The Effects of a Water Plant Structural Foundation on Non-Clog Pump Vibration

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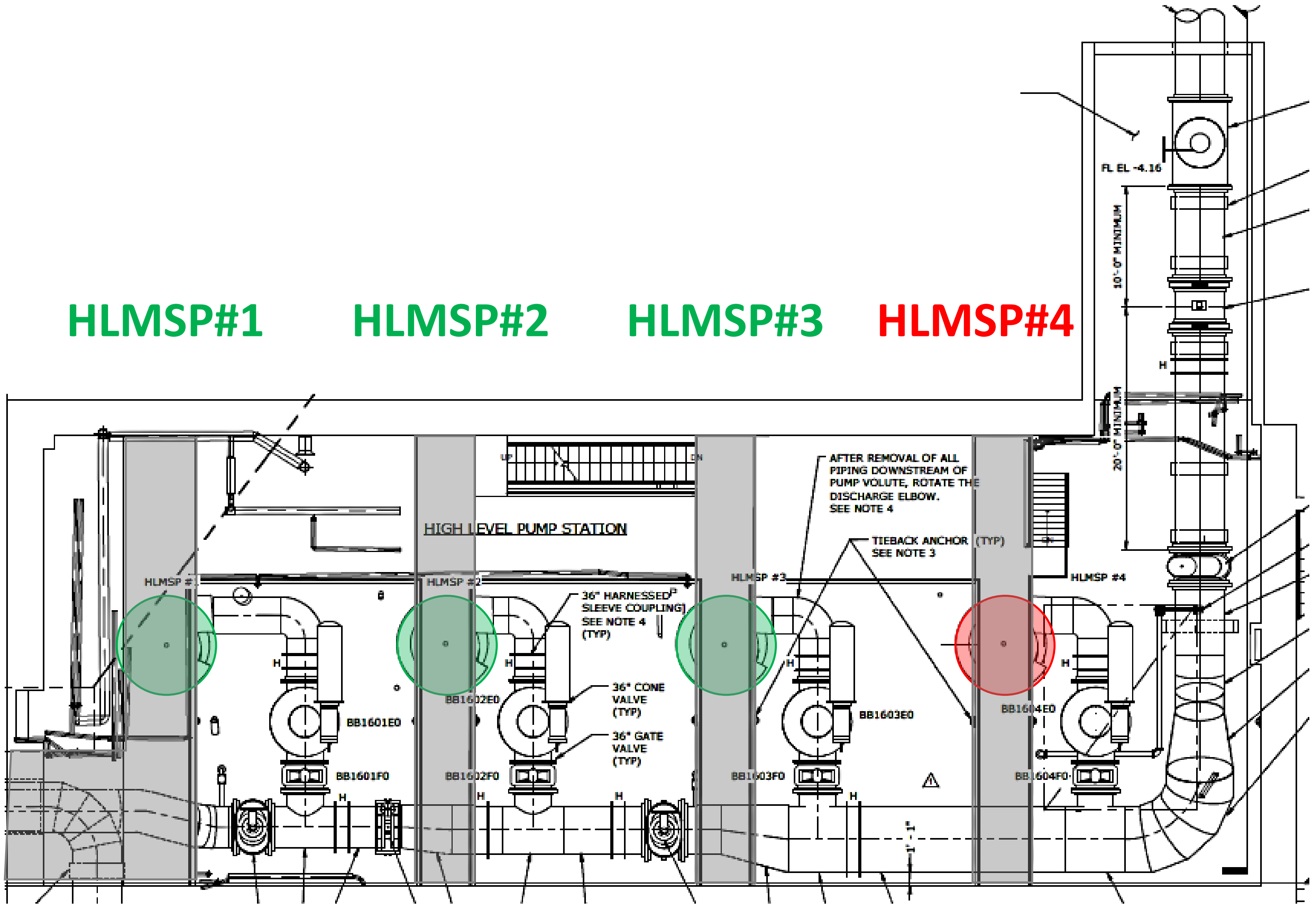
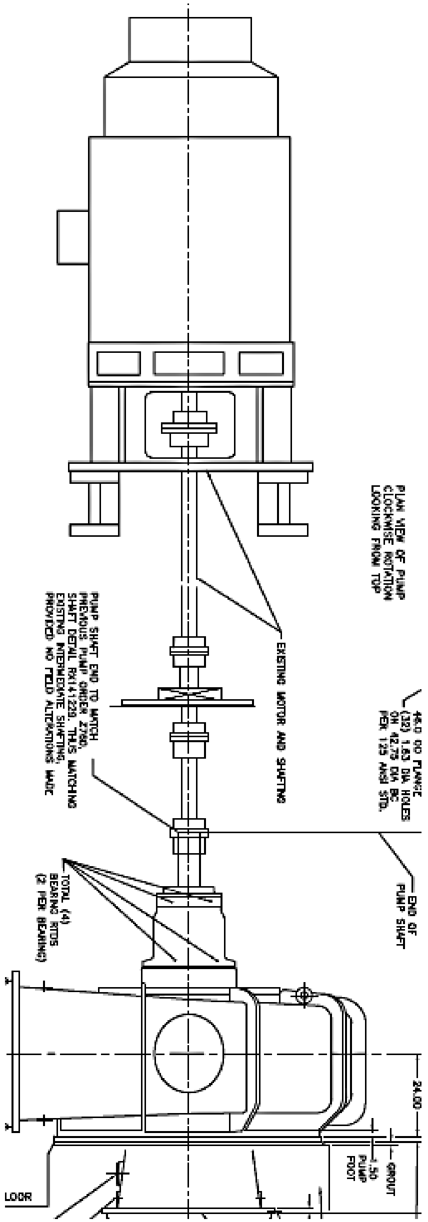
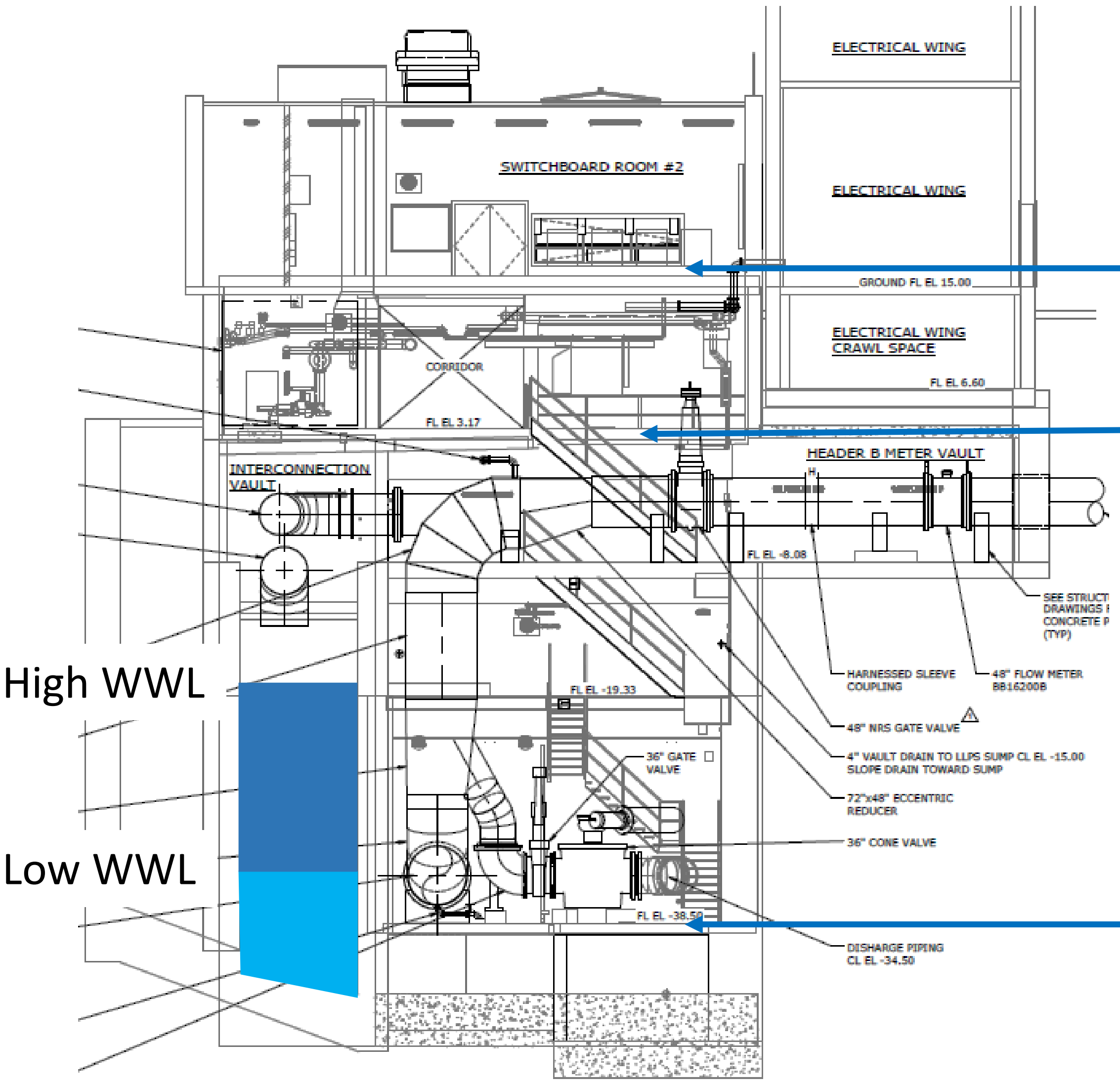
WWTP Site Layout – Plan View

Flow [GPM]	38,100
Flow [MGD]	26.5
Head [ft]	36.9
BHP [HP]	624
Efficiency	85%
RPM	393
Fluid	Raw Sewage
Temperature	85 ºF
SG	1.0



WWTP - Side View





Upper Level (Motor)

Intermediate Level (Bridge level)

Lower Level (Pump)

Site Photos

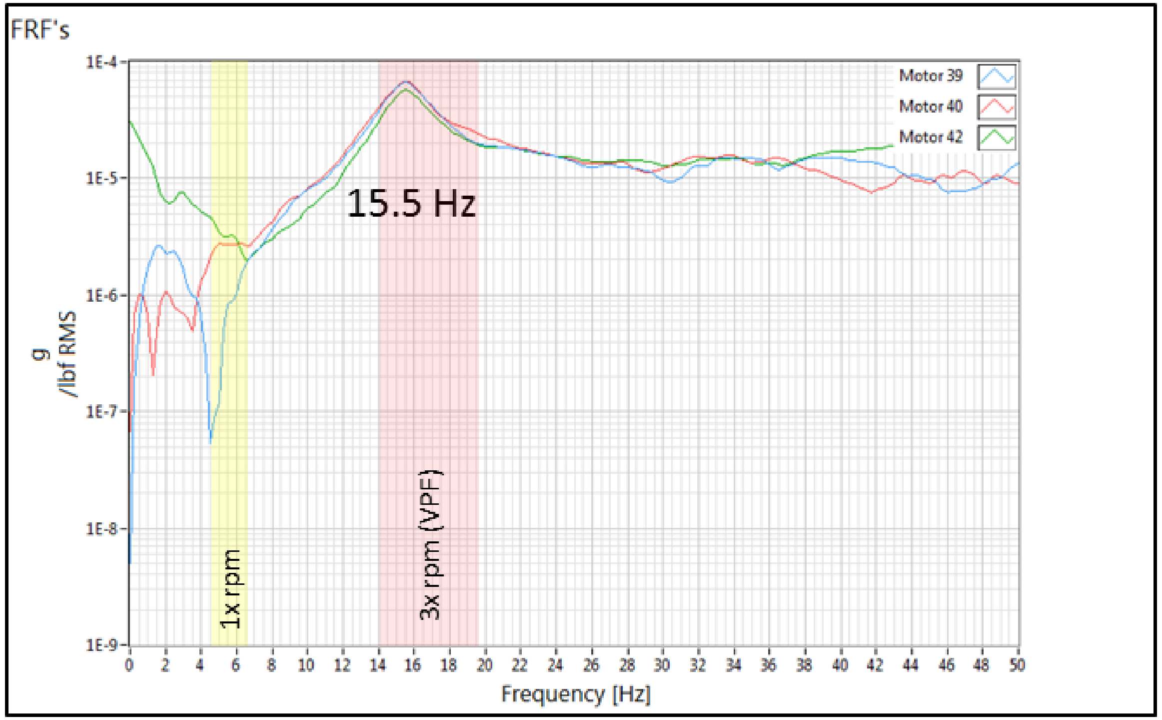
Background

- Original High Level Main Sewer Pumps (HLMSP#1 through HLMSP#4) were installed in 1963 (40 MGD).
- The pumps are driven by 450 HP induction motors through step resistors (six different speeds from 280 to 392 rpm).
- In early 2018 HLMSP#4 was replaced with a new pump (2016 design).
- In June 2018, high vibration was detected on the intermediate floor, and some vibration was at the motor level floor when the pump was operating at high speed operation.

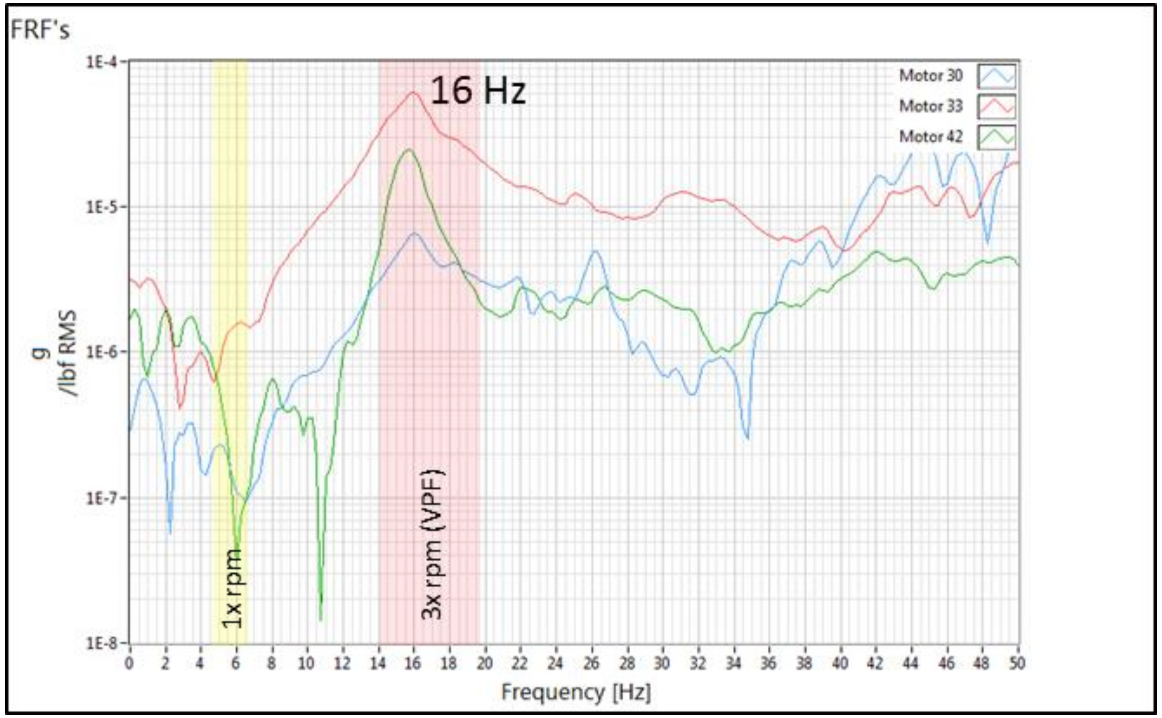
	1x rpm		VPF (3x rpm)
	cpm	Hz	Hz
Step 1	280	4.67	14.0
Step 2	299	4.98	15.0
Step 3	332	5.53	16.6
Step 4	360	6.00	18.0
Step 5	379	6.32	19.0
Step 6	392	6.53	19.6

Experimental Modal Analysis (EMA) Test

Experimental Modal Analysis (EMA) Test
HLMSP#3 & 4 Upper Level (Motor Level)

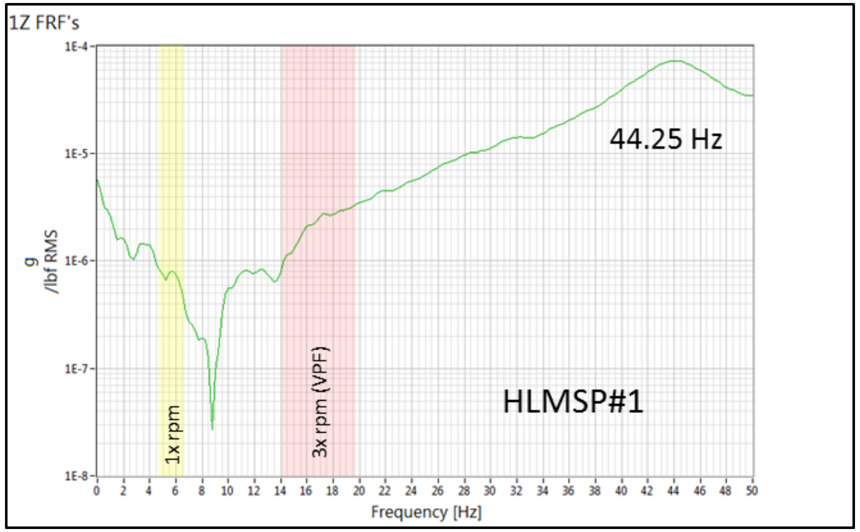


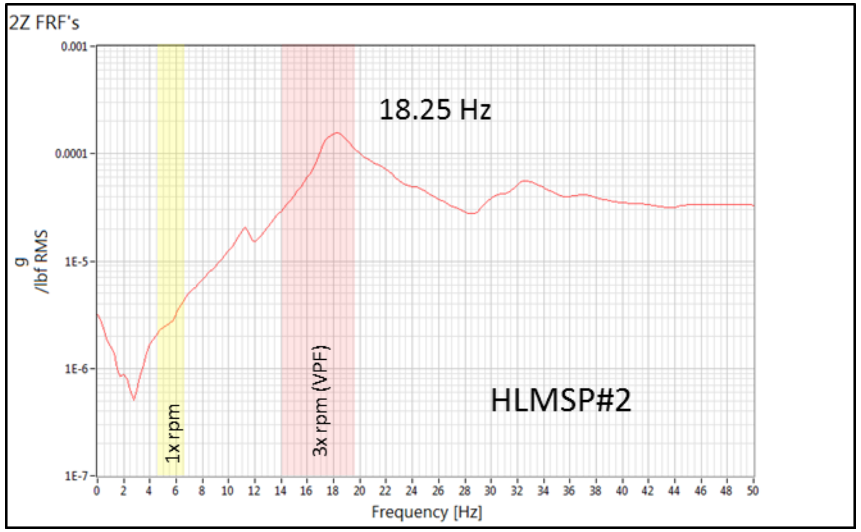
HLMSP#3 Vertical Direction

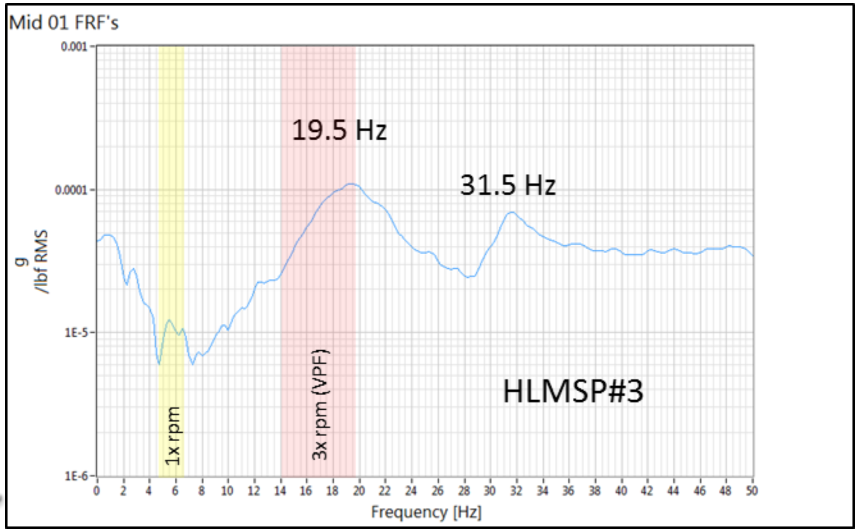


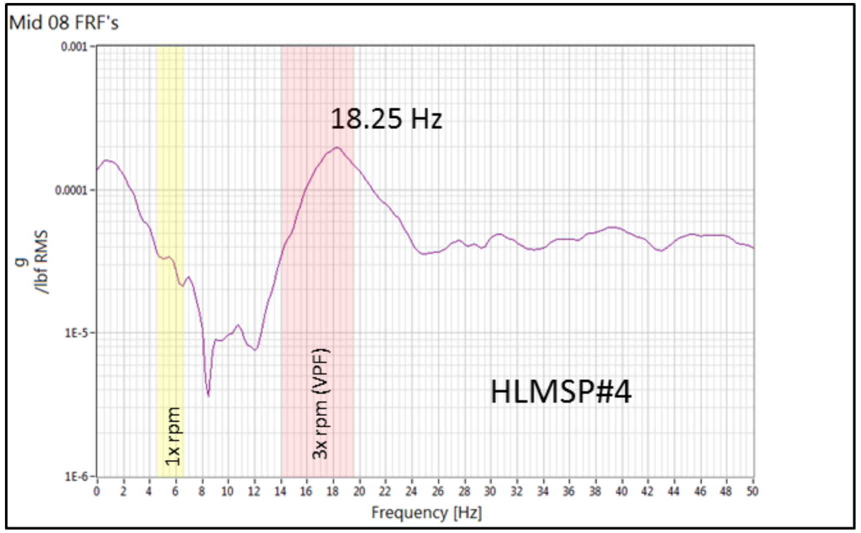
HLMSP#4 Vertical Direction

Experimental Modal Analysis (EMA) Test
HLMSP#1, 2, 3 & 4 Bridge (Intermediate Level)

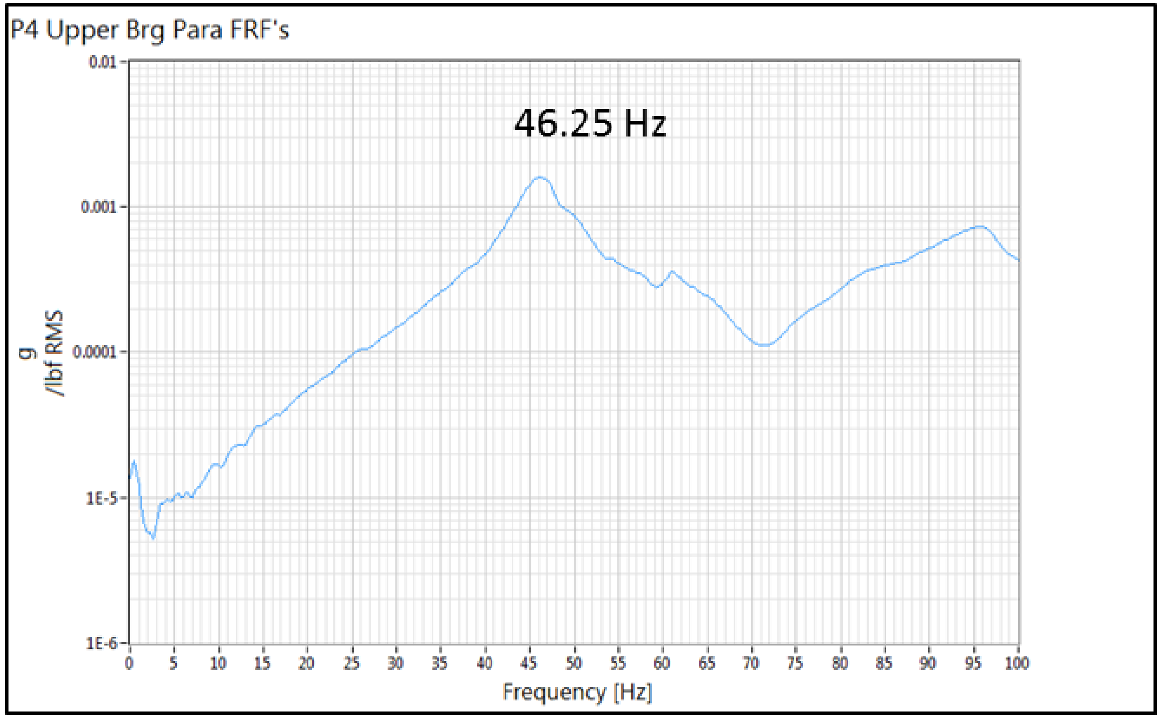




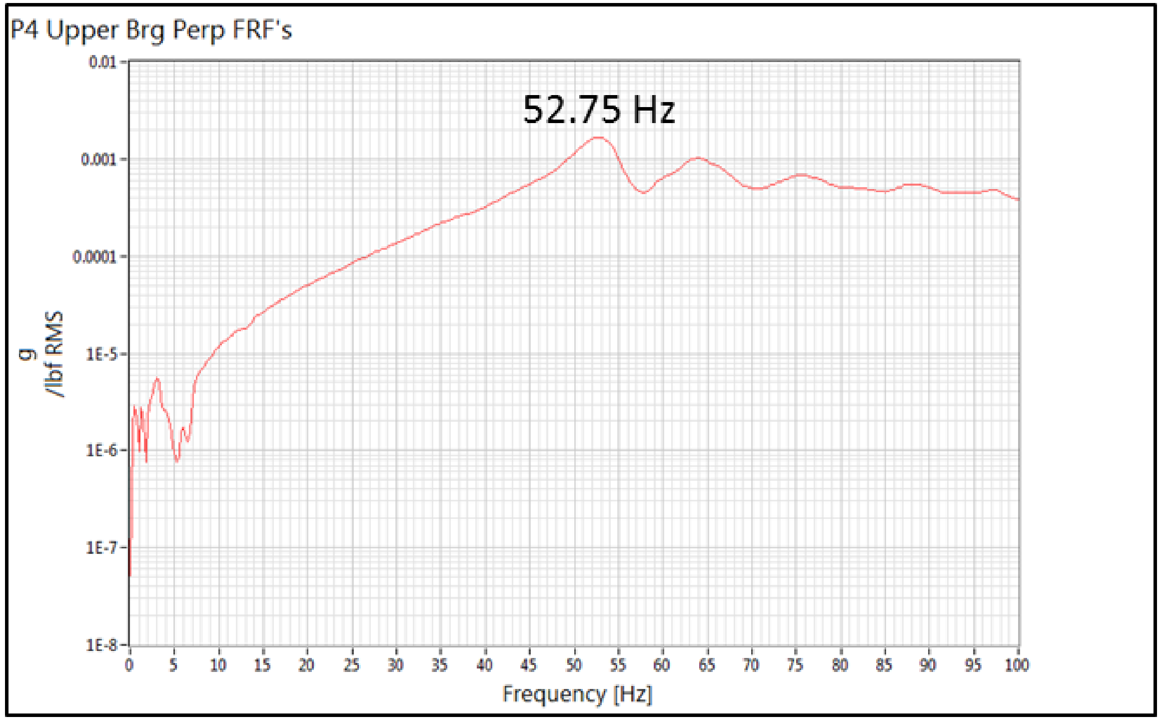




Experimental Modal Analysis (EMA) Test
HLMSP#4 Bearing Tower



HLMSP#4 Pump – Parallel Direction

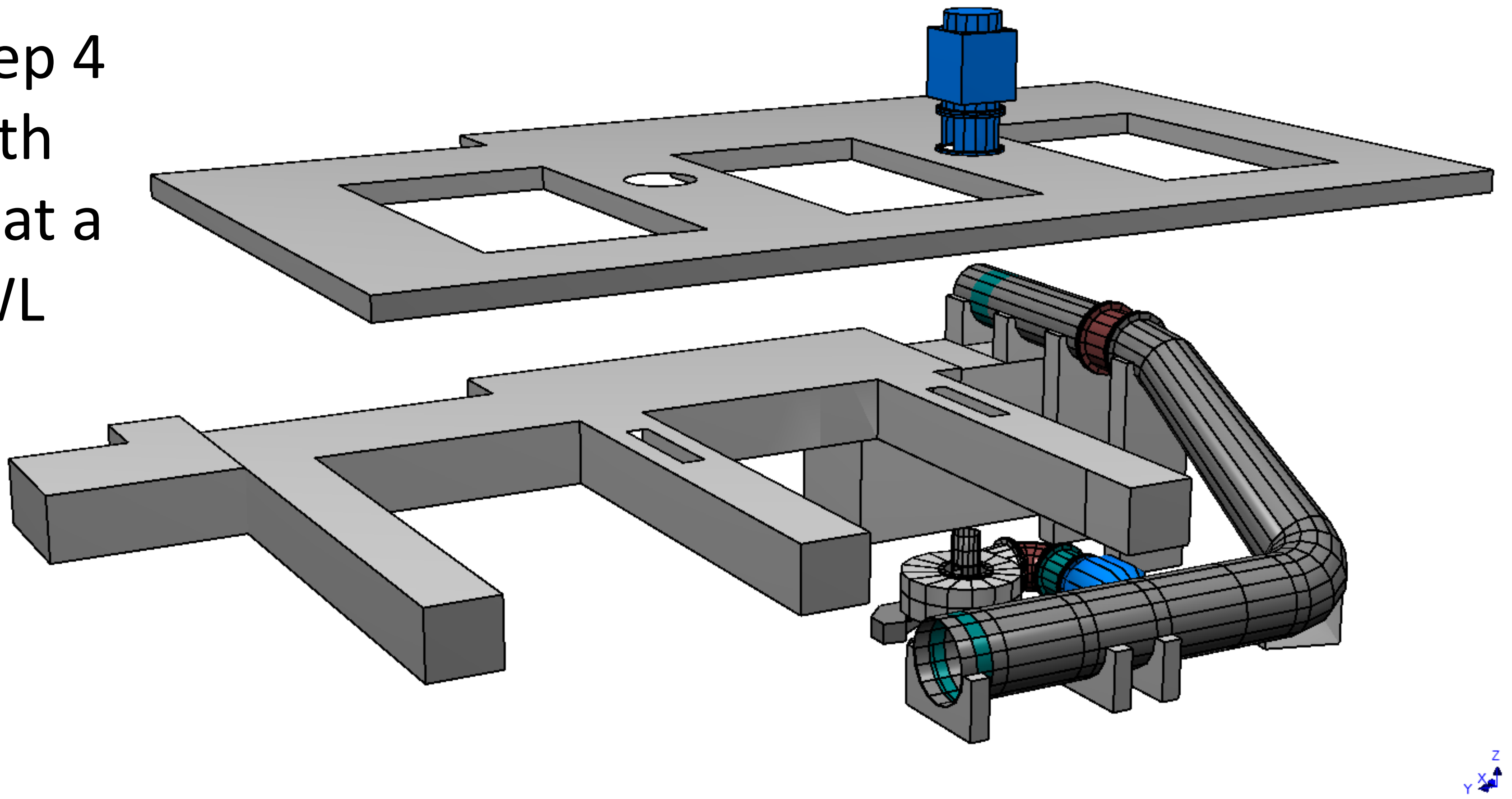


HLMSP#4 Pump – Perpendicular Dir.

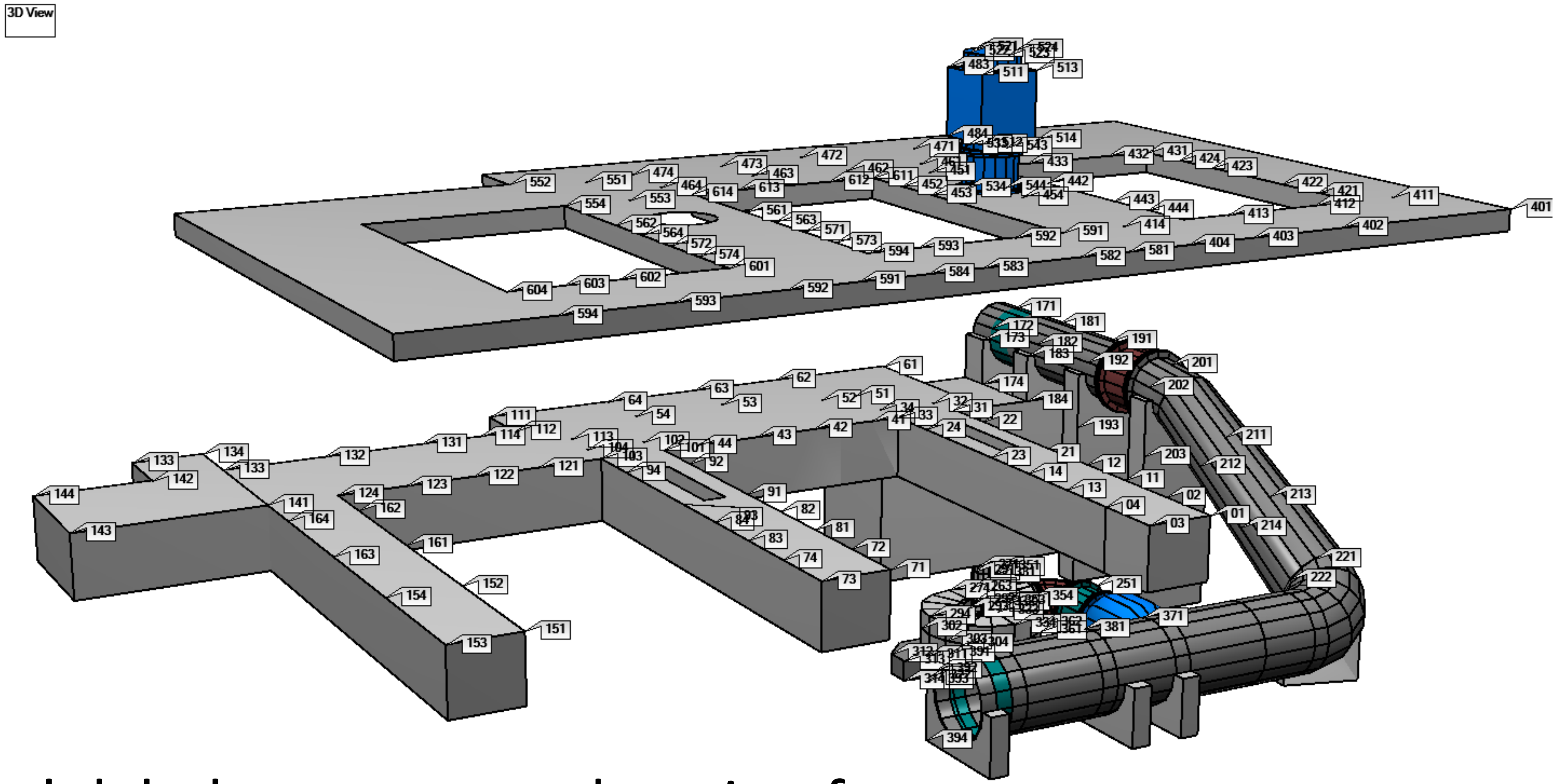
Operating Deflection Shape (ODS) Testing

Operating Deflection Shape (ODS) Detailed Computer Model

Data taken over 4 hours at Step 4 (360 rpm) with VPF at 18 Hz at a constant WWL

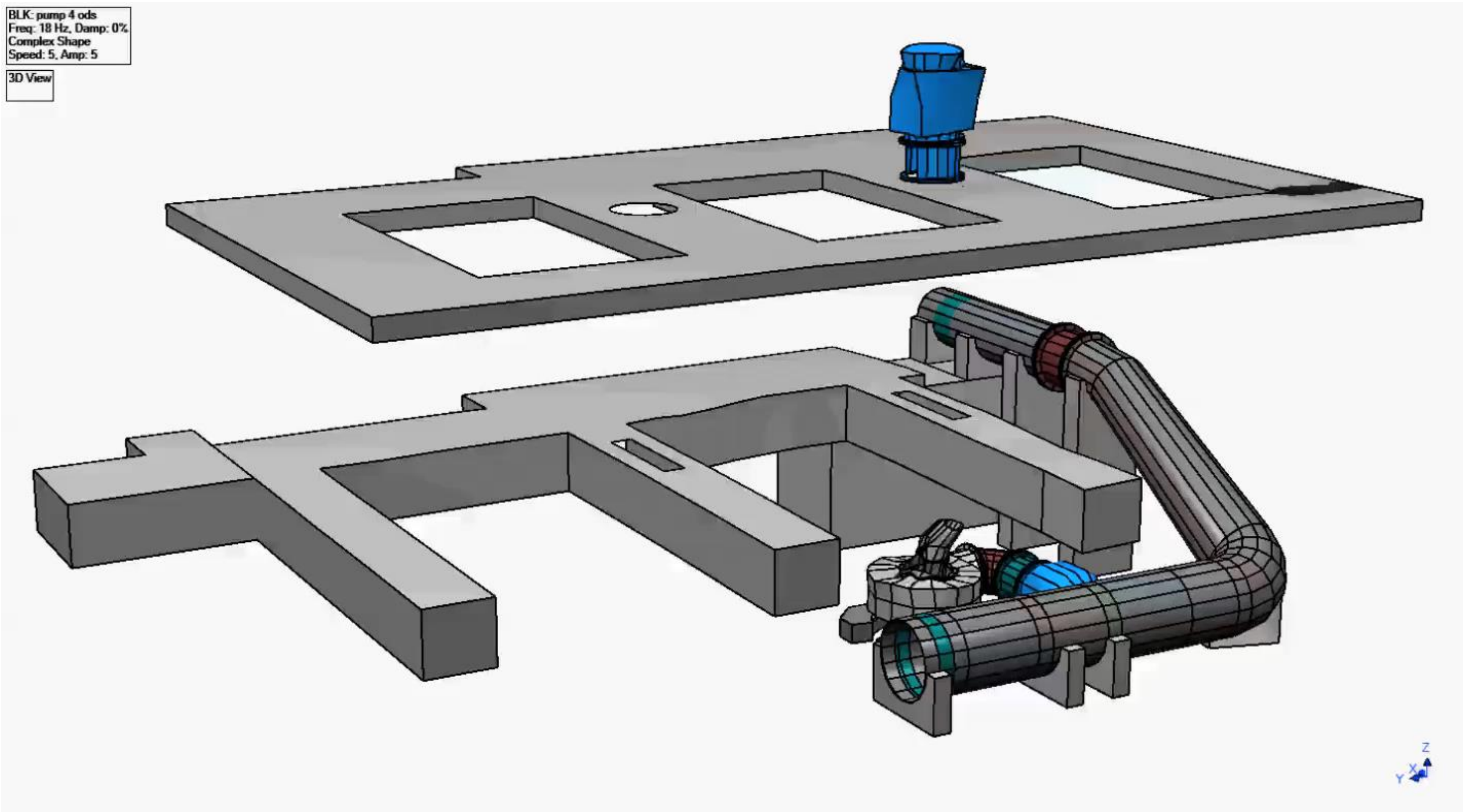


Operating Deflection Shape (ODS) Over 720 vibration locations / directions



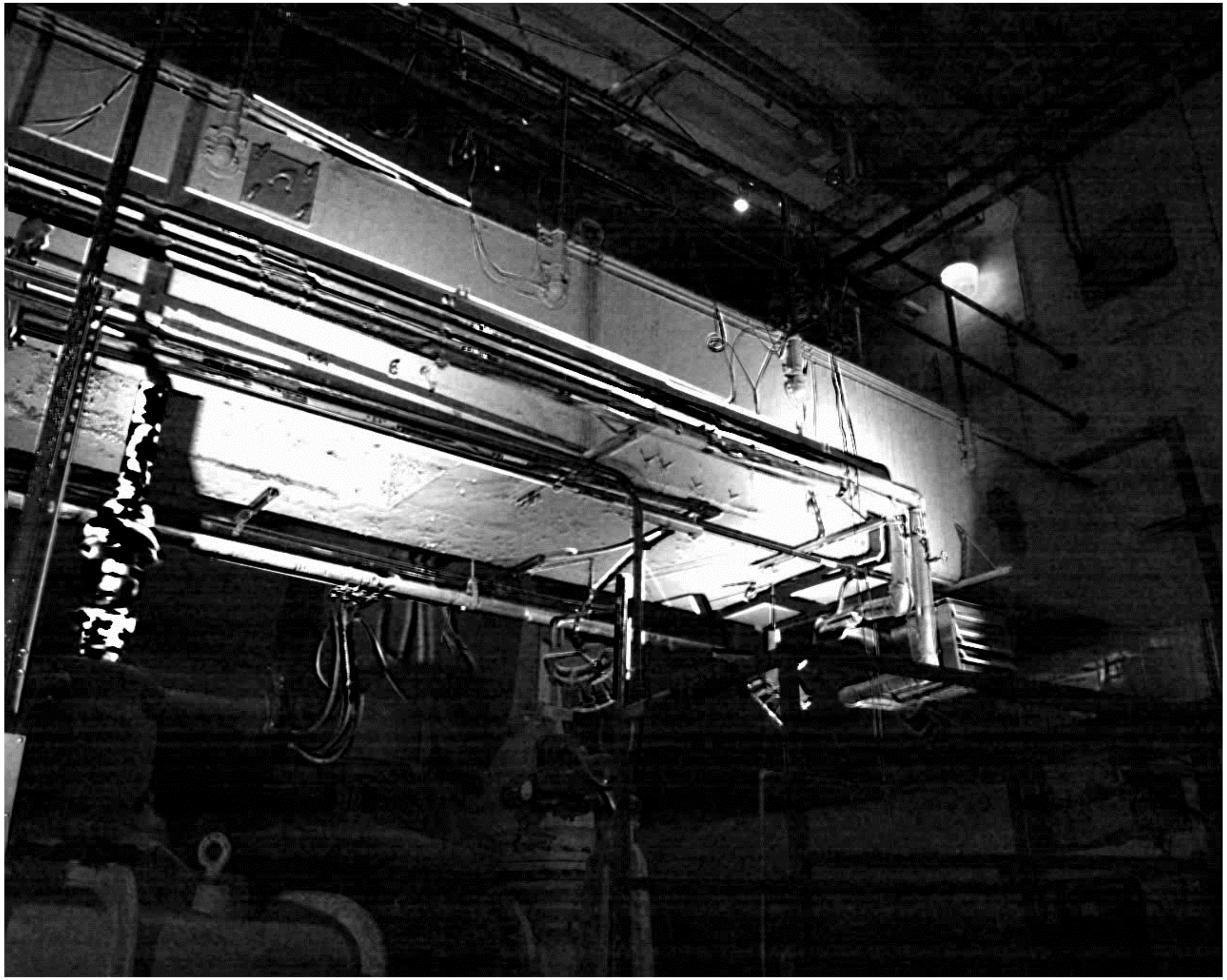
Each label represents a location for a tri-axial accelerometer

HLMSP#4 ODS Animation at 3x rpm of Step 4 (VPF or 18 Hz) with High WWL

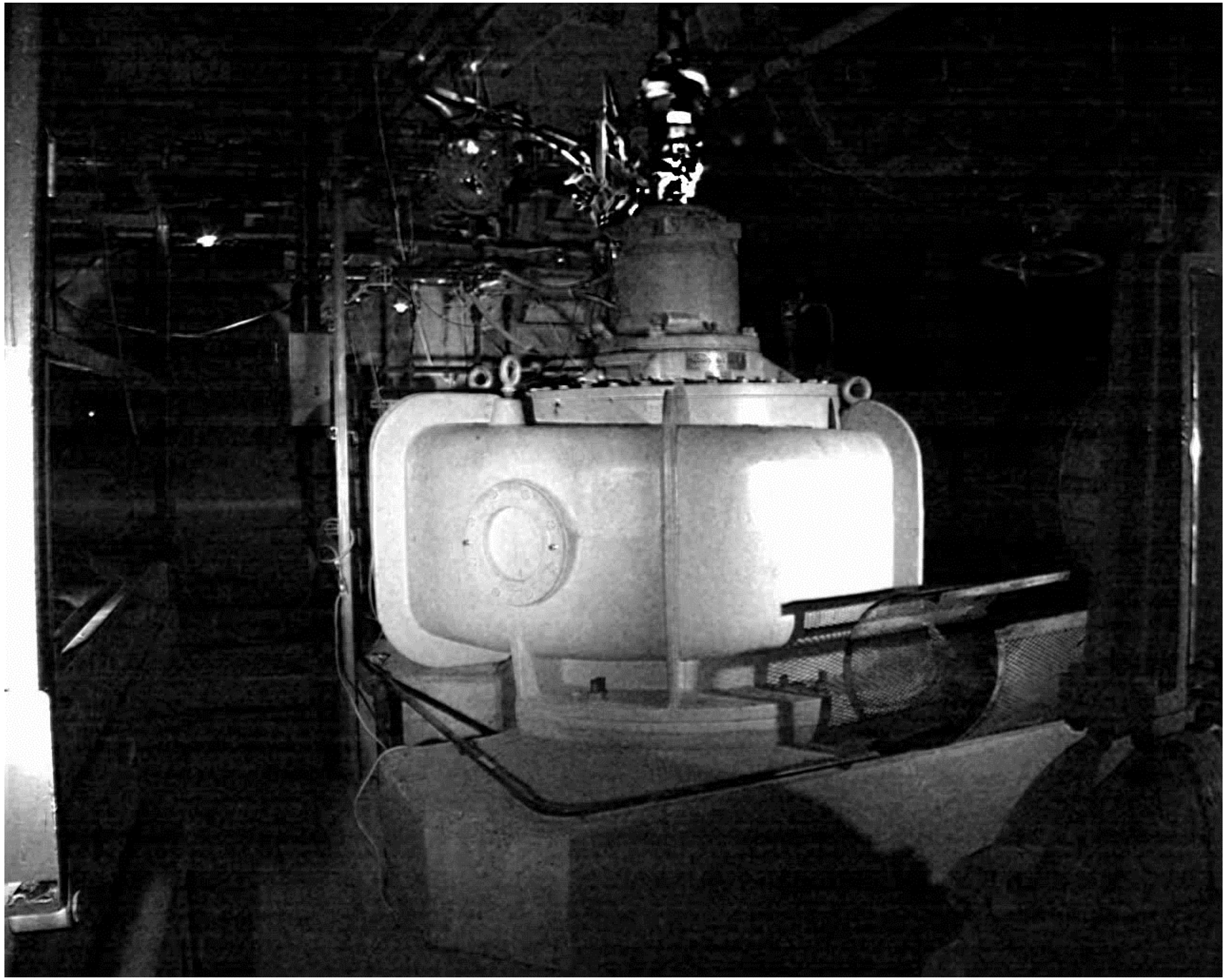


Motion Amplification Video (MAV) Testing

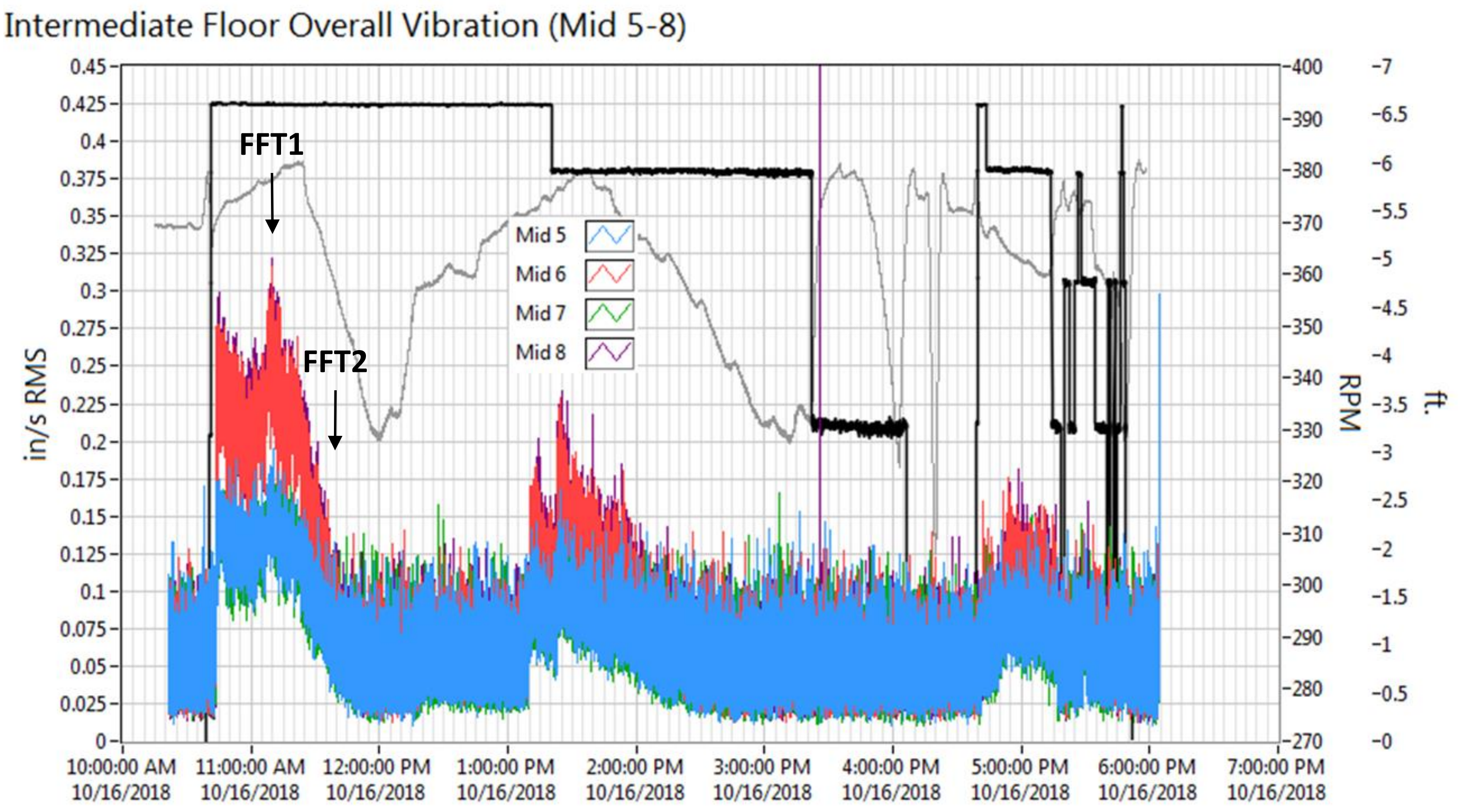
HLMSP#4 Intermediate Bearing MAV at 19 Hz (VPF at Step 5)



HLMSP#4 MAV at 19 Hz (1xVPF at Step 5)

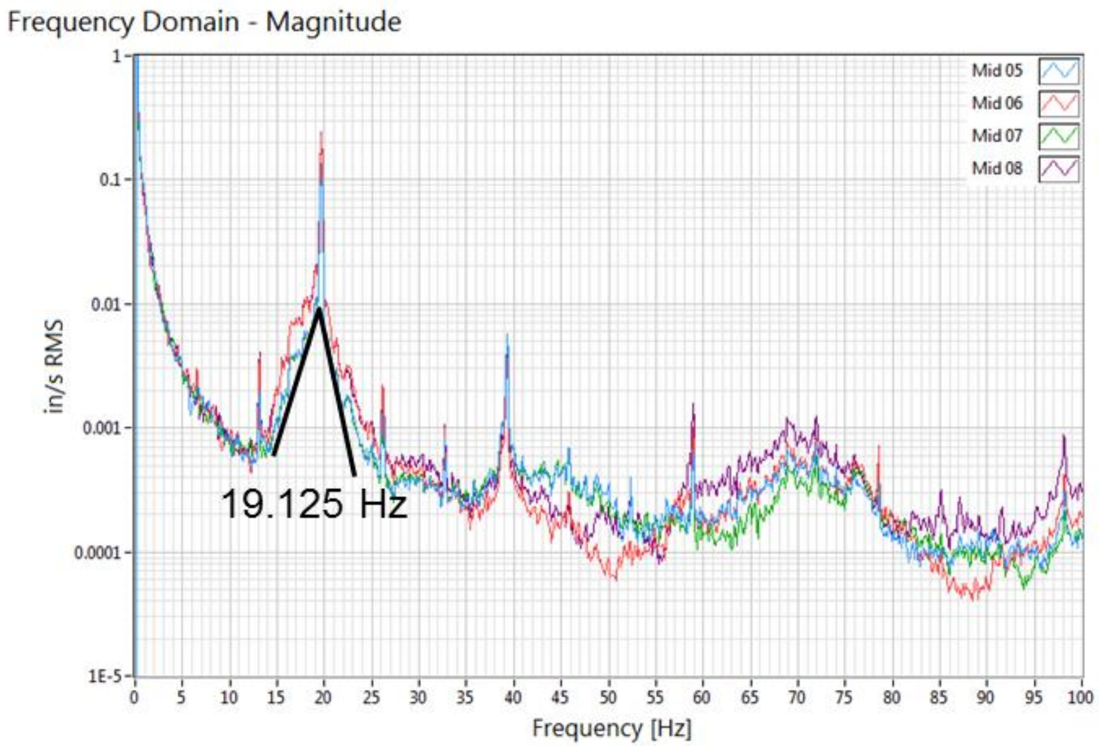


Overall Vibration at the HLMSP#4 Bridge (intermediate level) at Different WWL and Operating Speeds



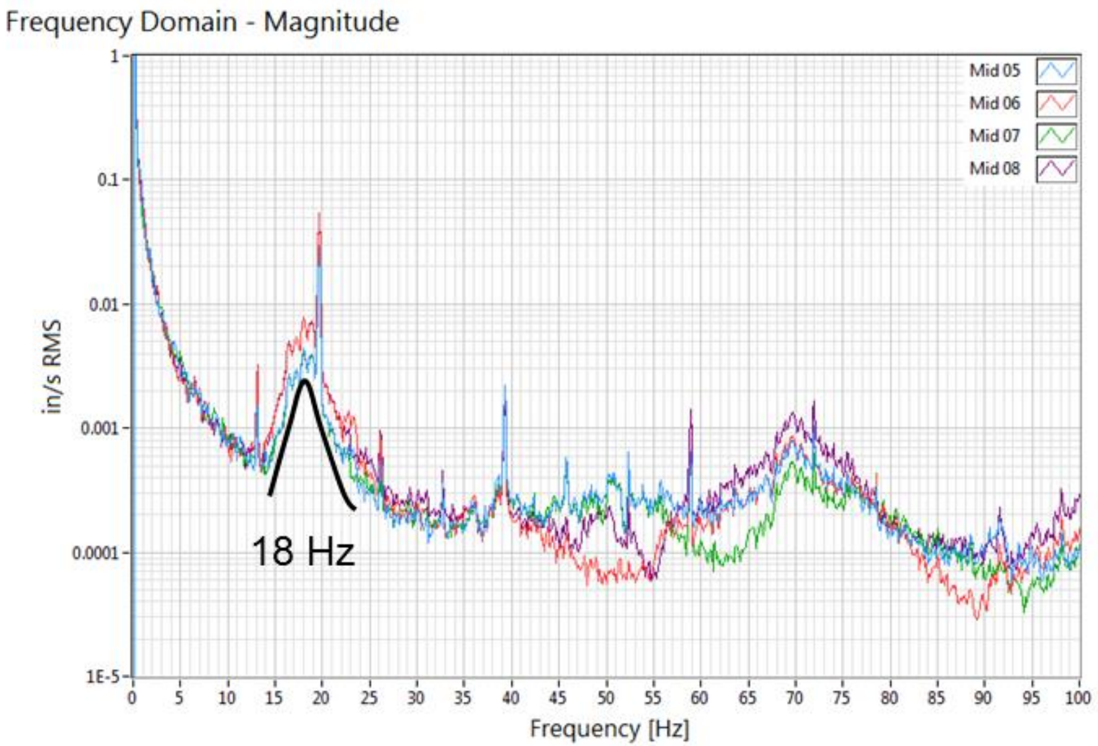
Intermediate Floor Spectra

(Same Speed & Different WWL)



FFT1

Step 6 (390 rpm) and 6 ft WWL



FFT2

Step 6 (390 rpm) and 4 ft WWL

Conclusions

1. Upper and intermediate floor vibrations exceeded the recommended limit of 0.032 in/s RMS for *Workshop and non-sensitive areas* by a factor of 10, where the vibration can be distinctly felt.
2. HLMSP#4 bearing tower vibration was higher than the HI spec of 0.34 in/s RMS for operation within the POR, but was within the HI spec of 0.44 in/s RMS for operation within the AOR. The pump operates outside the AOR at Steps 5 and 6 at high WWL. This vibration caused lateral and vertical motion of the pump.
3. Pump vibration was transmitted to the intermediate bearing through the drive shaft (original drive shaft with four couplings). It was suspected that the teeth of the gear couplings were worn out due to prolonged use and potential lack of lubricant. These gear couplings are supposed to permit and tolerate axial motion (axial slip).

Conclusions

4. The stiffness of the HLMSP#4 bridge has been compromised due to looseness detected between the bridge and the south side wall of the station, which is part of the wet well. This looseness at the wall connection caused non-linear changes in the structural natural frequency of the bridge. When the WWL was high, the water contained in the well compressed the bridge increasing the vertical bending mode of the bridge to 19.1 Hz, which fell into resonance with vane pass frequency (VPF) of the pump at Step 5 (19.0 Hz). Once the water level was reduced, the structural natural frequency of the bridge was also reduced down to 18 Hz. This increased the separation margin from the main excitation source (VPF).

Recommendations

1. Replace all four gear couplings in order to properly accommodate axial motion from the pump shaft. The intermediate bearing should also be replaced.
2. If the drive shaft and couplings are to be replaced, it is recommended to use flexible couplings (shim-pack). A detailed FEA analysis should be conducted prior to replacing the drive shaft in order to avoid potential torsional and lateral resonances with 1x rpm and VPF excitation sources.
3. The structural connection of the intermediate level bridge of HLMDL#4 with the wet well wall should be inspected by a qualified structural/ civil engineer to determine if the joint has been compromised.

Recommendations

4. The pump station should consider supporting the bridge of HLMSP#4 from the pump level using vertical I-beams anchored at the top and bottom or by using an additional concrete pier. Additional supports should also be considered near the north side of the station.