	0	0	0	0	0	0	
54	-1.9		-1	0	0	0	0	0	0	-1	0	0	-1	-1	-1	0	0	
55	-1.8		0	-3	0	0	-1	0	0	0	0	0	0	0	0	-1	-1	
56	-1.7		0	-10	0	0	0	0	0	0	0	0	0	0	0	0	0	
57	-1.6		0	-13	0	-1	0	0	0	0	0	0	0	0	0	0	0	
58	-1.5		-1	-21	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	
59	-1.4		0	-32	0	0	0	0	-1	-1	-1	0	0	0	0	0	120	
60	-1.3		-1	-42	0	0	0	0	0	-2	0	0	0	0	0	0	120	
61	-1.2		0	-69	0	0	0	-1	0	0	0	0	0	0	0	0	120	
62	-1.1		-2	-112	0	0	-1	-1	-3	0	-1	-1	239	240	479	119	239	
63	-1		0	-178	-1	-1	-2	-1	-6	-4	-7	238	479	479	948	828	1068	
64	-0.9		-2	-259	-2	-1	-4	-1	-8	-22	209	221	942	1308	1428	3444	4513	6300
65	-0.8		-4	-396	-2	-2	-234	-2	108	332	1243	2925	4161	4868	5818	9385	17341	21984
66	-0.700		-8	-691	234	1423	2364	1875	5654	7857	12840	16838	17813	23037	32782	38727	54173	74730
67	-0.600		-26	-1129	2349	4748	12092	17301	21137	28706	43736	55636	68390	80538	88023	102995	135440	186889
68	-0.500		-68	-1779	14500	27542	41882	60335	74001	98428	122001	141988	165362	199015	208812	261344	303190	341459
69	-0.4		-225	6395	53359	85901	119893	153723	180966	219554	257957	298028	324047	366728	402267	428509	473932	512507
70	-0.3		-739	44167	134058	180282	225610	271331	311331	347966	384860	384411	468007	509849	555416	588864	616298	632292
71	-0.2		1556	79024	127771	199443	113832	286730	317460	302178	107695	56218	190585	436687	506146	521425	534542	512173
72	-0.1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
73	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
74	0.1		2012	77715	134970	198068	108813	282547	318114	298936	109230	51844	199460	440317	504504	516282	535344	513978
75	0.2		-656	42601	128362	181684	230230	275745	311490	348442	365541	392847	463763	509257	549103	589908	617807	633950
76	0.3		-245	6556	55026	84951	116934	154795	178452	219319	252949	298386	321521	365653	408338	433628	469661	507511
77	0.4		-72	-1501	14375	27301	40565	58671	77924	100072	121271	139381	165529	197723	211544	260986	302242	342408
78	0.5		-32	-1304	2708	5936	18589	16705	20311	28826	45531	55391	67555	82666	87902	101928	139834	186411
79	0.6		-3	-690	-4	946	2606	2123	5537	7626	12130	17306	18292	23870	31835	36990	51087	75330
80	0.7		-1	-400	116	232	-5	106	451	1243	2928	3911	5107	5996	9505	9145	17702	21864
81	0.8		-3	-246	-1	-1	-2	-3	-8	-21	84	583	944	948	1788	3205	4633	6649
82	0.9		-3	-184	-1	-1	-3	0	-5	-1	-4	237	706	480	828	600	828	1897
83	1		-1	-106	0	0	-1	-1	-4	-1	-2	-2	120	119	359	119	359	119
84	1.1		0	-59	0	0	0	0	-1	0	0	0	120	0	0	0	120	1

Figure 8.

Visualizing “Over-testing” and “Under-testing” in Spreadsheet

	C	D	E	F	G	H	I	J	K	L	M	
63	0	-178	-1	-1	-2	-1	-6	-4	-7	238	479	
64	-2	-259	-2	-1	-4	-1	-8	-22	209	221	942	
65	-4	-398	-2	234	-2	108	332	1243	2925	4151	4868	
66	-8	-691	234	1423	2364	1875	5654	7857	12840	16838	17813	
67	-26	-1129	2349	4748	12092	17301	21137	28706	43736	55636	68390	
68	-68	-1779	14500	27542	41882	60335	74001	98428	122001	141986	163632	
69	-228	6395	53359	85901	119893	153723	180966	219554	257957	298028	324047	
70	-739	44167	134058	180282	225610	271331	311331	347966	358480	384111	468007	
71	1556	79024	127771	199443	113832	286730	317460	302178	107695	56218	190585	
72	0	0	0	0	0	0	0	0	0	0	0	
73	0	0	0	0	0	0	0	0	0	0	0	
74	2012	77715	134970	198088	108813	282547	318114	298936	109230	51844	199460	
75	-696	42601	128362	181684	230230	275745	311490	348442	365541	392847	463763	
76	-245	6556	55026	84951	116934	154795	178452	219319	252949	298384	321521	
77	-72	-1501	14375	27301	40565	58671	77924	100072	121271	139381	165529	
78	-32	-1304	2708	5936	11859	16705	20311	28826	45531	55391	67555	
79	-3	-690	-4	946	2606	2123	5537	7626	12130	17306	18292	
80	-1	-400	116	232	-5	106	451	1243	2928	3911	5107	
81	-3	-246	-1	-1	-2	-3	-8	-21	84	583	944	
82	-3	-184	-1	-1	-3	0	-5	-1	-4	237	706	
83	-1	-108	0	0	-1	-1	-4	-1	-2	-2	120	
84	0	-59	0	0	0	0	0	-1	0	0	0	

Figure 9.

As we can see, in this comparison, there are 100,000+ cycles of “Over-testing” at peak amplitudes around 0.1G to 0.4G, between 10 Hz and 22 Hz. Depending on the product, how it is packaged, and the specific failure mode, it may or may not make a difference.

Takeaway #6: Visualizing cycles of vibration over time

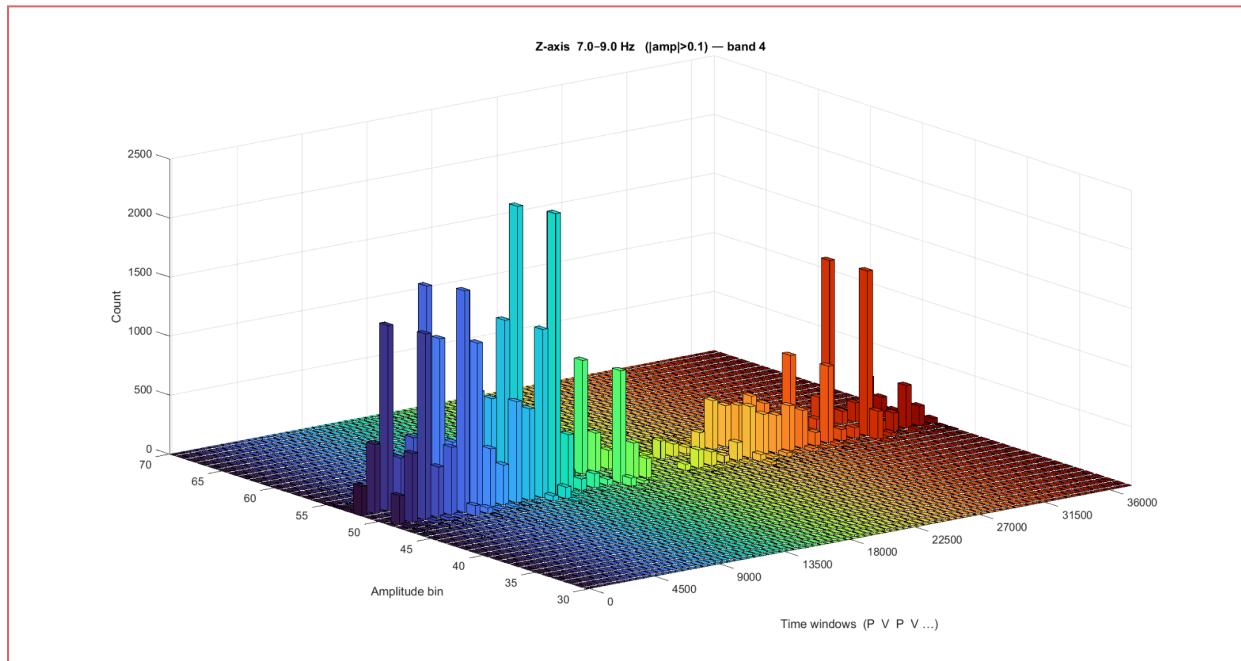


Figure 10.

Having precise timing of peak amplitudes also allows us to visualize the distribution of cycles over time. This can offer clues for road conditions if the transit route is known and timing correlated with it.

For example, the US Midwest 1 data set was broken down into 15 minutes segments, each showing a distribution of cycle count vs. amplitude. Figure 10 shows data for 9 to 11 Hz, and shows higher cycle counts in the first half of the data set.

Did the vehicle travel faster during the first half of the shipment? Were the road conditions worse? Did the vehicle paused more during the second half of the shipment? These are all interesting questions to explore as we look further inside the data.

Such visualization can be made for different frequency bands to see if it makes any difference, and there appears to be when we look at several other frequency bands between 7 and 21 Hz. The distribution of cycles over time are not all uniformed, which makes these plots really interesting to look at.

Visualizing cycles of vibration over time, US Midwest 1, 7 to 21 Hz

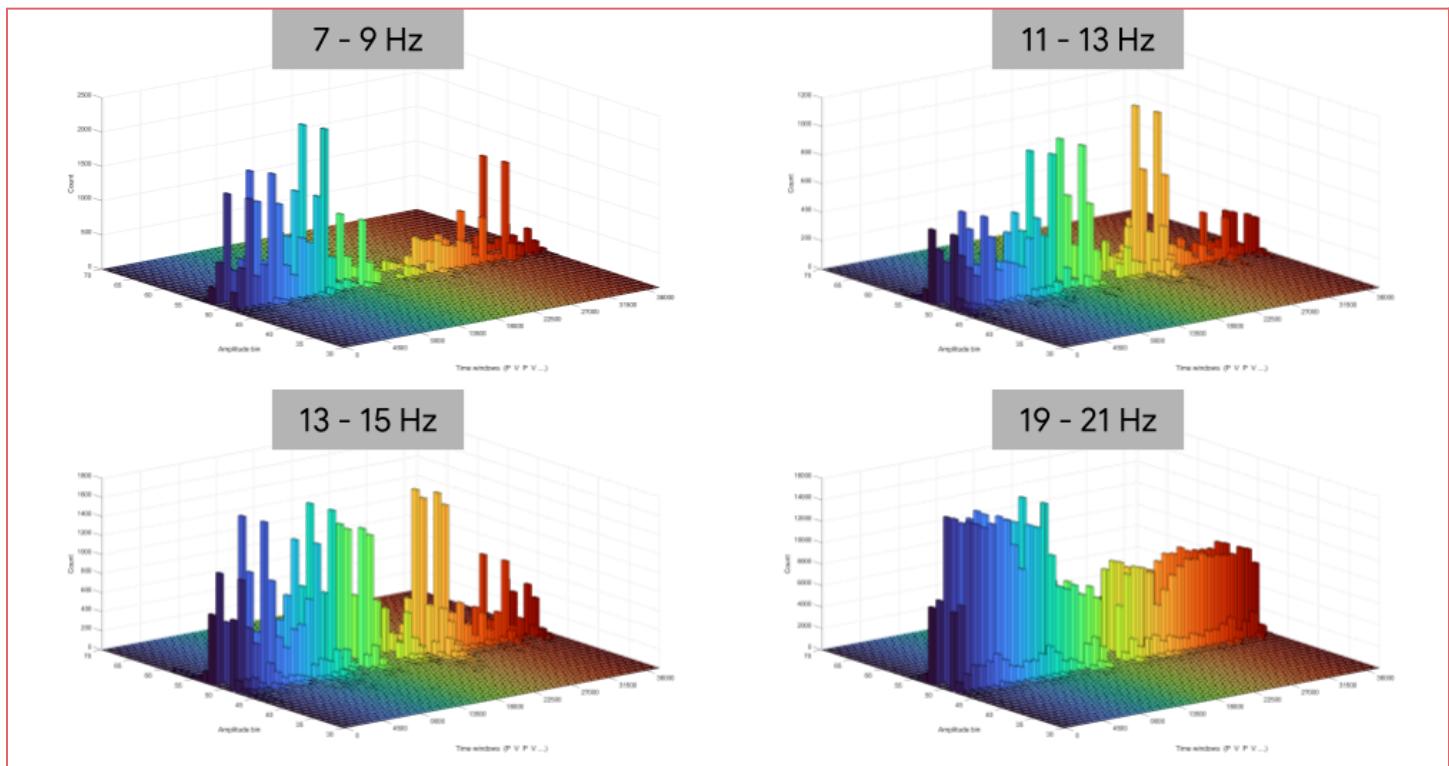


Figure 11.

Conclusion

At the end of the day, efforts put into this are meant to help us make more informed decisions in product design, product reliability, packaging design, and design verification/validation. The measurements techniques and test methodologies will continue to be debated and improved, as all engineering knowledge does, but new thinking provides new answers that previously were not easy or possible to obtain.

Q: Are road conditions and vehicle conditions the same everywhere around the world? A: No, they are not.

Q: Can measured data help us evaluate how appropriate test standards are for our unique situations? A: Yes, they can.

Q: Do we have a better sense of the range and variety of random vibration my products are expected to see?
A: We have a much better sense now than we ever did previously, but the world is big and the supply chain is incredibly complex, so we need more data coverage to be certain.

Q: Will we ever get to a point where all we have to do is enter the addresses of the origin and destination of a shipment, and get a customized analysis/test plan for our specific route of transportation? A: We will, with multiple solutions that are independently developed by people passionate about this area of work.

The methods and techniques developed in the course of this project are meant to be thorough so that it can independently be replicated and evaluated by anyone interested. But it is still important to remember the result should be simple to understand and the learnings easy to implement. I will continue to work on that as the project progresses.

Now that a lot of the technical details are published, it's nice to be able to switch gears and release results/findings for a change because that's what matters to most people. You will see that more and more as we move forward. In the meantime, I hope the material released thus far is enough to spark your interest into thinking about all of this from a different perspective.

As a company next door right at the heart of Silicon Valley once advertised: Think Different.