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Tuned Liquid Column Damper Inerter (TLCDI) for vibration control of fixed-base structures

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Abstract: In this paper, the use of a novel passive control device defined as Tuned Liquid Column Damper Inerter (TLCDI) is studied to mitigate the seismic response of fixed-base and structures. The TLCDI optimal parameters for pre-design purposes are obtained by means of a statistical linearization technique and an optimization procedure which considers the minimization of the structural displacement variance and a white noise process as base excitation. Closed-form expressions for the optima design parameters are determined under certain reasonable approximations. The validity of the proposed approach is assessed considering also non-white excitation processes as base random input. Further, the performance of the TLCDI-controlled structure is examined using a set of 44 real recorded seismic signals as external input.

Keywords: Tuned Liquid Column Damper, Inerter, Optimal design, Statistical Linearization Technique

1. Introduction

In the field of passive vibration control devices, the Tuned Mass Damper (TMD) and the Tuned Liquid Column Damper (TLCD) are among the most widely systems used for reducing structural vibrations. However, these devices may require large masses to be efficient. Consequently, inerter-based devices have gained increasing interest as lightweight solutions [1]. On this basis, following the same logical flow which led to the development of the Tuned Mass Damper Inerter (TMDI) [2] as a more efficient strategy compared to the classical TMD, the Tuned Liquid Column Damper Inerter (TLCDI) [3] has been recently proposed as a promising passive control device which exploits the synergetic beneficial features of the inerter and the TLCD. TLCDs, being simple U-shape liquid tanks, show some convenient characteristics such as low cost, easy implementation, lack of required maintenance, no need to add mass to the structure using the liquid as water supply. Unlike the classical TLCD, the proposed TLCDI is supposed to be able to translate through a sliding support and it is connected to the structure by a linear spring and a damper and to the ground by an inerter. In this manner, the TLCDI dissipates the structural vibrations by means of a combined action which involves the vertical motion of the liquid and the horizontal motion of the container.

2. Results and Discussion

The optimal design of the TLCDI plays a key role in achieving the best mitigation effect of the structural response. In this regard, in this paper, the TLCDI optimal design parameters are obtained for a classical single-degree-of-freedom (SDOF) fixed-base structure, as the one in Figure 1.
Notably, since the governing equations of the TLCDI are nonlinear, as shown in Eq. (1), in general this process may be rather complex, requiring time consuming numerical optimization procedures. Thus, in this study, approximate optimal TLCDI parameters are evaluated, in closed form, by taking into account a statistical linearization technique and some simplifying hypothesis.

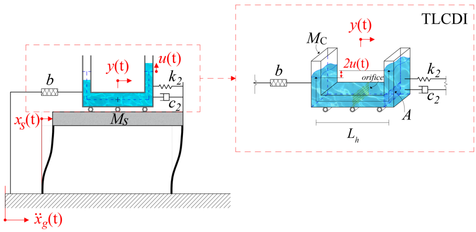

Fig. 1. Analyzed system: fixed-base TLCDI-controlled SDOF structure

$$\begin{cases} M_S\ddot{x}_S(t)+M_S\ddot{x}_S(t)+C_s\dot{x}_S(t)+K_Sx_S(t)-c_2\dot{y}(t)-k_2y(t)=-M_S\ddot{x}_g(t) \\ (\rho AL+M_c+b)\ddot{y}(t)+(\rho AL+M_c+b)\ddot{x}_s(t)+\rho AL_h\ddot{u}(t)+c_2\dot{y}(t)+k_2y(t)=-(\rho AL+M_c)\ddot{x}_g(t) \\ \rho AL_h\ddot{x}_S(t)+\rho AL_h\ddot{y}(t)+\rho AL\ddot{u}(t)+\dfrac{\rho A}{2}\xi|\dot{u}(t)|\dot{u}(t)+2\rho Agu(t)=-\rho AL_h\ddot{x}_g(t) \end{cases} \quad (1)$$

Specifically, an optimization procedure based on the minimization of the variance of the structural response is proposed. Notably, by assuming a white noise excitation and neglecting damping effects, pertinent analytical expressions for the optimal TLCDI parameters are provided and optimal design charts are presented as a ready-to-use practical design tool. In order to prove the accuracy of the proposed simplified technique, a comparison with the optimal values obtained through a more computationally demanding numerical procedure on the original system has been performed. Results show a satisfactory agreement in terms of control performance between the proposed analytical approach and the numerical one. However, it is worth noting that the use of analytical expressions provided by the proposed straightforward procedure leads to a significant reduction in computational effort. Therefore, the aforementioned formulation can effectively be regarded as a reliable tool to be employed for the optimal design parameters estimation. In this manner, the control performance of TLCDI for fixed-base structures is discussed for both white noise excitation and also considering a set of 44 real earthquake records. Finally, numerical analyses indicate that coupling the inerter with a TLCD device significantly reduces the structural responses compared to the uncontrolled structure and to other traditional devices.

References

[1] SMITH MC: Synthesis of mechanical networks: the inerter. *IEEE Trans Autom Control* 2002, **47**:1648-62.

[2] DE DOMENICO D, RICCIARDI G: An enhanced base isolation system equipped with optimal tuned mass damper inerter (TMDI). *Earthquake Engineering and Structural Dynamics* 2018, **47**: 1169-1192.

[3] WANG Q, TIWARI ND, QIAO H, WANG Q: Inerter-based tuned liquid column damper for seismic vibration control of a single-degree-of-freedom structure. *International Journal of Mechanical Sciences* 2020, **184**:1-15.