Development of Tuned Mass Damper Device for a Piping System under Seismic Load

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1. Introduction

A Tuned Mass Damper (TMD) is one of the widely used vibration control devices. After having been introduced in 1909 by Frahm, the TMD has been applied to a variety of industry fields in various forms. As the TMD doesn't need any support, it has a considerable benefit in applying to complex structures like a piping system. In this study, seismic response of a nuclear piping system with TMD is investigated and TMD device prototype is developed and manufactured based on the result.

2. TMD Design

To manufacture the TMD, design parameters such as TMD mass and target frequency shall be determined first. This section depicts how these parameters are solved for a given nuclear piping system.

2.1 Target Piping System

The target piping system consists of total 17.8 m pipes of NPS 2 or 3 inch, 7 elbows, and 2 reducers. It is weighing 523 kg including internal fluid. The system has a function of bypass connection when the main pipe line of steam generator is blocked accidentally.

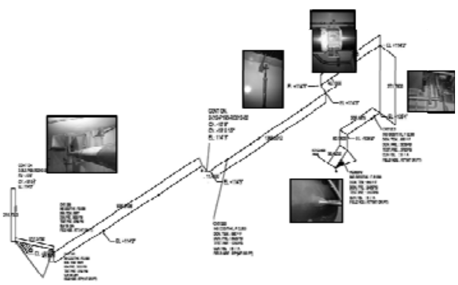


Fig. 1. Target piping system

Table I: Modal Analysis Results of the Piping System

Mode	Frequency	Modal Mass Ratio		
		EW	NS	VT
1	**2.0 Hz**	0.00	**0.55**	0.00
2	3.5 Hz	0.00	0.02	0.00
3	5.6 Hz	0.00	0.00	0.01

The TMD parameters shall be determined based on dynamic property of the target system. The TMD can reduce dynamic response of target system only if its natural frequency is synchronized with the TMD frequency. Modal analysis results are shown in Table I and the 1st mode is selected as a target mode.

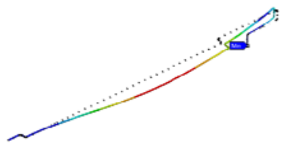


Fig. 2. 1st Mode shape of the piping system (2.0 Hz)

2.2 TMD Design Parameters

The key factor of TMD design is TMD mass ratio to the target system. Most of TMD design formulation utilizes the mass ratio as input parameter to solve TMD design parameters. While 1 % of TMD total mass ratio is used commonly, 16 kg of TMD mass equivalent to 3.1 % is used in this study. Reducing TMD travel range along with TMD mass increasing can minimize overall TMD equipment size. And to limit the TMD mass range additionally, the Sadek's equation is chosen which results in the most TMD optimized damping ratio among the well-known TMD formulations [1,2].

Table II: TMD Design Parameters by Sadek Equations

Piping modal mass, kg	287
Piping damping ratio	0.04
TMD mass, kg	16
TMD modal mass ratio	0.056
Optimal frequency ratio by Sadek	0.94
Optimal damping ratio by Sadek	0.268

3. TMD Prototype

Specific values of the TMD spring stiffness and damping coefficient can be solved from dimensionless parameters in Table II with consideration of TMD mass. The results are listed in Table III.

Table III: TMD Design Values

TMD mass, kg	16
TMD frequency, Hz	1.89
TMD spring stiffness, N/m	2,268
TMD damping coefficient, N s/m	103

3.1 TMD Mass

Total TMD mass is 16 kg and can be divided into several mass blocks by some weigh unit. Uncertainty of the target structure and TMD itself can be corrected by adding or removing these mass blocks.

3.2 TMD Spring

Spring stiffness can be achieved by selecting spring material and adjusting spring geometries. In addition, the spring free length and the most compressed length shall be considered so that that TMD mass doesn't crash on the target structure when it travels to the end.

3.3 TMD Damper

The TMD damper is selected from the commercials. The commercial rarely provides damping coefficient as a certain value, the damper is selected based on energy dissipation per cycle estimated with the maximum damping force and the maximum displacement at resonance frequency [3]. In the early design stage, as the frictional damping value between mechanical parts is hard to be known, a damper with adjustable maximum damping force is selected.

3.4 TMD Device Prototype

After the TMD manufactured, all the design values are estimated again from TMD assembly drawings, spring certification report, and commercial specifications. As the frictional damping value can be obtained only by a test, this value is neglected in the early stage of design. Precise values are to be uncovered through device test and real scale piping test with the TMD, which will be carried out in the next step.

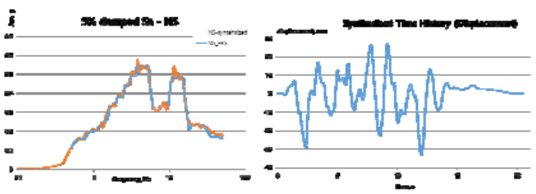
Table IV: TMD Prototype Features

TMD element	Design value	As-built value
Frame mass, kg	-	13
Moving mass[1)], kg	16	Min. 14
Spring stiffness, N/m	2,268	2,400
Damping Coeff. [2)], N s/m	103	-

1) Mass is adjustable.
2) Viscous damping from fluid damper

4. Numerical Analysis

The TMD performance is evaluated with as-built values in Table IV using ANSYS. The TMD damping ratio due to friction is recorded as 0.1 from the simple factory test. So, total TMD damping ratio of 0.234 (friction + 1 damper), and 0.368 (friction + 2 dampers) are used for the simulation. As the actual spring stiffness is more than design value, more masses of 1 ~ 2 kg are added to design value to lower the TMD frequency. Under the seismic load depicted in Fig. 3, the maximum bending moments are obtained from various parameters. Fig. 4 shows that the maximum bending moment on the piping system is reduced from 4,100 Nm to around 2,600 Nm regardless of the TMD parameters.



(a) Response spectrum (b) Time history data

Fig. 3. Seismic input data

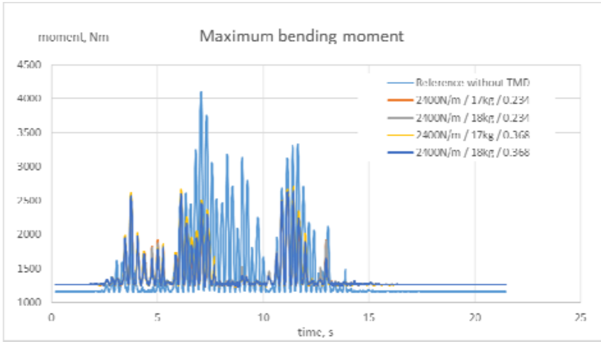


Fig. 4. Maximum bending moment in the entire piping system

5. Conclusions

The TMD prototype is manufactured based on the existing nuclear piping system according to the Sadek's equation and the effectiveness of TMD is confirmed using numerical analysis. In the next step, the TMD parameters will be ensured through the TMD device test and then the TMD performance will be proved by the real-scale piping system experiment.

ACKNOWLEDGEMENTS

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