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Editorial

Editorial for "Recent Advances in the Design of Structures with Passive Energy Dissipation Systems"

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1. Editorial

Civil engineering structures and infrastructures are inherently vulnerable to exceptional loads related to natural disasters, primarily earthquakes, tsunamis, strong winds, and floods. Consequently, one of the major challenges in the structural engineering field for the last decades has been to conceptualize, develop, and implement effective protective systems to mitigate such vulnerability, and to improve structural robustness and resilience. Base isolation and passive energy dissipation systems have demonstrated their effectiveness in coping with different kinds of environmental forces, including earthquakes and winds, as documented in theoretical and numerical studies and shaking table tests, as well as evidence from how they actually behaved during real catastrophic events. These structural protective systems traditionally include elastomeric bearings, lead rubber bearings, sliding friction pendulum, and various kinds of dampers, such as metallic, viscous, viscoelastic, friction dampers, tuned mass dampers and tuned liquid dampers.

The working mechanism underlying the aforementioned technologies is well known, and basic methods for their rational design and implementation are well established. Notwithstanding, there is an ever-growing interest in developing novel analytical and/or numerical tools to design structures equipped with optimally configured devices. Indeed, the design of such devices benefits from the current state-of-the-art algorithms and solvers for their optimization, which are constantly evolving. Other recent advances in this field concerns the development of cutting-edge models to reliably capture a series of complex nonlinear phenomena characterizing the hysteresis of such devices, calibrated based on experimental findings. On the other hand, the family of devices and dissipative elements for structural control keeps broadening due to the increasing performance demands of structures and due to new progress achieved in material science and mechanical engineering. In this context, recent advances include new strategies to develop the concept of energy dissipation into innovative devices, including negative stiffness devices, inerter-based systems, low-cost replaceable systems and dampers with a phased behavior. Although the development of new technologies generally follows established practice and underlies basic working principles, existing design methods for conventional devices are not always straightforwardly applicable to these new devices. Thus, there is an urgent need for revisiting design methodologies for such emerging technologies. Other significant contributions concern the development of hybrid protective systems based on energy dissipation devices that are conventional in their working mechanism, but that are combined together in a non-conventional arrangement so that their dynamic behavior is more effective than existing technologies.

Following these research motivations, this Special Issue collects 13 papers focused on structural protective systems applied to structures and infrastructures, including both traditional and innovative devices, using conventional and advanced design methodologies. In the Editors' opinion, each article contains undisputable scientific novelties from various perspectives (analytical, numerical, experimental, conceptual, implementation issues), proposes benchmark or emblematic engineering projects, and represents a major contribution in the design of structures with passive energy dissipation systems. The Editors hope that this article collection can somehow contribute, even if modestly, to the continuous research for more effective mitigation of the risks that natural disasters pose to humankind.

Some papers in the Special Issue concern the development of inerter-based vibration control strategies, and their deployment in civil engineering structures and infrastructures. The inerter modifies the inertial properties of the structures while adding negligible physical mass, and it may be a cost-effective solution for both seismic [2,4] and wind [1,3] vibration control. Some other papers concern the development of efficient design methods that exploit state-of-the-art algorithms and solvers for the optimization of the devices [11,13]. One paper concerns the challenging task of designing lead rubber bearings considering different performance requirements [10]. The performance of some variants and improvements of the classical concept of tuned mass damper is also analyzed in various applications and configurations [6,8,12]. Novel dissipation devices are finally developed and analyzed from an experimental and a numerical point of view [5,7,9]. A brief description of each article is given below.

In paper [1], Wang et al. present free vibration analysis of a taut-cable with two inertial mass dampers (IMDs) either symmetrically placed along the cable, or installed at the same end of the cable. The results in terms of the supplemental modal damping ratio provided by the IMDs for the two installation configurations and for different values of the damping coefficient are obtained by complex modal analysis, and are critically discussed. The novel contributions of this paper are twofold: (1) the authors demonstrate that IMDs have a superior control performance over traditional viscous dampers (VDs); (2) they also notice that a single IMD may be incapable of providing supplemental modal damping in a super-long cable, especially for the multimode cable vibration mitigation. A wide parametric study is presented to investigate the effect of damper positions and damper properties on the control performance of the cable in practical applications.

In paper [2], Xie et al. propose a novel inerter-based vibration control system called cable-bracing inerter system (CBIS), in which tension-only cables are interposed in between the inerter device and the main frame for translation-to-rotation conversion. This paper has the merit of contributing to widening the knowledge on the possible implementation technologies of the inerter, besides the rack-and-pinion mechanism, ball-screw device, fluid inerter, and inerter with clutch. Although in this paper the analysis is limited to a single-degree-of-freedom (SDOF) system equipped with the proposed CBIS, the authors demonstrate that this configuration can effectively be used for rapid seismic retrofit of structures, benefitting from ease of installation, deformation relaxation at the connecting joints, and an adaptive layout for nonconsecutive-story deployment. The proposed system reveals a mass amplification effect and a non-contacting damping mechanism. Through a parametric study, the influence of dimensionless parameters, such as inertance-mass ratio, stiffness ratio and additional damping ratio on vibration mitigation are studied in terms of displacement response and force output. A performance-oriented multi-objective design framework is also established in order to identify the parameters of the CBIS that can satisfy the target vibration mitigation.

In paper [3], Wang et al. investigate the wind-induced response control of high-rise buildings through inerter-based vibration absorbers, including the tuned mass damper inerter (TMDI) and the tuned inerter damper (TID). The analysis is performed on a real 340 m tall building analyzed as case study. A realistic wind-excitation model is adopted, based on experimental measurements from wind tunnel tests obtained for a scaled prototype of the benchmark building, which accounts for the actual cross-section of the structure and the existing surrounding conditions. The results are analyzed in terms of wind-induced displacement and acceleration response. Performance-based optimization of the TMDI and the TID is carried out to find a good trade-off between displacement and acceleration-response mitigation, with the installation floor being an explicit design variable, in addition to frequency and damping ratio, and considering different wind directions. The authors demonstrate that the optimally designed TMDI/TID can achieve better wind-induced vibration mitigation than the conventional tuned mass damper (TMD), while allocating lower or null attached mass, especially in terms of acceleration response.

In paper [4], Zhao et al. propose a displacement-dependent damping inerter system (DDIS) for seismic response control. This configuration is alternative to conventional configurations of commonly used inerter systems utilizing a velocity-dependent damping. The proposed configuration implies a displacement-dependent element (DDE) in parallel to the inerter device and in series with a tuning spring, which is found to generate a larger control force in the early stage of excitation in comparison to a viscous-damping inerter system (VDIS). The DDE is governed by a bilinear elastoplastic constitutive behavior. Although in this paper the analysis is limited to a SDOF system equipped with the proposed DDIS, the authors demonstrate the influence of various DDIS-parameters through a wide parametric study based on stochastic dynamic analysis. The stochastic linearization method is used to handle the nonlinear terms, and three performance indicators related to the displacement, acceleration and filtered energy response are analyzed. Then, the seismic response is evaluated in the time domain, taking the non-linearity into account and considering both artificial and natural records. It is found that the interaction between inerter, spring and the DDE is particularly effective for the structural control. The inerter amplifies the deformation of the DDE in the DDIS by over 60%; thus, the DDIS is characterized by a higher energy dissipation capability, namely as damping enhancement effect. Because of the damping and mass-enhancement mechanism, the proposed DDIS considerably reduces the structural displacement and acceleration, and is more effective than a VDIS especially the early stage of the seismic response.

In paper [5], Zheng et al. investigate, from an experimental and numerical point of view, a novel curved steel plate damper to improve the seismic performance of structures. Analytical formulae to determine the key design parameters of the damper, namely elastic stiffness, yield strength, and yield displacement, are derived. Experimental tests are carried out on four prototypes of metallic dampers, characterized by different geometric properties, so as to identify the most effective combination of parameters in terms of stability of hysteresis and energy dissipation performance. Finite element simulations are also performed to simulate the loading process of the specimens, to investigate the strain and stress distributions and to validate the design formulae proposed in this research work.

In paper [6], Meng et al. propose a two-degree of freedom tuned mass damper (2DOFs TMD) for vibration mitigation of a suspension bridge. The simultaneous action of the two TMDs makes it possible to control both bending and torsional modes of the bridge deck. Parameters of the proposed 2DOFs TMD are optimized through a control problem, with decentralized static output feedback for minimizing the response of the bridge deck, and a graphical approach is introduced to arrange flexible beams properly according to the exact constraints. It is found that the synthetic approach, based on both the graphical approach and parameterized compliance, is an effective way to design the TMD with the expected DOFs, in order to accomplish expected modes. Moreover, experimental findings on a small scale prototype demonstrate the ability of the TMDs of suppressing several vibration modes under laboratory conditions.

In paper [7], Mena et al. develop a new low-cost energy dissipation system for application to precast concrete structures. This solution is particularly appealing for residential structures in developing countries, in which precast footings, precast structural walls, and precast concrete slabs are present. The system is based on a new connection between the precast foundation and the precast structural wall, through a series of threaded steel bars that undergo plastic deformation during a seismic event. The advantages of the new system are experimentally evaluated via pushover tests performed on a single connection, on a structural frame, and on a real-scale three-story precast concrete building. Based on the obtained experimental results, the proposed device proves to be an effective strategy to increase the ductility and to mitigate the structural damage in the structural members, as the energy dissipation is mostly concentrated in the low-cost energy dissipation device. It is concluded that the proposed energy dissipation device makes it possible to reach the performance level of "immediate occupancy", according to the American standards ACI374.2R-13.

In paper [8], Stanikzai et al. investigate the seismic response of different structural control systems, including traditional base isolated buildings and three hybrid control solutions combining the base isolation (BI) with: (a) a single TMD at the top of the building; (b) multiple tuned mass dampers (MTMDs); (c) distributed tuned mass dampers (d-TMDs). The structural control performance of the various vibration absorbers is studied considering two buildings (5-story and 10-story), and including a set of 40 earthquake ground motions, with different scale factors to capture different intensity levels. An incremental dynamic analysis (IDA) with increasing peak ground accelerations (PGAs) is performed to develop simplified fragility curves for the maximum target isolator displacement. In line with other literature studies, the combination of BI and TMD leads to a significant reduction of the isolation bearing displacements, along with a reduction of the top floor acceleration and base shear. Additionally, it is found that the MTMDs placed at the top floor and d-MTMDs on different floors of the buildings are more efficient in reducing the probability of failure of the BI building when compared to a single TMD solution.

In paper [9], Zhu et al. propose a so-called horizontal-connection and energy-dissipation structure (HES), which could be employed for horizontal connection of prefabricated shear wall structural system. This system consists of an external replaceable energy dissipation (ED) zone, mainly for energy dissipation, and an internal stiffness lifting (SL) zone for enhancing the load-bearing capacity. The ED zone may be easily replaced after damage at the end of the seismic event, while the SL zone can increase the load-carrying capacity. Through the combination of the two zones, the load-displacement curves of the HES exhibits a "double-step" behavior, which is desired to meet performance requirements at different levels of the earthquake excitation. The system is investigated through detailed finite element simulations aimed at investigating the influence of the design parameters of the connections, such as aspect ratio, shape of the plate in the ED zone and displacement threshold in the SL zone. A customized hysteretic behavior is obtained, and a phased energy dissipation performance can be particularly useful for improving the seismic performance of prefabricated shear wall structures against large and super-large earthquakes.

In paper [10], Ju et al. study the vibration mitigation effects of base isolation realized with lead rubber bearings (LRBs) in high-tech factories. The authors consider a wide spectrum of external excitations in terms of disturbing frequencies, namely seismic, wind and moving crane loads. They also develop a three-dimensional finite element model, including soil-structure interaction effects. The authors critically discuss the obtained results in view of the achievement of different performance requirements under different types of external excitation. In particular, large initial stiffness is useful to reduce micro-vibrations due to moving crane loads and wind loads, as well as during small or moderate earthquakes, while small final LRB stiffness is necessary to reduce the seismic displacements during strong earthquakes. It is found that the effectiveness of the seismic isolation is excellent for earthquakes with short dominant periods but it decreases with increasing the dominant periods. Since micro vibration is a major concern for high-tech factories, an appropriate design of LRBs should entail a large initial stiffness and a small ratio of the final stiffness over the initial stiffness.

In paper [11], Naranjo-Pérez et al. develop a motion-based design method under uncertainty conditions for the vibration mitigation of stay cables under wind-induced vibrations. A robust design of the devices is carried out based on a constrained multi-objective optimization problem, wherein the a multi-objective function is defined in terms of characteristic parameters of the damping devices, and an inequality constraint is additionally included to guarantee an acceptable probability of failure of the structural system. Following the United States Federal Highway Administration guidelines, the design criterion is governed by the compliance of the vibration serviceability limit state, quantitatively indicated by a reliability index being greater than a threshold value. The performance of the proposed design method is numerically validated considering the longest stay cable of the Alamillo bridge (Spain) equipped with different passive damping devices, namely viscous, elastomeric and friction dampers. The proposed motion-based design method turns out to be more effective than a conventional method, by reducing the size and the budget of the devices, which facilitates its feasibility of implementation.

In paper [12], Rupakhety et al. explore the effectiveness of shared tuned mass damper (STMD) in reducing seismic pounding of adjacent buildings. The authors carefully revisit the idea of STMD reported in a paper from the literature [*Earthq. Eng. Struct. Dyn.* **2001**, *30*, 1185–1201]. In particular, they noted that, strictly speaking, such solution does not act like a shared tuned mass damper. Optimal parameters of the STMD are evaluated by minimizing the cost function using a genetic algorithm. Two optimal (tuning) parameters are found: the first solution corresponds to the device being tuned to one of the two buildings, thus being a classical TMD, and not a shared TMD; the second solution corresponds to a very stiff system, in which the TMD mass hardly moves, thus it is equivalent to a viscous connection between the two adjacent buildings. In the second solution, the TMD mass introduces no benefit while, counterproductively, it adds unnecessary load to the structure. Any reduction in response resulting from the STMD is due to the viscous coupling of the two buildings, rather than to the tuned vibration of the STMD mass. Based on the authors' study, the STMD strategy is not effective. This conclusion is obtained based on results from a large set of real earthquake ground motions, including 462 ground motion records from 110 earthquakes recorded in Europe and the Middle East.

In paper [13], Palacios-Quiñonero et al. develop an optimal passive actuation scheme of multibuilding systems composed of both interstory and interbuilding linear viscous dampers. Unlike other literature studies that are limited to one or at the most two adjacent buildings, the paper addresses a set of five identical planar frames. Optimization is carried out using a hybrid discrete-continuous formulation, based on $H\infty$ objective function combined with genetic algorithm approaches and parallel computing techniques. The optimal position and the optimal damping coefficient of the devices are determined through the developed design procedure. Three different classes (or configurations) of distributed damping systems are analyzed, with the frames being subjected to the El Centro ground motion. The resulting seismic performance is analyzed in terms of the peak interstory drift response of the various buildings and story-accelerations peak values, with an eye for the pounding risk. The proposed design methodology proves to be very effective from a computational point of view, and promising for application to large-scale multibuilding systems.

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