An Innovative Semi-active Cell Tuned Liquid Mass Damper for Wave Vibration Control of Offshore Jacket Structure

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1. INTRODUCTION & OBJECTIVE

Offshore structures face harsh environments, e.g., waves, wind, and operational activities induce vibrations that impact structural integrity and performance. Various vibration control strategies have been explored, including passive mitigation techniques like tuned mass dampers (TMDs)[1,2], multiple TMDs (MTMD)[3,4], tuned liquid column dampers (TLCDs)[5,6], and multiple TLCDs[7,8] etc. Such control systems are effective but often require large masses for significant vibration reduction. Regarding passive vibration control, studies on TMD and TLCD applications to mitigate wave-induced vibration is worth mentioning. However, the application of TLDs in this regard has not been explored much. Even most of the existing studies predominantly focus on shallow tanks, overlooking the potential of deep storage tanks as vibration control devices. The present study proposed a modification of the deep storage tank by employing compartmentalization, shown in Fig.1 (a), to obtain a compliant cell-tuned liquid mass damper (CCTLMD) that utilizes maximum water mass as a mass damper by maximizing the impulsive mass to control wave-induced vibrations in jacket platforms. Further, a semi-active mechanism is introduced to overcome the tuning difficulty. Specifically, a multi-layer magnetorheological elastomer (MRE) isolator is used to support the compartmentalized storage tank, creating a semi-active variable-stiffness effect as shown in Fig.1 (b) to addresses the detuning limitations. The effectiveness of the proposed semi-active cell-tuned liquid mass damper (SCTLMD) in mitigating wave-induced vibrations of an offshore jacket platform modelled as a single-degree-of-freedom (SDOF) system is numerically demonstrated under four different sea state conditions.

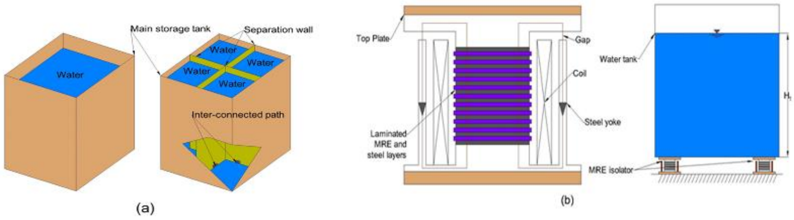

Fig.1 (a) Compartmentalization of water storage tank, (b) schematics of MRE isolator, and water storage tank supported by MRE isolator the storage tank after division

The primary task of the present study is to investigate the efficiency of the proposed SCTLMD system in mitigating wave-induced vibration. For simplicity, the lumped mass model [9] is adopted to reproduce the vibration characteristics of the SCTLMD system following similar studies [10,11]. In the lumped mass model, the total water mass in the jth cell tank is divided into impulsive mass (m_{it_j})and convective mass (m_{ct_j}), connected to the rigid tank wall with a linear spring of stiffness k_{ct_j} and a linear viscous damper with damping coefficient c_{ct_j} as shown in Fig.2a.

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The entire system can be idealized as a dual TMD system connected to the structure with a spring damper arrangement having a current (I) dependent spring stiffness and damping coefficient $k_d(I)$ and $c_d(I)$, respectively, as shown in Fig.2a. The mass of the tank is added to the total impulsive mass of the storage tank.

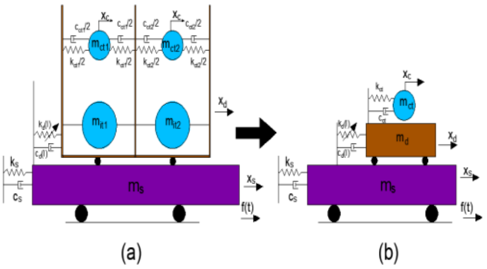

Fig.2 (a) Conceptual model of convective and impulsive masses and (b) idealized CCTLMD model with SDOF system

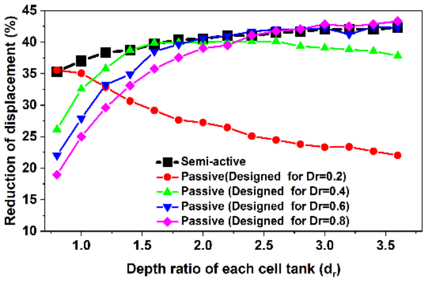

Fig.3 Variation of displacement reduction of the passive system design for a particular depth ratio (D_r) with varying water depth comparison with the semi-active system (SDOF)

Let us consider that a water storage tank is attached to an N-DOF system and converted into a SCTLMD system by incorporating n_t number of cell tanks. The total impulsive mass and convective mass for the idealized dual TMD system are, $m_{it} = n_t \times$impulsive mass of the j^th^ cell tank (m_{it_j}) and, $m_{ct} = n_t \times$ convective mass of the jth cell tank (m_{ct_j}). The equation of motion of the N-DOF structure with SCTLMD system under wave load can be expressed as,

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=[L]\{f(t)\}+[Q]\{F_{SCTLMD}\} \tag{1}$$

Where, $[M],[C]$ and $[K]$ represents the mass, damping and stiffness matrix of the structure, respectively. $\{f(t)\}$ is the external load vector and $\{F_{SCTLMD}\}$ is the control force generated by the proposed SCTLMD system. $[L]$, and $[Q]$ are the location vector of external force and the control force generated by the SCTLMD, respectively. The response of the structure with SCTLMD is obtained by solving Eq.1. The control force can be obtained by numerically solving the following equation,

$$F_{SCTLMD}(I,t)=k_d(I).x(t)+c_d(I).\dot{x}(t)+\alpha(I).x(t)^3 \tag{2}$$

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

The effectiveness of the proposed SCTLMD is studied by considering a jacket platform model as an SDOF system having mass of 180000 Kg and time period of 3s. To demonstrate the improved performance and robustness of the proposed SCTLMD with respect to corresponding passive system i.e., the CCTLMD, the variations of response reductions with varying depth ratio (d_r) are compared in Fig.3. It can be noted that, the CCTLMD system, designed for higher depth ratio, the performance is almost similar to the SCTLMD when the water level is higher in the tank. But there is a drastic reduction in the performance of CCTLMD system for a lower water level. This is due to the fact that for higher water level, the detuning effect is compensated by the higher mass ratio and the passive system also performs satisfactorily. The percentage reduction of platform displacement with varying divisions of the tank is studied in Fig.4. The division are considered as $2\times2, 4\times4,$ and 8×8 corresponding to 4, 16, and 64 number of cell tanks, respectively. The passive

CCTLMD is designed for a depth ratio (D_r) of 0.8, and the performance is compared for the depth ratio (D_r) of 0.2 and 0.3 for both CCTLMD and SCTLMD. It is noted that as the passive system is designed for higher depth ratio, the performance of CCTLMD is inferior for lower water level. Although, with the increasing number of divisions, as the mass ratio increases the tuning ratio shifts towards the designed depth ratio (i.e., $D_r = 0.8$), the performance improves. Whereas, the performance of the proposed SCTLMD system is noted to be robust for any divisions due to variable stiffness mechanism as the system is already tuned and providing optimum performance irrespective of number of divisions, though a slide improvement is also observed with increasing number of divisions. In order to depict the time-varying performance of SCTLMD in controlling wave-induced vibration, a typical displacement response time history under uncontrolled, passive and semi-active control systems are shown in Fig. 5 for each load case. It is observed that the performance of SCTLMD in controlling structural displacement is superior to CCTLMD for all the loading scenarios.

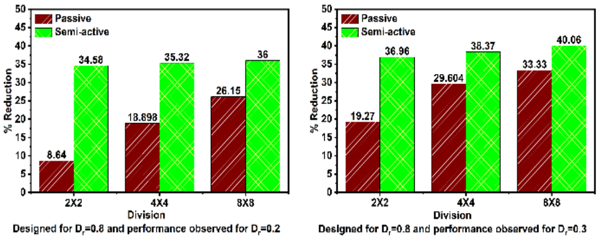

Fig.4 Comparison of response reduction for passive system and semi-active system with different numbers of division in storage tank

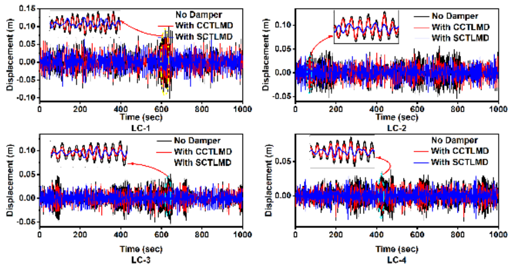

Fig.5 Typical time history plots of structural displacements of the SDOF system without damper, with CCTLMD and with SCTLMD

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