CASE STUDY
ANALYSIS OF CENTRIFUGAL FAN HIGH AMPLITUDE VIBRATION

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Abstract: A request was received to determine the root cause of very high amplitude vibration of a spray dryer fan. The fan was an AMCA Arrangement 8, 500 Hp. The fan's vibration amplitudes had reportedly been trending up. Balancing the fan had not reduced vibration to acceptable levels. The analysis used visual inspection, vibration data, operating deflection shape analysis (ODS) and experimental modal analysis to determine the root causes. Problems identified included operation at the 1st critical speed of the fan rotor, anchor bolt failures, loose bolting, improperly sized bolting, improperly installed anchor bolts, lack of grouting during installation, extensive corrosion and erosion of the fan housing. Recommendations were provided to properly install anchor bolts and steel reinforcement to anchor the fan to the foundation. This article discusses the findings of the inspection and vibration analysis process. The client decided not to install the recommended base stiffening but rather to replace the fan.

Keywords: Anchor Bolts, Bolting, Concrete Foundation. Experimental Modal Analysis, Operating Deflection Shape Analysis.

Background: The AMCA Arrangement 8 fan, shown in **Figure 1**, had an operating speed of 1195 RPM, direct driven by a 500 HP motor using a Rexnord Omega coupling. The fan capacity was 84,000 CFM. The fan base was fabricated of A36 HRS (hot rolled steel) and bolted directly to a concrete foundation with no grout. The wheel hub fit to the shaft was a straight interference fit, using set screws and an end cap. It was reported that the fan's vibration had been steadily increasing and anchor bolts had broken. It was also reported that the fan was recently balanced.

Figure 1. AMCA Arrangement 8 Fan.

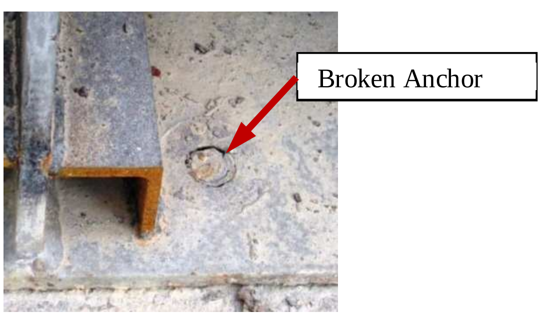

Figure 2. Broken Anchor Bolts on Fan Base.

Figure 3. Unsupported Wing for Anchor Bolts.

Visual Inspection: With the fan shutdown and locked out, a visual inspection of the duct work, fan housing and wheel were made. One of the broken anchor bolts is shown in **Figure 2**. Bolt fatigue failure often occurs when there is inadequate stretch length of the bolts. For this fan installation, only about ½” of stretch length was provided for the anchor bolts, see **Figure 5**. The rule of thumb is a stretch length of 10 to 12 bolt diameters. An effort had been made to reduce vibration of one corner of the fan base by welding a stiffener and installing an anchor bolt, see **Figure 3**. Motor and bearing housing hold down bolts had washers that were too thin and the washer ID too large, see **Figure 4**. The fan bearings were unshielded, see **Figure 8**. During the original installation of the fan, no grout was used between the fan base and the concrete, see **Figure** 5.

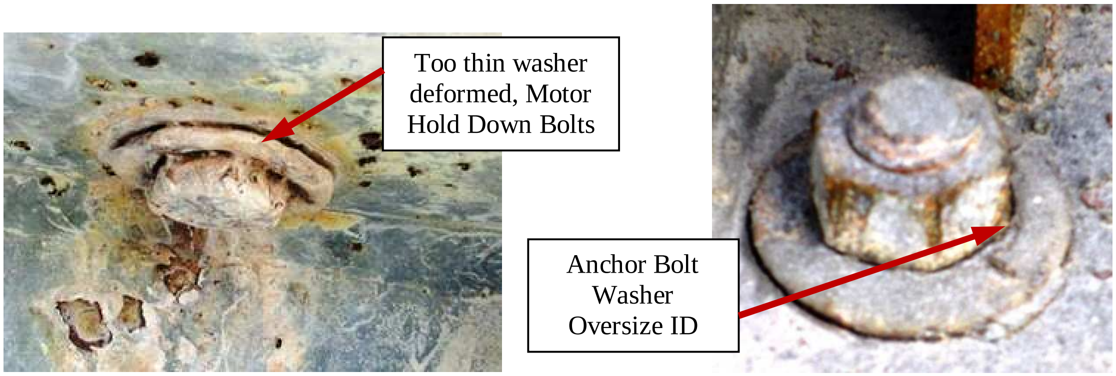

Figure 4. Washers Were Too Thin and the Washer ID Too Large (Corners Of Nuts Contacting the Washers)

Fan hub had a straight fit and keeper washer to prevent the hub moving off the fit. However, there was about 1/8” gap between the retainer washer and the hub, see **Figure 6**.

During original installation of the fan, no grout was used between the fan base and the concrete, see **Figure** 5.

Figure 5. No Grout Under Fan Base. Pronounced Movement Between Base and Foundation.

Figure 6. Wheel Hub and Retaining Bolt & Washer Gap.

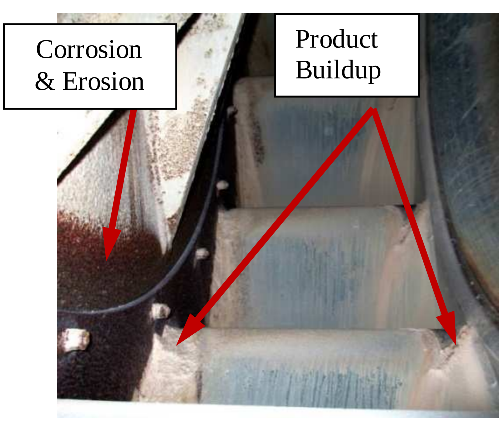

Figure 7. Material Buildup on Fan Wheel.

Figure 8. Bearings Were Unshielded.

The fan wheel had some product buildup on the fan blades, see **Figure** 7. The fan wheel and fan housing exhibited corrosion and erosion. The housing had been patched in several locations by welding thin material to the inside of the housing to cover holes. The fan bearings were unshielded, see **Figure 8**.

Vibration Analysis: Vibration data were measured using a portable spectrum analyzer. The frequency spectrum showed most vibration at 1X run speed frequency. Highest amplitude at the bearing housings was in the horizontal direction. Spectra and time domain data measured at the fan end bearing housing are shown in **Figures 9 & 10**. Multiples of the run speed frequency was in the frequency spectrum in the vertical direction.

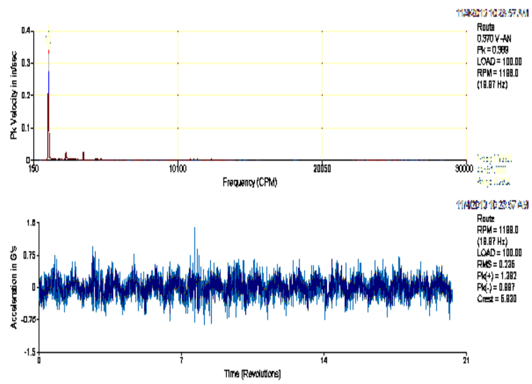

Figure 9. Frequency & Time Domain Data Measured on the Fan End Bearing Housing Horizontal.

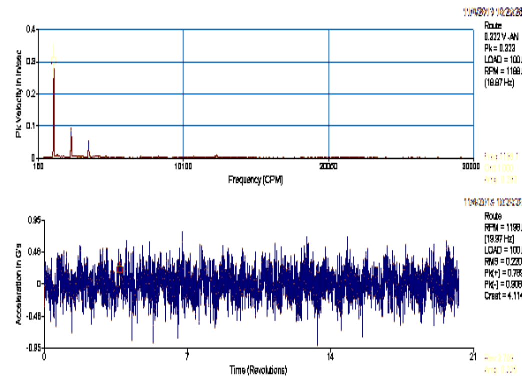

Figure 10. Frequency & Time Domain Data Measured on the Fan End Bearing Housing and Vertical.

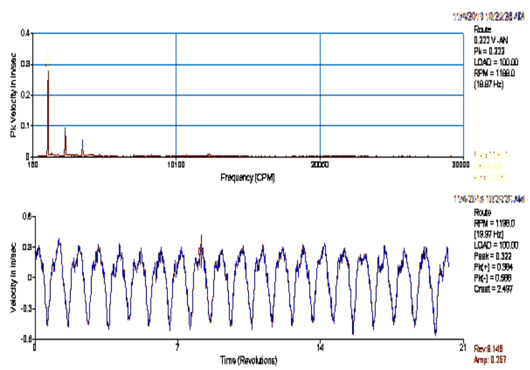

Figure 11. The Data on the Fan End Bearing Housing Vertical Direction, Time Data in Velocity in/sec.

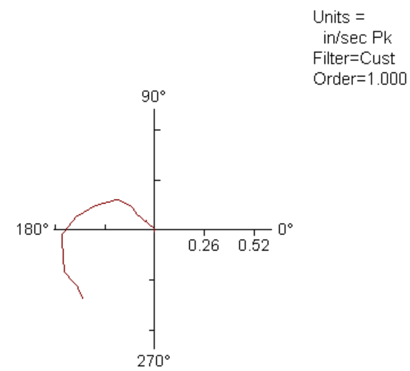

Figure 12. Polar Plot 1X Amplitude & Phase Lag During Coastdown.

Plotting the bearing housing vertical vibration time domain data in velocity clearly showed non-sinusoidal vibration due to the loose bearing housing hold down bolts , see **Figure 11**.

Coast down data was measured at the fan coupling end bearing. Reflective tape on the shaft and a laser tachometer provided the once per revolution signal. The coast down data in polar format, shown in **Figure 12**, showed that the fan was operating at a natural frequency.

The coast down data is also plotted in bode format in **Figure 13**. Close inspection of the data shows that the vibration amplitude decreases then increases before dropping dramatically. The data clearly indicated the fan was operating at the 1st critical and that the critical was split or bifurcated due to asymmetric support stiffness.

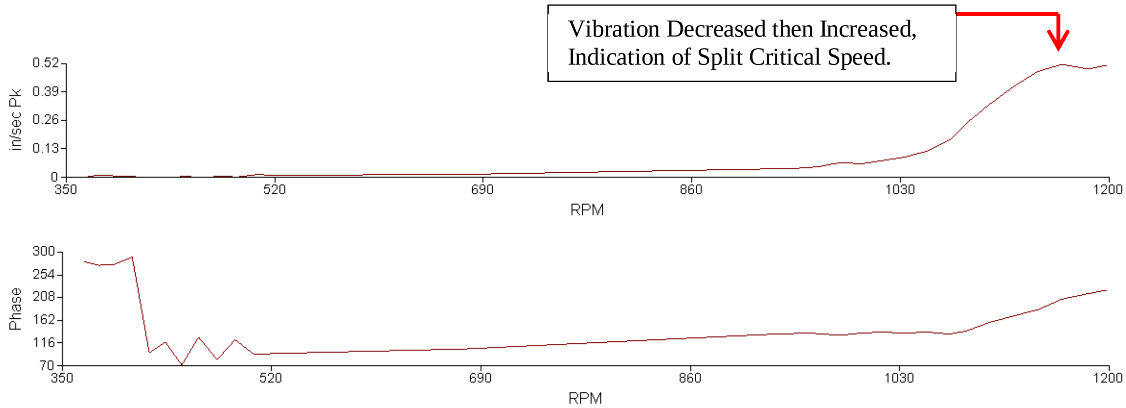

Figure 13. Bode Plot During Coastdown, Fan Coupling End Bearing Horizontal Direction.

Modal Analysis: As additional confirmation of a critical speed near the fan running speed frequency, modal driving point measurements were made on the fan bearing housings and the fan wheel. A medium sledge modal hammer and accelerometer were used. The frequency response function (FRF) measured on the fan wheel in the axial direction at the rim is shown in **Figure 15**. Two natural frequencies were measured at 1069 and 1200 CPM as indicated by the cursors. A rigid body rocking mode of the fan was at 1406 CPM.

FRF were also measured at five locations along the fan shaft, see **Figure 14**. The FRF were curve to determine the mode shape of the rotor natural frequencies near run speed. The shaft natural frequency mode shape is shown in **Figure 16**. The mode shape showed little flexure of the shaft was occurring. This indicated that the rotor mode (1st critical) was primarily controlled by the low stiffness of the bearings & pedestal due to loose anchor bolting.

Figure 14. Portion of Fan Shaft Showing Location of Modal Test Points.

Figure 15. Modal Data Fan Wheel Axial Direction Shows Rotor 1st Critical Near Run Speed.

To more clearly illustrate what we were looking for in the modal test data, a model of an overhung fan is used to illustrate the expected response. A rotor dynamic model of a typical overhung fan is shown in **Figure 17**. This <u>model is not of this particular fan but is similar</u>. The fan 1st critical mode shape calculated by the rotor modeling software has the mode shape shown in **Figure 18**. This is similar to the shape measured by the modal data FRF, **Figure 16**, except that the measured mode shape shows very little shaft flexure due to the low support stiffness.

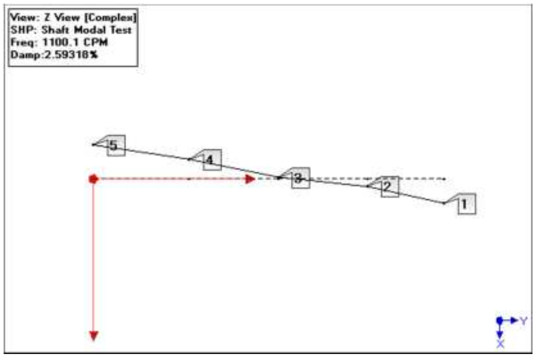

Figure 16. Modal Test of Exposed Fan Shaft Between Bearings.

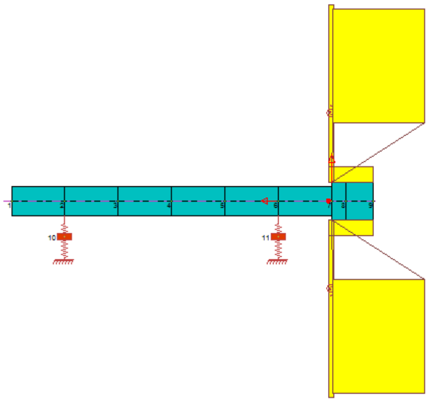

Figure 17. Example of Overhung Fan Rotor Model.

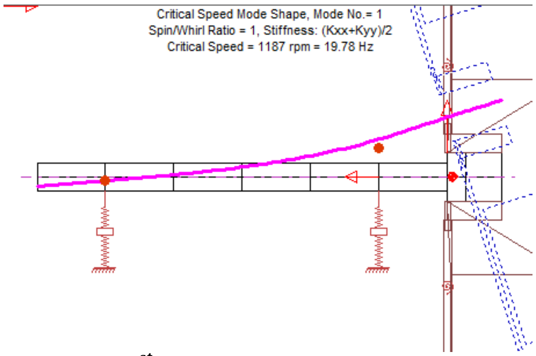

Figure 18. 1st Critical Speed Mode Shape of Typical Overhung Fan.

Fan ODS: Cross channel vibration data were measured at various locations on the motor, fan base and concrete for an ODS. The vibration data were measured using a CSI 2130 2 channel analyzer, uploaded to AMS software then the ODS FRF exported to ME'scopeVES software. The model, shown in **Figure 19**, was developed using ME'scopeVES software. Vibration amplitude is labeled for several points on the model shown in **Figure 20**.

The vibration shape or pattern was rocking side-to-side, pivoting about a centerline just above the surface of the concrete base. The motor and wheel end bearing exhibited movement relative to the bearing support plate confirming loose attachment.

There was very low amplitude vibration of the concrete pad indicating it had very little participation in the fan vibration.

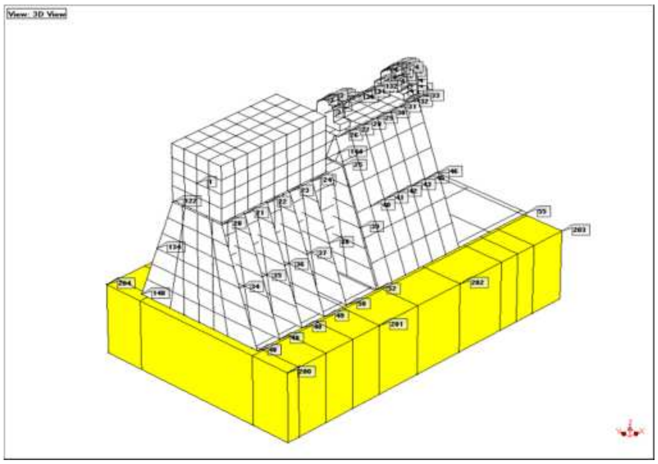

Figure 19. Fan Model Developed in ME'scopeVES.

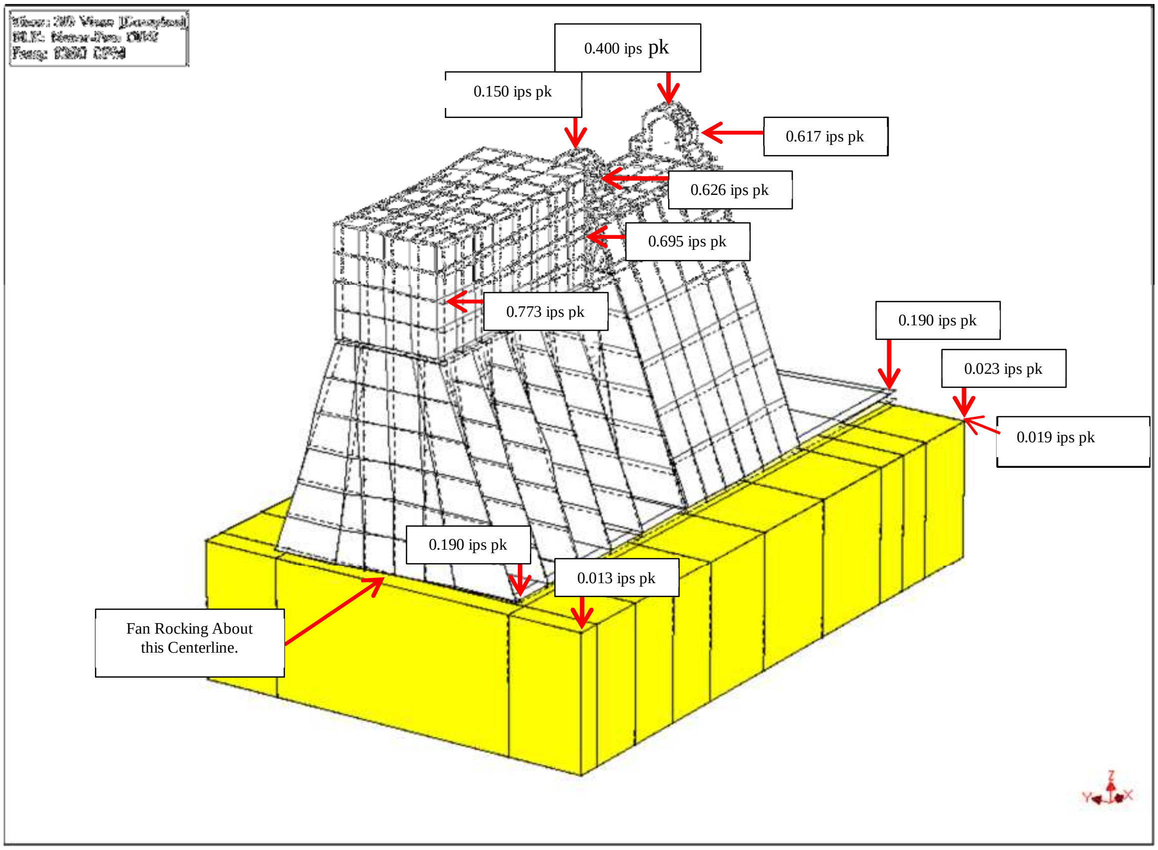

Figure 20. Animated ODS at Fan Run Speed Frequency.

Conclusions: Based on visual inspection and vibration test data conclusions were as follows:

- Resonant frequencies of the rotor/bearings and fabricated fan base were measured near the run speed frequency of the fan. The resonant frequencies of the rotor and support system calculated to have an amplification (Q) factor of 10.4. This resulted in significant amplification of the vibration forcing function of unbalance causing very high amplitude vibration.

- The anchor bolts on the bottom of the fan pedestal were fastened through a base plate which was too thin. Anchor bolts installed in the concrete pad were installed so that only about ½” bolt stretch could be obtained.

    - Typically a sleeve is installed around the bolts to prevent concrete and grout from contacting the bolts. This provides stretch over an adequate length of the bolt of 10 to 12 diameters to prevent over stressing during tightening.
    - Several bolts had broken and others were loose causing excessive flexure of the fabricated base.
    - The anchor bolt washers were too thin. This resulted in deformation of the washers and the inability of the bolted assembly to stay properly tensioned. The use of double spherical washers would prevent bending loads on the bolts.

- The severe rocking motion of the entire fan assembly was a result of wheel unbalance amplified by the natural frequency near running speed and the loose mounting of the fan assembly to the concrete foundation. The ODS animation showed the rocking motion to be approximately about the center of the base parallel to the drive centerline.

- The motor hold down bolts had flat washers which were too thin and had deformed into the base holes. This created a loose mounting and allowed relative motion or vibration of the motor to the base.

- The fan bearing hold down bolts used flat washers. Both bearing housings exhibited looseness but the fan end bearing had significant relative motion to the bearing support plate.

Recommendations: Recommendations were made to improve attachment of the fan pedestal to the concrete, motor attachment bolts, the fan shaft bearing housing mounting bolts and the fan wheel attachment bolt, washer and the hub to shaft fit.

1. The concrete anchor bolts must have a minimum free stretch length of 10-12 times the bolt length for optimal tensioning and resulting clamping force. Double spherical washers should be used to prevent side loads on the bolts.

2. Fan hub to shaft fit is optimally a taper fit with advance calculated to allow for centripetal and thermal coefficient of expansion to maintain an interference fit.

3. The fan base to concrete foundation should be fully grouted to provide vibration free service.

4. All attachment bolts for bearings and the electric motor should be grade 8, with thick washers under both the bolt head and the nut. Washer clearance to bolt should be no more than 1/32nd inch.

5. The primary forcing function causing vibration is unbalance forces generated by the fan wheel assembly. Cleaning the particulate build-up might help. However, the condition of the wheel itself, as a result of corrosion and erosion, plus operating on a 1st critical speed may make further balance improvement improbable.

6. Drawings are provided showing the installation of a 3/4″ thick X 4″wide steel plate welded to the existing frame and providing for new anchor bolt locations. This may provide an immediate solution to reduce vibration also coupled with replacement of the fan wheel and housing.

7. The fan bearings should be replaced in the near future with sealed or at minimum, shielded bearings assemblies. The current open bearing arrangement allows contamination from weather related elements as well as air borne particulates.

8. Consider a total replacement of the fan, drive, inlet ducting, and foundation which would provide the best life cycle costs. If variable flow is required, a variable speed motor should be considered. Straight fan blades tend to collect particulates in the process gas or fluid less that curved blades.

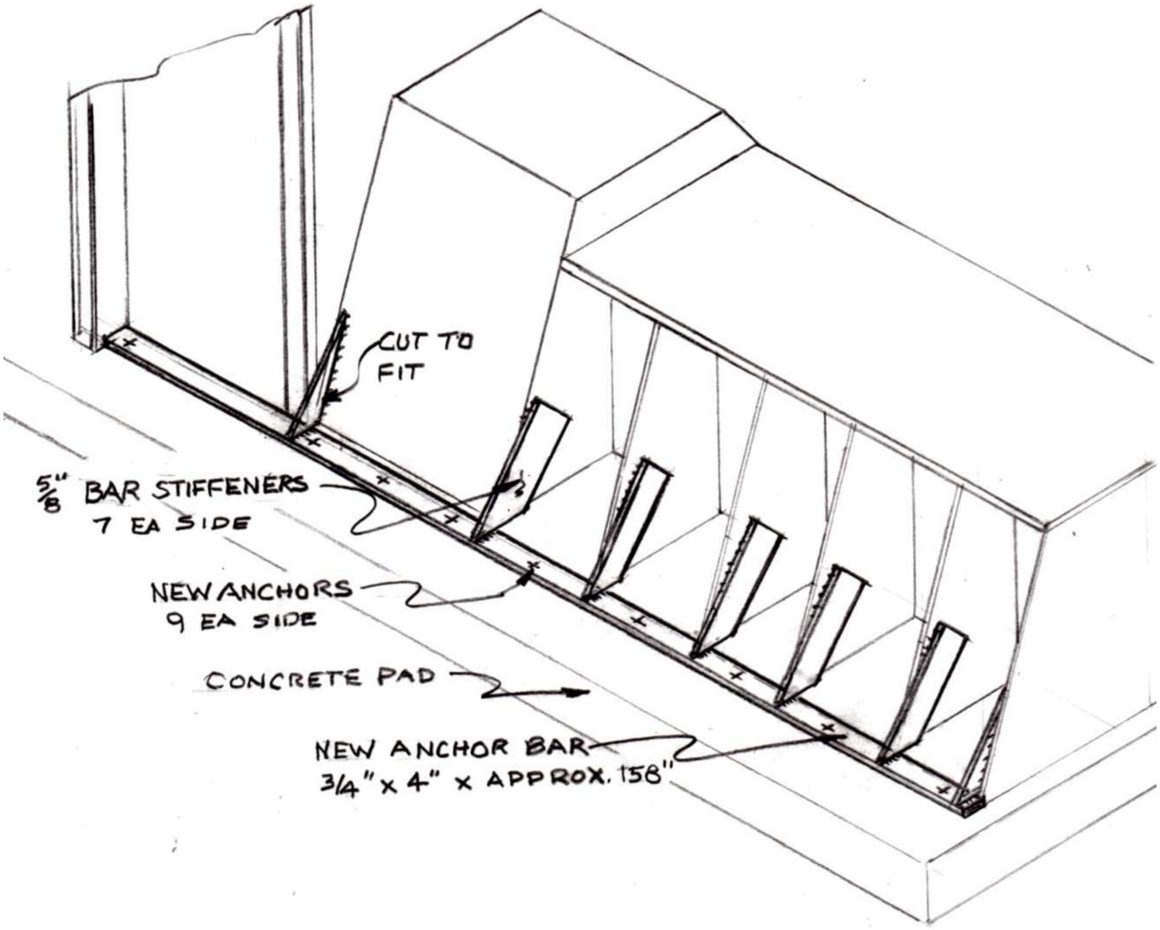

Figure 20. Anchor Bar and Bracing Isometric Sketch.

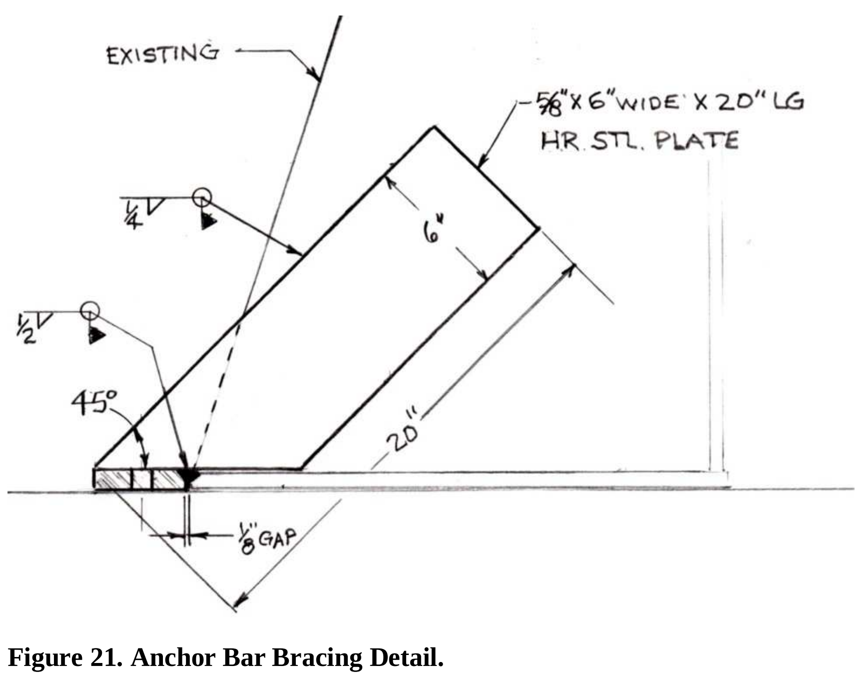

Figure 21. Anchor Bar Bracing Detail.

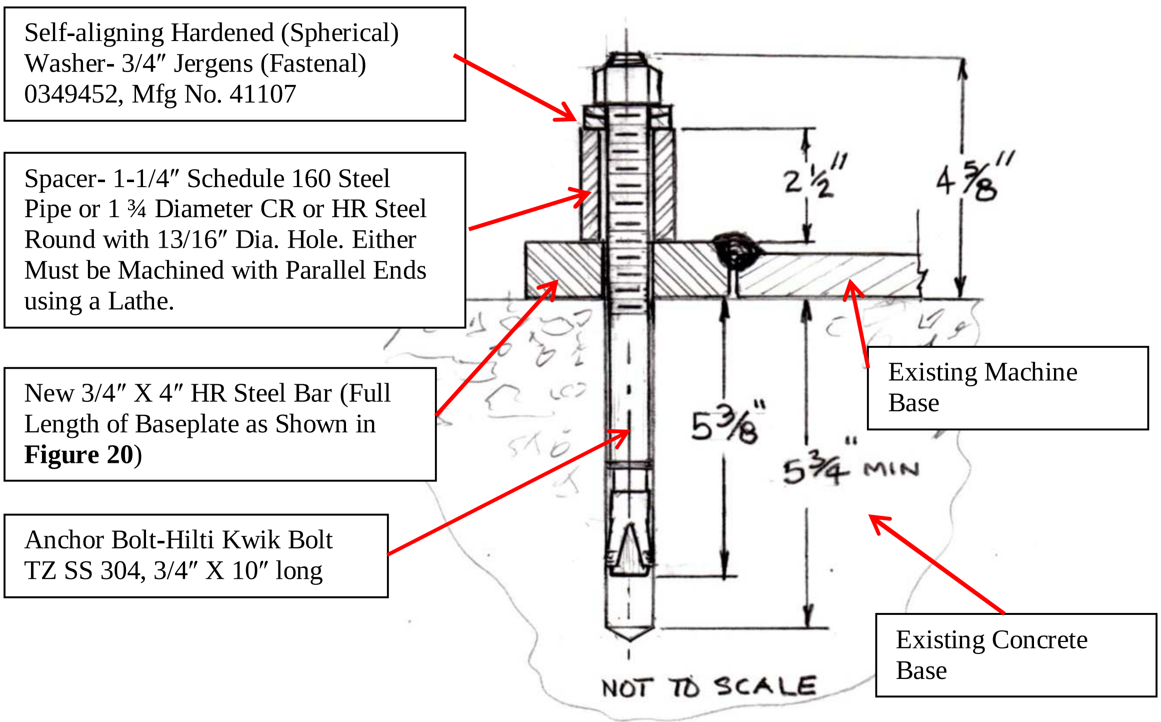

Figure 22. Anchor Bolt Installation Detail.

Note:

- Install anchors using the new anchor bar as a template.
- Make sure a 1/8 inch gap is left between bar and original frame for better weld penetration. Bar may be tacked but not welded.
- When welding the anchor bar bracing, tack weld the 6" side first.
- After anchors are **installed and torqued and anchor bar bracing is welded into place**, then proceed to **weld the bar to the bottom fan base last**.

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