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Investigation of Seismic Response Reduction by Tuned Mass Damper in Surge Line

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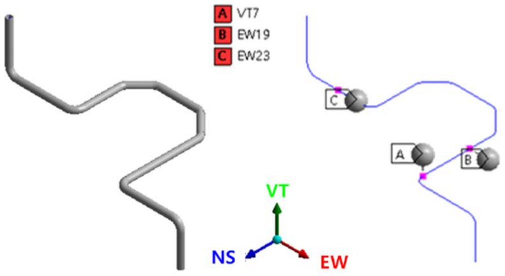
1. Introduction

A Tuned Mass Damper (TMD), or also known as a dynamic absorber, is one of the most widely used vibration control devices. The concept of TMD was introduced in 1909 when Frahm developed a vibration control device called dynamic vibration absorber. Since then, the TMD is being applied to a variety of industry fields in diverse forms. As TMD doesn't need any support, it can have a considerable benefit in complex structures like pipe system. In this study, the seismic responses of RCS Surge Line due to an application of TMD are investigated. Based on such investigation, the effect of TMD in RCS Surge Line is quantified.

2. TMD Design

Basically, a TMD is a device composed of mass, spring and damper which are tuned with a major frequency of the target structure. To achieve the best performance of the TMD, determining TMD attaching location and target structure frequency is also important design parameter. In this study, TMDs are introduced to reduce the maximum NS-Directional bending moment of the end of the surge line which is in junction with the hot leg, because that area is the most fragility under seismic load.



(a) Surge line layout (b) TMD location

Fig. 1. RCS Surge Line

To determine the TMD locations and target frequency, base excitation harmonic analysis with unit acceleration is conducted. For that, 4% of structural damping is applied to pipe system.

As shown in Fig. 2, the moment FRF has dominant 5 peaks which are coincident with natural frequencies within ZPA frequency (40Hz). And it can be confirmed that the NS-Directional bending moment has a peak in 7.9Hz (VT), 19.45Hz (EW) and 23.48Hz (EW) response mainly with consideration of a given floor response spectrum as well as moment FRF. So, the 3 TMDs targeting for those frequencies are selected and each TMD is attached to where the maximum absolute deflection occurs for each mode shape as shown in Fig. 1-(b).

Each TMD mass is distributed and restrained so as for total TMD mass not to exceed 1% of total surge line system mass. To seek the TMD stiffness and damping coefficient, with them as design variables, numerical optimization that minimizes the maximum moment FRF for each mode is adopted.

Table 1 Summary of mode analysis results

Mode	Frequency	Mass ratio(total : 6475 kg)		
		EW-Dir.	VT-dir.	NS-Dir.
1	7.95	0.025	**0.358**	0.000
2	11.06	0.018	0.078	0.000
3	12.67	0.011	0.073	0.002
4	19.45	**0.143**	0.061	0.001
5	23.58	**0.372**	0.035	0.004
6	26.60	0.025	0.027	0.074

Table 2 TMD design parameters

Target (Hz)	Dir.	Mass (Kg)	Damping (N s/m)	Stiffness (N/m)
7.95(A)	VT	40	274.6	92846
19.45(B)	EW	20	133.3	287760
23.58(C)	EW	40	1031.3	799320

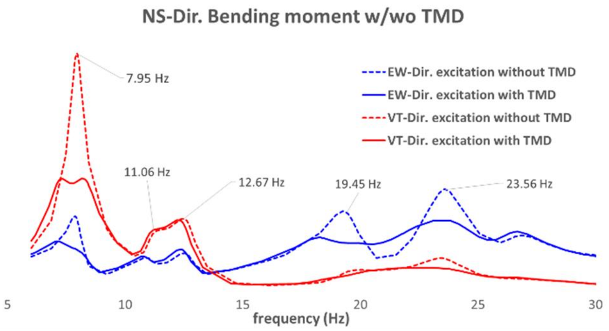


Fig. 2. Moment frequency response function (FRF)

3. Seismic Analysis

For looking into how TMDs affect the seismic performance of the target surge line under the actual earthquake excitation, time transient analysis is conducted with an artificial seismic motion generated from the given floor response spectrum.[1]

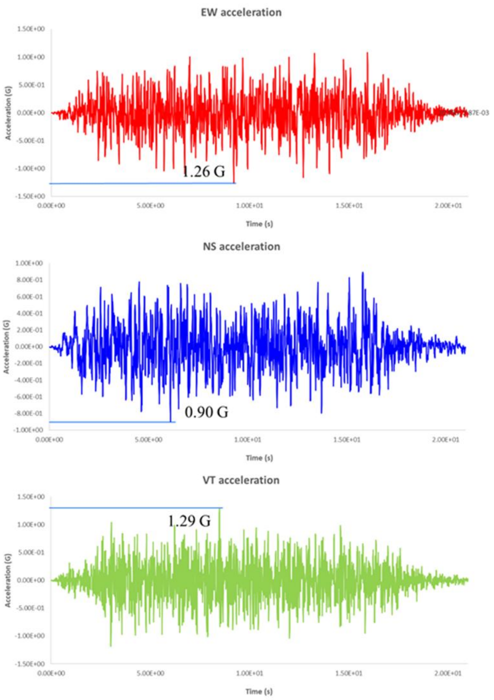


Fig. 3. Artificial seismic input motion

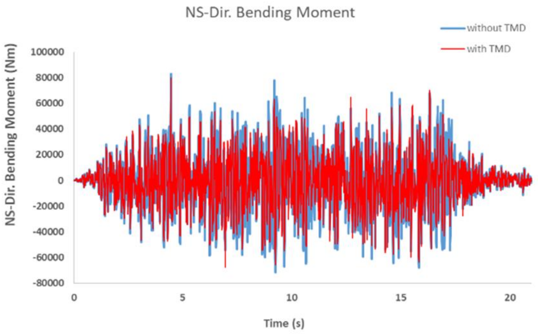


Fig. 4. Comparison of NS-Dir. bending moment in time domain

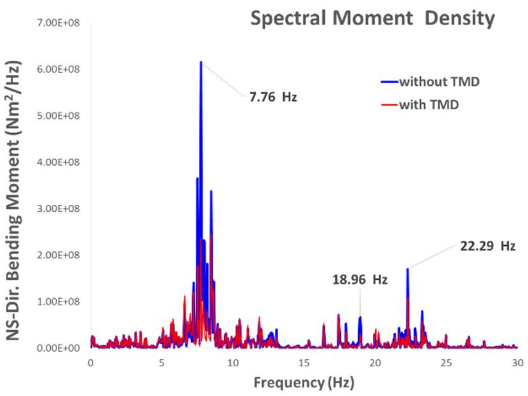


Fig. 5. Comparison of NS-Dir. bending moment in terms of spectral moment density

Fig. 4 shows NS-Dir. bending moment in time domain. The maximum bending moment occurs at 4.445s and it is only reduced by 4%. But, for other peaks, TMDs seem to work accordingly. TMD plays role of reducing dynamic amplitude after shock. To reduce response due to shock, damper would be more suitable than TMD. The effect of TMD is shown dramatically in frequency domain. The bending moment is also compared in form of spectral moment density. It is observed that the moment responses around the target TMD frequencies are reduced and this phenomenon is dominant around 7.8 Hz response as predicted in Fig. 2.

For quantitative evaluation of the TMD effect regarding the RCS Surge Line, Damage Equivalent Load for the bending moment is introduced. DEL has a constant load range that brings the same cumulated fatigue damage index from whole load ranges for a given reference cycle. DEL, S_{DEL} is defined as follow :

$$S_{DEL} = \left(\sum S^m \frac{n}{N_{ref}} \right)^{1/m} \qquad (1)$$

m : exponent of SN curve, 2.5 (IEEE-344)[2]
S : Load range
n : Cycle of S
N_{ref} : Reference cycle of S_{DEL}

S and n can be solved through rainflow counting. If ignoring mean load effect, for N_{ref} is 1, S_{DEL} is calculated for each as follow :

S_{DEL} without TMD : 547149 Nm
S_{DEL} with TMD : 49462 Nm

About 10% of fatigue load is decreased by TMD, which means that 21% of permissive cycle is increased for m=2.5.

4. Summary and Conclusion

This study investigated how much the system response is reduced to some extent when applying TMD to RCS surge line system under the earthquake loading. Without any modification of surge line itself, TMD brings reduction of the maximum load and fatigue load of RCS surge line. Thus, the TMD is judged as one of effective tools for enhancing seismic performance of nuclear piping system.

ACKNOWLEDGEMENTS

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