ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 11, Issue 10, October 2024

Vibration Assessment for Steel Structure with Viscous Damper Application in Oil & Gas Industry

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Abstract— ***Excessive vibration can cause fatigue failure in structure which may lead to serious structural integrity, operational and safety concerns in oil and gas facilities. Piping vibration at an offshore facility has resulted in several welding failures at its small-bore connection. Vibration measurement on the piping system classified it as severe risk according to recognized international standard and guideline. There are several methods to resolve the piping vibration issue by transferring the load to the structure. Consideration was made on factors such as the effect to the existing structure due to rectification work, construction complexity and cost. Viscous dampers were proposed to be installed as it transmits less vibration to the structure, thus minimising structural modification. This paper presents a case study on the impact of piping vibration to steel structure and its effect after viscous dampers installation.***

Index Terms— ***assessment, fatigue, integrity, modification, structure.***

I. INTRODUCTION

At an offshore facility suspected due to vibration issue, several welding failures were observed at the small-bore connection (SBC) of 30" nitrogen piping system from centrifugal compressor causing integrity, operational, and safety concern.

Vibration assessment was conducted as part of the root cause investigation process. Findings from the preliminary vibration assessment indicated that the piping was experiencing severe vibration, thus operation team shutdown one of the nitrogen facilities for the SBC welding crack repair and installation of support bracing to mitigate the issue. However, failure of the welding cracks re-occurs after the mitigation.

Further detailed vibration assessment found that the dominant vibration frequency appeared at low frequency range between 2Hz to 3Hz with velocity RMS-amplitude exceeding Energy Institute [4] vibration severity criteria. This vibration response was due to change of flow behavior inside the pipe and additional dynamic load imposed to the piping and structure.

There are several methods to resolve the vibration issue with main consideration on live operating offshore construction complexity. Viscous dampers were proposed as it has more advantages as compared to other typical vibration support systems such as hydraulic snubbers, rigid struts, vibration clamps, etc. One of the dominant advantages of viscous damper is that it will only transfer a minimal dynamic load from vibrating piping to the structure. In addition, the installation can be carried out without the needs to shut down the facility.

This paper discusses on the vibration assessment, advanced structural analysis, and the findings for pre and post installation of viscous dampers.

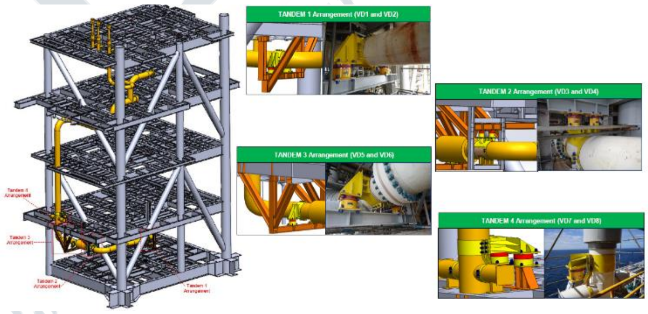

Fig. 1 Overview of Viscous Dampers Installation Location (Source: PETRONAS [5]).

II. METHODOLOGY

The vibration assessment of the supporting structure integrity was performed through site assessments coupled with an advanced structural analysis using Finite Element Analysis (FEA), as detailed in Fig. 2 below. The assessment was conducted to analyse the reaction of the structure for the following two conditions:

- Pre-modification of existing structure due to imposed dynamic load from the piping.
- Post-modification of existing structure with pipe clamped to viscous dampers and its supporting structures.

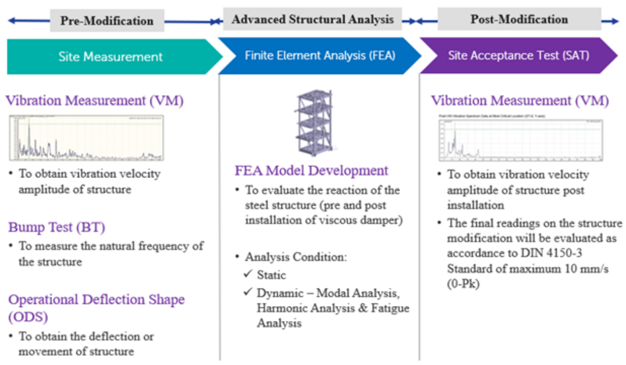

Fig. 2 Work Processes for Structural Vibration Assessment (Source: PETRONAS [5]).

1) Site Measurement

Vibration measurement (VM) and operational deflection shape (ODS) were performed during normal operating condition (online), whereas bump test (BT) was conducted during shutdown (offline) window. Readings were taken on multiple points of the pre-modification structure as part of the assessment verification and validation process.

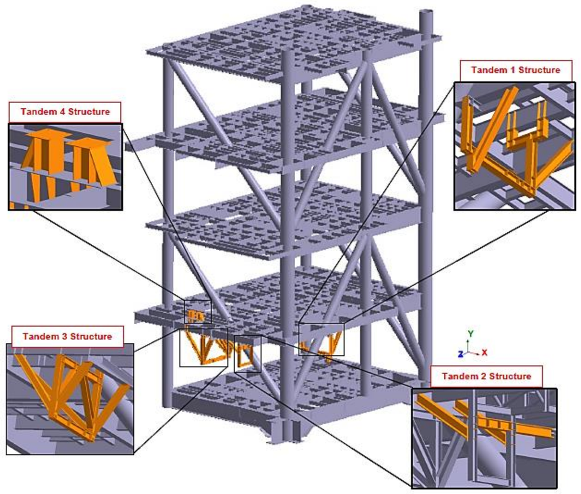

Fig. 3 FEA Model of Structure 2 (Post-Modification) (Source: PETRONAS [5]).

2) Finite Element Analysis (FEA)

Two FEA models were created for structural analysis which are existing structure pre-modification (Structure 1) and structure post-modification with viscous dampers and its additional supporting structure installation (Structure 2, as shown in Fig. 3 above). Each analysis case was analyzed for both static and dynamic condition, as presented in Table I.

Table I Structural Analysis Condition.

Analysis Case	Analysis Condition	Static Analysis	Dynamic Analysis		
			Modal Analysis	Harmonic Analysis	Fatigue Analysis
Structure 1	Pre-Modification	✓	✓	✓	✓
Structure 2	Post-Modification	✓	✓	✓	✓

Static analysis was performed to determine the integrity of the structure when being subjected to non-time dependent static load. Structural supports were added to support the viscous dampers. Dynamic analysis involved modal analysis to determine dynamic characteristic of the system (natural frequency and mode shape) which used as an input for the harmonic analysis.

Harmonic analysis was conducted to investigate the dynamic response into the structure in term of stress and deflection as well as velocity response. Fatigue analysis determined the fatigue life of the modified steel structure assembly when being subjected to cyclic loading due to vibration based on a worst-case scenario condition where the highest calculated stress being applied constantly at excitation frequency of 3 Hz throughout the system life cycle.

3) Site Acceptance Test (SAT)

Vibration on structure modification shall be operationally acceptable and fall under safe criteria as per DIN 4150-3 Standard [3] of maximum 10 mm/s (0-peak) at any axis at similar operating condition. Final readings taken on the post-modification structure were evaluated against the vibration acceptable criteria to observe on the behavior of the structure.

III. RESULT AND DISCUSSION

1) Pre-Modification Assessment

a. Finite Element Analysis (FEA) Model Validation – Velocity Response

The vibration measurement (VM) velocity reading (mm/s 0-peak) measured at site against FEA simulation velocity response were compared to check the accuracy of the model with deviation results of less than 10%, as shown in Table II. Thus, the simulation model is within the reasonable accuracy.

Table II Structure Velocity Response (VM Versus FEA Model).

Point	Axis	Frequency (Hz)	Site VM	FEA Model	Variation
			Velocity (mm/s 0-Peak)	Velocity (mm/s 0-Peak)	
ST-1	X	23.50	0.1550	0.1575	1.61%
	Y	23.50	0.1030	0.1046	1.55%
	Z	23.50	0.0700	0.0713	1.86%

b. FEA Model Validation – Operational Deflection Shape (ODS) and Bump Test (BT)

Operational Deflection Shape (ODS) data was extracted based on BT result to evaluate the dynamic characteristic of the structure against simulation. The results for measured BT and against calculated natural frequency from modal analysis simulation varies less than 10%, thus the model is within the reasonable accuracy. Table III shows the BT result measured

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 11, Issue 10, October 2024

on structure and Fig. 4 shows the result validation of the model.

Table III Bump Test (BT) Site Measurement Versus FEA Modal Analysis.

Point	Axis	Bump Test	FEA Modal Analysis	Variation
		Natural Frequency		
BT-S1	X	12.50	12.44	0.48%
	Z	12.50	13.51	8.08%
BT-S2	X	12.00	12.44	3.68%
	Z	12.50	13.51	8.08%

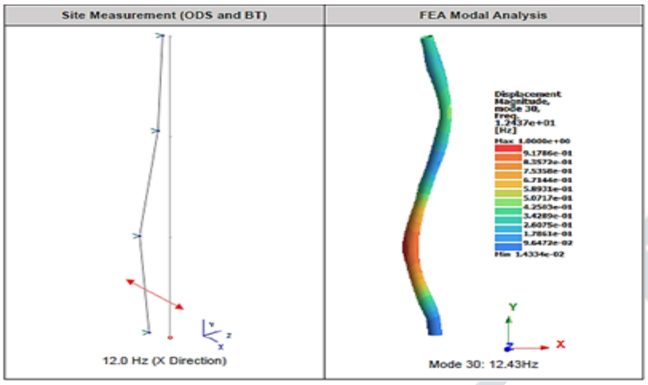

Fig. 4 Result Validation (Source: PETRONAS [5]).

2) Pre-Modification Assessment

Based on the static and dynamic analyses performed on the structure, the results indicated that steel structure post-modification are safe since the maximum equivalent stress is below the allowable stress. Dynamic displacement at the support structure supporting viscous dampers is within allowable displacement at 3 Hz excitation frequency to meet DIN 4150-3 [3] criteria of 0.53 mm (0 to Peak). Summary of the analysis result are tabulated in Table IV below.

Table IV Summary of Analysis Result.

Modal Analysis	Fundamental Natural Frequency	Post-Modification
		4.18 Hz
Static Analysis	Maximum Overall Von Mises Stress < 150 MPa	PASS (49 MPa)
	Maximum Overall Structure Displacement (mm)	5.42
Dynamic Analysis	Maximum Overall Von Mises Stress From DC (0 Hz) to 15 Hz < 150 MPa	PASS (17 MPa)
	Maximum Overall Structure Displacement (mm) from DC (0 Hz) to 15 Hz	0.78
	Maximum Displacement @ 3 Hz (mm)	0.04 – 0.11
Fatigue Analysis	Fatigue Life @ 3 Hz	OK

Failure criterion was based on Von Misses Stress criteria whereby the equivalent stress value of the steel structure shall not exceed the ASTM A36 material allowable stress of 150 MPa, calculated using safety factor of 1.67 for Allowable Stress Design (ASD) method as per AISC 360-16 [1]. Fig. 5 shows the FEA result plots for post-modification dynamic analysis.

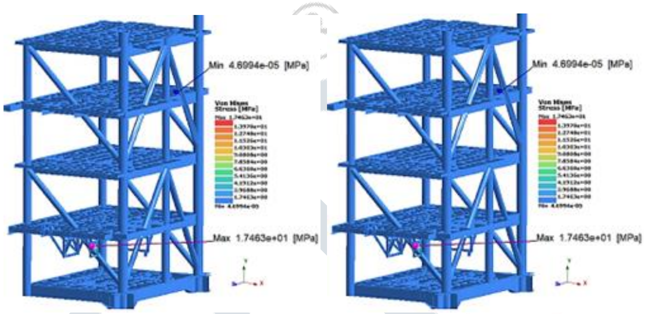

Fig. 5 Overall Static (Left) and Dynamic (Right) Stress Result for Post-Modification (Source: PETRONAS [5]).

Fatigue analysis of the structure modification design was evaluated against the material S-N curve in accordance with ASME Section VIII Division 2 – Part 3 [2]. The rigidity of the structure successfully met the best practice criteria of minimum 5 times stiffer than the viscous dampers equivalent stiffness at 3 Hz excitation frequency to ensure the viscous dampers can work effectively.

3) Site Acceptance Test (SAT) Result

Vibration levels were taken at the post-modification structure to observe the behavior of the steel structure. The evaluated vibration levels at all measurement points for post-modification structure were operationally acceptable and fall under safe criteria as per DIN 4150-3 [3] standard of maximum 10 mm/s (0-Peak) amplitude as shown in Table V below.

Table V Summary of Vibration Measurement Result Post Modification at Point S7.

Point	Axis	Post-Modification			DIN 4150-3 Vibration Severity Criteria
		Frequency (Hz)	Amplitude (mm/s 0-Peak)	Overall (mm/s 0-Peak)	
S7	X	2.50	1.71	5.60	SAFE
	Y	6.00	1.10	3.64	
	Z	51.30	0.41	4.11	

IV. CONCLUSION

Based on post installation result measured and continuous monitoring on VM result (after 3 months installation), the vibration levels on piping and structure were observed to be under acceptable limit thus enabling safe operation of the offshore facility as per design. It can be concluded that with installation of viscous dampers and its supporting structures, vibration issue can be resolved with minimum modification of existing structure which resulted in time, cost, and overall scope optimization. The installation work was completed safely without shutdown requirement and within project schedule.

V. ACKNOWLEDGEMENT

The authors would like to acknowledge PETRONAS Group Technical Solution (GTS)'s management, stakeholder, and contractor in providing continuous support for successful execution of the project.

REFERENCES

[1] American Institute of Steel Construction, "Specification for Structural Steel Buildings, AISC 360-16, 2016.

[2] ASME Boiler and Pressure Vessel Code, Section VIII: Rules for Construction of Pressure Vessels; Division 2 Alternative Rules - Part 3, 2019.

[3] DIN 4150-3: 1999 "Structural Vibration: Part 3 – Effect of Vibration on Structures", International Standard, 1999.

[4] Energy Institute "Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework", Second Edition, January 2008.

[5] PETRONAS, Provision of Viscous Dampers Rectification Solution at Centrifugal Compressor (Compander) Discharge Piping, Internal Report, 2023.