Sifre, Wayne

From: Farnholtz, Thomas
Sent: Tuesday, May 02, 2017 11:43 AM
To: Sifre, Wayne; Sifre, Wayne; Sifre, Wayne; Sifre, Wayne
Subject: FW: Palo Verde B HPSI Doc
Attachments: SI analysis of HPSI vibes.pdf

Wayne –

Here is the first of two emails on the PV B HPSI pump vibration issues.

Thank you.

Tom.

From: Miller, Geoffrey
Sent: Tuesday, May 02, 2017 7:43 AM
To: Farnholtz, Thomas <Thomas.Farnholtz@nrc.gov>
Subject: FW: Palo Verde B HPSI Doc

Tom,

Do you have someone who could take a look at the attached analysis to assess the validity of the conclusions and identify any potential Code compliance issues?

Thank you,

Geoff

From: Peabody, Charles
Sent: Monday, May 01, 2017 4:07 PM
To: Miller, Geoffrey <Geoffrey.Miller@nrc.gov>
Subject: B HPSI Docs

See attached, we will be calling momentary.

Charley Peabody
Palo Verde Sr. Resident Inspector

Hearing Identifier: WCS_CISF_Saf_Public
Email Number: 3

Mail Envelope Properties (51f2c5e2ec23413bb0e7f42f7d67fe8b)

Subject: FW: Palo Verde B HPSI Doc
Sent Date: 5/2/2017 11:43:24 AM
Received Date: 5/2/2017 11:43:36 AM
From: Farnholtz, Thomas

Created By: Thomas.Farnholtz@nrc.gov

Recipients:
"Sifre, Wayne" <WCS-CISFSafHrgPEm.Resource@nrc.gov>
Tracking Status: None
"Sifre, Wayne" <Wayne.Sifre@nrc.gov>
Tracking Status: None
"Sifre, Wayne" <WCS-CISFSafHrgNPEm.Resource@nrc.gov>
Tracking Status: None
"Sifre, Wayne" <WCS-CISFSafHrgNPR.Resource@nrc.gov>
Tracking Status: None

Post Office: R4PWMSMRS02.nrc.gov

Files	Size	Date & Time
MESSAGE	779	5/2/2017 11:43:36 AM
SI analysis of HPSI vibes.pdf	1677280	

Options
Priority: Standard
Return Notification: No
Reply Requested: No
Sensitivity: Normal
Expiration Date:
Recipients Received:

Report No.: 1700546.402
Revision 0
Project No.: 1700546.00
April 2017

Palo Verde HPSI 2B Pump Vibration Evaluation

Prepared for:

Arizona Public Service
Contract No. 500610504

Prepared by:

Structural Integrity Associates, Inc.
San Jose, California

Prepared by: ____________________ Date: 04/24/2017
Minghao Qin

Prepared by: ____________________ Date: 04/24/2017
Miroslav Trubelja

Reviewed by: ____________________ Date: 04/24/2017
Rich L. Bax

Approved by: ____________________ Date: 04/24/2017
Miroslav Trubelja

Structural Integrity Associates, Inc.

REVISION CONTROL SHEET

Document Number: 1700546.402

Title: Palo Verde HPSI 2B Pump Vibration Evaluation

Client: Arizona Public Service

SI Project Number: 1700546.00 Quality Program: ☐ Nuclear ☒ Commercial

Section	Pages	Revision	Date	Comments
1.0	1-1 – 1-3	0	04/24/17	Initial Issue
2.0	2-1 – 2-11			
3.0	3-1 – 3-3			
4.0	4-1 – 4-9			
5.0	5-1			
6.0	6-1			
7.0	7-1			
App. A	A-1 – A-6			

Table of Contents

Section | Page

List of Tables

List of Figures

1.0 INTRODUCTION

The three units at Palo Verde Nuclear Generating Station (PVNGS) each contain a High Pressure Safety Injection (HPSI) system. Each HPSI system has two identical centrifugal pumps, referred to as 1A, 1B, 2A, 2B, 3A and 3B, for Units 1, 2, and 3, respectively. Generally, the duty cycle of these pumps is short as they are put into operation only during testing and emergency conditions. Several of these pumps (3B, 1A, and 2A) have experienced elevated vibration levels in the past in the horizontal direction. In each case, the cause of the high vibration levels was determined to be resonance around the pump running speed and the problem was resolved by tuning the structure via stiffening the support pedestals. The objective of this tuning has been to move the horizontal natural frequencies of the pumps above the pump running speed. HPSI Pump 2B has also had elevated vibration measurements and what makes the current scenario somewhat more challenging is the fact that Pump 2B, similar to Pump 2A, has particularly low natural frequencies. Thus, implementation of the modifications has the potential to move a lower natural frequency closer to the running speed, which is unacceptable.

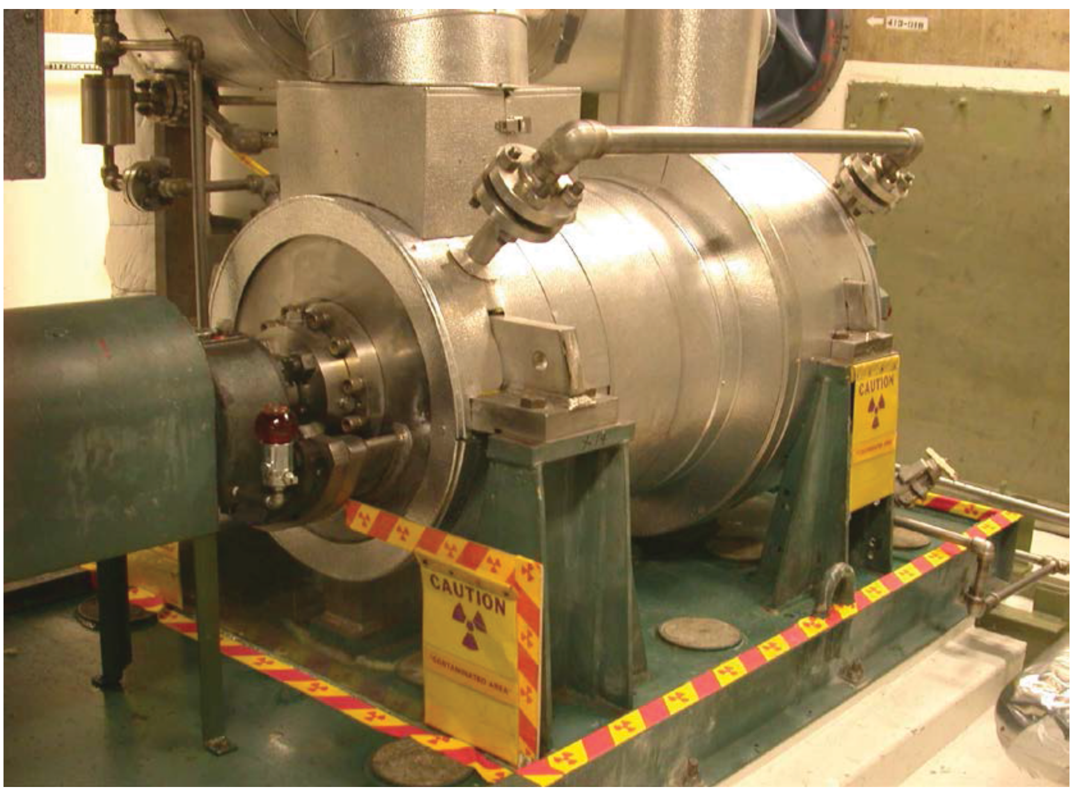

Figure 1-1. Typical Unmodified HPSI Pump at Palo Verde Nuclear Generating Station

1.1 Machine Description

The pumps are an eight stage horizontal design rated to deliver 850 GPM at a head of 2850 feet (2050 psi). Two pole AC induction motors, delivering about 1000 HP at their nominal running speed of 3600 rpm, drive the pumps.

A structural representation of the pump-motor combination is given in Figures 1-2 and 1-3. The basic structure consists of a rectangular frame made of “C” channels bolted to the concrete bed, a ½ in. base plate welded at its periphery to the above mentioned frame, and a set of four pedestals, welded to the base plate, each with varying cross sections made up of “C” channel frames. The pedestals help to “hang” the pump. The inter-space bounded by the base plate, the concrete foundation bed and the “C” frames are filled with grout in order to support the base plate, distribute the load and transmit the pump load to the foundation over a wide area.

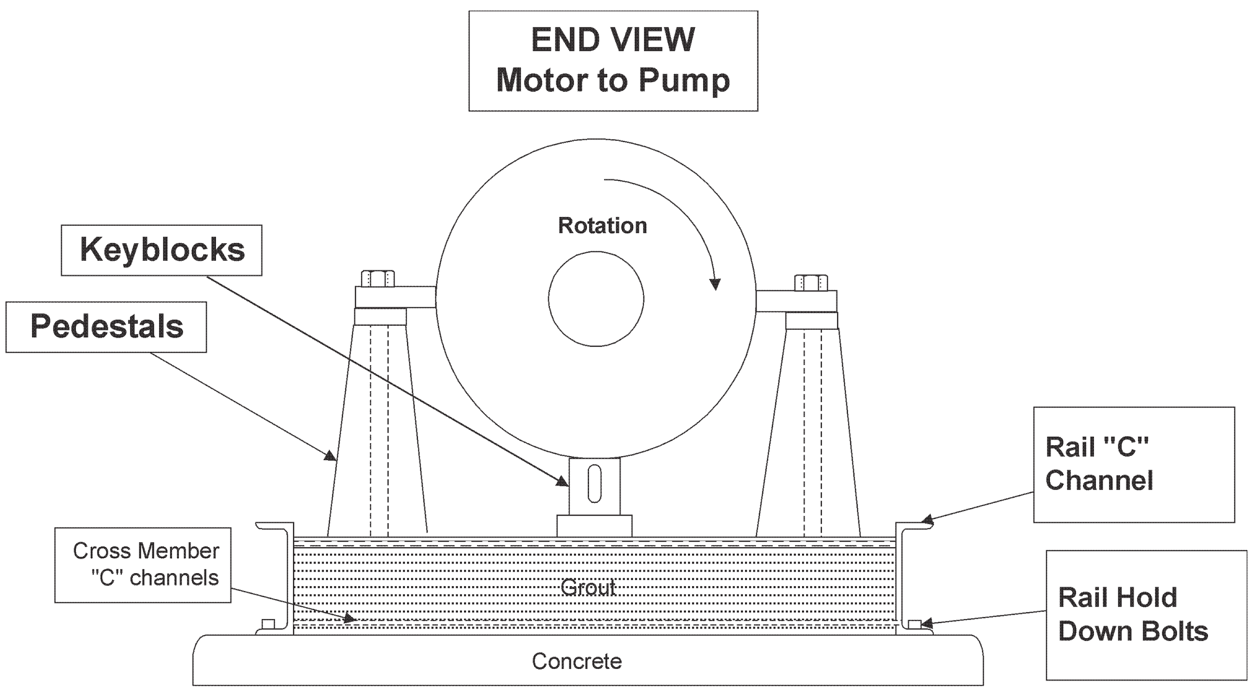

Figure 1-2. End View of a Typical Palo Verde Pump Structure
Note: From the motor-end, the rotation is CW

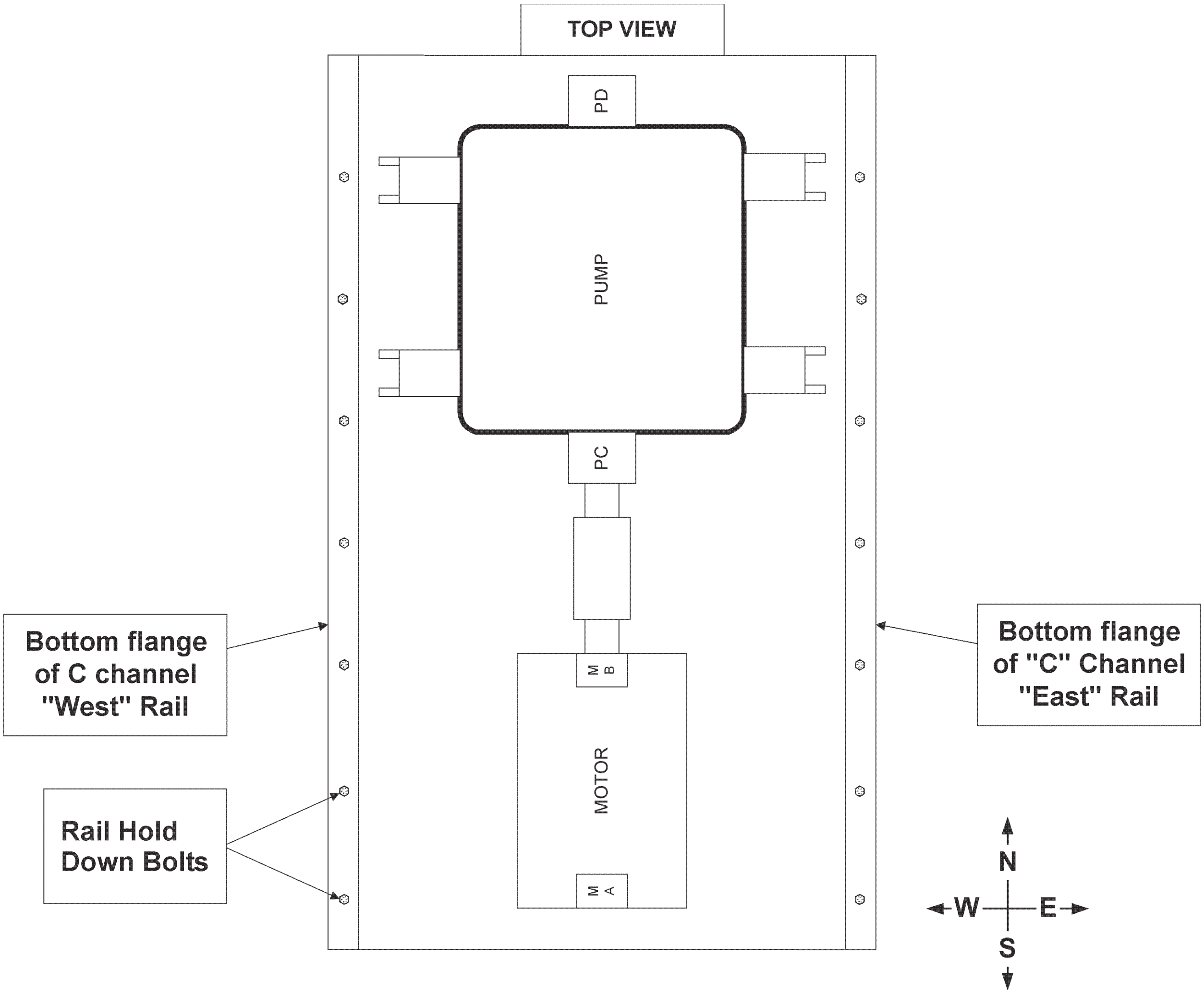

Figure 1-3. Top View of a Typical Palo Verde Pump and Motor Structure

A set of two "C" channels are also placed underneath each pedestal and welded at their ends to the boundary frame as additional support to carry the load. These "C" channel crossbeam members are not currently attached to the base plate. However, the "C" channels do provide vertical restraint to the base plate provided they are in contact with the base plate. The pumps are restrained from rotation by a set of two mating key blocks at the two axial ends of the pump. The key block at the motor side (South end) is pinned to somewhat constrain axial, vertical, and rotational motion. The key block at the North end is slotted to allow for axial thermal expansion, but prevents rotational and horizontal motions. A certain amount of additional structural stiffness is provided due to the inlet and outlet pump piping.

2.0 BACKGROUND

Although no hydraulic performance degradation of the pumps has been observed to date on any of the pumps, excessive lateral vibration levels have been measured on several. A condition above a velocity response of 0.325 in/sec (which translates to 1.72 mils peak to peak of sinusoidal displacement amplitude at 60 Hz) is considered as ALERT level per the limits imposed by the ASME Code and the PVNGS Inservice Testing Program. The increased vibration levels have been attributed to seal replacements and foundation degradation that could allow support resonant frequencies to shift towards the running speed.

2.1 Historical Vibration Trends

Vibration measurement studies conducted in 2002 indicated that the worst vibration occurred in the E-W direction on pump 3B at the Pump Outboard Horizontal (POH) measurement location with a velocity response of 0.583 in/sec, well above ALERT level. Pump 1A was also at ALERT level with an E-W velocity response of 0.349 in/sec. The pump outboard horizontal vibration levels on Pump 2A had been near ALERT levels and rose significantly above the ALERT level after a seal replacement. All of these pumps underwent structural modifications that reduced these levels under the limits. In 2017 Pump 2B also started exhibiting elevated vibration levels in excess of ALERT levels and is therefore considered for similar modifications.

Figure 2-1 shows the vibration trends in terms of velocity response (in/sec) for all pumps from 1997 to 2006. These measurements were made when the pumps were operated at their “mini” flow conditions, a flow between 150 to 180 GPM. It has also been observed that at full flow conditions (around 850 GPM) the vibration levels are generally lower, perhaps due to better hydrodynamic balancing at rated flow.

More recent vibration trends [5], presented in Figures 2-2 through 2-4, show that vibration levels for all the pumps were below the 0.325 in/sec ALERT level, except for 2017 values at Pump 2B, which was as high as 0.421 in/sec.

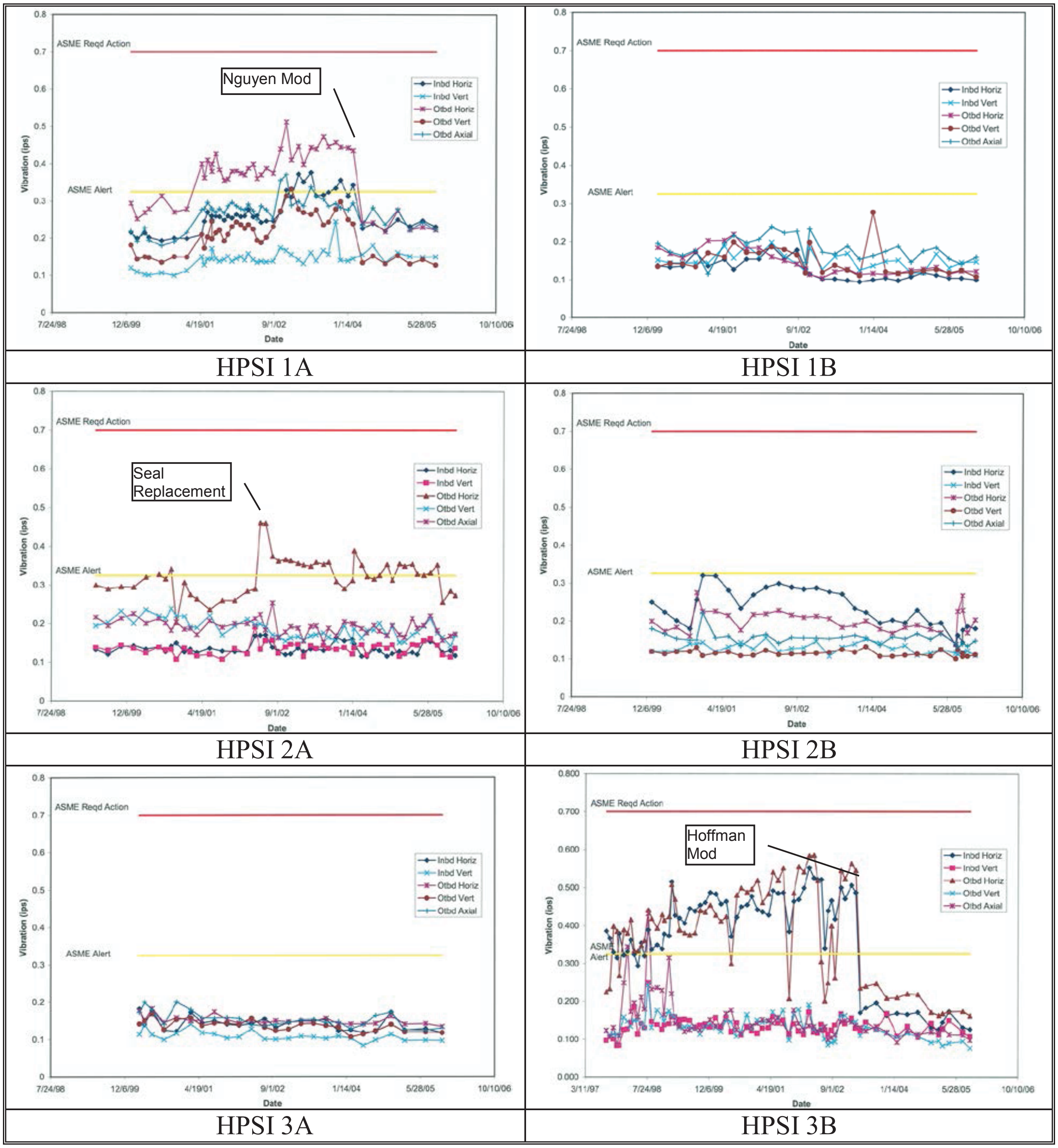

Figure 2-1. Measured Velocity Trends at “Mini” Flow Levels, 1997 to 2006 (by PVNGS)

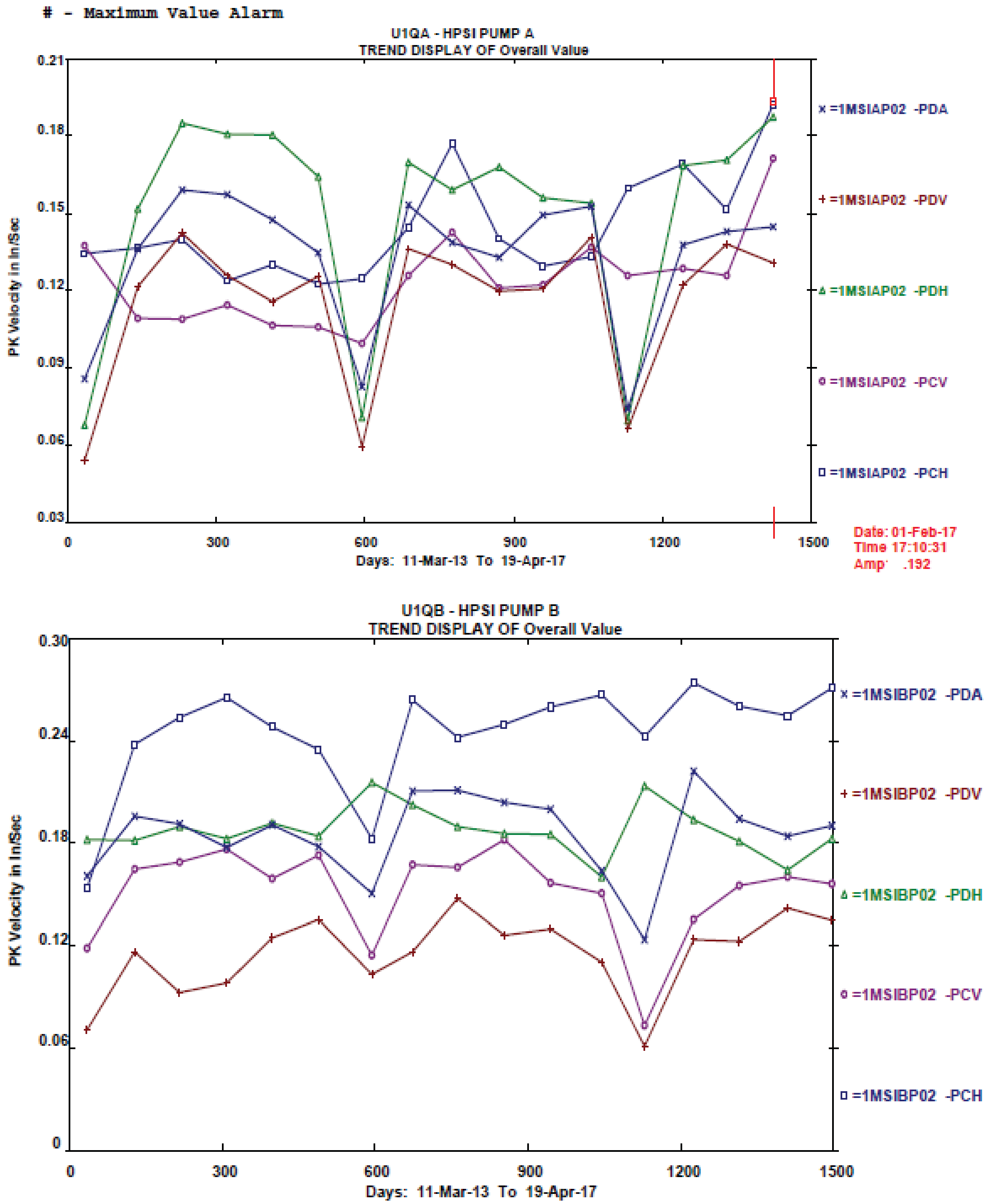

Figure 2-2. Measured Unit 1 Velocity Trends, 2013 to 2017 (by PVNGS)

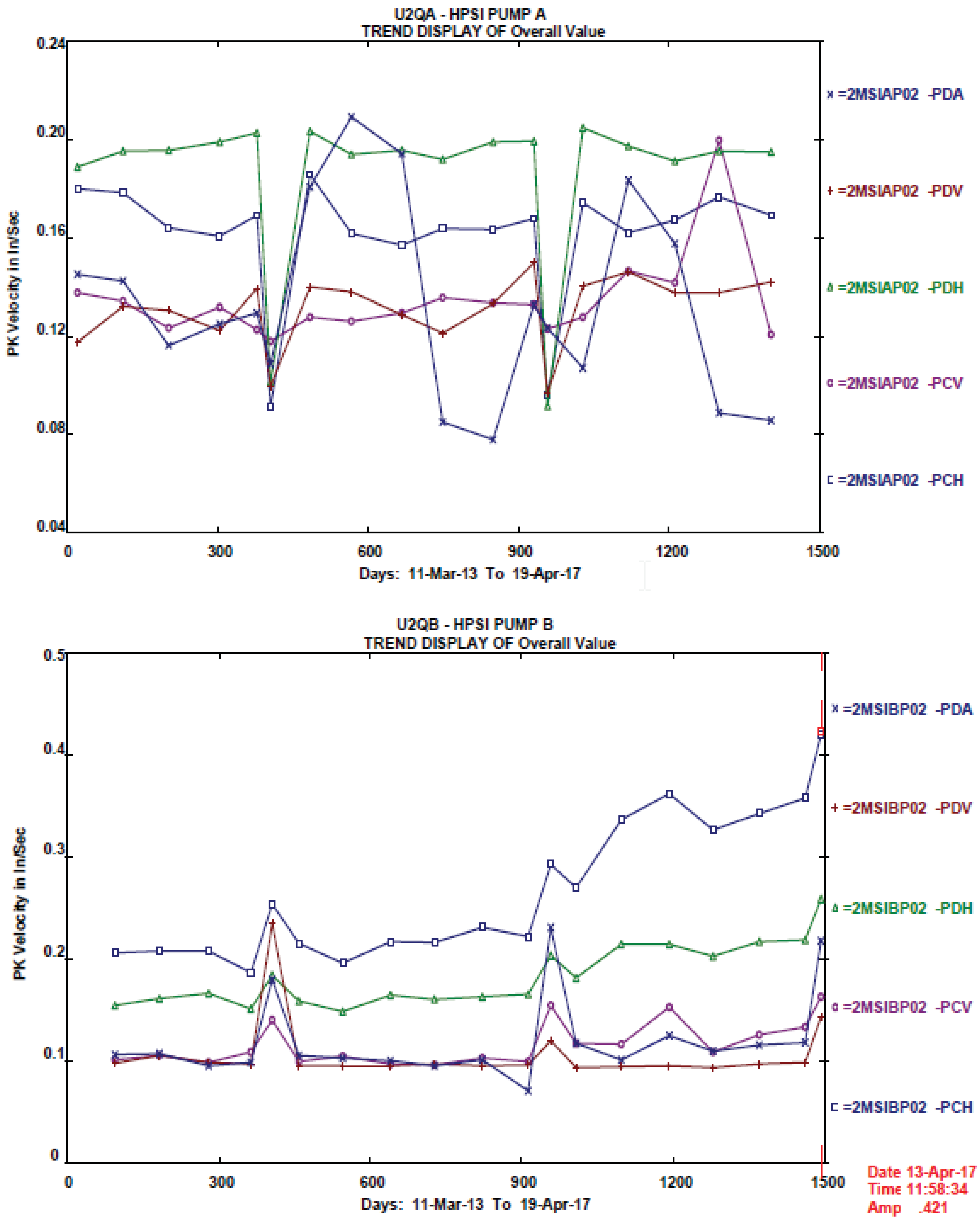

Figure 2-3. Measured Unit 2 Velocity Trends, 2013 to 2017 (by PVNGS)

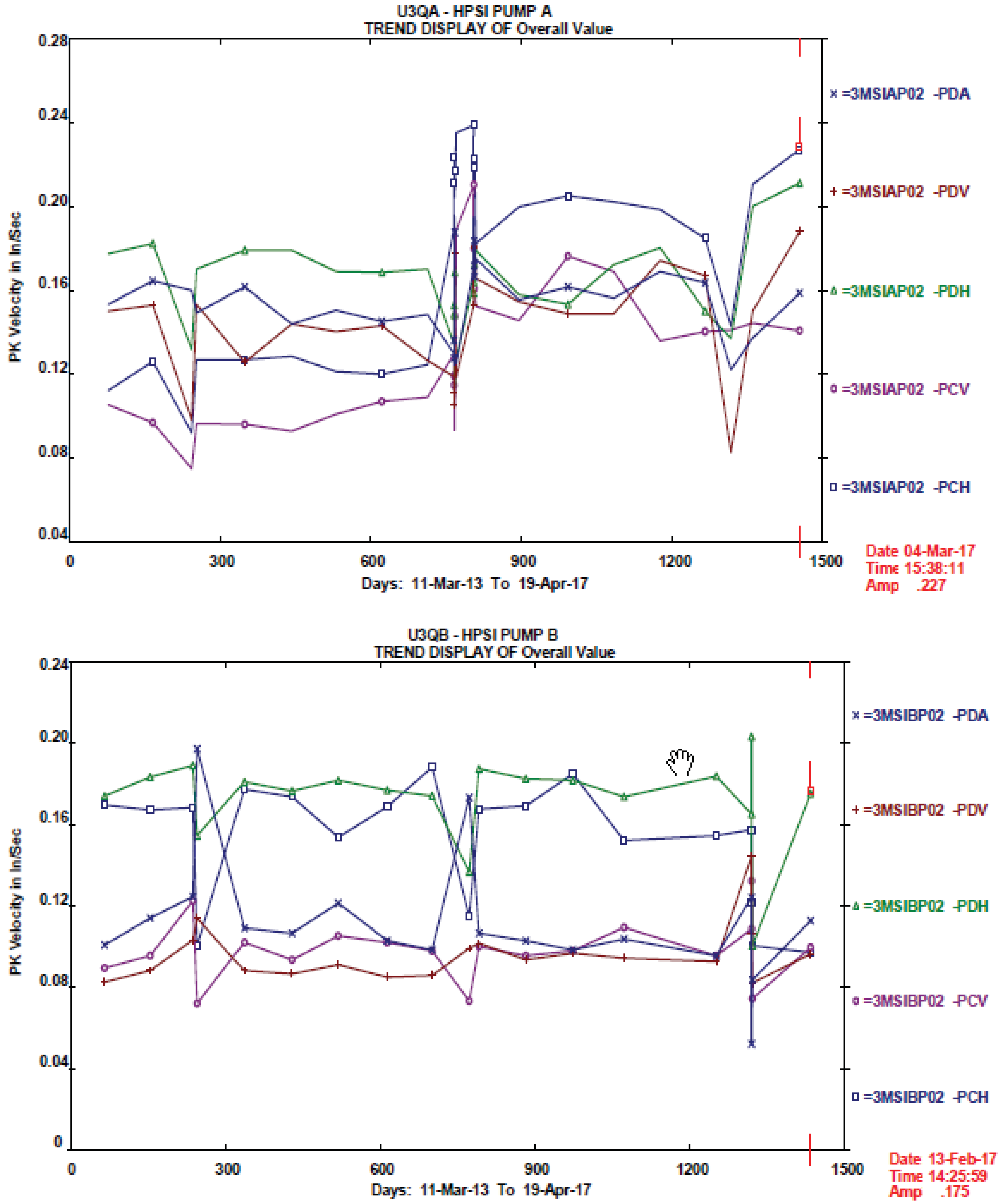

Figure 2-4. Measured Unit 3 Velocity Trends, 2013 to 2017 (by PVNGS)

2.2 Past Structural Modifications

The cause of the elevated vibration levels on the PVNGS HPSI pumps was determined to be resonance due to the fact that the natural frequency of the structure was near the machine running speed. The natural frequencies were identified via impact testing and analyzing running speed data. The measurement locations for the impact testing are given on Figure 2-5 below:

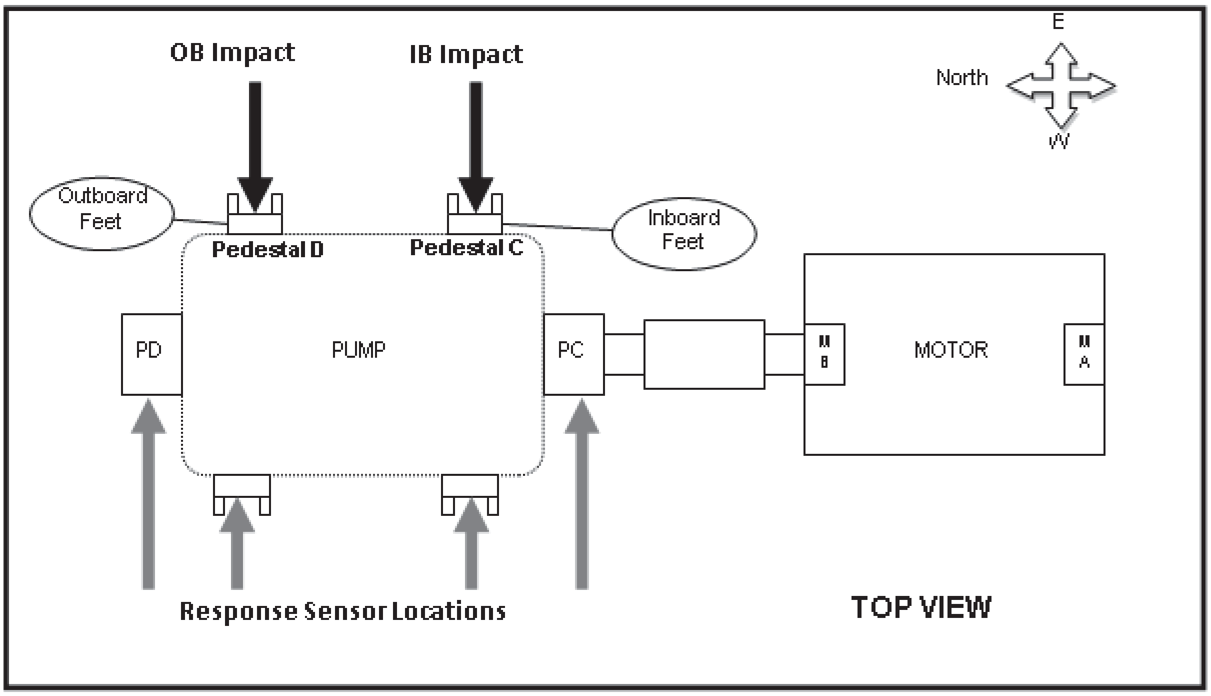

Figure 2-5. Impact Test Measurement Locations for Static Natural Frequencies

2.2.1 The "Hofmann" Modification

In the Fall of 2002, Structural Integrity was contracted to evaluate modification concepts, which would then be applied to pump 3B in order to reduce the vibration levels. The subsequent "Hofmann" repair concept documented in Structural Integrity Report SIR-03-013 [1] was successfully applied to pump 3B in the Spring of 2003.

The "Hofmann" modification consisted of welding a standard 10x30 "C" channel to the outboard face of each pedestal. In addition, a pair of 0.5 inch thick stiffener plates were welded into the support frame such that one was aligned with either side of the installed “C” channel (See Figure 2-6).

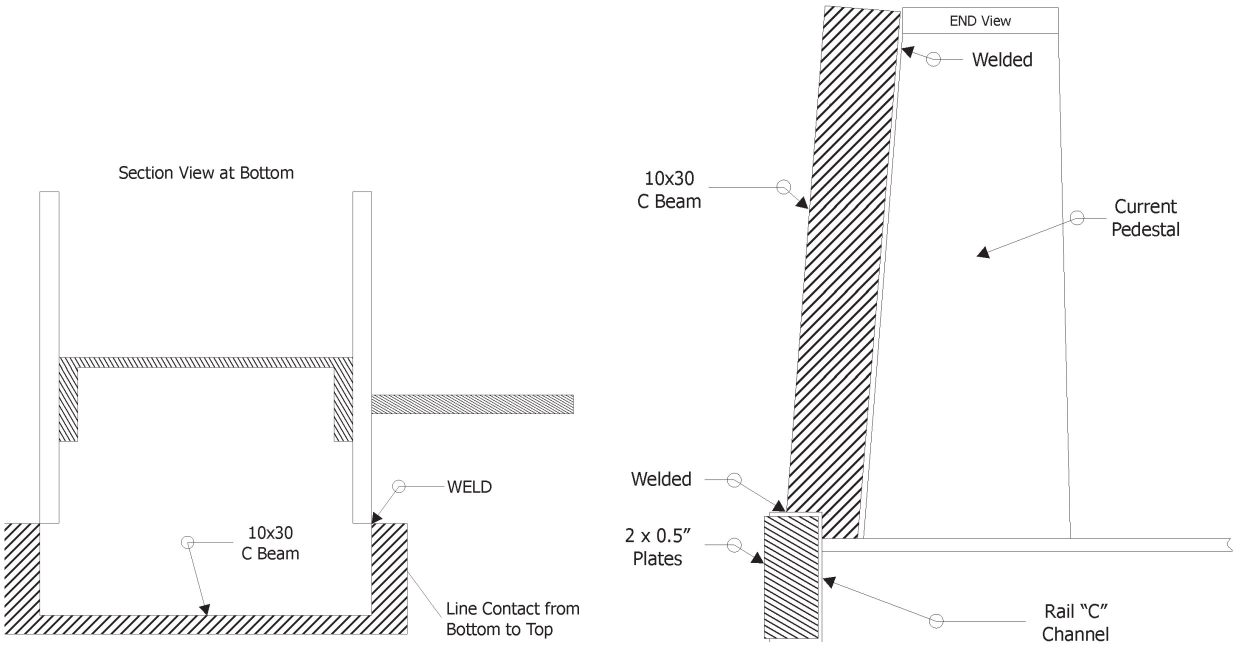

Figure 2-6. Cross Section & Side View of the “Hofmann” Modification

Prior to installation, Structure Integrity evaluated the “Hofmann” modification via finite element analyses using the ANSYS software package [2]. The finite element model constructed used to evaluated the “Hofmann” modification is shown in Figure 2-7. The test results following the installation (See Figure 2-8) of the modification were very favorable.

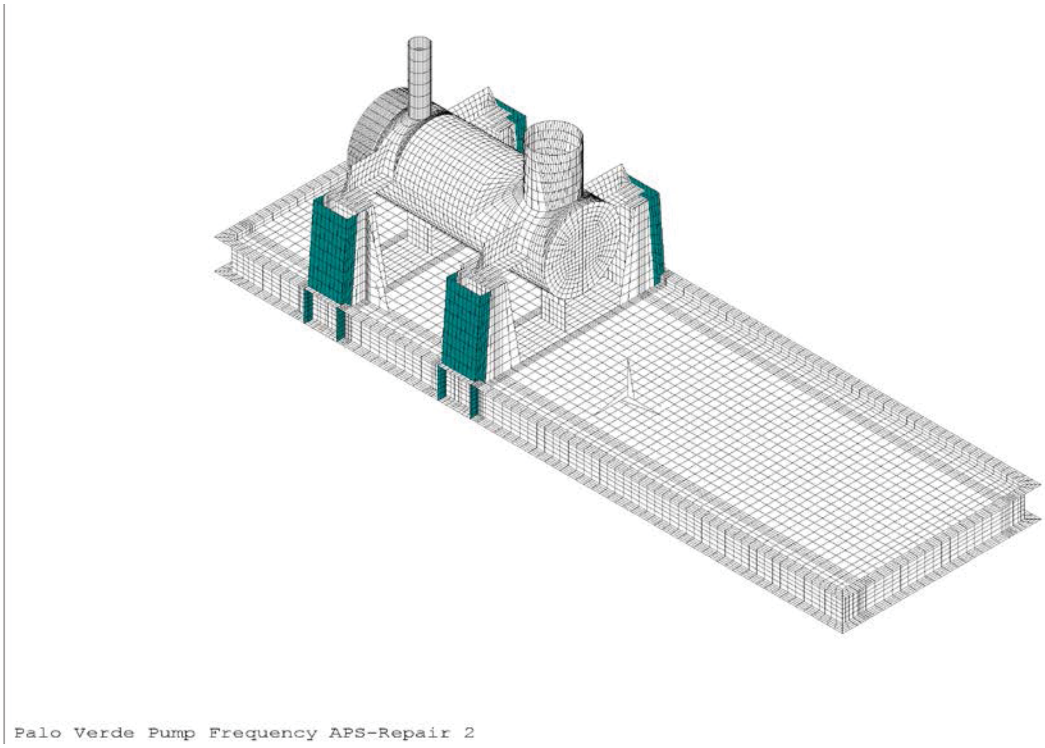

Figure 2-7. Finite Element Model of "Hofmann" Modified Pump Structure

Figure 2-8. Field Implementation of "Hofmann" Modification on Pump 3B

Under operating conditions, when the pump was running, the amount of the frequency shift was somewhat less, about 8 Hz due to the "Hofmann" modification. Both values were acceptable because the natural frequency of the structure was above running speed even before stiffening the pedestal.

2.2.2 The "Nguyen" Modification

Subsequently, Structural Integrity was again contracted to develop modification concepts for pump 1A, which was another pump at ALERT levels. The natural frequencies of this pump were found to be below running speed. In the Dynamic (Running) condition, the application of the "Hofmann" modification to Pump 1A could have resulted in the natural frequency remaining near the forcing function of the pump resulting in a continued resonance condition and elevated velocity response. Therefore, the "Hofmann" modification was deemed unacceptable for implementation on pump 1A and a revised repair was developed. The revised repair became known as the "Nguyen" modification, and consisted of box beam reinforcements instead of C channels as shown on Figures 2-9 and 2-10.

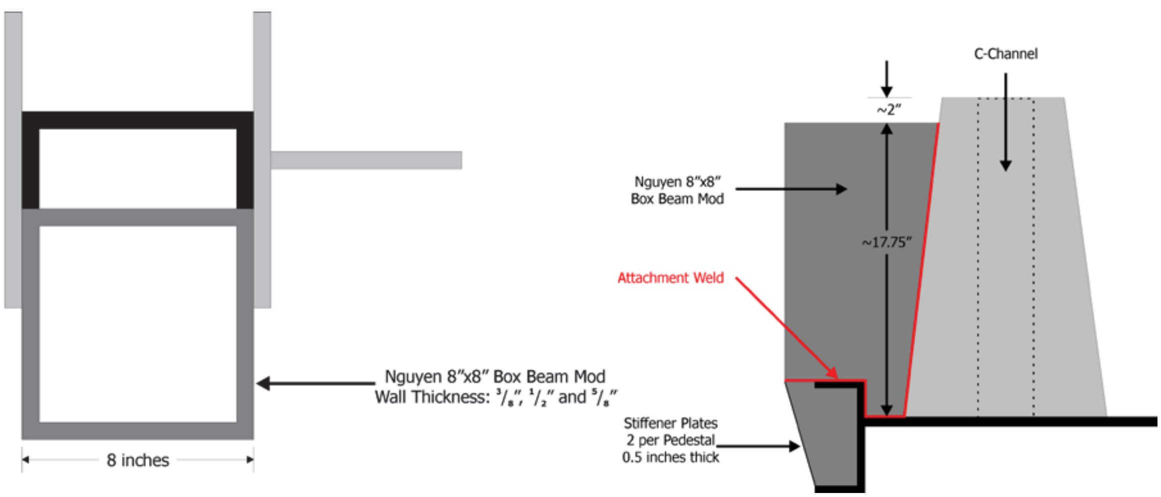

Figure 2-9. Cross Section & Side View of the "Nguyen" Modification

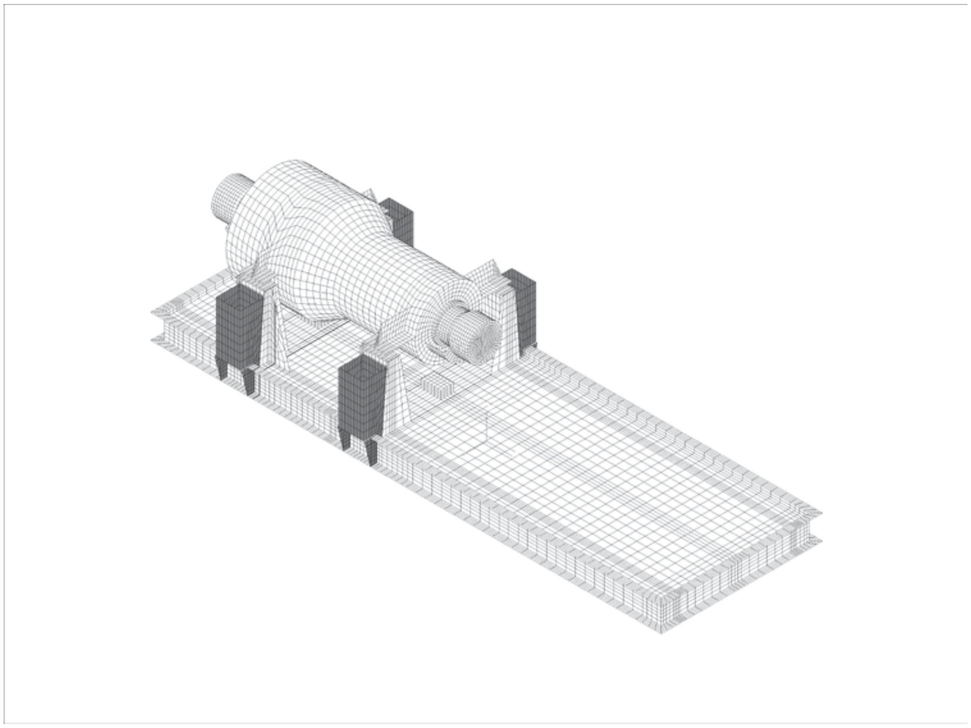

Figure 2-10. Finite Element Mesh of PVNGS HPSI Pump with "Nguyen" Modification

Finite element analysis on the Nguyen modification predicted an increase of the 55.46 Hz fundamental mode to 80.18 Hz. The implemented "Nguyen" modification on Pump 1A (see Figure 2-11) yielded a frequency increase of 12 Hz while the pump was running.

A second "Nguyen" modification was also applied to Pump 2A in 2006, when that pump also produced ALERT level vibration, and a first modal frequency below the running speed. The "Nguyen" modification (see Figure 2-12) generated similar frequency improvements.

Figure 2-11. “Nguyen” Modification Implemented on HPSI Pump 1A

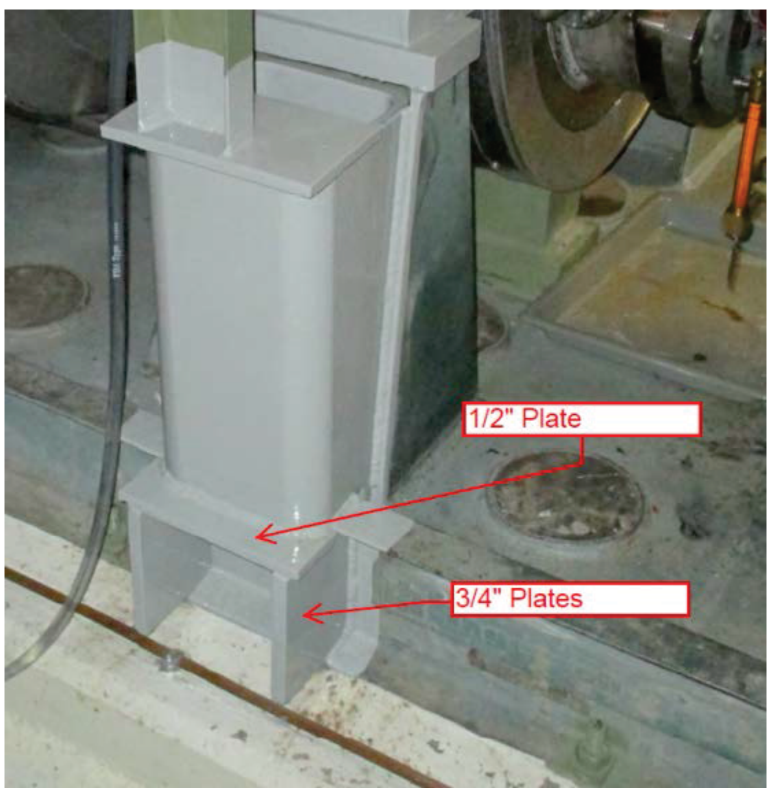

Figure 2-12. “Nguyen” Modification Implemented on HPSI Pump 2A

3.0 PUMP 2B VIBRATION DATA REVIEW

3.1 Steady State Levels

During the spring 2017 outage, attempts were made to bring Pump 2B vibration levels into acceptable range through maintenance efforts such as shaft realignment and lubrication similar to activities performed in 2008 when the pump exceeded the ALERT criteria (see Figure 3-1) [6]. Following the maintenance, the steady state vibration levels on Pump 2B have been noted to be between 0.35 and 0.40 in/s overall on the pump outboard horizontal location and below 0.25 in/s elsewhere on the pump [7].

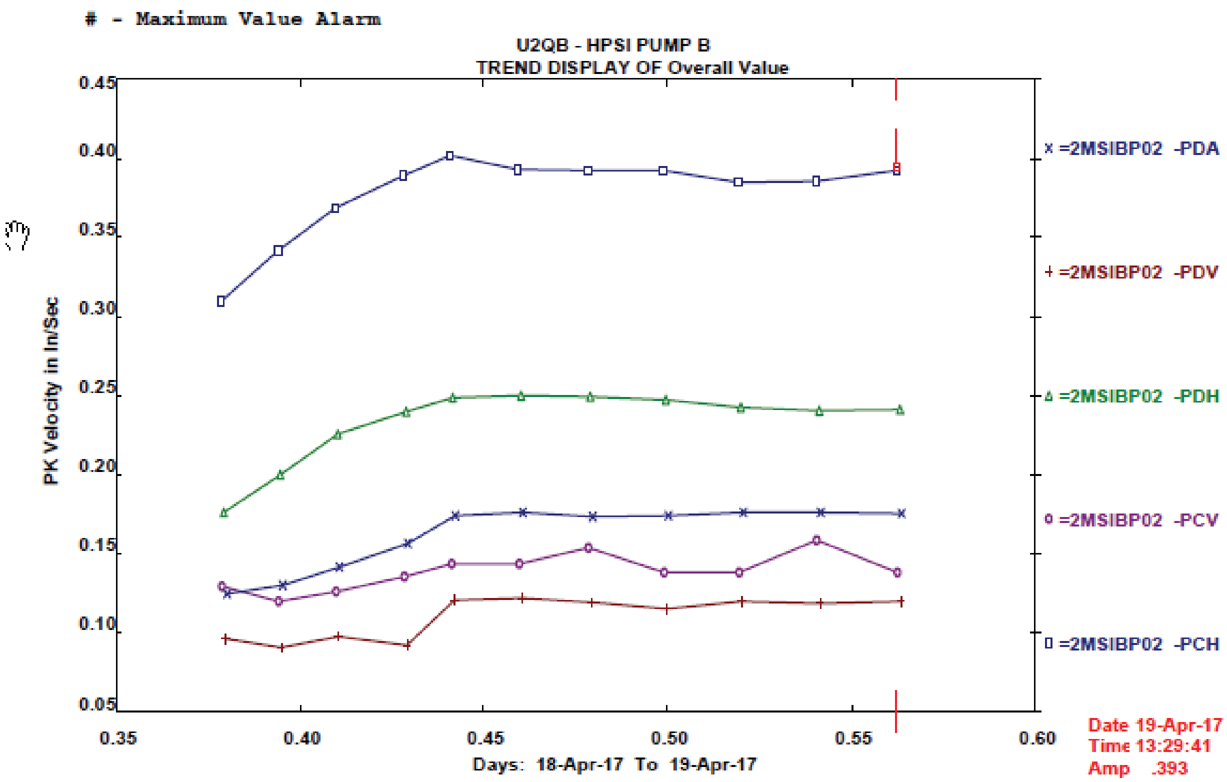

Figure 3-1. HPSI Pump 2B Vibration Values

3.2 Impact Test Results

Impact tests were performed in April 2017 on pump 2B to locate the static natural frequencies. Four natural frequencies were found at 42.25, 61.00, 70.50 and 79.25 Hz [8] as illustrated in Figure 3-2.

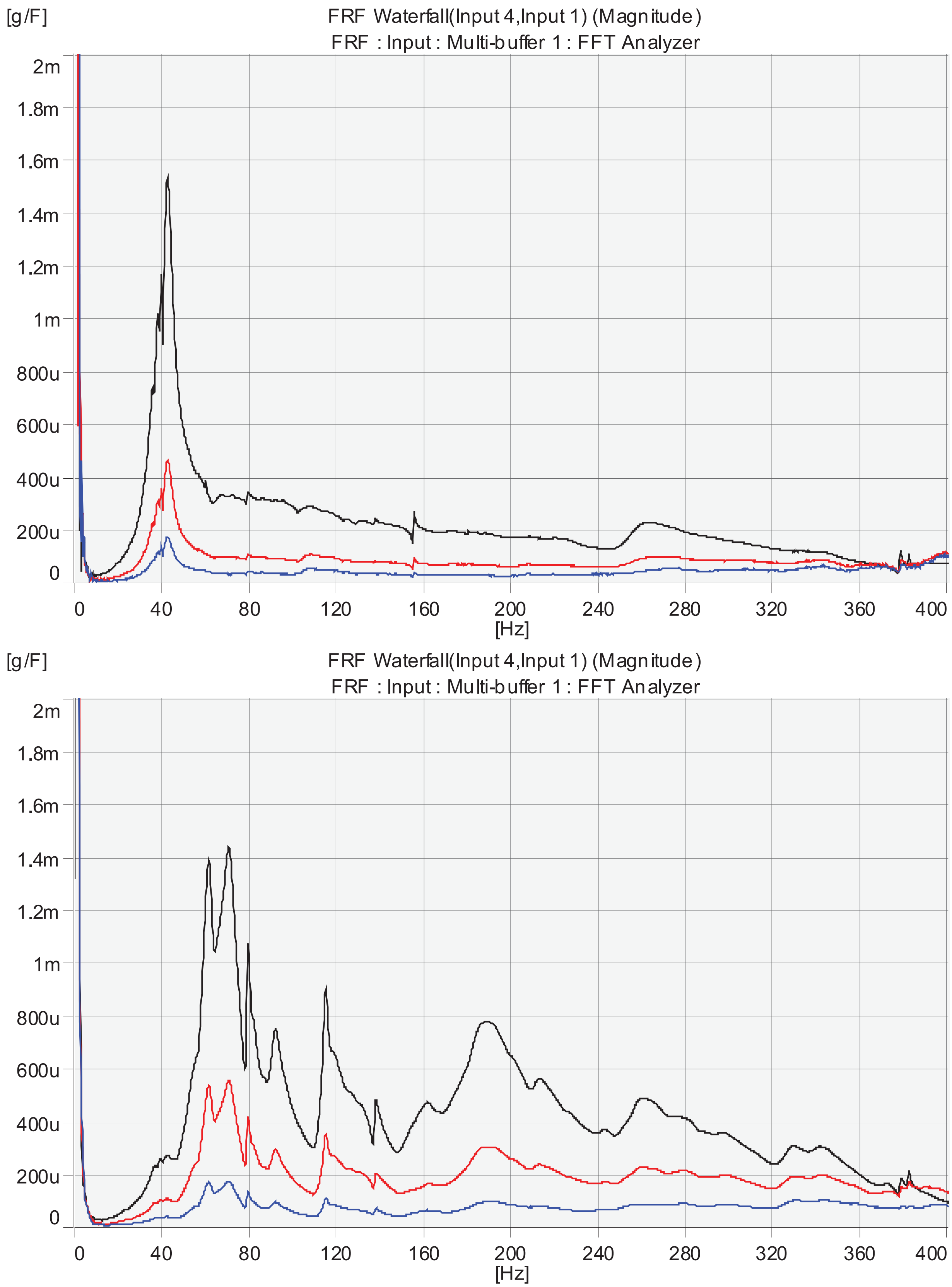

Figure 3-2. HPSI Pump 2B Impact Test Results

3.3 Coast Down Waterfall Plots

Coast down data collected in April 2017 [8] was processed into waterfalls to determine if the above observed vibration modes were excited, and if any other modes could be discerned. Figure 3-3 shows the obtained response from the inboard pedestal location, in the West horizontal direction. Dynamic frequencies identified were 40, 56, 59, 68 and 70 Hz. Two of these modes appear to be just below running speed, thus these modes are the probable cause of the current high vibration.

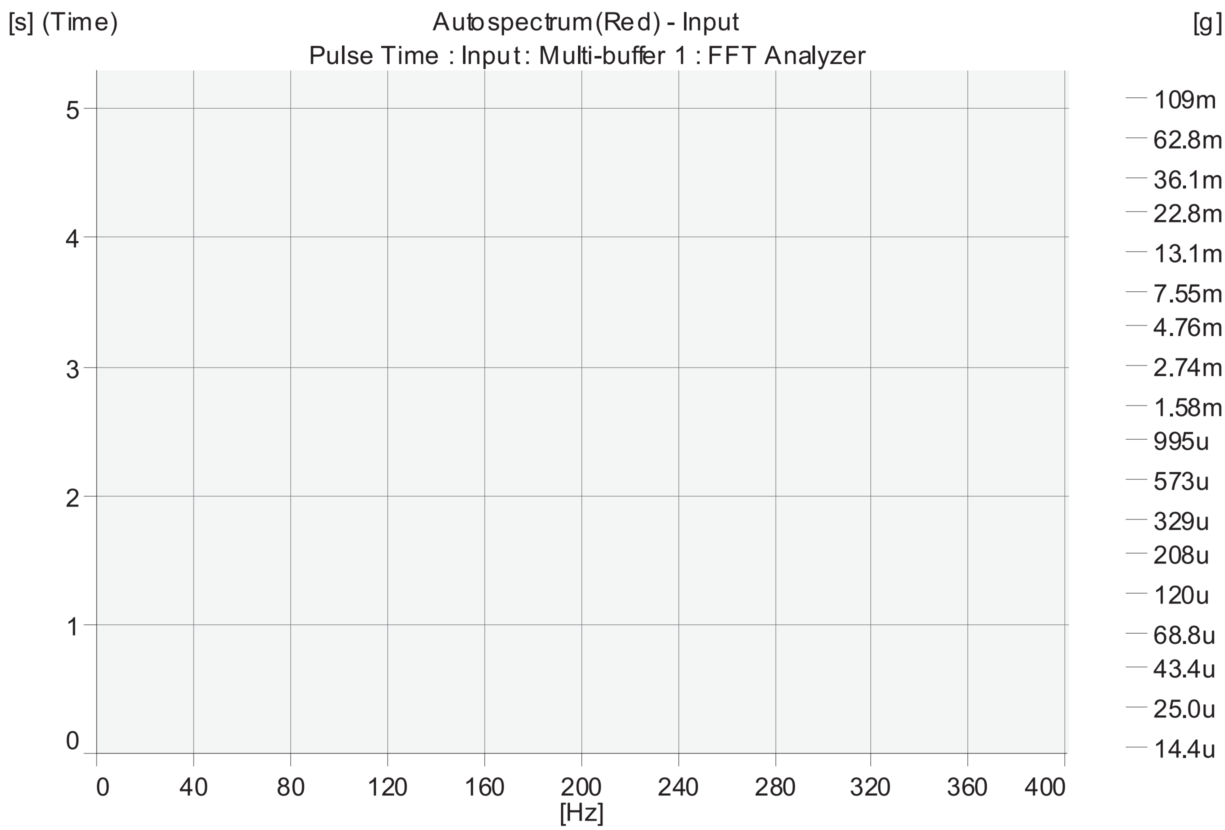

Figure 3-3. HPSI Pump 2B Coast Down Test Results

3.4 Observations

Based on the coast down data comparisons, the response of pump 2B is somewhat similar to that of 2A in that they both contain natural frequencies both above and below the running speed. The objective of any pump modifications would be to move the natural frequencies above the pump running speed with care taken that none of the resulting frequencies are too close to 60 Hz running speed.

4.0 FINITE ELEMENT ANALYSIS

As part of the finite element work performed in Reference 4 in support of Pump 2A, a series of permutations on the base model were performed to explore their impact on the natural frequency of the HPSI pump support structure. A review of the results in Table 4-1 of Reference 4 determined that Case 10a of the basic support structure produced static-based natural frequencies similar to that measured for Pump 2B: 44.77 Hz (Transverse), 63.76 Hz (Axial), and 75.68 Hz (Transverse).

Thus, the Case 10a model will be used as the baseline for modification work to support Pump 2B. However, the work done in Reference 4, was performed using earlier versions of ANSYS, namely Release 5.7 [2] and Release 8.1 (w/Service Pack 1). It was, therefore, necessary to update the model so that it could be used with Structural Integrity's current version of ANSYS, Release 14.5 (w/Service Pack 1) [3].

The approach for analyzing Pump 2B was then performed as follows:

a. Update the Case 10a finite element model developed previously for Pump 2A [4] for use with ANSYS 14.5 [3],
b. Analyze the revised pump structure using the finite element code ANSYS [3],
c. Evaluate the "Hofmann" modifications,
d. Evaluate the "Nguyen" modification, and
e. Assess the improved response.

4.1 Baseline Model

A detailed three-dimensional (3D) FEM of the pump and support structure was generated in ANSYS 14.5 [3], based on Case 10a of Reference [4]. The FEM consisted of SHELL63 elements for the pump case; pump shaft bearing housing, the pump pedestal support, and base plate. The pump shaft is not considered separately in the model except that its inertia is included in directly in terms of an effective density of an equivalent cylindrical structure. Figure 4-1 shows a plot of the model.

Base line Model: This case is the same as Case 10a of Reference [4]. The fundamental frequencies, using ANSYS 14.5, were calculated as 44.68 Hz (Transverse), 63.66 Hz (Axial), and 75.62 Hz (Transverse).

The original fundamental frequencies generated using the older versions of ANSYS [2] were 44.77 Hz (Transverse), 63.76 Hz (Axial), and 75.68 Hz (Transverse). The differences in frequency change are negligible between ANSYS versions.

4.1.1 Baseline Model with "Hofmann" Modifications

Based on baseline model, a 3D model with the "Hofmann" modification was analyzed.

Hofmann Stage 1: The "Hofmann" modification is applied to the outboard pedestals only. Figure 4-2 shows a plot of the model. The fundamental frequencies were calculated as 60.89 Hz (Transverse), 67.58 Hz (Axial), and 80.22 Hz (Transverse).

Hofmann Stage 2: The "Hofmann" modification is applied to both outboard and inboard pedestals. Figure 4-3 shows a plot of the model. The fundamental frequencies were calculated as 64.87 Hz (Transverse), 71.66 Hz (Axial), and 98.09 Hz (Transverse).

4.1.2 Baseline Model with "Nguyen" Modifications, Including Triangle Supports

Based on baseline model, a 3D model with the "Nguyen" modification, including triangle supports was analyzed.

Nguyen Stage 1: The "Nguyen" modification is applied to the outboard pedestals only. Figure 4-4 shows a plot of the model. The fundamental frequencies were calculated as 65.07 Hz (Transverse), 70.01 Hz (Axial), and 81.78 Hz (Transverse).

Nguyen Stage 2: The “Nguyen” modification is applied to both outboard and inboard pedestals. Figure 4-5 shows a plot of the model. The fundamental frequencies were calculated as 69.89 Hz (Transverse), 75.40 Hz (Axial), and 105.40 Hz (Transverse).

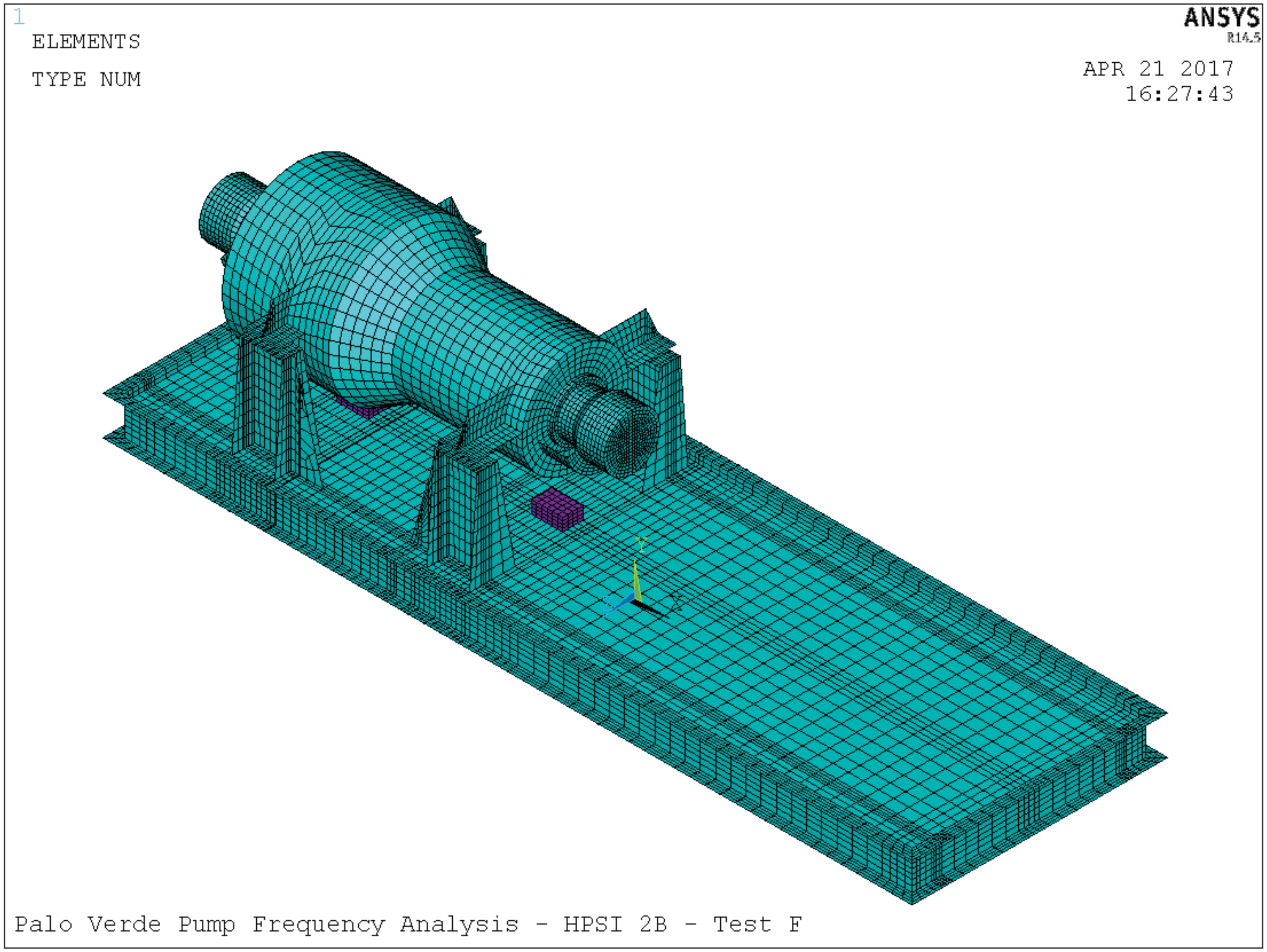

Figure 4-1. Finite Element Model (Baseline) of the Unmodified Pump Structure for Pump 2B

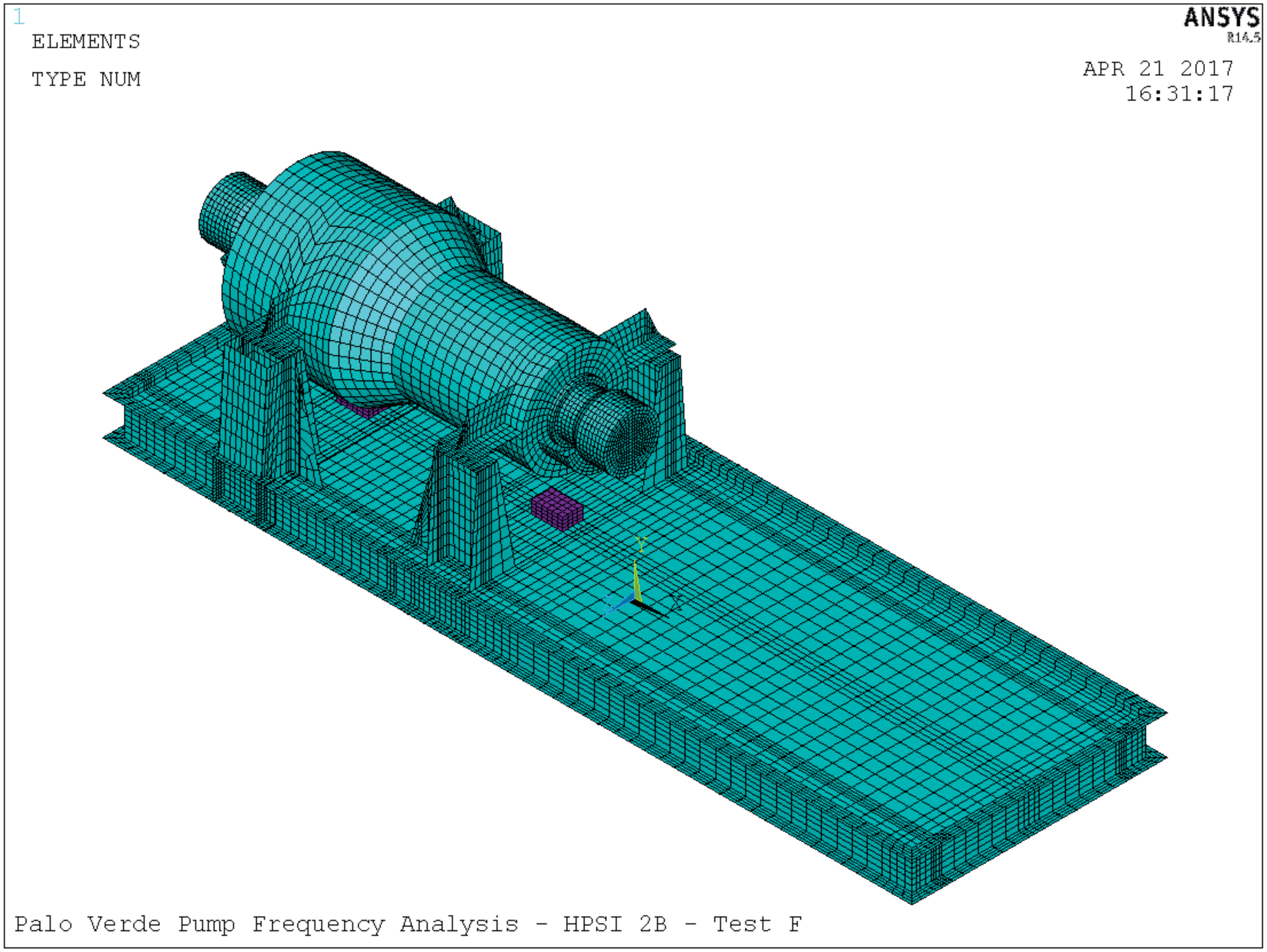

Figure 4-2. Finite Element Model of “Hofmann” Modification on Outboard Pedestals Only

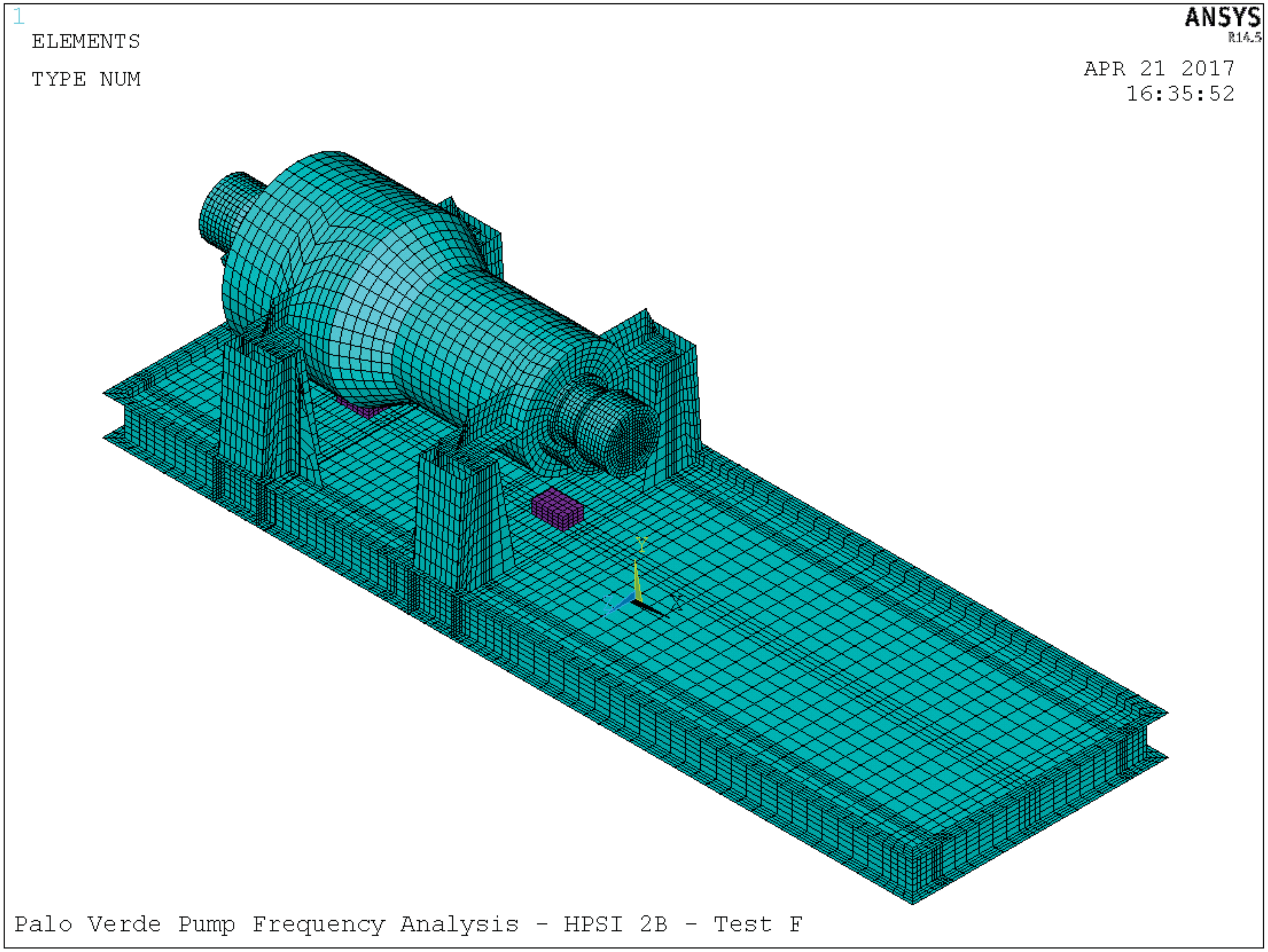

Figure 4-3. Finite Element Model of “Hofmann” Modification on Outboard and Inboard Pedestals

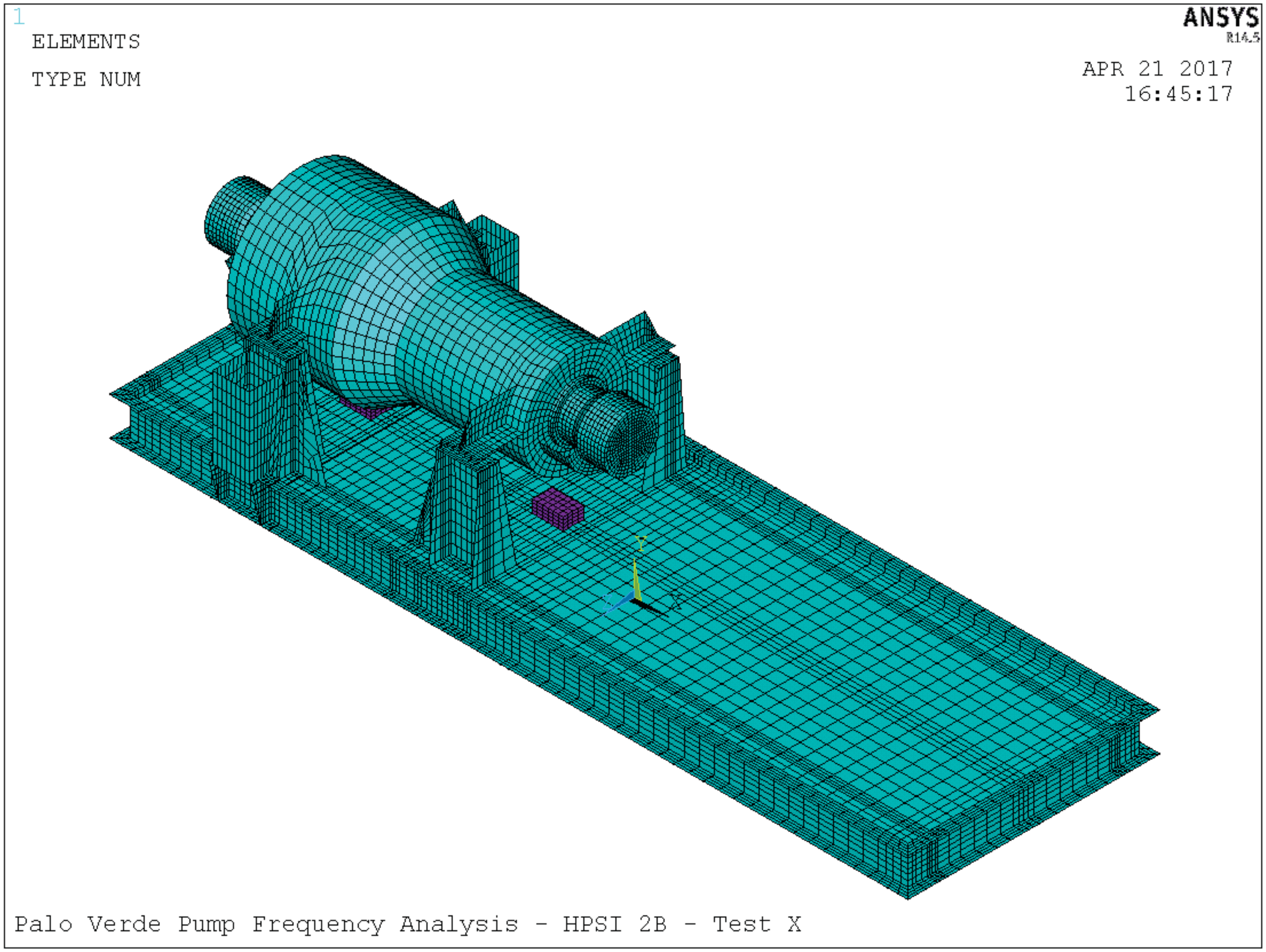

Figure 4-4. Finite Element Model of "Nguyen" Modification on Outboard Pedestals Only

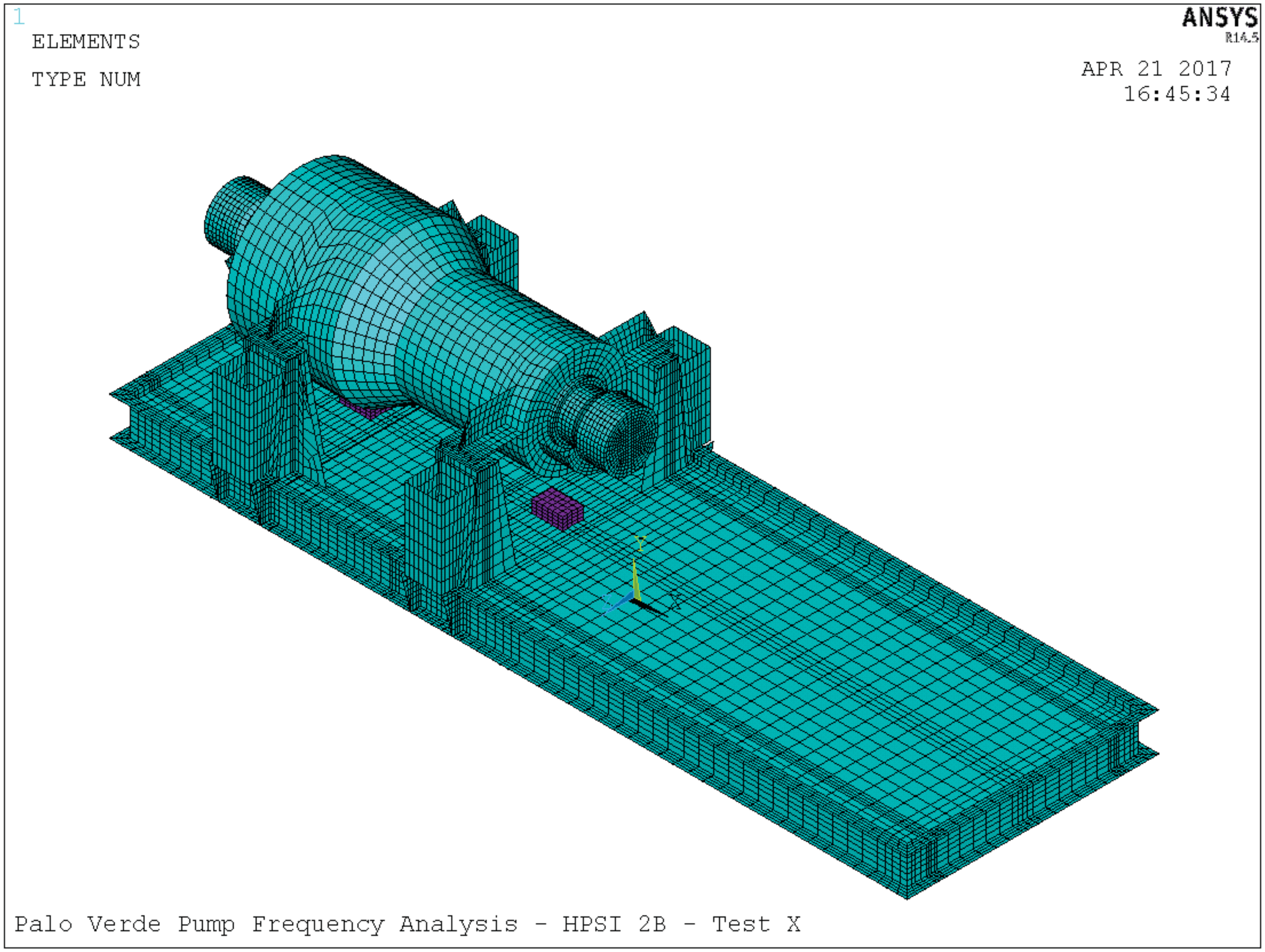

Figure 4-5. Finite Element Model of “Nguyen” Modification on Outboard and Inboard Pedestals

Table 4-1. ANSYS Static Modal Frequency Results

Case	Description	1st Transverse Mode (Hz)	1st Axial Mode (Hz)	2nd Transverse Mode (Hz)	File Name
Baseline	Original model based on case 10a of previous report [4].	44.68	63.66	75.62	GEOM2B-FF-j.INP
Hofmann Stage 1	From Baseline, Add "Hofmann" Modification to outboard pedestals only.	60.89	67.58	80.22	GEOM2B-FF-j-Hoffman-Stage 1.INP
Hofmann Stage 2	From Baseline, Add "Hofmann" Modification to outboard and inboard pedestals.	64.87	71.66	98.09	GEOM2B-FF-j-Hoffman-Stage 2.INP
Nguyen Stage 1	From Baseline, Add "Nguyen" Modification to outboard pedestals only.	65.07	70.01	81.78	GEOM2B-FX-p-Nguyen-stage 1.INP
Nguyen Stage 2	From Baseline, Add "Nguyen" Modification to outboard and inboard pedestals.	69.89	75.40	105.41	GEOM2B-FX-p-Nguyen-stage 2.INP

Note: As indicated in Section 3.2 and 3.3, the dynamic modal frequencies appear to be ~5 Hz less than their static equivalent.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the dynamic analyses of the PVNGS pump structure, the following conclusions can be made. The dynamic behavior of pump 2B is similar in complexity to pump 2A. However, the lowest observable operating resonance frequency appears to be 40 Hz for Pump 2B versus 53 Hz for Pump 2A.

Application of the “Hofmann” modification alone to the outboard end of pump 2B (Stage 1) could produce dynamic fundamental frequencies that bracket the operating speed by ~3 to 4 Hz (56 Hz, 63 Hz, 75 Hz).

Application of the “Hofmann” modification to both the inboard and outboard ends of pump 2B (Stage 2) could produce dynamic fundamental frequency that is essentially at the operating speed (60 Hz, 67 Hz, 93 Hz). Therefore, the “Hofmann” modification is not considered a viable repair option.

Application of at least the “Nguyen” modification to the outboard end of pump 2B (Stage 1), much like the “Hofmann” Stage-2, could produce dynamic fundamental frequency that is essentially at the operating speed (60 Hz, 65 Hz, 77 Hz).

Only the application of the “Nguyen” modification to both the inboard and outboard ends of pump 2B (Stage 2) is expected to produce dynamic fundamental frequency that are above the operating speed (65 Hz, 70Hz, 100 Hz). Therefore, the “Nguyen” Stage 2 modification is considered a viable repair option.

Due to the uncertainty associated with the transfer of mathematical modeling results to the physical structure, the modified structure should be impact tested to confirm the frequency of the structure has increased. The change in the frequency response must be assessed and compared to the acceptance criteria provided in the next section.

6.0 ACCEPTANCE CRITERIA

Based on the observed vibration response during impact and coast down testing, there is an apparent 5 Hz drop between static and dynamic response of the 2B HPSI pump [9]. Assuming that this remains true during modification, no natural frequencies are desired to be found below 70 Hz during impact confirmatory testing. That way a 10% separation between natural frequencies and the running speed would be maintained after the 5 Hz drop for operation.

7.0 REFERENCES

1. Structural Integrity Report SIR-03-013, Rev. 0, “Palo Verde HPSI Pump Vibration,” SI File No. PV-03-401.
2. ANSYS/Mechanical, Revision 5.7, ANSYS Inc., December 2000.
3. ANSYS/Mechanical APDL, Release 14.5 (w/Service Pack 1 UP20120918), ANSYS, Inc., Sep. 2009.
4. Structural Integrity Report SIR-06-420, Rev. 0, “Palo Verde HPSI 2A Pump Vibration Evaluation,” SI File No. PV-15-402.
5. Email from Mark Brutcher (APS) to Miroslav Trubelja (SI) et al., Subject: “13MSIA BP02 HPSI Historical Vibe Data For All Six Pumps Mini and Full Flow (04-19-17),” on 4/19/17 at 3:26 PM, Attachment: “13MSIA-BP02 HPSI Pump Overall Vibe Levels and Trends Mini and Full Flow (04-19-17).pdf,” SI File No. 1700546.202.
6. Email from Dominic Macedonia (APS) to Miroslav Trubelja (SI) et al., Subject: “RE: Report Palo Verde,” on 4/17/17 at 10:17 AM, Attachment: “2MSIBP02 Vibration Evaluation R0.pdf,” SI File No. 1700546.202.
7. Email from Mark Brutcher (APS) to Miroslav Trubelja (SI) et al., Subject: “2MSIBP02 U2 B HPSI PMT Vibe Levels Trends and Spectra (04-19-17),” on 4/19/17 at 3:45 PM, Attachment: “2MSIBP02 U2 B HPSI PMT Vibe Levels Trends and Spectra (04-19-17).pdf,” SI File No. 1700546.202.
8. Email from Mark Brutcher (APS) to Miroslav Trubelja (SI), Subject: “RE: Steady State and Coastdown Data following Lubrication of Pedestal Pads,” Sent April 21, 2017 at 7:08 AM, Attachment “HPSI 2B Dynamic Testing Prelim Results.docx,” SI File No. 1700546.201.
9. Email from David King (APS) to Miroslav Trubelja (SI), Subject: “RE: Steady State and Coastdown Data following Lubrication of Pedestal Pads,” Sent April 21, 2017 at 6:56 AM, SI File No. 1700546.201.

APPENDIX A

TYPICAL AND RELEVANT MODE SHAPES

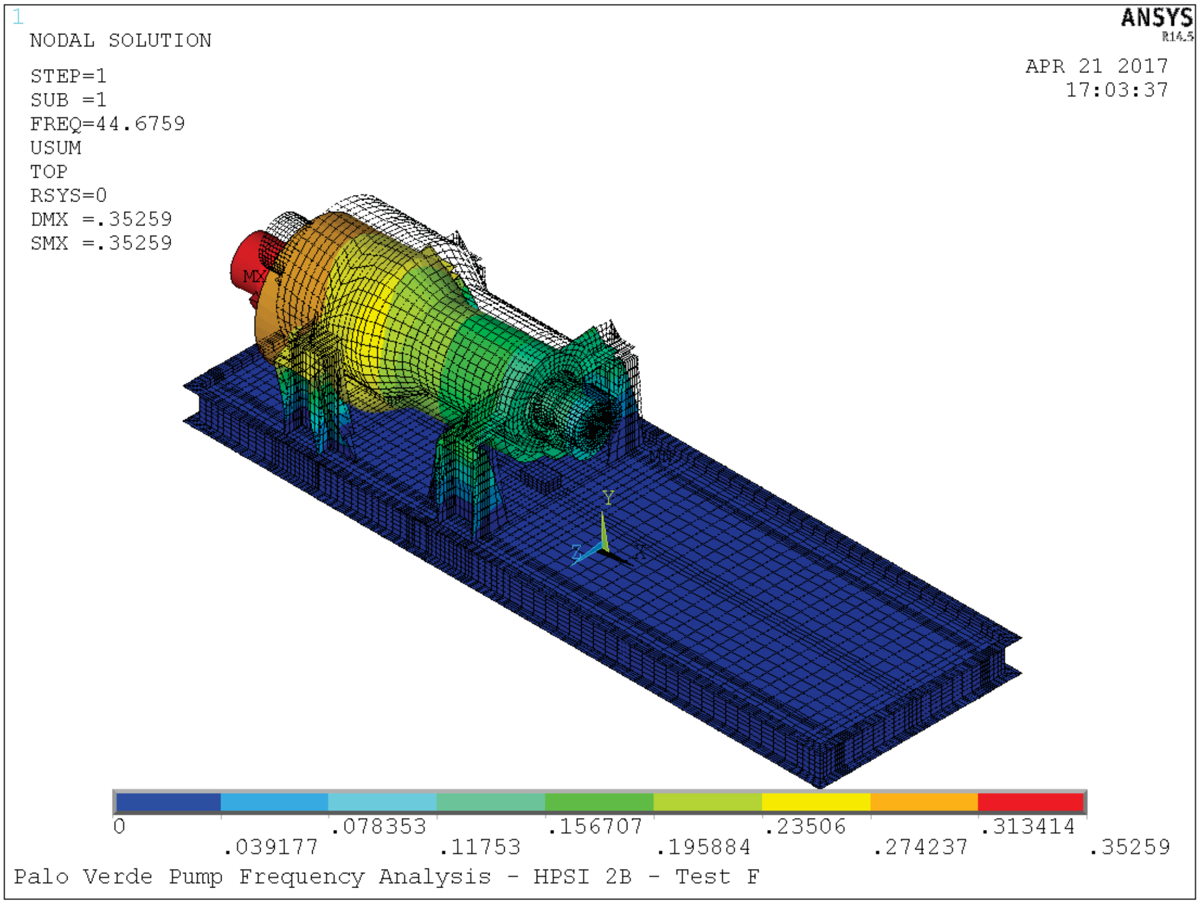

Figure A-1. Baseline – First Transverse Mode

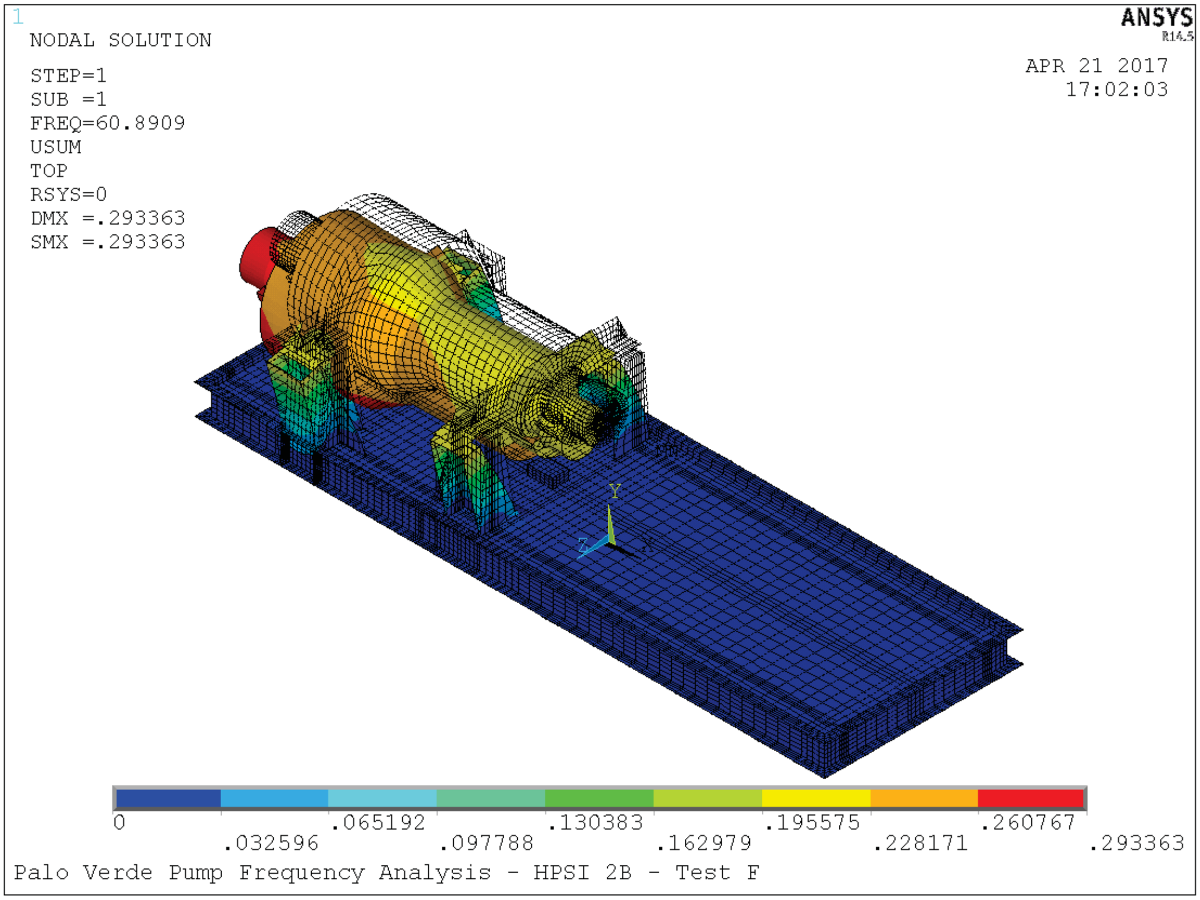

Figure A-2. Hofmann Stage 1 – First Transverse Mode

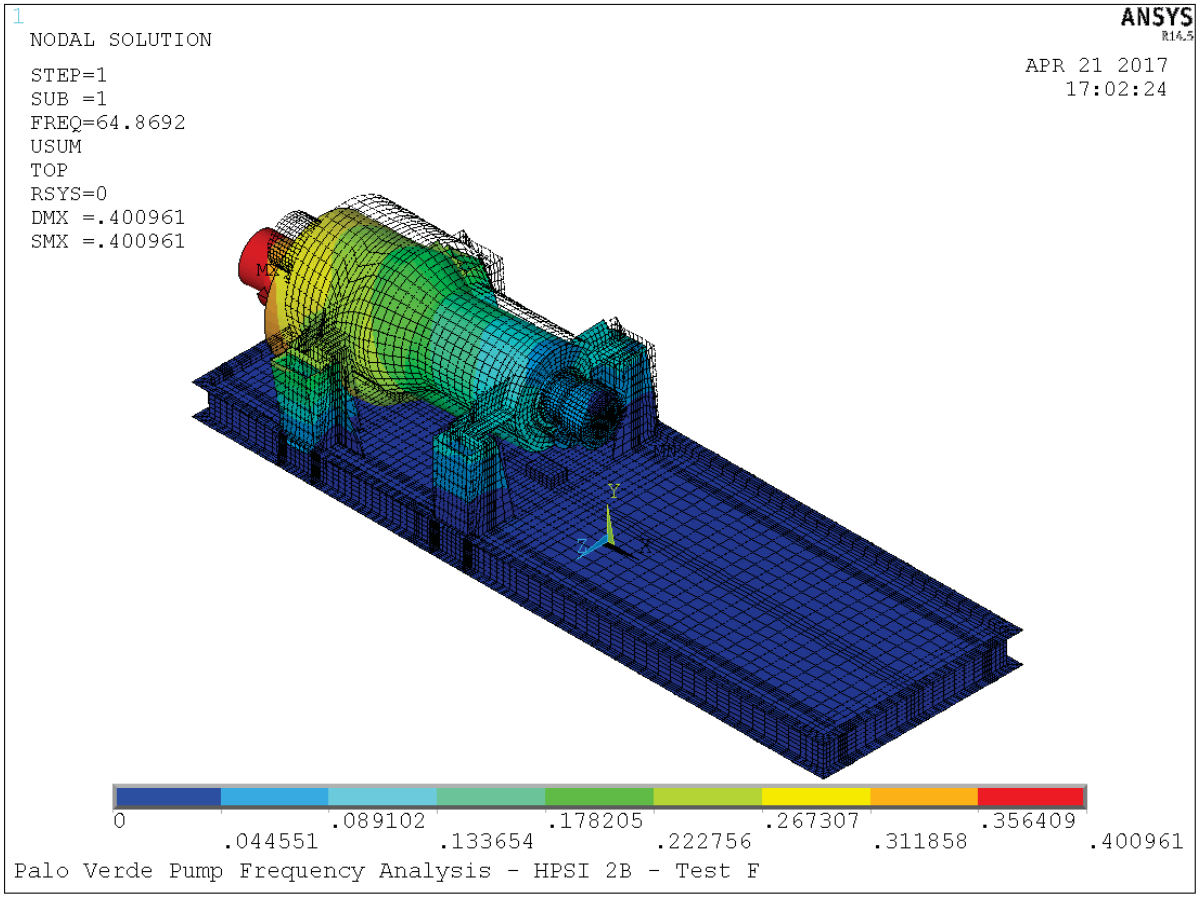

Figure A-3. Hofmann Stage 2 – First Transverse Mode

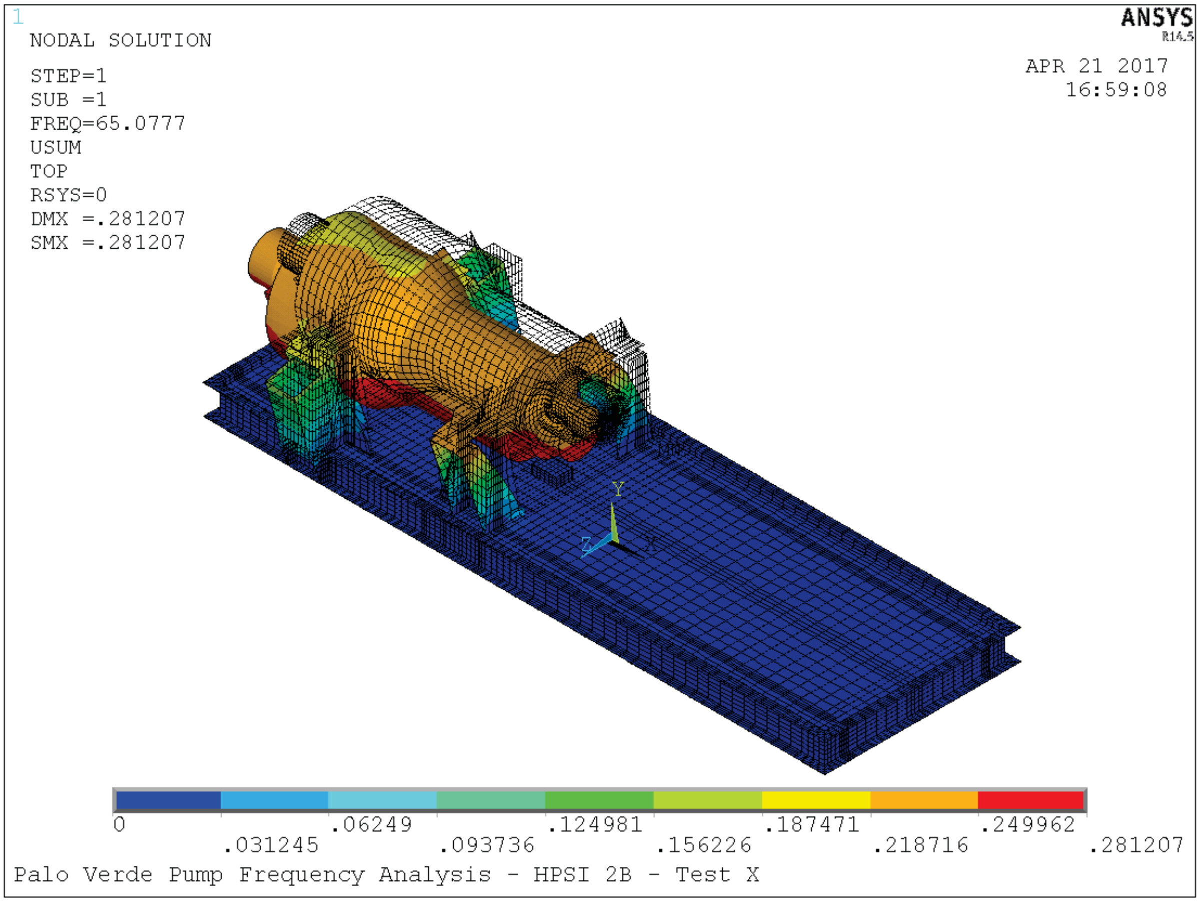

Figure A-4. Nguyen Stage 1 – First Transverse Mode

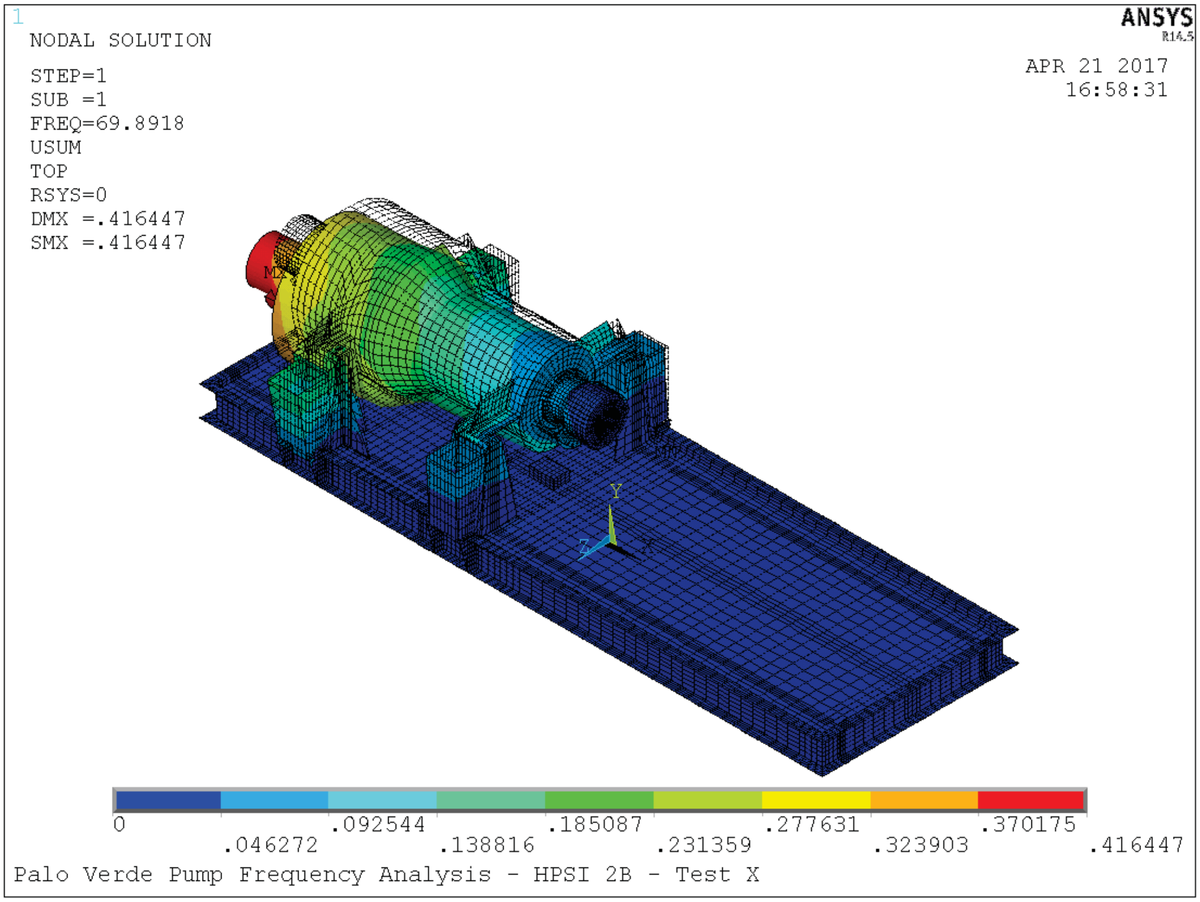

Figure A-5. Nguyen Stage 2 – First Transverse Mode