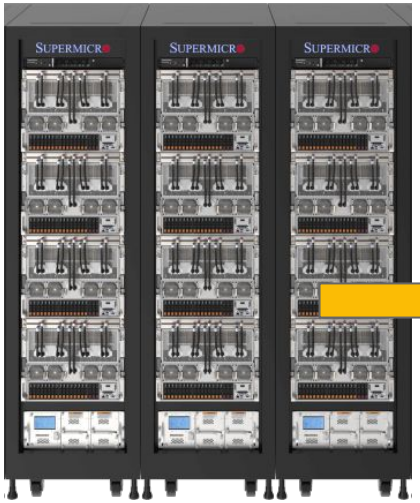
Open Random Vibration Testing Sketch Board

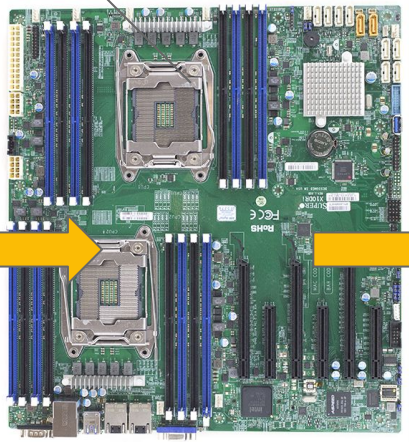
April 2024

01

Impact of Vibration on Components in Populated Racks

Classical View - Compression and Tension Leads to Fractures





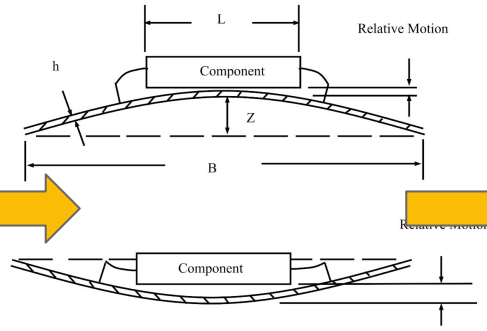
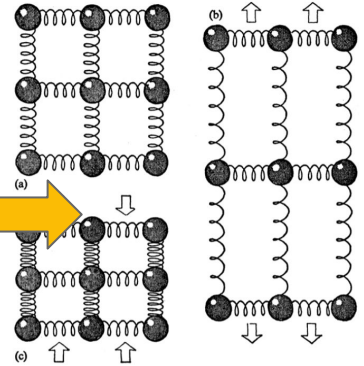
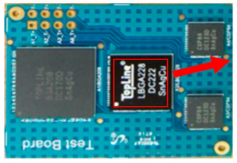
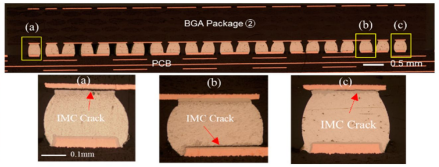


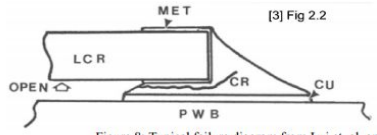
Figure 3. Circuit Board Bending Deflection







Intermediate or complete fractures causes reliability and FPY issues



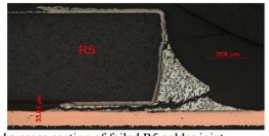


Figure 8: Typical failure diagram from Lui et. al. and a cross-section of failed R5 solder joint

IPC/JEDEC-9703 March 2009

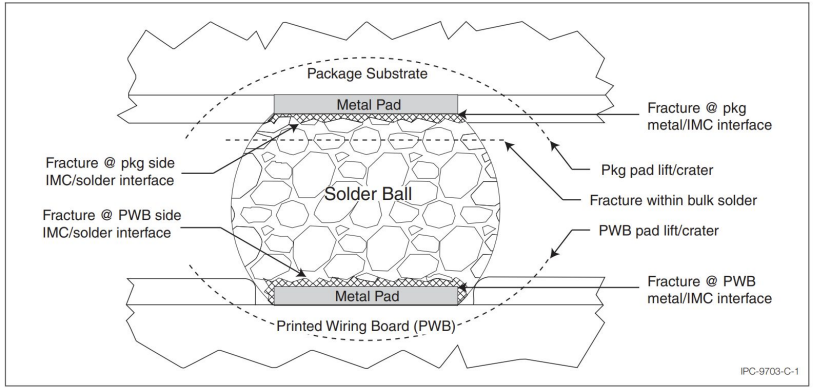
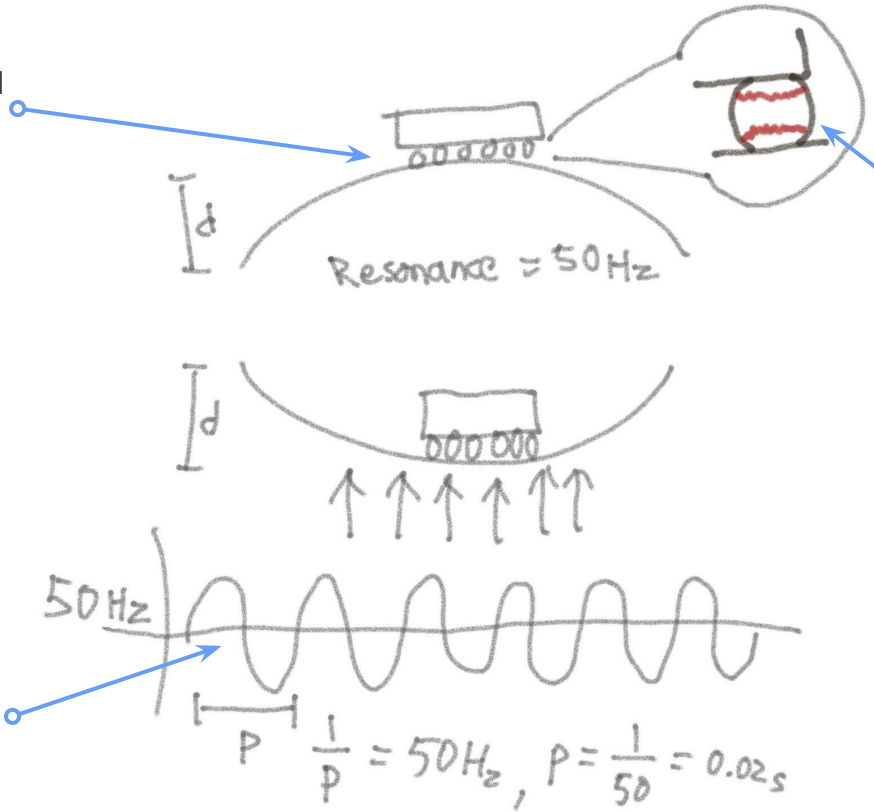


Figure C-1 BGA Solder Joint Failure Modes

Classical Explanation of Vibration on Board + Component

Board + Component with Resonance @ 50hz, subjected to 50hz vibration, leads to board deflection

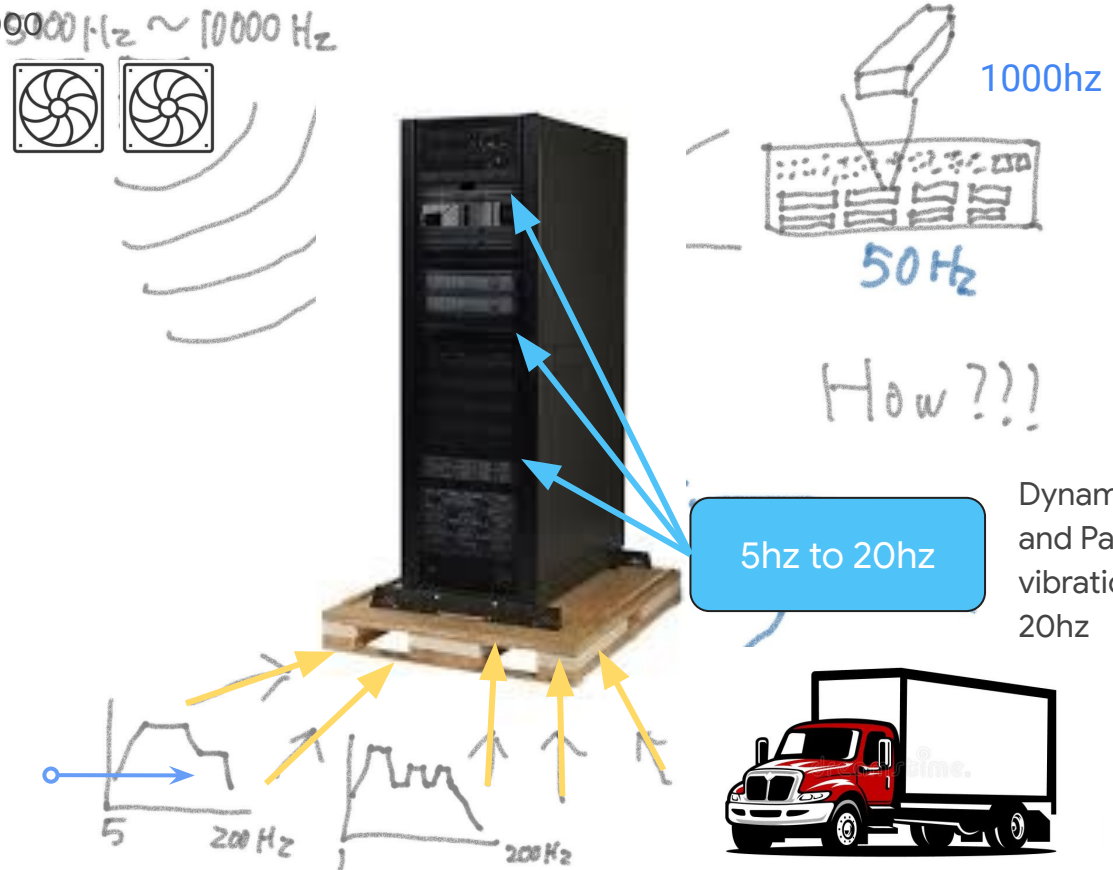


Board Deflection create mechanical stress at solder joint, which leads to fracture

Input excitation of 50hz from environmental conditions

Board and OSFP resonance do not normally align with environmental conditions. So how do they happen?

Fan speed range from 5000 to 20000 rpm
(83 to 332 hz)

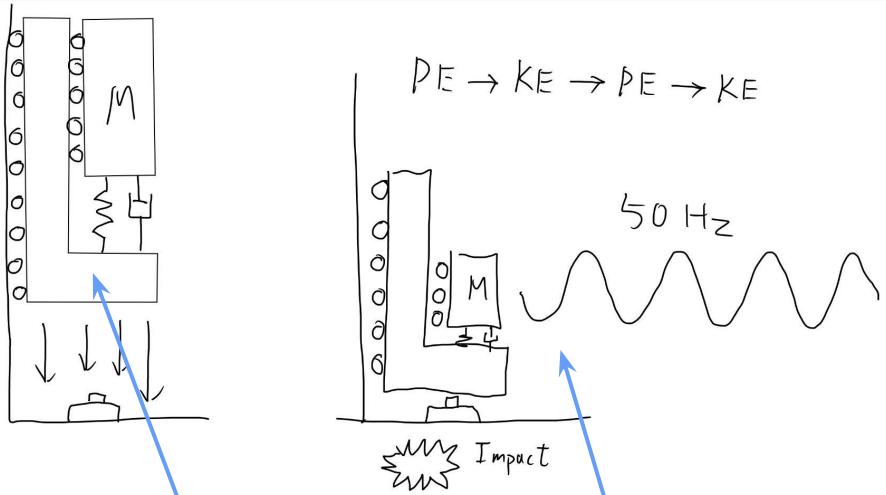


Board resonance at 50hz, Component resonance at 1000hz

Dynamic behavior of Rack and Packaging causes vibration to narrow to 15 to 20hz

Environmental Conditions from transportation range from 1 to 200hz

Alternative View: Vibration as a result of impact (Gaberson)

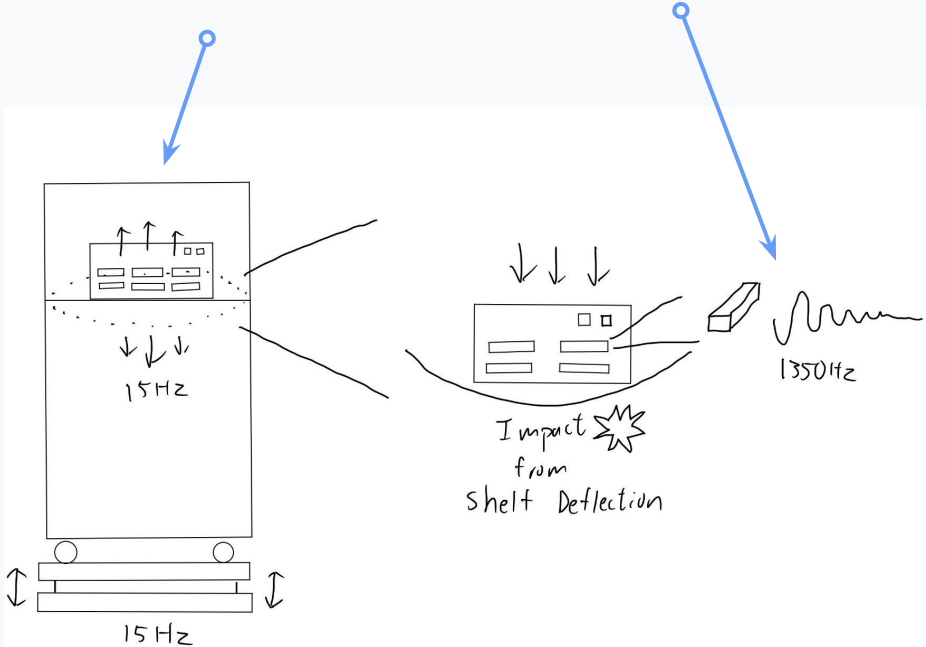


A “Shock Table Wheeled Bogey” experience free fall impact when released above ground.

Potential Energy of mass M is converted to Kinetic Energy at impact, then alternate between Spring Energy and Kinetic Energy until both settles to 0 due to friction.

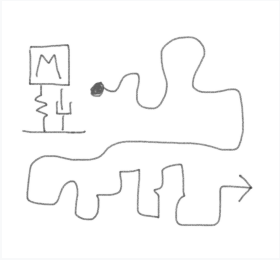
Likewise, a switch installed inside a rack experience impact when shelves deflect due to movement during transportation and handling.

This leads to the conversion between PE, KE, and SE at the component level. The strain at boards and solder joints could eventually lead to fracture.

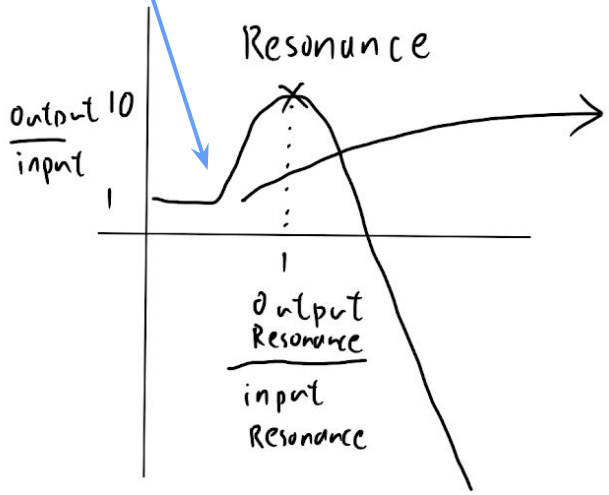


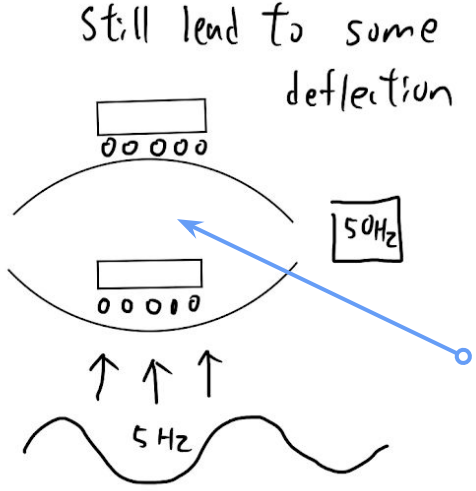
When things move, something is always shaking

Just because input and resonance frequencies don't line up doesn't mean things aren't vibrating.



Mass-Spring systems traveling through space cause changes of momentum that store and release energy in the spring in all kinds of interesting ways.





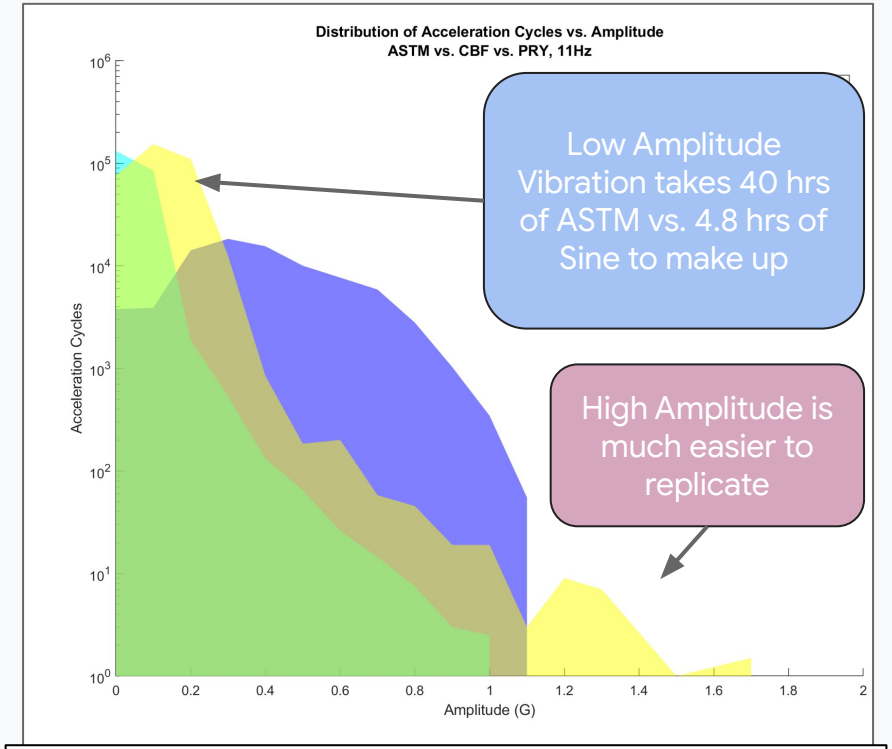
A 50hz board still deflect when vibrated at 5hz. Vibration leads to strain, which can still lead to fracture.

Standard Tests are very far from real world vibration conditions

Table 4-3 Mechanical Integrity Tests

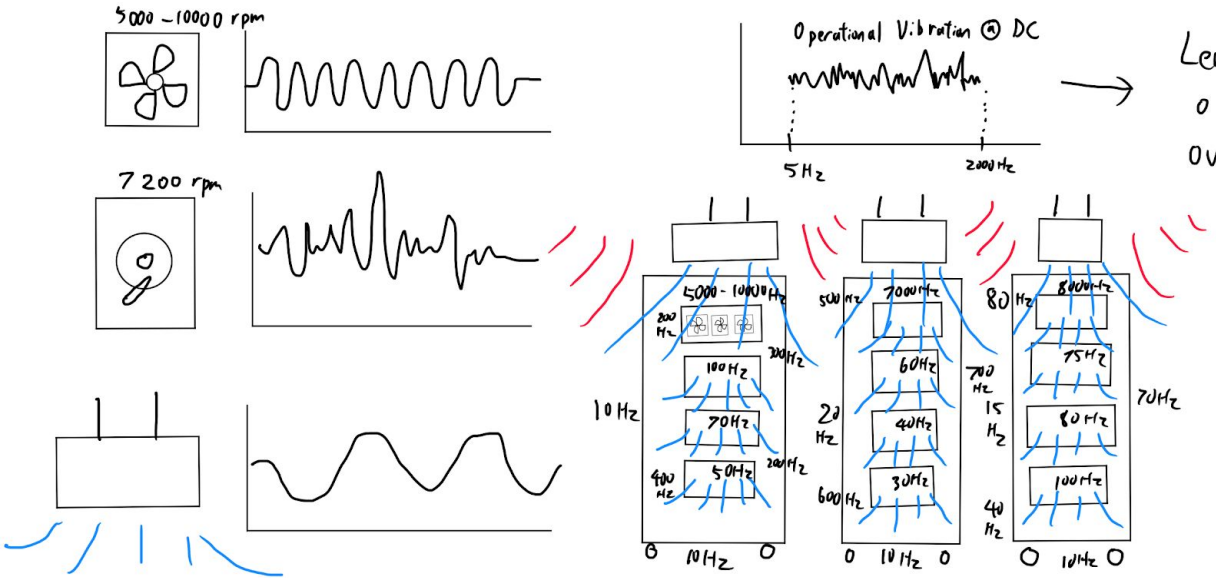
Test	Ref.	Additional Information[1]	Applicability[2, 3]
Mechanical Shock[4]	3.3.1.1	Condition A (500 g, 1.0 ms), 5 times/direction[5]	**R** for all optoelectronic diodes and modules
		300 g, 3 ms, 5 times/direction[5]	**R** for all optoelectronic integrated modules ≤ 0.225 kg
		50 g, 11 ms, 5 times/direction[5]	**R** for all optoelectronic integrated modules > 0.225 kg and ≤ 1.0 kg[6]
Vibration[4]	3.3.1.1	Condition A (20 g), 20 to 2000 to 20 Hz, 4 min/cy, 4 cy/axis, non-powered	**R** for all optoelectronic diodes, modules, and integrated modules
		5 g, 10 to 100 to 10 Hz, 1 min/cy, 10 cy/axis, powered	**O** for all optoelectronic integrated modules[7]

Typical Vibration Tests generate only a small numbers of stress cycles in test samples. For example, in this vibration test, only a handful of stress cycles is exercised for each frequency of interest.



It could take up to 40 hours of the standard ASTM d4169-14 truck transportation profile to duplicate the number of stress cycles measured in the real world.

Everything shakes at the Data Centers



Leads to millions of stress cycles over the hardware's life time.

Standard test profile doesn't begin to reflect such real world conditions.

Stress	Reference(s)	Conditions
Mechanical Vibration	GR-468, Table 4-3, GR-468 [R3-13].	Condition A (20 g), 20-2000-20 Hz, 4 min/cy, 4 cy/axis, non-powered
Mechanical Shock	GR-468, Table 4-3, GR-468 [R3-13].	Integrated modules: ≤ 0.225 kg. 300 g, 3 ms, > 0.225 kg & ≤ 1.0 kg, 50g, 11ms 5 times/direction

Cyclical forces at various combinations cause all rack structures and materials to vibrate at various resonance frequencies, which in turn add to the general vibration environment.

The result is a general random vibration that causes everything to shake slightly.

Many fast fans + Strong airflow + Flimsy sheet metals means everything is shaking at their own resonance frequencies.

Think of how many stress cycles are accumulated when everything shakes at resonance frequencies for one year.

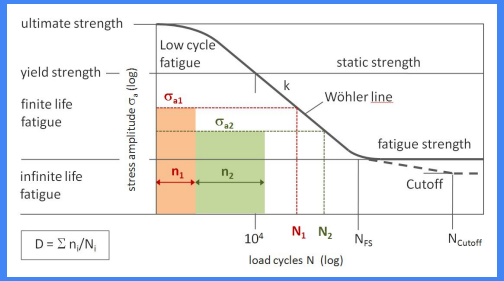
1350hz x 31.5 million seconds per year = 42.5 billion stress cycles per year

02

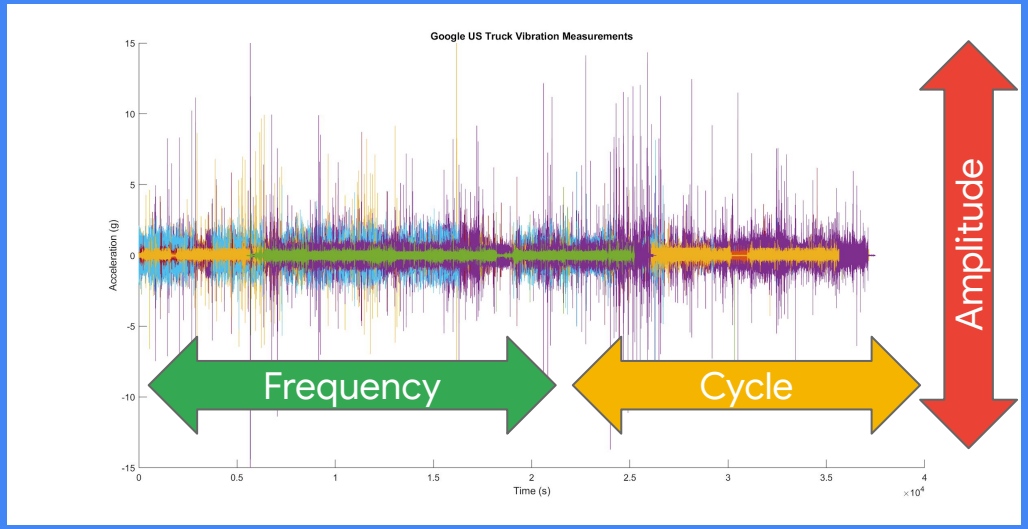
Fatigue Damage Calculation

Random Vibration Stress in Google's Data Center Supply Chain

Cumulative vs. Instant damage



Wide range of Amplitude, Frequency, and Cycles depending on Vehicle, Terrain, Region, and Season.



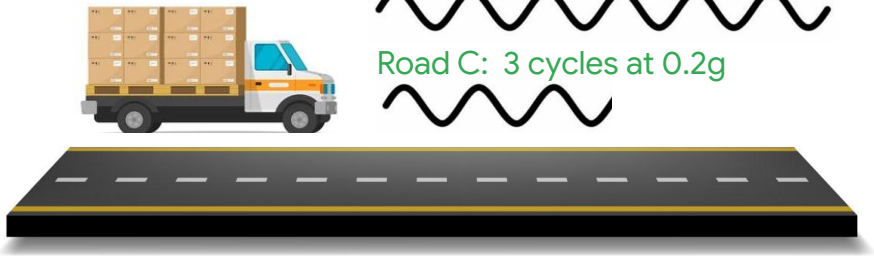
Correct Vibration = Correct Stress & Strain Replication

Analytics of 2 x 10^9 data points from years of field experiments

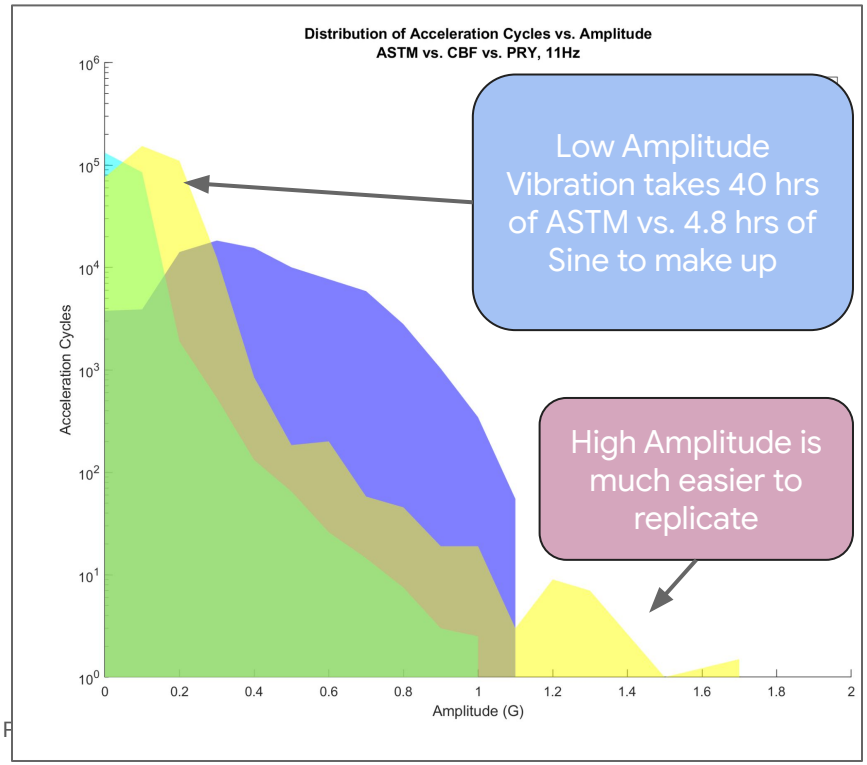
Road A: 6,000 cycles at 0.2g

Road B: 6 cycles at 0.2g

Road C: 3 cycles at 0.2g



First Mode: 11 hz



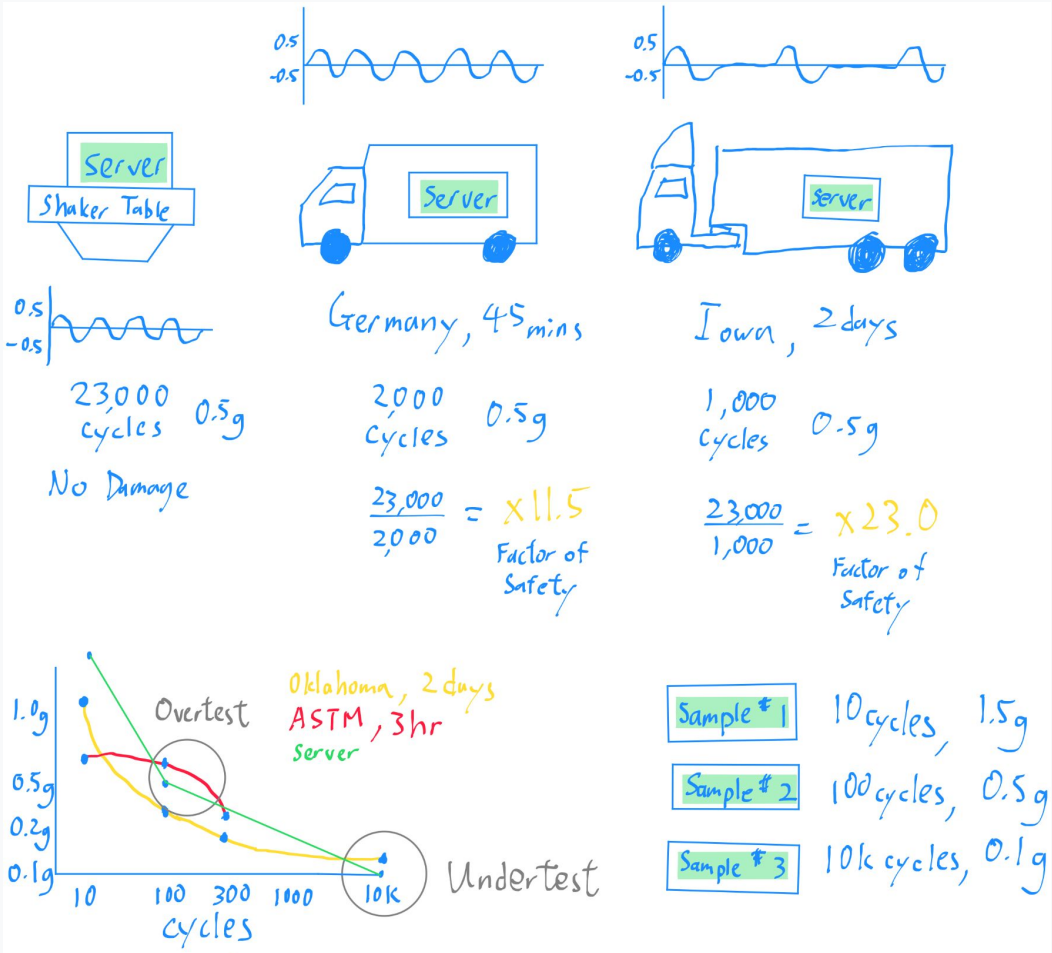
x.01 Factor of Safety	x10 Factor of Safety	x20 Factor of Safety
Road A	Road B	Road C
Pallet	Pallet	Pallet
Leaf Spring	Leaf Spring	Leaf Spring

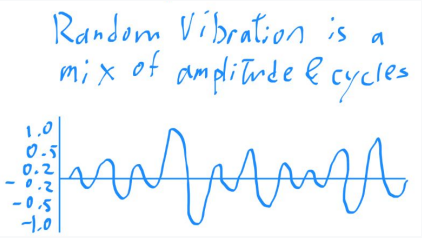
AMS

Shaker Table

Tested with No Fault @ 60 cycles at 0.2g

Factor of Safety and Stress-Cycle Curve

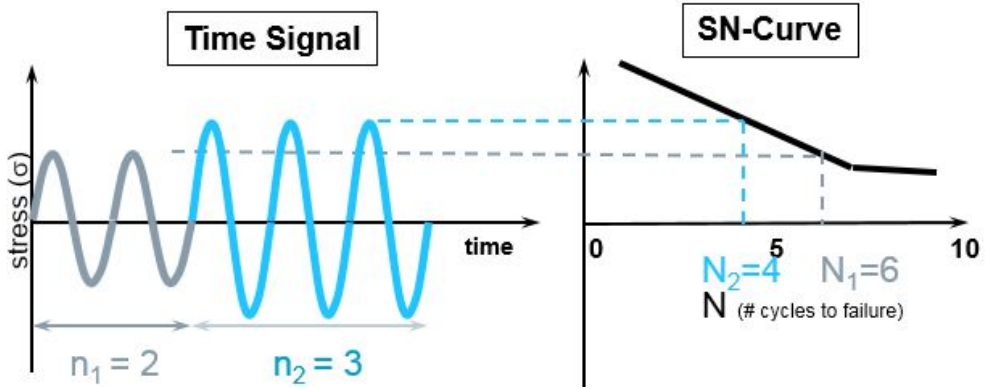




Types of vehicle and road conditions of a region contribute toward amplitude and cycle count of measured acceleration conditions.

Testing a few samples to failure is critical to determining the design's stress limit, failure modes, and whether it is **undertested** or **overtested** using Industry Standards.

First Fatigue Damage Calculation of a Google Server



Damage Tally

$D_1=n_1/N_1=2/6 = .33$

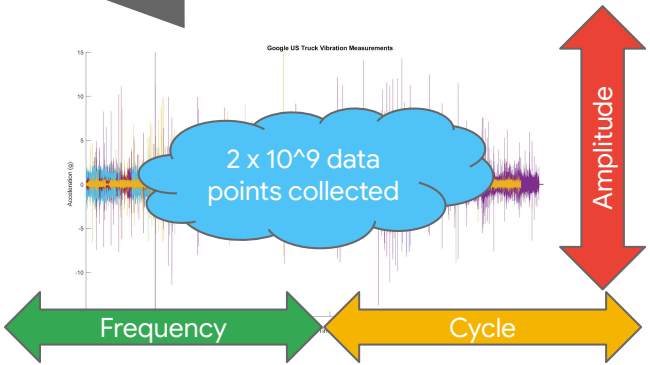
$D_2=n_2/N_2=3/4 = .75$

$D_{tot} = D_1 + D_2$

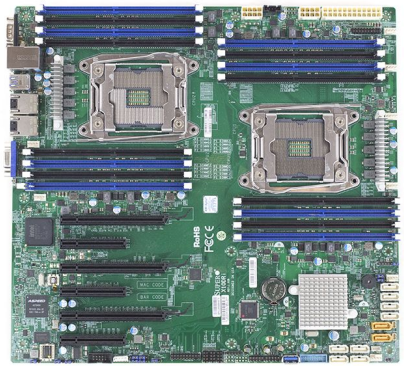
$D_{tot} = .33 + .75 = 1.08$

Factor of Safety =
1 / Fatigue Damage

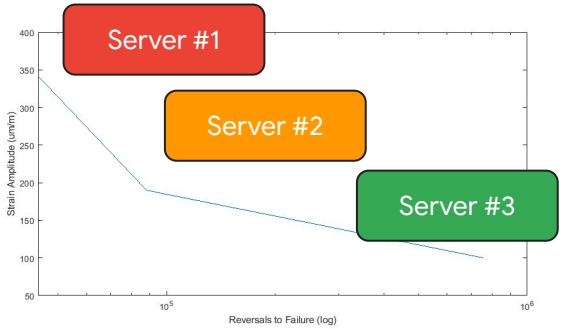
Requirements:
F.D. < 1.0 (0.7)
F.o.S. > 1.0 (1.43)



Measured Field Vibration (g)



Acceleration Input, Strain Output



Rainflow Counting of Measured Strain for Damage Tally

Durability Assessment Workflow for Vibration

Ability to leverage durable design, prioritize resources on vulnerable design, and assess risks objectively will leads to Reliability and Velocity in Product Development.

Demonstrated Durability in all Google DC Hardware