VIBRATION / RESONANCE CONTROL OF DYNAMIC EQUIPMENT FOUNDATIONS UTILIZNG A NON-METALLIC SOLUTION

By Anwar-ul-haq k. Bloch, Ahmed Al-jabr & Ziyad F. Al-zamil

PROBLEM STATEMENT / BRIEF INTRODUCTION

During the design and construction of cooling water closed/open loop dynamic equipment pump foundations, it is required to control the vibrations and resonance effects of the dynamic equipment on top of the civil foundations as per API requirements. In fact, those standards require that the civil foundations' natural frequencies are shifted away from the ±20% or 30% of the resonance frequency range of the dynamic equipment and that the vibration limits are adhered to. Actually, the main factors that influence the natural frequencies and vibration amplitudes are the overall system's mass (foundation + equipment) and the subgrade's stiffness properties.

Conventionally, to control the dynamic equipment vibrations and to fulfill the standard requirements, it was required to increase the foundation's mass (Large size of footings) in addition to improving the dynamic stiffness properties of the deeper levels of the soil underneath the foundation. In fact, the soil improvement measures are required to carried out by utilizing various rigorous techniques / methods, which should fulfill multiple testing requirements. Fundamentally, these conventional measures (i.e., soil improvement and / or increasing the foundation's mass) would lead to prolonged design and construction schedules, increased construction costs, and reduced design certainties due to the non-homogeneous stiffness properties of the underneath soil.

Hence, the utilization of the modern vibration control technique "Getzner Mattress system" was an opportunity to avoid the disadvantages of the conventional vibration solutions. In fact, the implementation of Getzner's Mattress system was proven to be a more cost-effective solution than increasing the foundation's mass and carrying out soil improvement techniques. The results show that with the help of the Getzner's Mattress system solution, the construction schedule plus construction / maintenance costs can be reduced and the design certainty can be enhanced.

INTRODUCTION

Dynamic excitation is mostly produced by large, powerful industrial equipment, which can cause damage to the machine itself, nearby machinery, sensitive equipment, and even nearby building structures can be affected as result of the vibrations. Additionally, transmitted vibrations can have a significant impact on underground infrastructure such as manholes, pipes, cables, etc. For that reason, it is crucial to control the vibration amplitudes and velocity levels on top of the foundation below the required limits, and it is important to shift the equipment foundation's natural frequencies away

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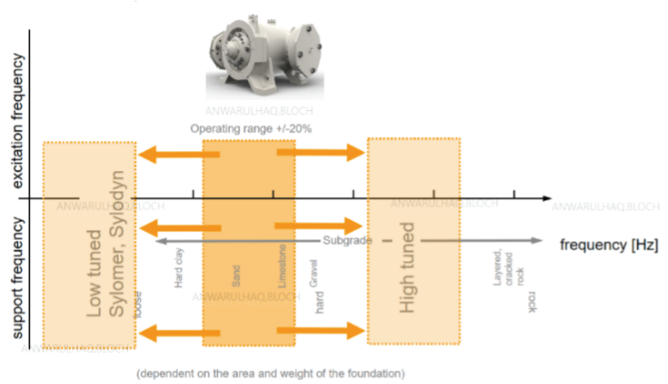

from the resonance range of the equipment (high tuned or low tuned solution). A symbolic diagram is shown above.

Actually, the six rigid body mode natural frequencies of the machine foundation should not coincide with the operating frequency of the machine (resonance zone). In fact, the zone of resonance is defined with +/-20% according to Saudi Aramco Standard SAES-Q-007, of the operating frequencies. When the foundation's natural frequencies are shifted lower than 80% of the equipment's operating frequencies, the solution is called low tuned. Otherwise, if the frequencies are higher than 120% of the operating frequencies, the solution is high-tuned. Actually, a low-tuned solution is preferred since it achieves better vibration amplitude results than a high-tuned solution.

During the design works of the ongoing Tanajib Gas Plant Project Department (TGPPD / Pkg-12) project, it was discovered that the existing soil's dynamic stiffness properties will lead to a conflict between the required natural frequencies and the resonance range zone. This means that relying on the existing soil's spring properties would lead to actual vibration amplitudes that are higher than the limits, in addition to a high vibration transmission.

The objective of this paper is to compare the conventional way of ground improvement with the latest non-metallic solution of "Getzner Mattress System" option to mitigate vibrations and overcome resonance challenges, in addition to sharing the realized benefits in terms of cost-time analysis by comparing both techniques.

DESIGN REQUIREMENTS

As per the design requirements, rotary equipment with a horsepower (HP) of greater than 500, require a detailed dynamic analysis for each equipment foundation. Actually, the design HPs in our cases are 1,770 HP (1,320KW) and 1,420HP (1,931 KW) for closed -loop and open-loop pumps respectively.

The purpose of the dynamic analysis is to prove that the six body mode frequencies are outside of the non-permissible frequency range and that the actual vibration levels will be lower than the specified limits.

The input that is required to initiate a dynamic analysis including the machinery details, foundation layout drawings and dimensions, and subgrade dynamic properties. In fact, the machinery details include input about the mass of the pump, center of gravity, rotating masses, balance quality, RPM, and general arrangement drawing.

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CHALLENGES FOR DYNAMIC FOUNDATION DESIGN, CONSTRUCTION AND REALIZED BENEFITS

TYP. CONSTRAINTS FOR PUMPS DYNAMIC FOUNDATIONS	EFFECT ON DYNAMIC FOUNDATIONS CONVENTIONAL CONSTRUCTION	REALIZED BENEFITS OF USING GETZNER MATTRESS
Area (Plot) Constraints	Soil type, Foundation size	Optimized plot (foundation size) design with the use of the existing soil
Non-homogeneous nature of the soil	Potential uncertainties in design calculations	The calculated vibration results are more accurate since the used stiffness is more accurate due to the homogeneous nature of the Getzner's mattress
Potential need for soil improvement measures	Time consuming and potentially more expensive	Avoid the need to replace the soil due to the possibility of adjusting the subgrade's stiffness with the Getzner's mattress only leading to schedule and cost optimizations
Potential need to increase the foundation mass	Risk exceeding allowable bearing pressure, foundation size constraints	The foundation width can be reduced by up to 40% without increasing the thickness.

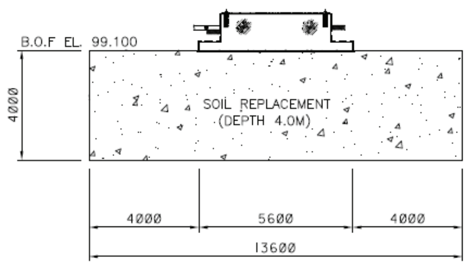
Top Realized benefit is "Reduced construction Cost and schedule".

CONVENTINAL SOIL REPLACEMENT METHOD PLAN FOR DYMANIC PUMPS FOUNDATIONS

When building a high-tuned pump foundation, it is frequently possible to regulate the vibration amplitude and natural frequencies by enhancing the dynamic stiffness of the subgrade's soil. This will enable the pumps to run within operating frequencies without causing resonance.

In fact, the replacement of the soil with structural fill using dynamic compaction is one of the practical solutions for enhancing the performance of the soil. This works best in permeable and granular soils since cohesive soils can absorb and reduce the technique's efficiency. Actually, this procedure is mostly applied to avoid the danger of excessive vibration by adjusting the system's stiffness in a way that would help in fulfilling the vibration and frequency requirements.

CONVENTIONAL SOIL REPLACEEMENT METHOD



SOIL REPLACEMENT SECTION

Sketch to show soil replacement in a conventional way

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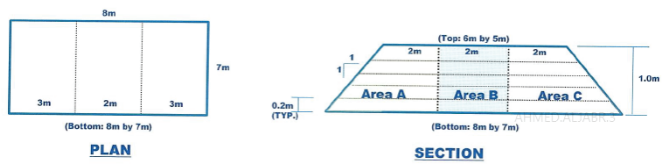
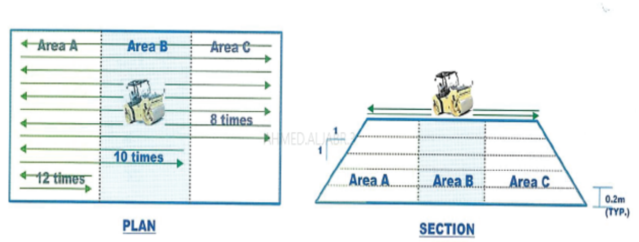
Base course material will be prepared as show in the below figures.



For the compaction, the area is divided into three parts and compacted by a 10-ton roller to achieve the required dynamic shear modulus as illustrated in the below figure.



GETZNER SYLOMER MATTRESS METHOD

BASE MATS - INSTALLED ON LEAN CONCRETE

Getzner mats are installed next to each other leaving no gaps between the mats. The joints

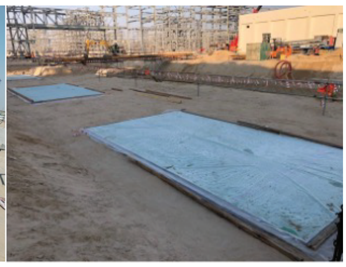
need to be taped by any duct tape

SIDE MATS – AFTER CASTING FOUNDATIONS

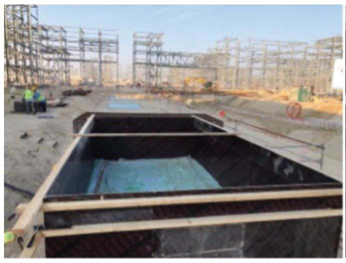
Side mats must also be installed on the side walls of the foundation using an adhesive

TGPPD SITE (COOLING WATER DYNAMIC PUMPS FOUNDATIONS) WITH USE OF GETZNER MATRESS

CLOSED-LOOP COOLING WATER PUMPS



CLOSED-LOOP COOLING WATER PUMPS



FORMWORK ONGOING

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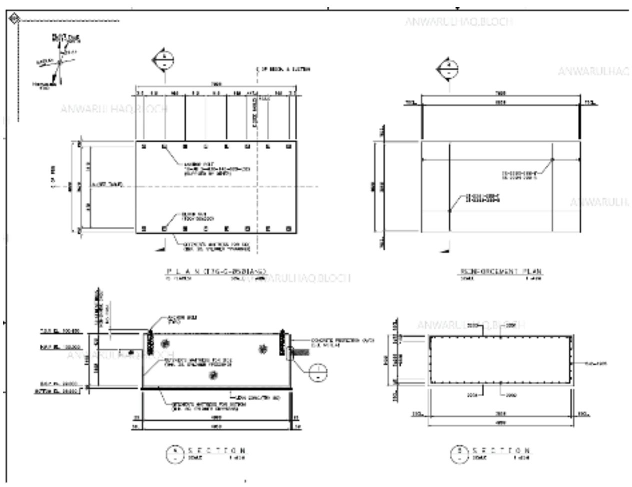

IFC drawing for the use of Getzner mattresses in TGPPD

COMPARISION BETWEEN SOIL REPLACEMENT CONVENTIAL METHOD AND USING GETZNER (SYLOMER) FOR DYNAMIC PUMPS FOUNDATIONS CONSTRUCTION (COST AND TIME IMPACT)

Cost and Schedule Comparison Table:

ITEM	(1) SOIL REPLACEMENT CONVENTIAL METHOD	(2) GETZNER (SYLOMER) MATTRESS	DIFFERENCE (2-1)
WORK METHOD	Soil replacement with aggregate base course from bottom of the foundation to 4~5m below	Installation of Getzner "Sylomer" mattress on the sides and the bottom of the foundation only for lower than finished ground level	Time saving, easy to install, long life, maintenance free.
Excavation/Backfill	9,000m3 / 1,400m3	1,000m3 / 600m3	-8,000m3 / -800m3
Aggregate Base Course	7,300m3	N/A	-7,300m3
Compaction Testing	Test for each layer with specified inspector and special 3rd party equipment	No Test	429 MH
Sylomer Mattress	N/A	480m2	+480m2
Concrete / Rebar	335m3 / 41.5ton	347m3 / 21.8ton	+12m3 / -19.7ton
Cost	312,000 USD	258,000 USD	-54,000 USD (17.3%)
Construction Duration	4.8 Months	2.0 Months	-2.8 Months (58%)

At Pkg-12 in TGPPD (Tanajib Gas Plant Project Department) site for 10 numbers of dynamic pumps there is significant reduction in construction time (58%) and cost saving (17.3%) relative to conventional construction by ground improvement technique.

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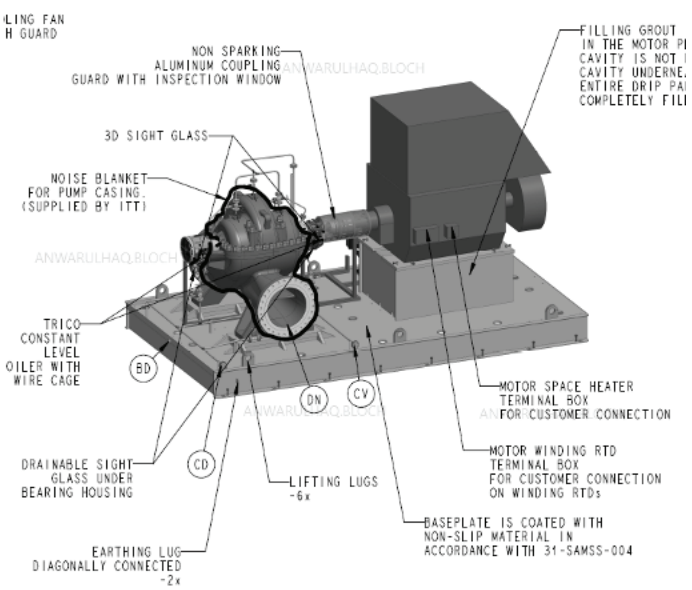
Result Comparison Table:

PUMP FOUNDATIONS DESIGN	MASS OF CONCRETE PER FOUNDATION (M3)	AMPLITUDE (mm)	MAXUMIM ALLOWABLE AMPLITUDE (mm)	VELOCITIY (mm/sec)	MAXUMIM ALLOWABLE VELOCTIY (mm/sec)	REMARKS
CONVENTIAL WAY DESIGN	35.1	0.0025	0.0245	0.344	3	UNDERNEATH SOIL IMPROVEMENT IS REQUIRED Depth = 5m Width = 14.0m Length = 14.0m
WITH USE OF GETZNER MATRESSES	30.5	0.0035	0.0245	0.438	3	No Soil improvement Required.

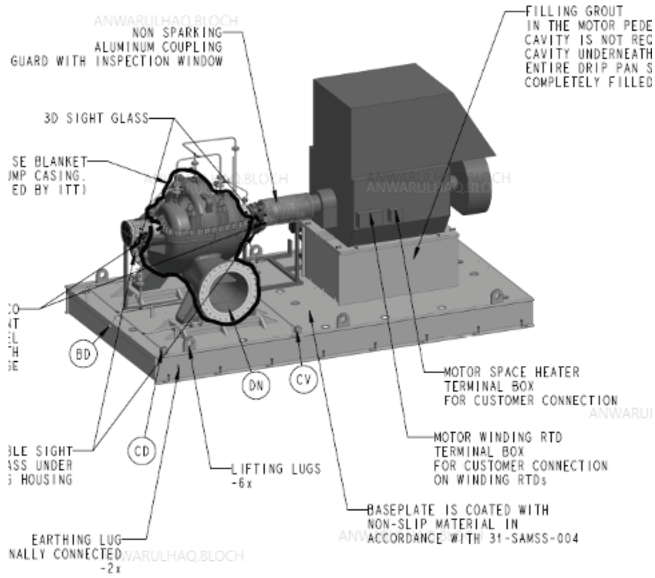
WEIGHTS	WEIGHTS ARE APPROXIMATE	
ITEM	lbs	kg
PUMP	20809	9439
UPPER CASING	3788	1718
PUMP ROTATING ASSEMBLY	2264	1027
COUPLING	331.8	150.5
DRIVER	21826	9900
BASEPLATE	22046	10000
JB & STAND	132	60
OTHER	110	50
TOTAL	65254.8	29599.5

DRIVER SPECIFICATIONS	
MFR. : TECO MOTORS	
POWER: 1420 kW (1931 HP)	FRAME: 560B
PHASE: 3	RPM : 890
HERTZ: 60	VOLTS: 4000
ENCLOSURE: IC611 TEACC), IP55	

OPEN-LOOP PUMPS (T76-G-0501 A~E)



CLOSED-LOOP PUMPS (T76-G-0503 A~E)



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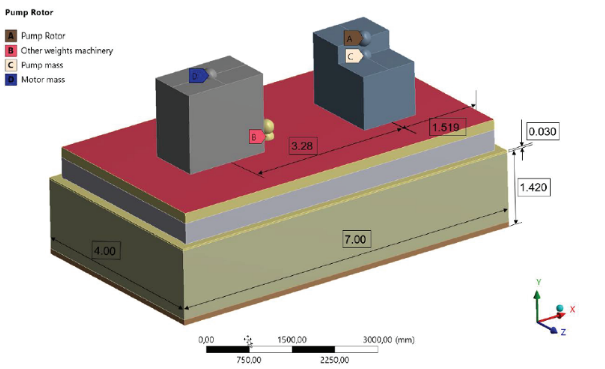
WEIGHTS	WEIGHTS ARE APPROXIMATE	
ITEM	LBS	Kg
PUMP	11629	5275
UPPER CASING	2235	1014
PUMP ROTATING ASSEMBLY	1237	561
COUPLING	270.9	122.9
DRIVER	16755	7600
BASEPLATE	18739	8500
JB & STAND	132	60
OTHER	110	50
TOTAL	47635.9	21607.9

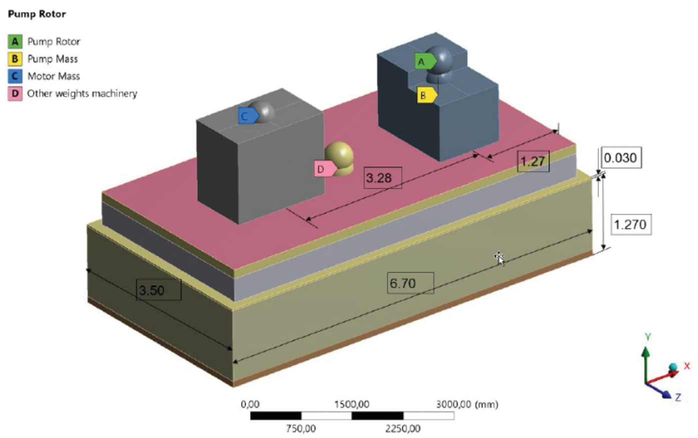
DRIVER SPECIFICATIONS	
MFR: TECO MOTORS	
POWER: 1320 kW (1770 HP)	FRAME: 5008
PHASE: 3	RPM : 1190
HERTZ: 60	VOLTS: 4000
ENCLOSURE: IC611 (TEAAC), IP55	

Note: All above design information and sketches are taken form issued site IFC drawings.
Below models were generated by "GETZNER ENGINEERING" using software ANSYS for TGPPD / Pkg-12 Project

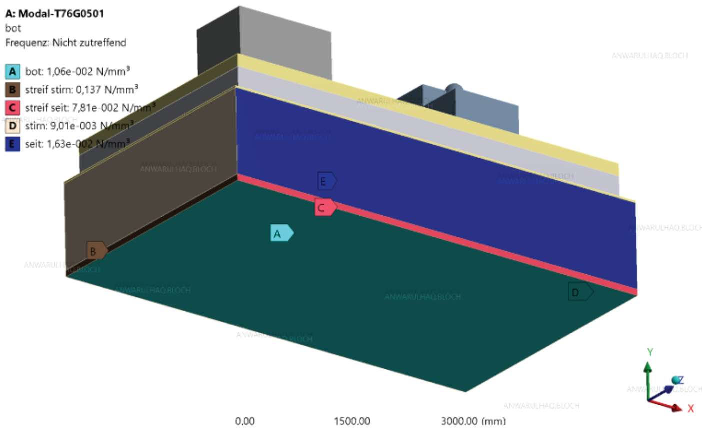
DYNAMIC ANALYSIS
Model on Ansys for the open-loop pump



Model on Ansys for the closed-loop pump



Model on Ansys showing the elastic bedding using Getzner's Sylomer product



Dynamic Analysis - Results
The dynamic analysis of the block foundation is carried out in two steps.
– modal analysis to determine the rigid body mode shapes and the bending mode shapes (necessary to choose the appropriate damping value)
– harmonic analysis, carried out for the dynamic loads of every machine component separately

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The modal analysis results for both pump types show that the six body mode shapes are outside of the resonance range.

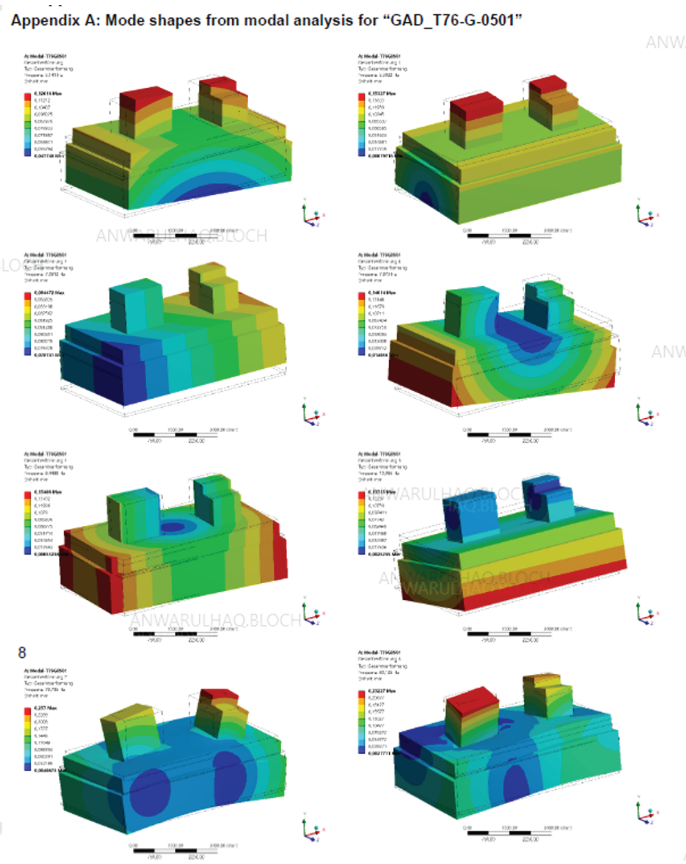
Open-loop Pump:

mode no.	frequency [Hz]		type of mode
1	5,1	rigid body modes	longitudinal deformation
2	5,4		lateral deformation
3	7,1		vertical deflection
4	7,9		lateral rotation
5	8,4		vertical rotation
6	10,1		Longitudinal rotation
7	79,7	bending	longitudinal bending mode
8	80,1		.
...	...		

Closed-loop Pump:

mode no.	frequency [Hz]		type of mode
1	6,2	rigid body modes	lateral deformation
2	6,5		longitudinal deformation
3	8,6		vertical deflection
4	9,8		lateral rotation
5	10,1		vertical rotation
6	12,1		Longitudinal rotation
7	60,8	bending	longitudinal bending mode
8	77,8		.
...	...		

MODE SHAPES OF COOLING WATER OPEN-LOOP PUMPS (T76-G-0501 A~E) by ANSYS



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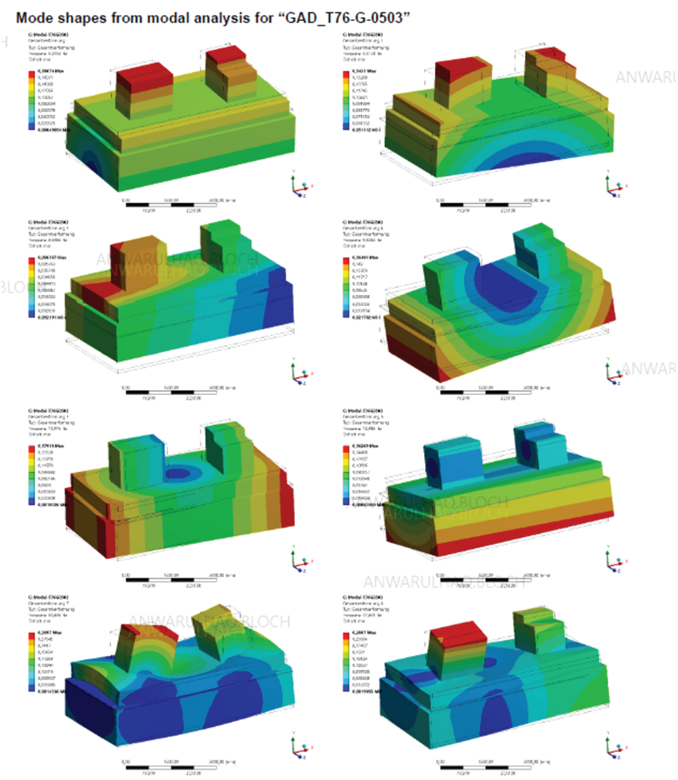
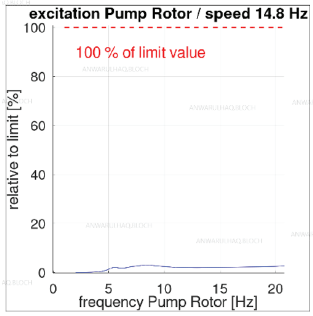
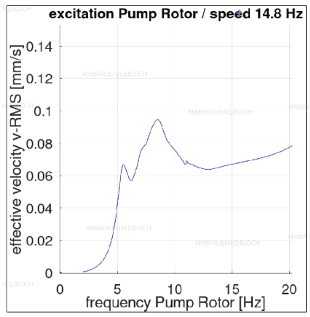
MODE SHAPES OF COOLING WATER CLOSED-LOOP PUMPS (T76-G-0503 A~E) by ANSYS

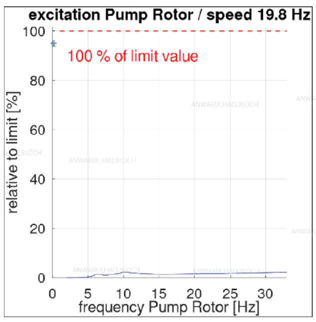


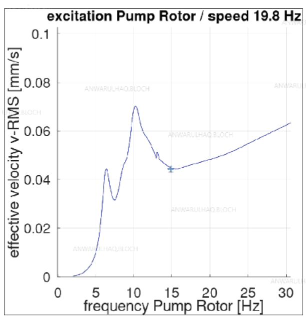
The harmonic analysis results show that the vibration requirements are fulfilled since the vibration levels are below the limits for both pumps:

Velocity values at top of foundations open-loop pumps (T76-G-0501 A~E) By ANSYS









Velocity values at top of foundations closed-loop pumps (T76-G-0503 A~E) By ANSYS

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CONCLUSION

Tanajib Gas Plant Projects, Package-12, “Utilities, Flare and Piperack” successfully implemented the “Vibration Control Technique” for the first time to mitigate the resonance/vibrations effect of dynamic equipment for cooling water dynamic pumps. The vibration control technique is a special elastomeric polyurethane material. The implementation of this advanced technique led to significant time saved on construction activities and reduced the size of foundations up to 40%. The involved construction activities were planned for 4.8 months but completed in 2.0 months instead, as a consequence for embarkment of this technique by time savings of up to 58 %.

The “Vibration Control Technique” is easy to install, maintenance free and has a proven track record of working to control dynamic equipment vibrations – even in subsoil waterlogged areas.