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Effect of Seawater Exposure on Impact Damping Behavior of Viscoelastic Material of Pounding Tuned Mass Damper (PTMD)

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Abstract: The pounding tuned mass damper (PTMD) is a novel vibration control device that can effectively mitigate the undesired vibration of subsea pipeline structures. Previous studies have verified that the PTMD is more effective and robust compared to the traditional tuned mass damper. However, the PTMD relies on a viscoelastic delimiter to dissipate energy through impact. The viscoelastic material can be corroded by the various chemical substances dissolved in the seawater, which means that there can be possible deterioration in its mechanical property and damping ability when it is exposed to seawater. Therefore, we aim to conduct an experimental study on the impact behavior and energy dissipation of the viscoelastic material submerged in seawater in this present paper. An experimental apparatus, which can generate and measure lateral impact, is designed and fabricated. A batch of viscoelastic tapes are submerged in seawater and samples will be taken out for impact tests every month. Pounding stiffness, hysteresis loops and energy dissipated per impact cycle are employed to characterize the impact behavior of the viscoelastic material. The experimental results suggest that the seawater has little influence on the behavior of the viscoelastic tapes. Even after continuous submersion in seawater for 5 years, the pounding stiffness and energy dissipation remains at the same level.

Keywords: pounding tuned mass damper (PTMD); vibration control; viscoelastic material; damping; impact; seawater

1. Introduction

As the oil exploration moves from offshore to deep and ultradeep waters [1], subsea pipeline structures, such as jumpers and risers, have been more extensively used for conveying crude oil or natural gas. However, these pipeline structures are often flexible and have low damping, which makes them very susceptible to vibrations induced by currents, vortex and pressure changes of internal fluids among other causes. These vibrations may cause machinery downtime, leaks, fatigue failure and sometimes catastrophic explosions [2,3]. Therefore, suppressing these undesired vibrations is of great necessity.

One family of the commonly used add-on devices includes the helical strakes [4,5], shrouds [6,7], fairings [8] and splitters [9], which aims to mitigate the vortex induced vibration (VIV) by breaking the vortex shedding in the flow direction or changing the surface roughness and thus, reducing the drag coefficient and width of the lock-in region [10–12]. Although the effectiveness of these add-on devices have been proven by extensive studies and experiments, there still remains some shortcomings that limit their applications, including expensive machinery cost, difficulty in installation and susceptibleness to marine growth or storm damage [11]. Another low cost yet effective VIV suppression equipment is the pipe in pipe (PIP) system [11–13]. The PIP system utilizes a specially designed soft spring and a dashpot to replace the traditional hard centralizer. Therefore, the inner pipe and the outside pipe can work together to resist the dynamic excitations.

Many other systems share a similar vibration problem with the pipeline structure that is slender and has low damping [14], with the vibration control of such systems having received significant attention [15–17]. The commonly used vibration control methods can be classified as active control [18–20], semi-active control [21–23], passive control [24–27] and hybrid control [28]. In general, passive vibration control, especially the tuned mass dampers (TMD) and impact dampers, have been extensively studied and are widely used in various structures due to their simplicity and effectiveness [29–31]. The TMD is a classical dynamic absorber, which can reduce the motion of the primary structure by generating an inertial force of the same frequency but opposite phase. TMDs are frequently implemented with energy dissipation components, such as viscous dampers [32], friction dampers [32,33], eddy-current components [17,31], etc. However, these devices often demand continuous maintenance to ensure the presence of the designed damping, which is impossible in some extreme circumstances, such as the subsea environment [34]. Another drawback of the TMD is the detuning effect: when the frequency of the TMD shifts away from the optimum value, the vibration control effectiveness will be dramatically decreased [17]. Compared with the TMD, the impact damper is easy to implement and maintenance free, with a relatively wide band of effective frequencies. Hence, the impact damper can be a complementary energy dissipating element for the TMD.

In previous studies, a novel damper that integrates the TMD and the impact damper with the help of the viscoelastic material was proposed and is named the pounding tuned mass damper (PTMD). The schematic of the PTMD is illustrated in Figure 1. As shown in the figure, the PTMD consists of two components: a classical tuned mass damper (TMD) and a delimiter covered with the viscoelastic material. Because of this TMD-delimiter configuration, the PTMD combines the two vibration control mechanisms of the classical TMD and the impact damper. Thus, when there is only a slight vibration of the primary structure, the tuned mass (m_2) will vibrate freely between the two delimiters like a TMD, absorbing the kinetic energy from the primary structure (m_1). When the motion of the primary structure exceeds a certain level, the tuned mass will pound on the delimiter and the PTMD will dissipate energy as an impact damper. From previous studies, the PTMD has been verified to be highly effective in reducing the vibration of buildings [35–40], bridges [41,42], transmission towers [43,44], offshore platforms [45,46], traffic signal poles [47,48] and subsea pipeline structures [49–53].

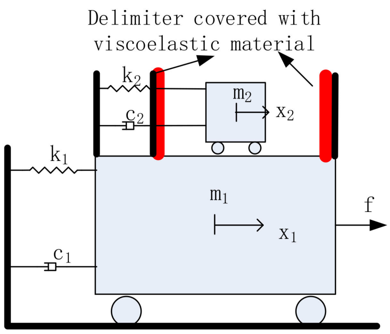


Figure 1. Schematic of the PTMD.

Even though the PTMD has been demonstrated to share the advantages of the impact damper, such as conceptual simplicity, moderate cost [30], high vibration control efficiency [35,41,47,49] and robustness to the detuning effect [50,51], it may also suffer from the defects of the impact damper. One major shortcoming of the impact damper is that the impacts between rigid mass and boundaries may increase the acceleration and cause a high level of noise [54,55]. Hence, subsequent researchers have proposed many solutions to address this issue. One group of solutions involve replacing the single mass with a number of smaller masses [30]. This idea has evolved to be used in new types of dampers, such as multi-unit damper [56,57], particle damper [58,59] and multi-unit particle dampers [60]. These dampers have been used in applications in many fields. Papalou et al. [61,62] used the particle damper to enhance the seismic performance of classical columns at historical monuments. Lu et al. [63] proposed a modified approach based on the discrete element method to simulate the behavior of the particle damper system and compared its vibration control effectiveness with a suspended TMD [64]. Another method to reduce the acceleration and noise problem is to add a flexible buffer zone between the mass and the boundary. Li and Darby [54,55] proposed to use sponge, rubber and plastic as the buffer material. The experimental results revealed that not only the accelerations, contact forces and the associated noise generated by collision were reduced by the buffer but also the vibration control effectiveness was also enhanced. Moreover, the buffer type design is also introduced to the particle damper. Zheng and Lu [65] put the particles in a container covered with rubber and named this damper as the buffered particle damper. The experimental results indicated that the buffered container enhanced the energy dissipation level and reduced the impact force and noise.

Due to the soft buffer zone being able to increase the energy dissipation and reduce the impact force and noise, the PTMD adapted this design. However, the viscoelastic material used in PTMD is a polymer composite and its damping ability may deteriorate in the subsea environment [66]. Therefore, it is necessary to investigate the influence of the seawater on the viscoelastic material before the PTMD is applied for subsea structures.

Over the past decades, the viscoelastic material has been intensively studied. Carbone et al. [67] studied the crack propagation in viscoelastic materials. Putignano et al. [68] investigated the contact mechanism between rough surfaces of the viscoelastic material. Zhang et al. [69] studied the fatigue behavior of the viscoelastic material that was subjected to continuous pounding. The effects of moisture and solvent on the viscoelastic foams have also been intensively studied. In the 1990s, Tucker [66] found that environmental stress due to real ocean conditions have clearly been shown to degrade polymer composite materials. Later on, Weitsman and Elahi [70] reviewed the effects of fluids on the deformation and durability of polymeric composites. Recently, Zhao et al. [71] studied the effect of seawater absorption on the viscoelastic composites. It is well known the chloride diffusion will cause damages to various materials [72,73]. Huo et al. [74] investigated the mechanical property of closed cell polyurethane foam immersed in salt water and the experimental results indicated that the flexural modulus and strength decreased by 8.9% and 13%, respectively, after 150 days of exposure to salt water. Saharudin et al. [75] tested halloysite nanotubes–polyester nanocomposites and found that the storage modulus, tensile properties and flexural properties of polyester and its nanocomposites decreased after seawater exposure. Yin et al. [76] investigated the aging of the polymethacrylimide (PMI) foam submerged in deionized and seawater. The test results suggest that the presence of ions in seawater increased the compressive and flexural strength. Even though studies have been carried out on the mechanical property of the viscoelastic material submerged in salt water, these researches mainly focus on the strength, fracture toughness or moisture absorption of the material. Investigations still need to be conducted on the damping behavior of the viscoelastic material exposed to saltwater to ensure the effectiveness of the PTMD in a subsea environment.

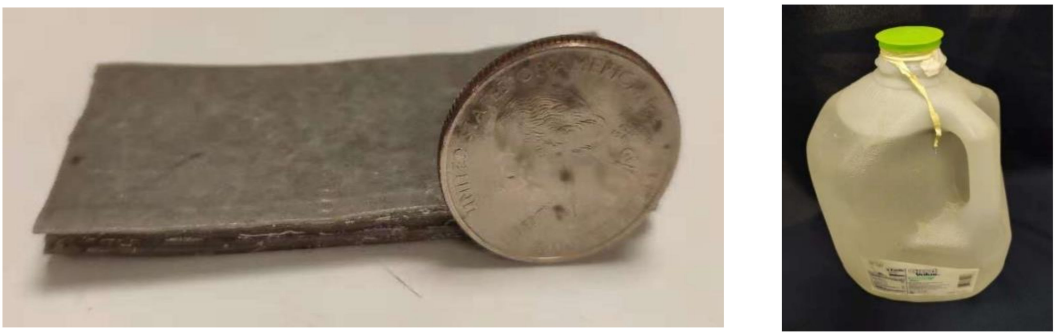
This paper presents an experimental study on the influence of the seawater on the damping capacity of the viscoelastic material. The samples of viscoelastic material were submerged in seawater for 5 years. Pounding tests were conducted after 9 months and during the 5th year. Pounding stiffness, hysteresis loops and energy dissipated per impact cycle were utilized to interpret the influence of the seawater.

2. Specimen Preparation and Experimental Setup

The specimens tested in this study were prepared with the same material as in previous studies [49,50] to ensure consistence. In previous studies, the impact layer of the PTMD consisted of 7 layers of 3M^{TM} VHB^{TM} 4936 dual adhesive tapes. Its typical properties can be found in Table 1. To prepare the specimens of this study, the dual adhesive tape was first cut into 80 mm long pieces before 7 pieces were adhered together as one specimen. The dimensions of each specimen are approximately 80 mm × 40 mm × 10 mm. Figure 2a shows one sample of the viscoelastic materials. In this experimental study, all the specimens were submerged in a tank of seawater (Figure 2b), which was collected from the harbor of east Houston, Texas. Every month, three pieces of samples will be taken out to test their mechanical properties with the experimental devices illustrated in Figure 3. It is important to note note that the three specimens were disposed after testing instead of being put back into the seawater. In the next test, another three samples were taken out for testing. In another word, the samples tested in a previous test will not be tested in the following test(s).

Table 1. Typical parameters of the 3M^{TM} VHB^{TM} 4936 dual adhesive tape.

Thickness	Main Ingredient	Normal Tensile	Dynamic Overlap Shear	90° Peel Adhesion
1.6 mm	Acrylic foam	620 kPa	550 kPa	30 N/cm



(a) (b)

Figure 2. Specimen preparation: (**a**) viscoelastic sample; (**b**) samples in seawater.

As shown in Figure 3, the main structure of the experimental apparatus is a flexible beam made of a 0.2 mm spring steel plate supported by two aluminum columns. The spring steel is mounted on a mass block and a motor. When the motor rotates the unbalanced weight, the spring steel beam will vibrate vertically and impact the viscoelastic material beneath it. A load cell is installed under the viscoelastic material to record the pounding force. A laser senor is placed on top of the mass block to measure its displacement. The sampling frequency is 1 kHz. The testing temperature was maintained around 20 °C.

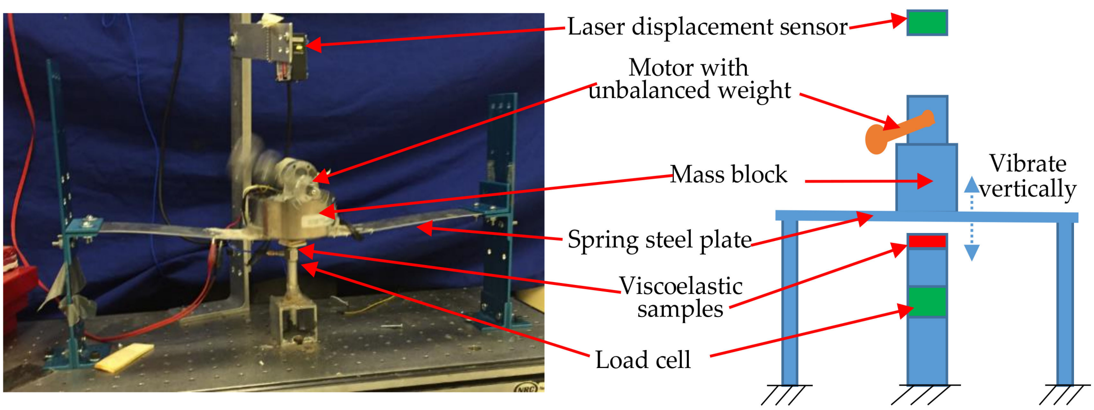


Figure 3. Experimental setup.

3. Results and Discussion

3.1. Influence on the Pounding Stiffness

In previous studies [43], a nonlinear pounding force model was proposed and validated experimentally for simulating the collision of an object on viscoelastic material. The pounding force model is based on a Hertz contact element in conjunction with a damper that is active only during the approach period of the impact. Its expression is described as follows:

$$F = \begin{cases} \beta\delta^{3/2} + c\dot{\delta} & \text{(approach period of impact)} \\ \beta\delta^{3/2} & \text{(restitution period of impact)} \end{cases} \tag{1}$$

where δ describes the deformation of the colliding bodies; $\dot{\delta}$ denotes the relative velocity between them; β is the pounding stiffness; and c is the pounding damping, which at any instant of time can be obtained by:

$$c = 2\xi\sqrt{\beta\delta\frac{m_1 m_2}{m_1 + m_2}} \tag{2}$$

$$\xi = \frac{9\sqrt{5}}{2}\frac{1 - e^2}{e(e(9\pi - 16) + 16)} \tag{3}$$

where m_1 and m_2 are the masses of the two colliding bodies; and ξ is the impact damping ratio correlated with the coefficient of restitution e, which is defined as the relation between the post-impact (final) relative velocity, $\dot{\delta}_f$ and the prior-impact (initial) relative velocity, $\dot{\delta}_0$.

In this nonlinear pounding force model, the pounding stiffness β is the only unknown parameter, which can be estimated based on the recorded pounding force and the displacement of the colliding bodies. In this study, the pounding force model explained in Equations (1)–(3) is established in MATLAB/Simulink environment and the pounding stiffness can be attained by the embedded Curve Fitting Toolbox. The estimation method is the nonlinear least-squares method.

At the beginning of this study, three pieces of viscoelastic material samples were tested. After this, the specimens were tested every month and the estimated pounding stiffness is shown in Table 2. Initially, the pounding stiffness varied from 48,258 N/m$^{1.5}$ to 53,417 N/m$^{1.5}$. After submersion in seawater for up to 5 years, the pounding stiffness increased from 45619 N/m$^{1.5}$ to 53,943 N/m$^{1.5}$. This is still very close to the initial value, which suggests that the seawater has little influence on the behavior of the viscoelastic material.

Table 2. Estimated pounding stiffness (unit N/m$^{1.5}$).

Initial	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m	5 Year
48,258	52,854	45,657	52,776	45,619	47,462	53,313	53,943	47,848	50,754	50,793
51,335	53,221	46,887	52,493	50,100	53,910	46,269	49,303	46,506	53,625	51,562
53,417	46,997	50,629	47,807	51,063	51,356	51,846	49,369	46,316	47,525	48,739

3.2. Influence on the Hysteresis Loops

The hysteresis loops of the viscoelastic material are shown in Figure 4. The first subplot shows the hysteresis loops before the viscoelastic tapes were submerged into seawater. Subplot 2 to Subplot 10 correspond to the tapes being submerged for 1–9 months. Subplot 11 shows the hysteresis loops when the samples was submerged for 5 years. Subplot 12 compares all the hysteresis loops.

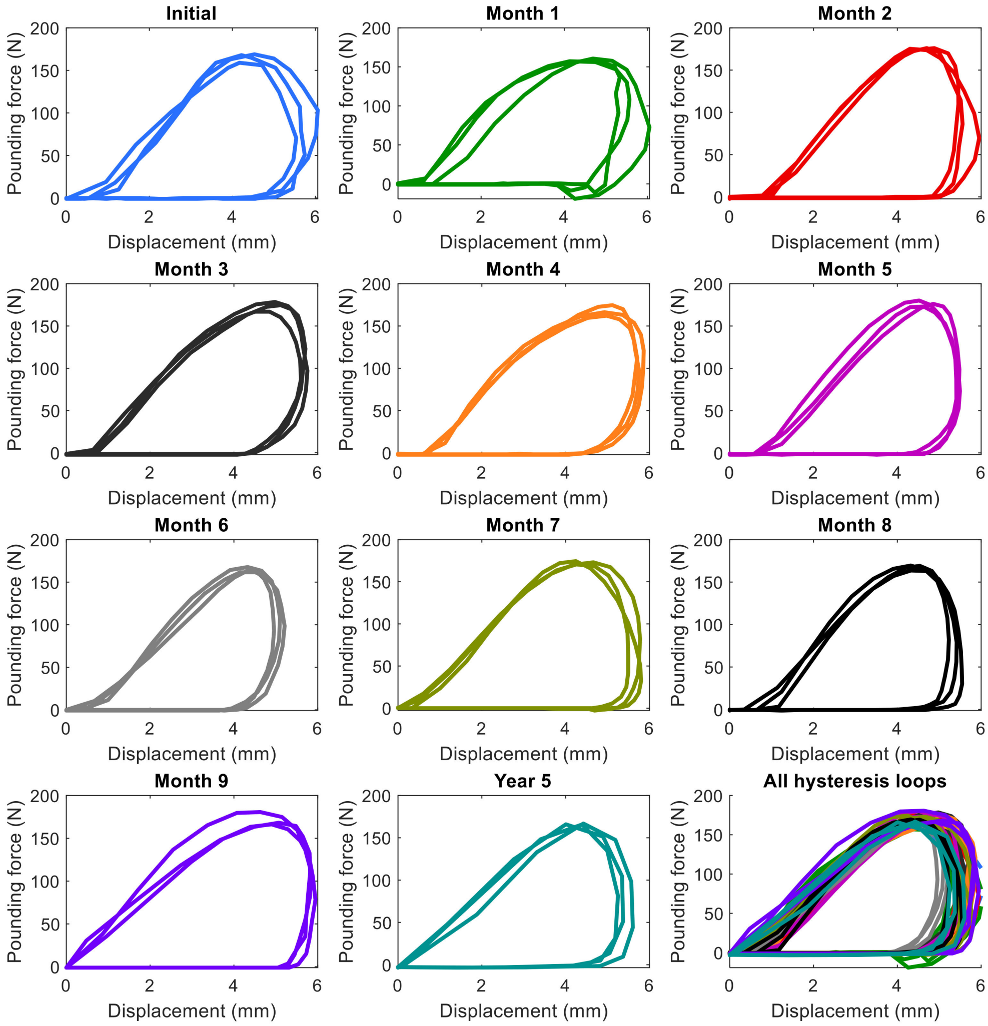


Figure 4. Hysteresis loops initially and submerged in seawater.

Remark 1: As illustrated from these figures, the shapes of the hysteresis loops are very similar, which indicates that the seawater has little influence on the mechanical properties of the viscoelastic material.

Remark 2: Although all the hysteresis loops in Figure 4 are very similar, minor differences are still observed among these loops. The cause of these minute differences may be the different impact points during the impacts although these locations are very close to each other.

Remark 3: From the subplots in Figure 4, we also notice that there is a slight decrease in the stiffness measured during the 5th year as compared to previous years. It is possible that the seawater has a "softening" effect on the viscoelastic material over a long period, which should be further studied.

3.3. Influence on the Energy Dissipation

The areas surrounded by the hysteresis loops normally indicate the energy dissipated by the viscoelastic material. In Figure 4, the areas surrounded by the hysteresis loops of initial condition and that of the submerged viscoelastic tapes are also very similar, which implies that the seawater has little influence on the damping effect of the viscoelastic material.

To further quantify this issue, the energy dissipated per cycle is computed as follows:

$$\Delta W = \int F\delta \, d\delta \tag{4}$$

where ΔW denotes the dissipated energy; F is the impact force and δ denotes the deformation of the viscoelastic material. Due to the limitation of the experimental apparatus, the intensity of impact is not precisely controlled. Since ΔW can be influenced by the impact intensity, a normalized parameter $\Delta\overline{W}$ is defined as:

$$\Delta\overline{W} = \Delta W/\delta_{\max} \quad (5)$$

where δ_{max} is the maximum impact depth.

Figure 5 shows the dissipated energy as a function of submerged time. The blue triangle denotes $\Delta\overline{W}$ of each sample. The red round is the average $\Delta\overline{W}$, since three specimens were tested each month. In the initial condition, the viscoelastic material dissipated an average energy of 80.5 J/m per cycle. During the five years of submerging, $\Delta\overline{W}$ varies from 73 to 98 J/m per cycle, which is still at the same level compared with the initial condition. This implies that the seawater has little influence on the damping capacity of the viscoelastic material.

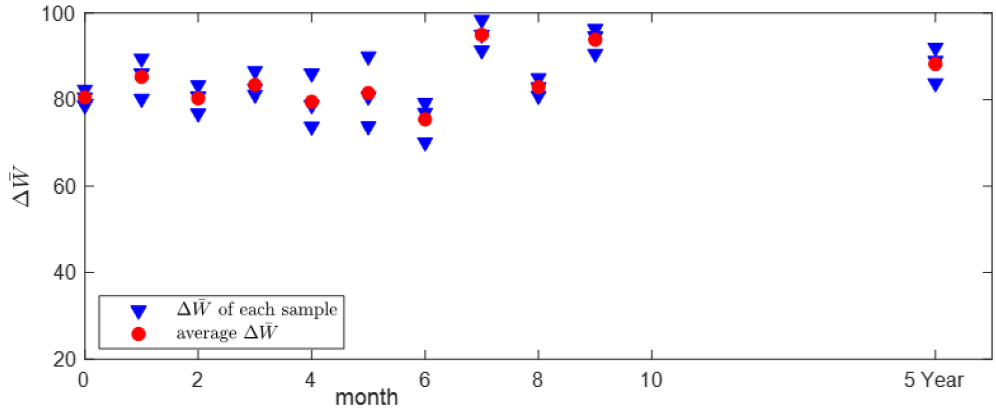


Figure 5. Dissipated energy per cycle during the testing period.

4. Conclusions and Future Work

This paper presents an experimental study focusing on the influence of the seawater on the property and damping ability of the viscoelastic material to ensure the vibration control effectiveness of the PTMD in a subsea environment. A batch of viscoelastic tapes were submerged in seawater for up to 5 years. Impact tests were conducted to compare the pounding behavior of the samples with the initial condition. The pounding stiffness, hysteresis loops and the energy dissipated per pounding cycle are used to interpret the impact property and damping ability of the viscoelastic material. The experimental results imply that seawater has little influence on the pounding behavior of the viscoelastic material. Therefore, the Pounding Tuned Mass Damper (PTMD) with viscoelastic material to dissipate the pounding energy can be used for vibration control of structures in a subsea environment. We notice that there is a slight decrease in the stiffness of the viscoelastic material measured during the 5th year as compared to previous years. As a future task, we will investigate the cause of this decrease in stiffness of the viscoelastic material over a long period in the seawater.

Author Contributions: All authors discussed and agreed upon the idea and made scientific contributions. P.Z., D.P. and S.C.M.H. designed the experiments. P.Z. wrote the paper. P.Z. and D.P. performed the experiments and analyzed the data. S.C.M.H. proofread and revised the paper.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Song, L.; Fu, S.; Cao, J.; Ma, L.; Wu, J. An investigation into the hydrodynamics of a flexible riser undergoing vortex-induced vibration. *J. Fluids Struct.* **2016**, *63*, 325–350. [CrossRef]
2. Carruth, A.L.; Cerkovnik, M.E. Jumper VIV–new issues for new frontiers, In Proceedings of the Sixteenth International Offshore and Polar Engineering Conference, Lisbon, Portugal, 1–6 July 2007; 2796–2081.
3. Lu, Y.; Liang, C.; Manzano-Ruiz, J.J.; Janardhanan, K.; Perng, Y. Flow-induced vibration in subsea jumper subject to downstream slug and ocean current. *J. Offshore Mech. Arct. Eng.* **2016**, *138*, 021302–021302-10. [CrossRef]
4. Gao, Y.; Yang, J.; Xiong, Y.; Wang, M.; Peng, G. Experimental investigation of the effects of the coverage of helical strakes on the vortex-induced vibration response of a flexible riser. *Appl. Ocean Res.* **2016**, *59*, 53–64. [CrossRef]
5. Zeinoddini, M.; Farhangmehr, A.; Seif, M.S.; Zandi, A.P. Cross-flow vortex induced vibrations of inclined helically straked circular cylinders: An experimental study. *J. Fluids Struct.* **2015**, *59*, 178–201. [CrossRef]
6. Cicolin, M.M.; Assi, G.R.S. Experiments with flexible shrouds to reduce the vortex-induced vibration of a cylinder with low mass and damping. *Appl. Ocean Res.* **2017**, *65*, 290–301. [CrossRef]
7. Kumar, N.; Kolahalam, V.K.V.; Kantharaj, M.; Manda, S. Suppression of vortex-induced vibrations using flexible shrouding—An experimental study. *J. Fluids Struct.* **2018**, *81*, 479–491. [CrossRef]
8. Lou, M.; Wu, W.G.; Chen, P. Experimental study on vortex induced vibration of risers with fairing considering wake interference. *Int. J. Naval Archit. Ocean Eng.* **2017**, *9*, 127–134. [CrossRef]
9. Liang, S.; Wang, J.; Hu, Z. VIV and galloping response of a circular cylinder with rigid detached splitter plates. *Ocean Eng.* **2018**, *162*, 176–186. [CrossRef]
10. Wang, C.; Cui, Y.; Ge, S.; Sun, M.; Jia, Z. Experimental Study on Vortex-Induced Vibration of Risers Considering the Effects of Different Design Parameters. *Appl. Sci.* **2018**, *8*, 2411. [CrossRef]
11. Nikoo, H.M.; Bi, K.; Hao, H. Passive vibration control of cylindrical offshore components using pipe-in-pipe (PIP) concept: An analytical study. *Ocean Eng.* **2017**, *142*, 39–50. [CrossRef]
12. Nikoo, H.M.; Bi, K.; Hao, H. Effectiveness of using pipe-in-pipe (PIP) concept to reduce vortex-induced vibrations (VIV): Three-dimensional two-way FSI analysis. *Ocean Eng.* **2018**, *148*, 263–276. [CrossRef]
13. Bi, K.; Hao, H.; Chen, W. Effectiveness of Using RFHDS Connected PIP System for Subsea Pipeline Vibration Control. *Int. J. Struct. Stab. Dyn.* **2018**, *18*, 1840005. [CrossRef]
14. Agrawal, B.N.; Mcclelland, R.S.; Song, G. Attitude control of flexible spacecraft using pulse-width pulse-frequency modulated thrusters. *Space Technol.—Kedlington* **1997**, *17*, 15–34. [CrossRef]
15. Song, G.; Cai, S.; Li, H.N. Energy dissipation and vibration control: modeling, algorithm and devices. *Appl. Sci.* **2018**, *8*, 801. [CrossRef]
16. Tang, J.; Cao, D.; Ren, F.; Li, H. Design and experimental study of a VCM-based whole-spacecraft vibration isolation system. *J. Aerosp. Eng.* **2018**, *31*, 04018045. [CrossRef]
17. Chen, J.; Lu, G.; Li, Y.; Wang, T.; Song, G. Experimental study on robustness of an eddy current-tuned mass damper. *Appl. Sci.* **2017**, *7*, 895. [CrossRef]
18. Ma, G.; Xu, M.; Zhang, S.; Zhang, Y.; Liu, X. Active Vibration Control of an Axially Moving Cantilever Structure Using PZT Actuator. *J. Aerosp. Eng.* **2018**, *31*, 04018049. [CrossRef]
19. Gu, H.; Song, G. Active vibration suppression of a flexible beam with piezoceramic patches using robust model reference control. *Smart Mater. Struct.* **2007**, *16*, 1453. [CrossRef]
20. Xu, X.Z.; Wu, W.X.; Zhang, W.G. Sliding Mode Control for a Nonlinear Aeroelastic System through Backstepping. *J. Aerosp. Eng.* **2017**, *31*, 04017080. [CrossRef]
21. Xu, Z.D.; Xu, F.H.; Chen, X. Intelligent vibration isolation and mitigation of a platform by using MR and VE devices. *J. Aerosp. Eng.* **2016**, *29*, 04016010. [CrossRef]
22. Huo, L.; Song, G.; Nagarajaiah, S.; Li, H. Semi-active vibration suppression of a space truss structure using a fault tolerant controller. *J. Vib. Control* **2012**, *18*, 1436–1453. [CrossRef]
23. Fu, W.; Zhang, C.; Sun, L.; Askari, M.; Samali, B.; Chung, K.L.; Sharafi, P. Experimental investigation of a base isolation system incorporating MR dampers with the high-order single step control algorithm. *Appl. Sci.* **2017**, *7*, 344. [CrossRef]
24. Huang, Z.W.; Hua, X.G.; Chen, Z.Q.; Niu, H.W. Modeling, Testing and Validation of an Eddy Current Damper for Structural Vibration Control. *J. Aerosp. Eng.* **2018**, *31*, 04018063. [CrossRef]

25. Liu, M.; Li, H.; Song, G.; Ou, J. Investigation of vibration mitigation of stay cables incorporated with superelastic shape memory alloy dampers. *Smart Mater. Struct.* **2007**, *16*, 2202. [CrossRef]
26. Huang, B.; Lao, Y.; Chen, J.; Song, Y. Dynamic response analysis of a frame structure with superelastic nitinol SMA helical spring braces for vibration reduction. *J. Aerosp. Eng.* **2018**, *31*, 04018096. [CrossRef]
27. Sun, W.; Wang, Z.; Liu, R.; Yan, X. Inverse identification of the frequency-dependent mechanical parameters of a viscoelastic core layer based on the vibration response. *Appl. Sci.* **2017**, *7*, 455. [CrossRef]
28. Demetriou, D.; Nikitas, N. A novel hybrid semi-active mass damper configuration for structural applications. *Appl. Sci.* **2016**, *6*, 397. [CrossRef]
29. Shi, W.; Wang, L.; Lu, Z.; Zhang, Q. Application of an artificial fish swarm algorithm in an optimum tuned mass damper design for a pedestrian bridge. *Appl. Sci.* **2018**, *8*, 175. [CrossRef]
30. Lu, Z.; Wang, Z.; Masri, S.F.; Lu, X. Particle impact dampers: Past, present and future. *Struct. Control Health Monit.* **2018**, *25*, e2058. [CrossRef]
31. Wang, W.; Dalton, D.; Hua, X.; Wang, X.; Chen, Z.; Song, G. Experimental study on vibration control of a submerged pipeline model by eddy current tuned mass damper. *Appl. Sci.* **2017**, *7*, 987. [CrossRef]
32. Wu, X.; Wang, J.; Zhou, J. Seismic performance analysis of a connected multitower structure with FPS and viscous damper. *Shock Vibr.* **2018**. [CrossRef]
33. Kim, S.Y.; Lee, C.H. Peak response of frictional tuned mass dampers optimally designed to white noise base acceleration. *Mech. Syst. Sig. Process.* **2019**, *117*, 319–332. [CrossRef]
34. Collette, F.S. A combined tuned absorber and pendulum impact damper under random excitation. *J. Sound Vib.* **1998**, *216*, 199–213. [CrossRef]
35. Lin, W.; Wang, Q.; Li, J.; Chen, S.; Qi, A. Shaking table test of pounding tuned mass damper (PTMD) on a frame structure under earthquake excitation. *Comput. Concr.* **2017**, *20*, 545–553.
36. Lin, W.; Lin, Y.; Song, G.; Li, J. Multiple Pounding Tuned Mass Damper (MPTMD) control on benchmark tower subjected to earthquake excitations. *Earthquake Struct.* **2016**, *11*, 1123–1141. [CrossRef]
37. Xue, Q.; Zhang, J.; He, J.; Zhang, C.; Zou, G. Seismic control performance for Pounding Tuned Massed Damper based on viscoelastic pounding force analytical method. *J. Sound Vib.* **2017**, *411*, 362–377. [CrossRef]
38. Xue, Q.; Zhang, J.; He, J.; Li, Y.; Song, X. Reducing vibration performance of pounding TMD on high-rise steel structures subject to seismic effects. *J. Haribin Eng. Univ.* **2017**, *38*, 412–418.
39. Wang, W.; Hua, X.; Wang, X.; Chen, Z.; Song, G. Numerical modeling and experimental study on a novel pounding tuned mass damper. *J. Vib. Control* **2018**, *24*, 4023–4036. [CrossRef]
40. Wang, W.; Hua, X.; Wang, X.; Chen, Z.; Song, G. Optimum design of a novel pounding tuned mass damper under harmonic excitation. *Smart Mater. Struct.* **2017**, *26*, 055024. [CrossRef]
41. Wang, W.; Wang, X.; Hua, X.; Song, G.; Chen, Z. Vibration control of vortex-induced vibrations of a bridge deck by a single-side pounding tuned mass damper. *Eng. Struct.* **2018**, *173*, 61–75. [CrossRef]
42. Yin, X.; Liu, Y.; Song, G.; Mo, Y.L. Suppression of bridge vibration induced by moving vehicles using pounding tuned mass dampers. *J. Bridge Eng.* **2018**, *23*, 04018047. [CrossRef]
43. Zhang, P.; Song, G.; Li, H.; Lin, Y. Seismic Control of Power Transmission Tower Using Pounding TMD. *J. Eng. Mech.* **2013**, *139*, 1395–1406. [CrossRef]
44. Tian, L.; Gai, X. Wind-induced vibration control of power transmission tower using pounding tuned mass damper. *J. Vibroeng.* **2015**, *17*, 3693–3701.
45. Xue, Q.; Zhang, J.; He, J.; Zhang, C. Control performance and robustness of pounding tuned mass damper for vibration reduction in SDOF structure. *Shock Vibr.* **2016**. [CrossRef]
46. Li, Y.; Zhang, J.; Xue, Q.; He, J.; An, N. PTMD's vibration reduction effect on the JZ20-2MUQ offshore jacket platform. *J Vibr. Shock* **2017**, *36*, 238–244.
47. Li, L.; Song, G.; Singla, M.; Mo, Y.L. Vibration control of a traffic signal pole using a pounding tuned mass damper with viscoelastic materials (II): Experimental verification. *J. Vib. Control* **2015**, *21*, 670–675. [CrossRef]
48. Zhao, N.; Lu, C.; Chen, M.; Luo, N.; Liu, C. Parametric Study of Pounding Tuned Mass Damper Based on Experiment of Vibration Control of a Traffic Signal Structure. *J. Aerosp. Eng.* **2018**, *31*, 04018108. [CrossRef]
49. Song, G.; Zhang, P.; Li, L.; Singla, M.; Patil, D.; Li, H.; Mo, Y. Vibration control of a pipeline structure using pounding tuned mass damper. *J. Eng. Mech.* **2016**, *142*, 04016031. [CrossRef]
50. Li, H.; Zhang, P.; Song, G.; Patil, D.; Mo, Y. Robustness study of the pounding tuned mass damper for vibration control of subsea jumpers. *Smart Mater. Struct.* **2015**, *24*, 095001. [CrossRef]

51. Jiang, J.; Zhang, P.; Patil, D.; Li, H.; Song, G. Experimental studies on the effectiveness and robustness of a pounding tuned mass damper for vibration suppression of a submerged cylindrical pipe. *Struct. Control Health Monit.* **2017**, *24*, e2027. [CrossRef]
52. Bordalo, S.N.; Morooka, C.K.; Tochetto, L.G.; Pavanello, R.; Song, G.; Bartos, J.C. Experimental assessment of the behaviour of a pipe vibration damper underwater. In Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering; Materials Technology; Petroleum Technology, San Francisco, CA, USA, 8–13 June 2014; Volume 5, p. V005T11A010.
53. Zhang, P.; Li, L.; Patil, D.; Singla, M.; Li, H.; Mo, Y.L.; Song, G. Parametric study of pounding tuned mass damper for subsea jumpers. *Smart Mater. Struct.* **2015**, *25*, 015028.25. [CrossRef]
54. Li, K.; Darby, A.P. An experimental investigation into the use of a buffered impact damper. *J. Sound Vib.* **2006**, *291*, 844–860. [CrossRef]
55. Li, K.; Darby, A.P. Modelling a buffered impact damper system using a spring-damper model of impact. *Struct. Control Health Monit.* **2009**, *16*, 287–302. [CrossRef]
56. Nayeri, R.D.; Masri, S.F.; Caffrey, J.P. Studies of the performance of multi-unit impact dampers under stochastic excitation. *J. Vib. Acoust.* **2007**, *129*, 239–251. [CrossRef]
57. Masri, S.F. Electric-analog studies of impact dampers. *Exp. Mech.* **1967**, *7*, 49–55. [CrossRef]
58. Yokomichi, I.; Araki, Y.; Jinnouchi, Y.; Inoue, J. Impact damper with granular materials for multibody system. *J. Pressure Vessel Technol.* **1996**, *118*, 95–103. [CrossRef]
59. Papalou, A.; Masri, S.F. Performance of particle dampers under random excitation. *J. Vib. Acoust.* **1996**, *118*, 614–621. [CrossRef]
60. Saeki, M. Analytical study of multi-particle damping. *J. Sound Vib.* **2005**, *281*, 1133–1144. [CrossRef]
61. Papalou, A.; Strepelias, E.; Roubien, D.; Bousias, S.; Triantafillou, T. Seismic protection of monuments using particle dampers in multi-drum columns. *Soil Dyn. Earthquake Eng.* **2015**, *77*, 360–368. [CrossRef]
62. Papalou, A. The Effect of Particle Damper's Position on the Dynamic Response of Classical Columns. *Periodica Polytechnica Civil Eng.* **2018**, *62*, 56–63. [CrossRef]
63. Lu, Z.; Lu, X.; Jiang, H.; Masri, S.F. Discrete element method simulation and experimental validation of particle damper system. *Eng. Comput.* **2014**, *31*, 810–823. [CrossRef]
64. Lu, Z.; Wang, D.; Li, P. Comparison study of vibration control effects between suspended tuned mass damper and particle damper. *Shock Vibr.* **2014**, *2014*, 1–7. [CrossRef]
65. Lu, Z.; Lu, X.; Lu, W.; Masri, S.F. Experimental studies of the effects of buffered particle dampers attached to a multi-degree-of-freedom system under dynamic loads. *J. Sound Vib.* **2012**, *331*, 2007–2022. [CrossRef]
66. Tucker, W.C. Degradation of graphite/polymer composites in seawater. *J. Energy Res. Technol.* **1991**, *113*, 264–267. [CrossRef]
67. D'Amico, F.; Carbone, G.; Foglia, M.M.; Galietti, U. Moving cracks in viscoelastic materials: Temperature and energy-release-rate measurements. *Eng. Fract. Mech.* **2013**, *98*, 315–325. [CrossRef]
68. Putignano, C.; Carbone, G.; Dini, D. Mechanics of rough contacts in elastic and viscoelastic thin layers. *Int. J. Solids Struct.* **2015**, *69*, 507–517. [CrossRef]
69. Zhang, P.; Huo, L.; Song, G. Impact fatigue of viscoelastic materials subjected to pounding. *Appl. Sci.* **2018**, *8*, 117. [CrossRef]
70. Weitsman, Y.J.; Elahi, M. Effects of fluids on the deformation, strength and durability of polymeric composites–an overview. *Mech. Time-Depend. Mater.* **2000**, *4*, 107–126. [CrossRef]
71. Zhao, Y.; Wang, Z.; Keey, S.L.; Boay, C.G. Long-term viscoelastic response of e-glass/bismaleimide composite in seawater environment. *Appl. Compos. Mater.* **2015**, *22*, 693–709.
72. Peng, J.; Hu, S.; Zhang, J.; Cai, C.S.; Li, L.Y. Influence of cracks on chloride diffusivity in concrete: A five-phase mesoscale model approach. *Constr. Build. Mater.* **2019**, *197*, 587–596. [CrossRef]
73. Likhanova, N.V.; Nava, N.; Olivares-Xometl, O.; Domínguez-Aguilar, M.A.; Arellanes-Lozada, P.; Lijanova, I.V.; Arriola-Morales, J.; Lartundo-Rojas, L. Corrosion Evaluation of Pipeline Steel API 5L X52 in partially deaerated Produced Water with High Chloride Content. *Int. J. Electrochem. Sci.* **2018**, *13*, 7949–7967. [CrossRef]
74. Huo, Z.; Mohamed, M.; Nicholas, J.R.; Anandan, S.; Chandrashekhara, K. Effect of salt water exposure on foam-cored polyurethane sandwich composites. *J. Sandwich Struct. Mater.* **2018**. [CrossRef]

75. Saharudin, M.S.; Wei, J.; Shyha, I.; Inam, F. Biodegradation of halloysite nanotubes-polyester nanocomposites exposed to short term seawater immersion. *Polymers* **2017**, *9*, 314. [CrossRef]
76. Yin, L.; Zhao, R. Moisture absorption and mechanical degradation studies of PMI foam cored fiber/epoxy resin sandwich composites. *Int. J. Eng. Res. Appl.* **2015**, *5*, 78–85.