EXTRACTING MORE INFORMATION FROM FIELD DATA

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Takeaway #6

“Over-testing” vs. “Under-testing” for Real-World Data vs. ASTM Standards

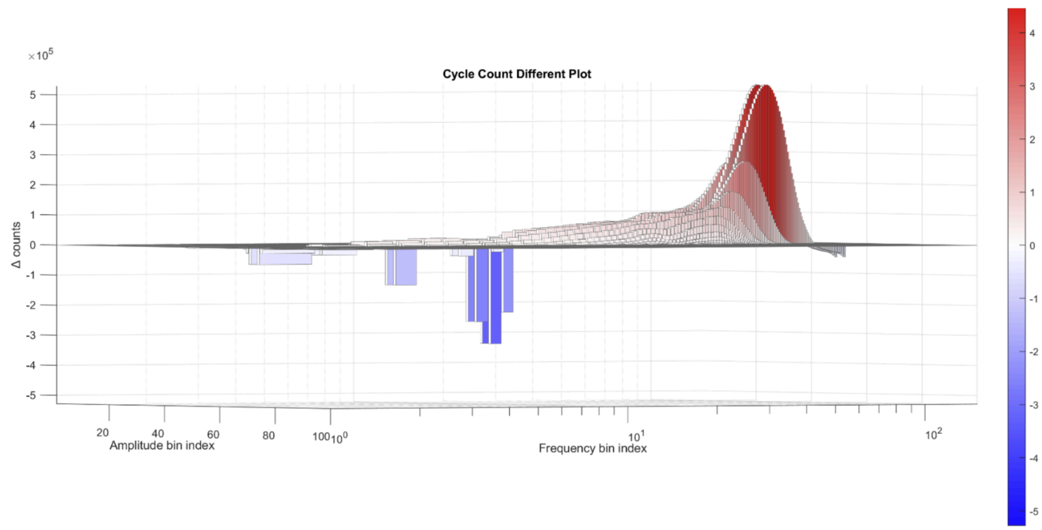


Figure 1.

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

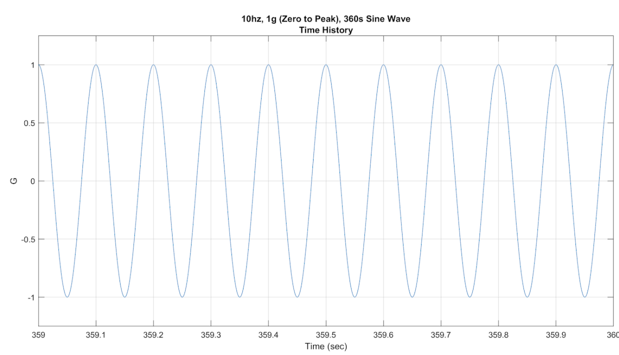


Figure 2.

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.

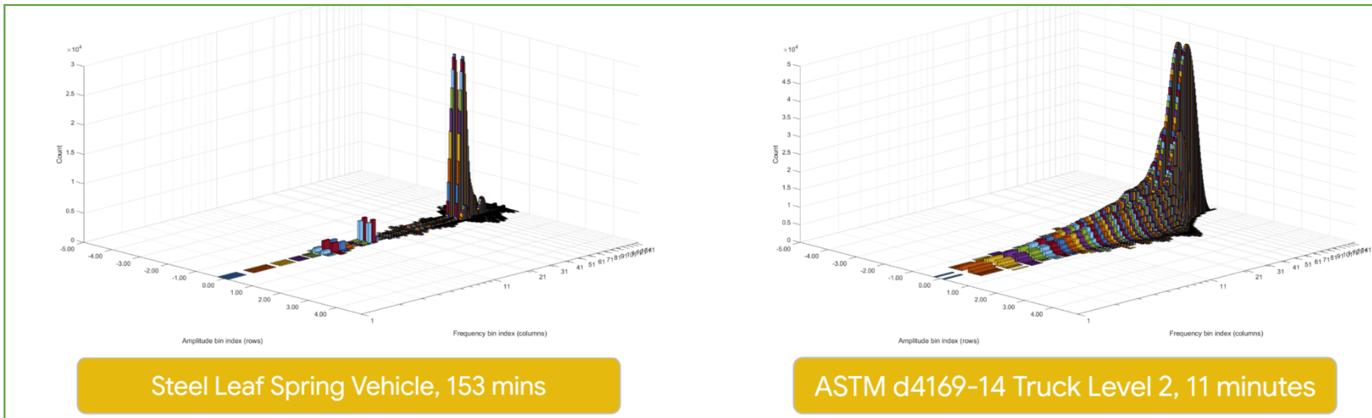
- Their individual cycles are aligned.

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 cycles of vibration over time	**Significant difference**
6. Visualizing “Over-testing” and “Under-testing”	**Unavailable from past method**

Table 1.

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

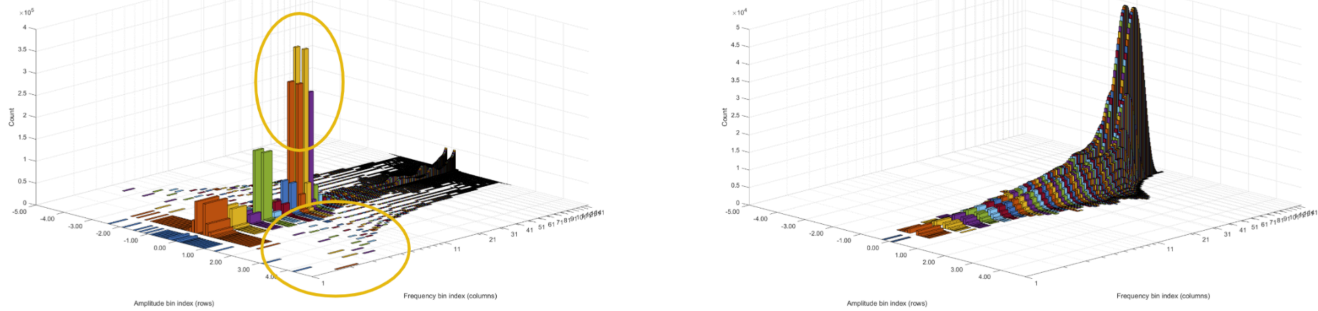


- Overall 3D histogram shape resemble one another
- Real-world data’s cycle counts are not as smoothly distributed over frequency
- Peak G amplitude is generally lowered in real-world data
- Shaker table profile easily envelope real-world data except for high frequency

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)



Google US Midwest 1, 14 hours

- Higher (low G) cycles between 9 to 11 Hz
- Higher Peak G amplitude at low frequencies

ASTM d4169-14 Truck Level 2, 11 minutes

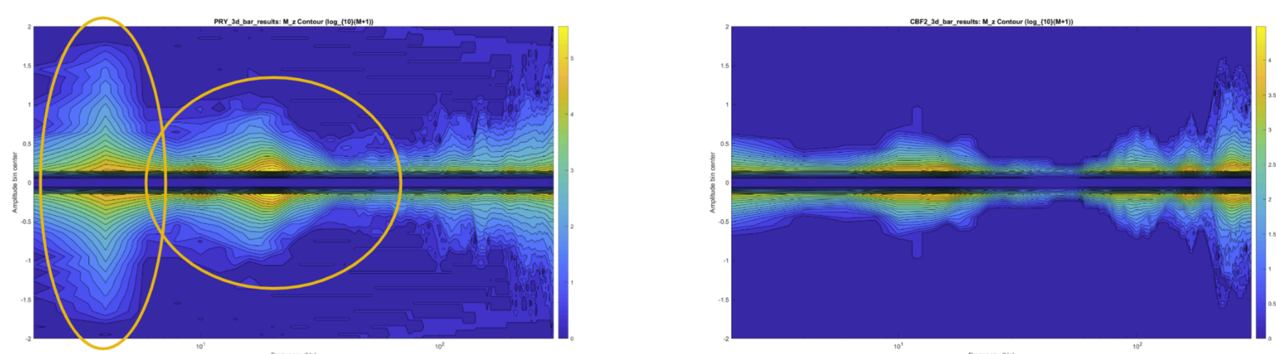
- Much higher High Frequency cycles
- Lower Peak G amplitude at low frequencies

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 d14169-14 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



Google US Midwest 1, Rear of Trailer, 14 hrs

- Much higher Peak G amplitude and cycles for 3 Hz to 5 Hz
- Higher Peak G amplitude for 5 Hz to 75 Hz

Google US Midwest 2, Rear of Trailer, 16 hrs

- Much lower Peak G amplitude and cycles for 3 Hz to 5 Hz
- Lower Peak G amplitude in general

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

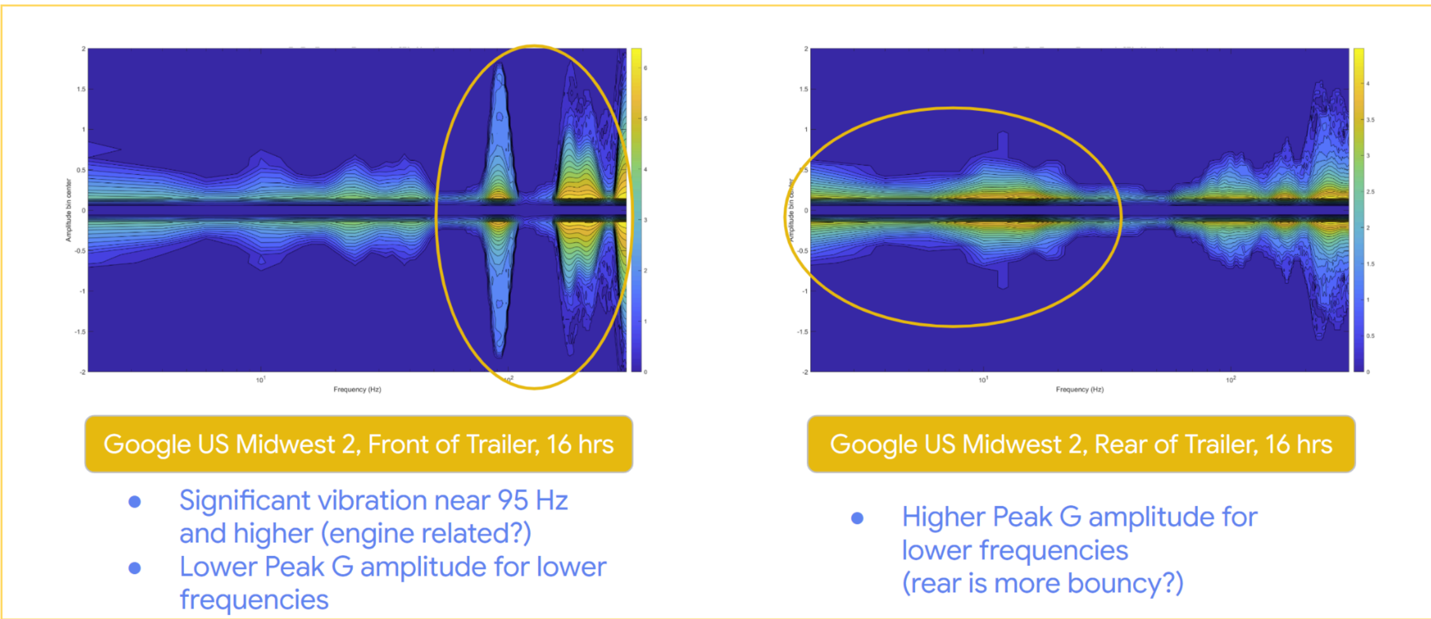


Figure 6.

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 cycles of vibration over time

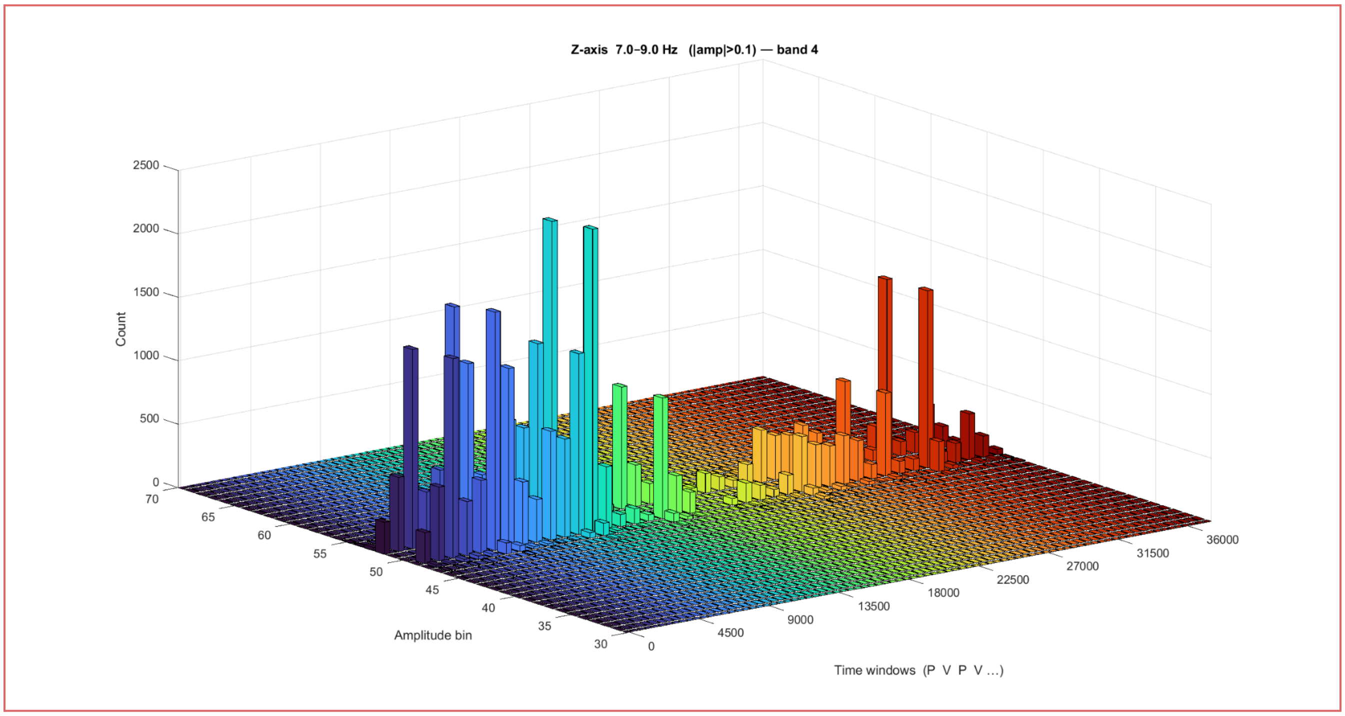


Figure 7.

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

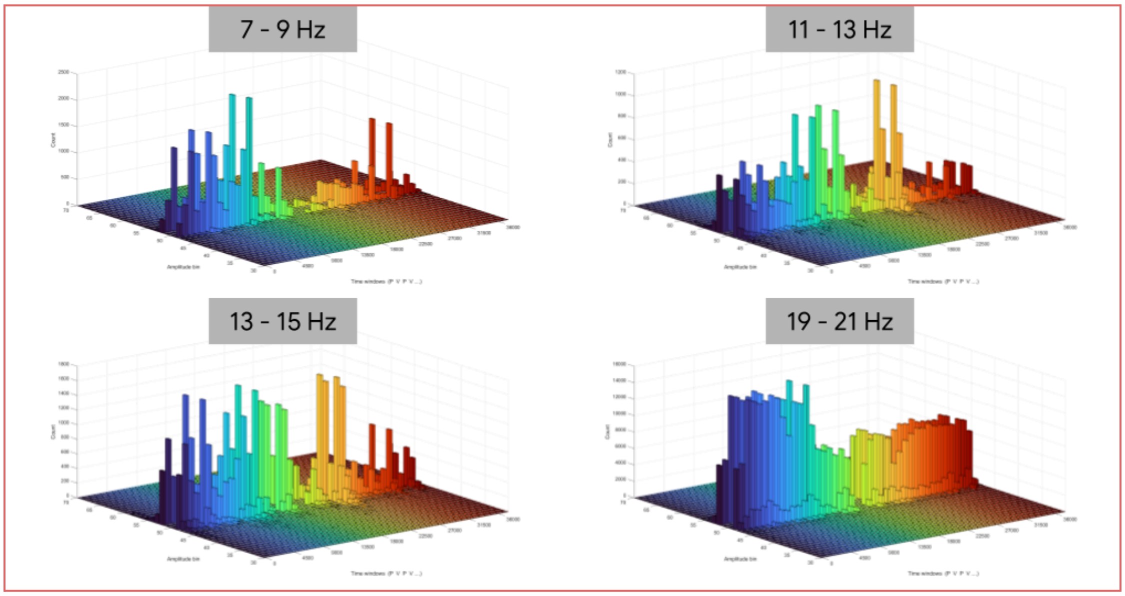


Figure 8.

Takeaway #6: 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

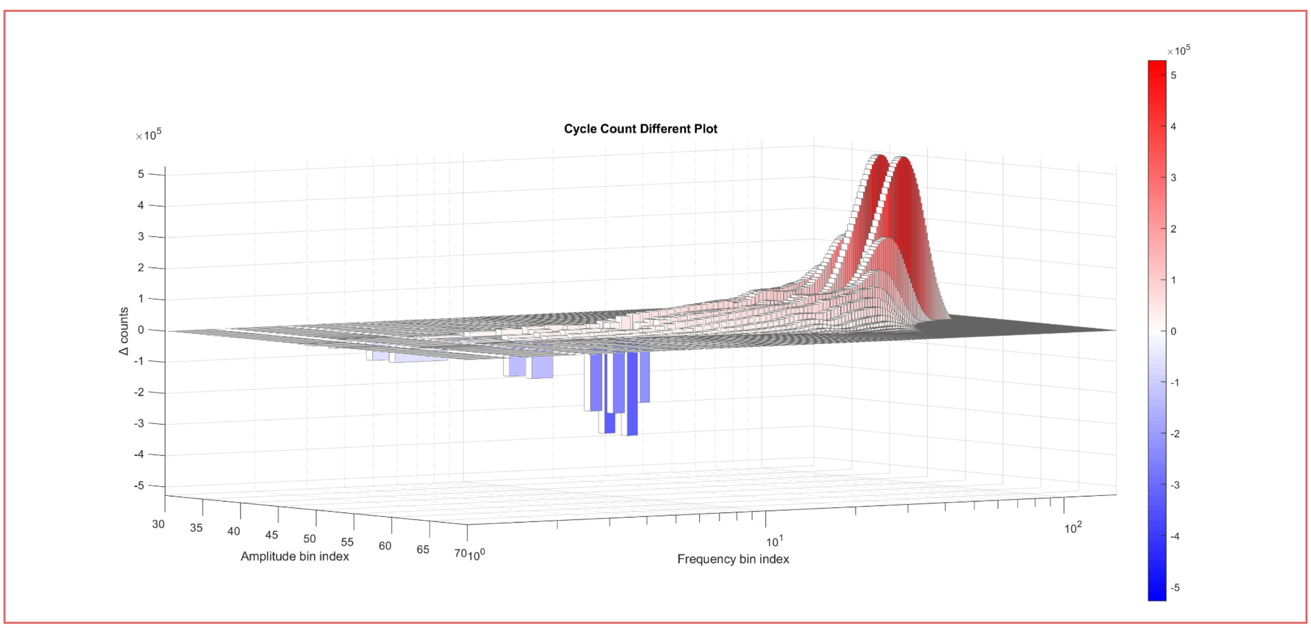


Figure 9.

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	-2.5		0	-1	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	0	
49	-2.4		-1	0	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	0	0	-1	-1	0	0	0	-1	
51	-2.2		0	0	0	0	0	-1	0	0	0	0	0	0	-1	-1	0	0	
52	-2.1		0	0	-1	0	0	0	0	-1	0	0	0	0	0	0	-1	-1	
53	-2		0	-1	0	0	0	0	0	0	-1	0	-1	0	0	0	0	0	
54	-1.9		-1	0	0	0	0	0	0	0	0	-1	0	-1	-1	-1	0	0	
55	-1.8		0	-3	0	0	-1	0	-1	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	0	
57	-1.6		0	-13	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	
58	-1.5		-1	-21	0	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	0	120	[illegible]
60	-1.3		-1	-42	0	0	0	0	0	-2	0	0	0	0	0	0	0	120	[illegible]
61	-1.2		0	-69	0	0	0	-1	0	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	119	[illegible]
63	-1		0	-178	-1	-1	-2	-1	-6	-4	-7	238	479	479	948	828	1068	1788	[illegible]
64	-0.9		-2	-259	-2	-1	-4	-1	-8	-22	209	221	942	1308	1428	3444	4513	6300	[illegible]
65	-0.8		-4	-398	-2	234	-2	108	332	1243	2925	4151	4868	5818	9385	8437	17341	21984	[illegible]
66	-0.700		-8	-691	234	1423	2364	1875	5654	7857	12840	16838	17813	23037	32782	38727	54173	74730	[illegible]
67	-0.600		-26	-1129	2349	4748	12092	17301	21137	28706	43736	55636	68390	80538	88023	102995	135440	186889	[illegible]
68	-0.500		-68	-1779	14500	27542	41882	60335	74001	98428	122001	141986	163632	199015	208812	261344	303190	341459	[illegible]
69	-0.4		-228	6395	53359	85901	119893	153723	180966	219554	257957	298028	324047	366728	402267	428509	473932	512507	[illegible]
70	-0.3		-739	44167	134058	180282	225610	271331	311331	347966	358480	384111	468007	509649	555416	588864	616294	632292	[illegible]
71	-0.2		1556	79024	127771	199443	113832	286730	317460	302178	107695	56218	190585	436687	506146	521425	534542	512173	[illegible]
72	-0.1		0	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	0	
74	0.1		2012	77715	134970	198088	108813	282547	318114	298936	109230	51844	199460	440317	504504	518282	535344	513978	[illegible]
75	0.2		-696	42601	128362	181684	230230	275745	311490	348442	365541	392847	463763	509257	549103	589080	617807	633950	[illegible]
76	0.3		-245	6556	55026	84951	116934	154795	178452	219319	252949	298384	321521	365653	408338	433628	469661	507511	[illegible]
77	0.4		-72	-1501	14375	27301	40565	58671	77924	100072	121271	139381	165529	197723	211544	260986	302242	342408	[illegible]
78	0.5		-32	-1304	2708	5936	11859	16705	20311	28826	45531	55391	67555	82666	87902	101928	139834	186411	[illegible]
79	0.6		-3	-690	-4	946	2606	2123	5537	7626	12130	17306	18292	23870	31835	36950	51087	75330	[illegible]
80	0.7		-1	-400	116	232	-5	106	451	1243	2928	3911	5107	5696	9505	9145	17702	21864	[illegible]
81	0.8		-3	-246	-1	-1	-2	-3	-8	-21	84	583	944	948	1788	3205	4633	6649	[illegible]
82	0.9		-3	-184	-1	-1	-3	0	-5	-1	-4	237	706	480	828	600	828	1897	[illegible]
83	1		-1	-108	0	0	-1	-1	-4	-1	-2	-2	120	119	359	119	359	119	[illegible]
84	1.1		0	-59	0	0	0	0	0	-1	0	0	0	120	0	0	0	120	[illegible]

Figure 10.

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 11.

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.

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.

Q1: Are road conditions and vehicle conditions the same everywhere around the world? A: No, they are not.

Q2: Can measured data help us evaluate how appropriate test standards are for our unique situations? A: Yes, they can.

Q3: 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.

Q4: 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. It's hard to look up and see what's really happening around us, when we've spent so much time trying to look inside the details. A.I. data centers, LLMs that write codes and conduct research, self driving cars, robots that backflip.

I hope the material released thus far is enough to spark your interest into thinking about all of this from a different perspective. It's been more than 7 years since I began measuring data in the real world. Even as I look at the data today, I still think to myself, "this stuff is still very interesting." Can shock and vibration keep up with time and technological advancement? I think it can, if we continue to challenge ourselves.

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