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Review

A State-of-the-Art Review of Passive Energy Dissipation Systems in Steel Braces

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Abstract: An extensive investigation of the international literature is carried out regarding the passive energy dissipation systems and more specifically the dampers that can be positioned in steel braces to increase the absorption of seismic energy and to protect them from buckling, such as Friction (FDs), Metallic (MDs), and Viscous dampers (VDs). This review paper systematically reviews/refers to 196 publications from the literature; it presents a brief overview of the steel braces frames and their problems. The efficacy of all of these types of dampers has been proved, as they have been used all around the world, and their comparison in experimental or numerical studies, applications, and optimization shows that there is no unilateral solution, as the appropriate selection of effective retrofit strategies takes into account parameters such as cost, duration, technical aspects, architectural needs, etc. Finally, the aim of this review paper is to systematically present an overview of passive energy dampers that can be installed on steel braces, summarize the advantages and the disadvantages of each one, compare global parameters such as the relation of velocity and damper force, economic details, and type of study, and facilitate future researchers working in the related field, for its better understanding and development.

Keywords: steel braces; passive energy dissipation systems; friction dampers; metallic dampers; viscous dampers

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1. Introduction

In the last decades, there have been numerous catastrophic earthquakes, resulting an increasing number of lost human lives due to building collapse and structural damage, with the most recent one in Turkey and Syria. The occurrence of such damage during earthquakes demonstrates the high seismic hazards, and requires structures such as residential buildings, lifeline structures, historical structures, and industrial structures to be designed very carefully to be protected from earthquakes [1]. In addition, existing reinforced concrete (RC) framed buildings with abrupt lateral changes in the structure at specific levels along the height, or in the plan, perform poorly with seismic loads, due to the irregular distribution of stiffness, strength, and mass.

To search for an appropriate solution to dealing with this natural disaster it is very important to understand the energy approach during an earthquake event. One part of the input seismic energy is dissipated by the inherent damping of the structures, but a large amount of energy is absorbed by the main structural system (beams, columns, walls). A structural design approach using energy dissipation systems (dampers) is now widely accepted and frequently applied in civil engineering, as the dampers will absorb the majority of the seismic energy, and as a result, prevent or mitigate such damages. The structural energy dissipation systems are divided into four major categories: passive, active, semi-active, and hybrid systems [2–8], and all of them can be used in new or existing buildings [9–13]. Table 1 summarizes the main information of these four categories.

Table 1. The existing structural energy dissipation systems.

Control System	Sub-Categories
Passive	✓ Dampers (friction, fluid viscous, metallic ...) ✓ Base isolation ✓ Tuned mass dampers
Active	✓ Adaptive control ✓ Active bracing ✓ Active mass dampers
Semi-active	✓ Semi-active dampers ✓ Semi-active base isolation ✓ Semi-active mass dampers
Hybrid	✓ Hybrid bracing ✓ Hybrid mass damping

On the other hand, the strength and stiffness of a building, as well as the lateral load-carrying capacity could be increased by adding shear walls in the construction. These shear walls that resist the lateral forces due to their high in-plane rigidity, may be either reinforced concrete (RC) or steel braced frames (BFs). The additional concrete walls within the frames of the load-bearing body offer a great increase in construction strength, but it is not always a feasible solution due to technical and operational problems [14,15]. On the other hand, steel-braced frames are systems constituting hinged joint or moment-resisting frames and braced bound to these frames concentrically or eccentrically. Such systems are generally used to supply stiffness and strength against lateral loads in low- and medium-rise buildings. The braced frames provide energy consumption under the effect of big lateral loadings under tensile loads but one of their disadvantages is the buckling risk [16,17].

The damped braces frames (DBs) can provide an effective way of overcoming the vulnerability resulting from setbacks as it is an easy and not expensive retrofitting solution. They can be categorized into the classical (e.g., cross, diagonal, and chevron) or geometrically amplified arrangement or/and the insertion of supplementary energy dissipation systems (e.g., friction, metallic yielding, viscous fluid, viscoelastic solid dampers, shape memory alloys).

This article focuses on passive energy dissipation systems and more specifically the dampers that can be positioned in steel braces. To achieve that goal, this review paper systematically reviews/refers to 196 publications from the literature and it is organized as follows: Section 2 presents a brief overview of the steel braces frames and their problems. Section 3 introduces and summarizes the friction dampers. Regarding the literature review of this article, 45 papers present FDs that could be added to steel braces, with the first one published in 1981 and 32% of them published in the last decade. Section 4 introduces and summarizes the metallic dampers, such as yielding, and lead or shape memory alloys dampers. Regarding the literature review of MDs, the first metallic damper was studied in the 80s, showing a smooth distribution in yielding dampers, while the increasing interest in SMA in recent years led to more than 59% of the works being published in the last decade. Section 5 introduces and summarizes viscous dampers such as viscoelastic solids, and viscous fluid dampers. These dampers present less diversity in shape and form but they have distracted the industry's interest. In Section 6, the author presents the general evaluation of seismic retrofitting techniques by comparing the three different categories of passive energy dissipation systems, as there is no unilateral solution. Finally, key concluding remarks have been pointed out in Section 7. This review paper aims to systematically present the overview of passive energy dampers that can be installed on steel braces and facilitate future researchers working in the related field for its better understanding and development.

2. Steel-Braced Frames

Steel BFs are generally used to supply stiffness and strength against lateral loads. By adding these frames, during a seismic event, the energy is dissipated through the steel-braced frames, which plasticize in tension and buckle in compression, while beams and columns are generally designed to remain in the elastic zone. Many experiments and analytical studies have been carried out to evaluate the seismic performance of steel-braced frames [18–20]. In Europe and all around the world, seismic guidelines simplified design criteria for DBs [21–25].

2.1. Concentrically Braced Frames

Concentrically Braced Frames (CBFs) are a class of braced frames resisting lateral loads through a vertical concentric truss system, the axes of the members aligning concentrically at the joints [26–30]. They are widely used for both mono- and multi-story buildings due to their high dissipative capacity and cheapness. Figure 1 illustrates all the types of these frames, such as diagonal bracing (Figure 1a), cross bracing (Figure 1b), chevron (Figure 1c,d), and K-shaped bracing (Figure 1e).

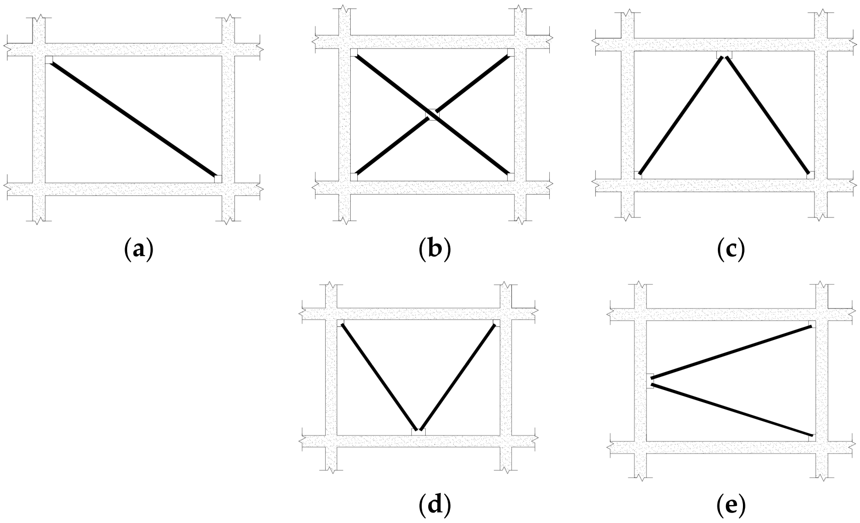


Figure 1. Concentrically Braced Frames: (**a**) single diagonal bracing, (**b**) cross bracing, (**c**) Λ bracing (chevron), (**d**) V bracing (chevron), (**e**) K bracing.

2.2. Eccentric Braced Frame (EBF)

Eccentric Braced Frame (EBF) configuration is similar to the concentrically braced frames with the exception that at least one end of each brace must be connected eccentrically to the frame which leads to a small connecting link often known as a ductile link. This link provides the structure's essential ductility and energy dissipation [31–37]. The difference between the concentric and eccentric bracing systems, as seen in Figure 2, is the presence of transverse stiffeners in the link beam due to the shear force and the flexural moment within it due to earthquake forces.

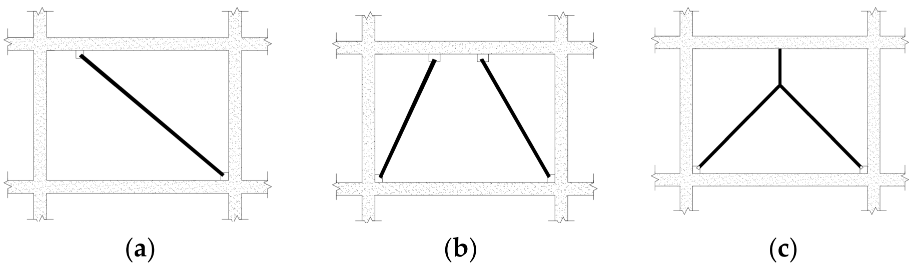


Figure 2. Several schematic models with eccentric bracing systems: (**a**) single diagonal bracing with eccentricity, (**b**) double diagonal bracing with eccentricity, (**c**) Λ bracing with eccentricity.

2.3. Inelastic Behavior of BFs

Numerous experimental and also numerical studies on the inelastic cyclic behavior of steel braces show that they exhibit non-symmetrical hysteretic behavior, with strength degradation under compressive load and the appearance of permanent deformations [37–41]. Other experimental studies have shown that steel braces fail after repeated loading cycles and the effective buckling length affects their response beyond the elastoplastic characteristics of the material [42–45]. Nip et al. [46] performed experimental tests on steel braces with square and hollow rectangular cross-sections under repeated cycle loading, confirming the non-symmetrical hysteretic behavior of the diagonal bars and the degradation of their strength under compressive load after a few loading cycles.

Similar results were presented by other studies [47–49]. In order to ensure that steel braces are a reliable seismic energy absorbing system, the engineering scientific community around the world has been oriented towards the following tactics:

1. Addition of seismic energy absorption dampers. This solution is the most common and is developed thoroughly in the following paragraphs (see Sections 3–5). The dampers that can be positioned in steel braces to increase the absorption of seismic energy and to protect them from buckling are Friction (FDs), Metallic (MDs), and Viscous dampers (VDs).

2. Increasing the rigidity of the steel braces. This solution is advantageous over the overall increase in stiffness (over-dimensioning) of the steel braces. Experimental research carried out by Sabouri-Ghomi and Ebadi [50–52] saw an improvement in their behavior by adding extra stiffness (steel blades) inside the steel braces, without increasing the cross-section. The results of their experimental study show a 19% increase in lateral forces under repeated cyclic loading, while the hysteretic loops represent uniform and stable energy absorption and reasonable ductility of the system.

3. Friction Dampers (FD)

The study of friction dampers in building applications has its beginning at the beginning of the 1980s when Pall et al. introduce the first friction damper which works based on the mechanism of solid friction for dissipating vibration energy [53]. According to their first experimental results, the braces, designed to perform under tension, did not work effectively under repeated cyclic loads. In 1982, they attached the friction pad to the cross brace junction with four links; this damper is commonly known as Pall Friction Damper (PFD) (Figure 3) [54–57]. Due to its ability to work both in tension and compression as well as to protect a structure from a severe seismic hazard, the PFD has been used and incorporated into several buildings all around the world [58–61], and many analytical, experimental, and optimization studies were conducted [62–66]. The required stiffness of the Library of Concordia University in Montreal is provided by 143 PFD, and this solution (involving the dampers) reduced the total construction costs by 1.5%.

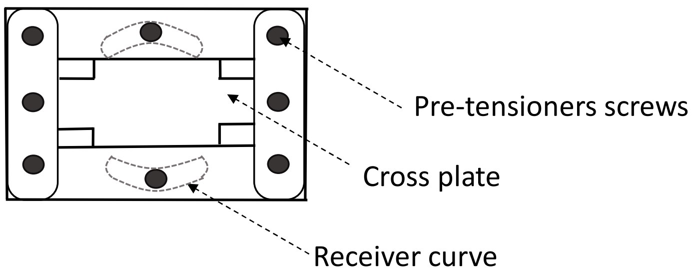


Figure 3. Pall friction damper.

Anagnostides et al. [67–69] proposed and investigated a new type of FD that was added to diagonal steel braces acting only in tension. The two configurations of this damper are presented in Figure 4. The first one consists of three plates connected with high-strength bolts applying a preload as shown in Figure 4a,b. The middle plate has slotted holes and can slip relative to the two outer plates when the applied load exceeds the frictional resistance of the joint. The second one consists of twelve friction joints incorporating frictional washers and four pin joints in the corners to accommodate the bracing members (Figure 4c,d). These dampers act only in tension and they have been further investigated and improved by other researchers.

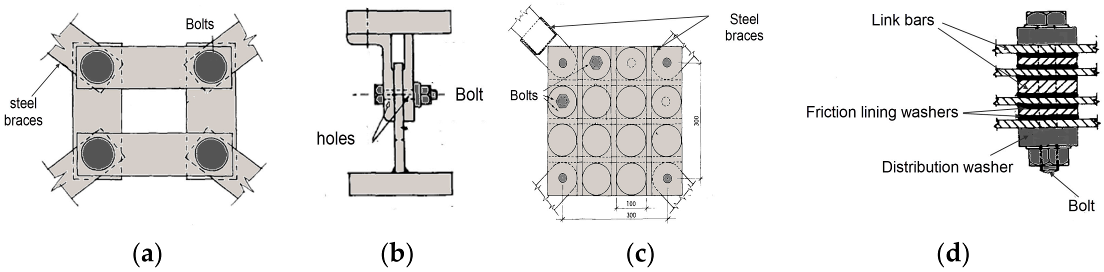


Figure 4. Improvement of PFD proposed by Anagnostides et al.: 1. three plates damper with high-strength bolts (**a**) longitudinal section, (**b**) cross-section. 2. twelve friction joints incorporating frictional washers (**c**) longitudinal section, (**d**) cross-section.

Wu et al. [70], based on the PFD, proposed its improvement to reduce the manufacturing original costs. The main difference is the shape of the inner steel plate, which has an inverted T-shape instead of a cruciform shape (Figure 5). From their study it was found that this improvement offers simplicity in analysis, reducing manufacturing cost and it is easier to operate as the number of pre-tensioner screws and slide screws was reduced (from six to four and from two to one respectively).

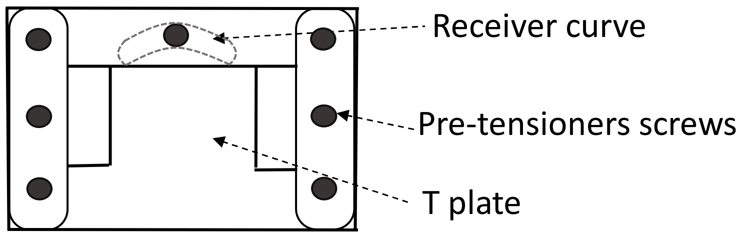


Figure 5. Construction of the improved Pall friction damper proposed by Wu et al.

Papadopoulos [71,72] proposed a variant of the PFD which, in addition to the regulation of the forces developed in the steel braces and the absorption of seismic energy, offers additional movement insurance to a desired level. This damper is illustrated in Figure 6 and it has triple action. The ultimate 'locking' of the device takes place when the tensile bars are aligned (Figure 6b). At that moment, the two diagonal steel bars are fully activated in tension, while the compressive diagonal bars retain the capability of axial movement. Simultaneously, the oval holes of device elements IV and V permit the kinetic functioning of the device for large horizontal floor displacements. From the experimental study conducted at the Laboratory of Structural Analysis & Dynamics of Structures at the Aristotle University of Thessaloniki, the hysteresis loops confirmed the efficacy of the device, as it can absorb seismic energy and the shape of loops to remain stable after many charging cycles [72].

In the same concept, Titirla et al. [72–75] proposed, fabricated, and investigated (both analytical and experimental) an innovative energy dissipation system known as CAR1, consisting of very simple materials and which does not need to be accomplished in the heavy industry, enabling its use in both developing and undeveloped countries (Figure 7). This damper presents a triple ability: (i) to Control the axial forces in the steel braces, (ii) to Absorb seismic energy, and (iii) to Retain the plastic displacements up to a desired level due to the restraint bolt (see Figure 7).

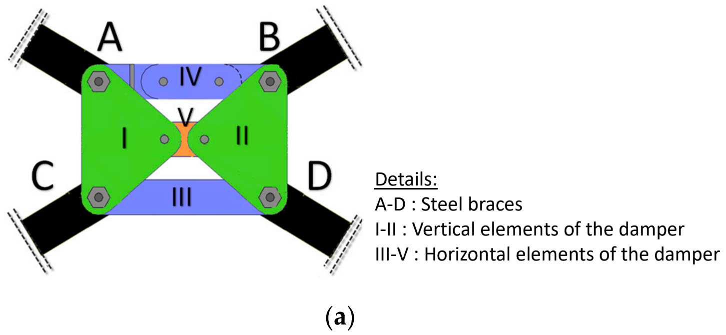


Figure 6. Construction of the improved Pall friction damper proposed by Papadopoulos, (**a**) inactive damper, (**b**) activation of the damper.

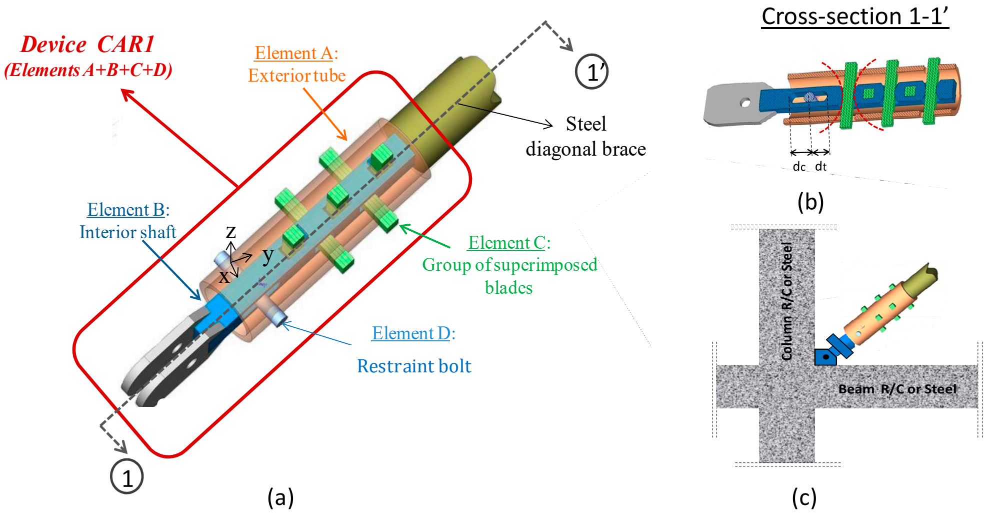


Figure 7. Description of CAR1 damper, proposed and investigated by Titirla et al. [73]. (**a**) The proposed steel device CAR1, (**b**) the cross section 1-1′ of the device CAR1, (**c**) connection of device in RC or Steel structures.

Mualla and Belev [76,77] proposed a rotational friction damper (RFD) consisting of a central steel plate, two side steel plates, and two friction rings, which are placed between the steel plates. The damper was tested experimentally at the Technical University of Germany and proved that it can be capable of receiving a load equal to 5000 kN, for displacements equal to 30 mm and 45 mm [78].

By the middle of 1991, Sumitomo friction dampers (SFD) had been incorporated in 31- and 22-story buildings in Japan [79]. This damper consists of inner wedges, outer wedges, outer cylinders, friction pads, and cup springs [80,81]. The hysteresis loop is similar to Coulomb's law of dry friction and the funding shows the efficacy of this damper in middle-rise and high-rise buildings.

Fitzgerald et al. [82], studied a slotted bolted connection (SBC) which works by sliding a channel bracing plate over a gusset plate interconnected by high-strength bolts. The damper is presented in the following figure. The damper can be operated with one or two screws. It has two stages of hysteretic behavior, the first came from the deformation of the main plates while the second one contained the incorporating deformations that develop when plates slide [83–85]. Many analytical and experimental studies were conducted [86–90]. This damper observes two stages of operation, the first came from the deformation of the main plates while the second one contained the incorporating deformations that develop when plates slide. A variant of the SBC device that uses sliding materials similar to the Sumitomo device, is presented by Constantinou et al. [91] for seismic reinforcement of bridges. The differentiation of the device is that it uses a surface of stainless steel and graphite-impregnated brass. Another SBC device was proposed by

Stefancu et al. [92], which consists of two steel plates that can be moved and three others that remain fixed. The plates are not in contact with each other but have a small gap between them, and the connection is made with pre-tensioned screws.

Another type of friction damper is the Energy Dissipating Restraint (EDR) damper studied by Ricther and Nims [93–96]. This damper consists of compression and friction wedges, springs, internal stopping components, and the cylinder. It converts the axial force of the spring to pressure, acting relative to the cylinder walls, thus creating the required friction surface. The damper can automatically return to its center cylinder and the frictional force developed is proportional to the displacement of the piston.

Zhou and Peng [97] proposed a new damper friction based on the EDR where the springs and wedges were replaced by a sliding shaft and a friction ring. Frictional force developed due to the radial stress resulting from the contact of the friction ring and the inner surface of the cylinder. The frictional force increases until the fuselage slips to achieve maximum displacement and the resulting hysteresis loop has a shape of a butterfly.

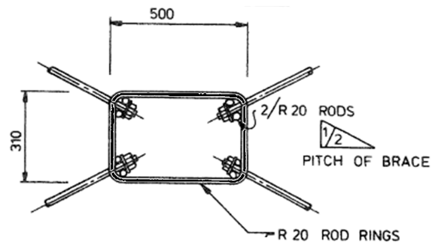
An elastic friction damper with recentering performance was developed by Kim et al. [98]. This damper is composed of polyurethane springs that provide recentering force by applying precompression, steel wires, and permanent magnet cubes that provide energy dissipation capability. The first results of this damper which is under further investigation confirmed that if such an elastic friction damper is applied to a braced frame structure, it can prevent permanent deformation and the seismic performance of the building can be improved.

4. Metallic Dampers (MD)

A metallic damper is a type of hysteretic damper made of metal that utilizes the plastic deformation of hysteretic materials, such as mild steel, to dissipate the input seismic energy. The application of that type of damper begins in Japan in the late 1960s and in New Zealand in the early 1970s. Recently there has been growth in Italy and the United States of America [99–101]. The advantages of metallic dampers compared to other types of dampers are the stable hysteretic behavior, rate independence, resistance against ambient temperature and reliability, and the fact that practice engineers are familiar with their material behavior [102–105].

4.1. Yielding Dampers

Tyler in 1985 studied a rectangular seismic absorption device made of round steel bars (Figure 8). As illustrated in Figure 8b, this rectangular device is integrated into the center point of diagonal steel bars. Energy is dissipated through inelastic deformation of the rectangular device assembly due to tension/compression of the diagonal steel bars [106].



(**a**)

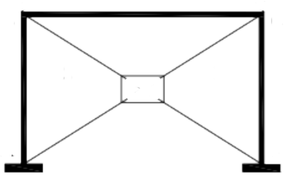
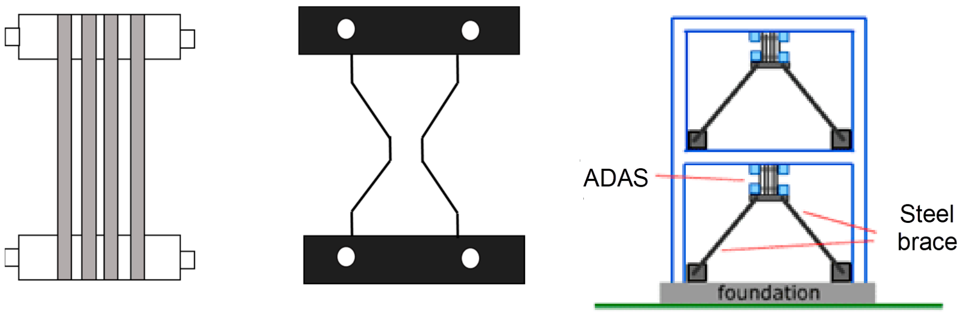

(**b**)

Figure 8. Premier metallic damper. (**a**) description of the rectangular metallic damper, (**b**) one story frame with the metallic damper.

The most popular metallic damper is the ADAS (Added Damping and Stiffness) damper studied by Whittaker [107,108] which is illustrated in Figure 9. The layout consists of flat steel plates in a row, in which their bottoms are connected to the top of the diagonal braces and their upper parts are connected at the ceiling level. This damper has been applied to many buildings and warehouses in the USA, Mexico, and Japan [100,109].



(**a**) (**b**)

Figure 9. (**a**) Description of ADAS damper, (**b**) two story frame with ADAS damper.

In the same concept, Tsai et al. [110] proposed the TADAS damper, with a triangular shape, using the flexural deformation of metal plates under out-of-plane bending and exhibiting a similar hysteretic loop to the ADAS damper. Different shapes of the metallic plate have been proposed the in last years, such as the honeycomb damper [111] or the slit damper [112,113]. Bagheri et al. introduced a U-shape metallic yielding damper (UMYD) as an energy dissipation system in steel building frames and showed that it can be operated with large displacements in the inelastic range and dissipate energy through the plastic deformation of the steel [114,115]. Due to its stable hysteretic behavior and the ability to transfer the inter-story shear force or axial load of a brace into the moment of the steel plate many analytical, experimental, and optimization studies were carried out [116–124].

A new metallic-yielding pistonic (MYP) damper is presented by Ghandil et al. for seismic control of structures [125]. A set of rectangular metallic yielding plates has been considered as an energy-dissipating part of this damper. According to its yielding mechanism and its special configuration, the story high-performance in seismic protection of structures at low-value story drifts is presented. Another damper consists of a combination of nested pipes that could change dynamic behavior parameters such as strength, stiffness, and damping ratio for energy absorption at different earthquake levels, and was proposed by Cheraghi and Zahrai [126]. The results show that it can reliably dissipate energy in different energy levels leading to ductility ratios of about 15 to 37 and equivalent viscous damping ratios of about 36 to 50%.

Casting multiplate damper (CMPD), which is composed of a set of energy-dissipating plates, was proposed by Chen et al., showing that a damper displays reasonably good seismic performance with sufficient deformation and energy dissipation capacity. In addition, the behavior of the damper could be adjusted for specific structures by changing the number and dimension of the energy-dissipating plates [127]. A Bar-Fuse Damper (BFD) is presented by Aghlara and Tahir for frame structures, which dissipates the energy with the replaceable bars as sacrificial elements through the flexural and tensile mechanism [128]. Thongchom et al. [129,130] proposed a new metallic damper consisting of five plates: shear plate, flange plate, X-stiffeners, middle plate, and boundary plates (Figure 10). The middle plate and boundary plates do not contribute to resisting the applied load while the shear plate, flange plate, and X-stiffeners share the shear strength.

The buckling-restrained brace (BRB) is another type of steel damper (Figure 11), it was initially introduced by Takeda et al. in 1976 [131] and deals with the buckling problem of tension and compression steel braces. Later the BRB was studied by several researchers [132–134] and developed with different configurations, such as circular core (CBRB), cross and crosswise core, and linear core [135–140]. Between the metal joint and the concrete, a suitable coating is placed, which allows the joint to slide relative to the concrete. This method of construction allows the system to accept axial, compressive, and tensile forces, which are received only by the metal link located at its core construction, due to slippage. The outer mantle of the concrete is intended to limit the free-bending length of the metal joint [132].

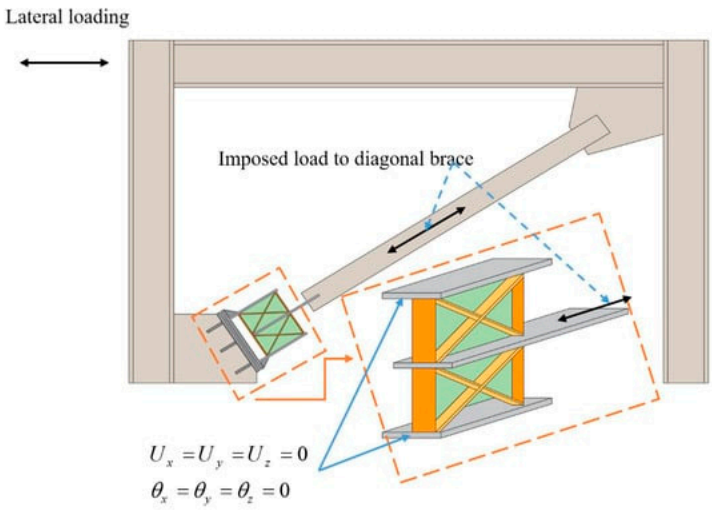


Figure 10. A new MD that improves the behavior of the shear dampers [129].

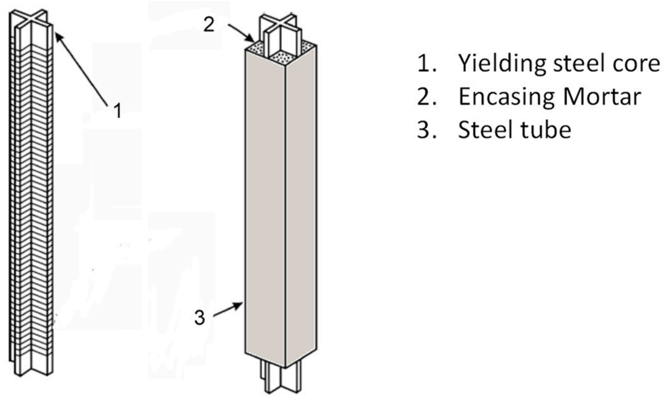


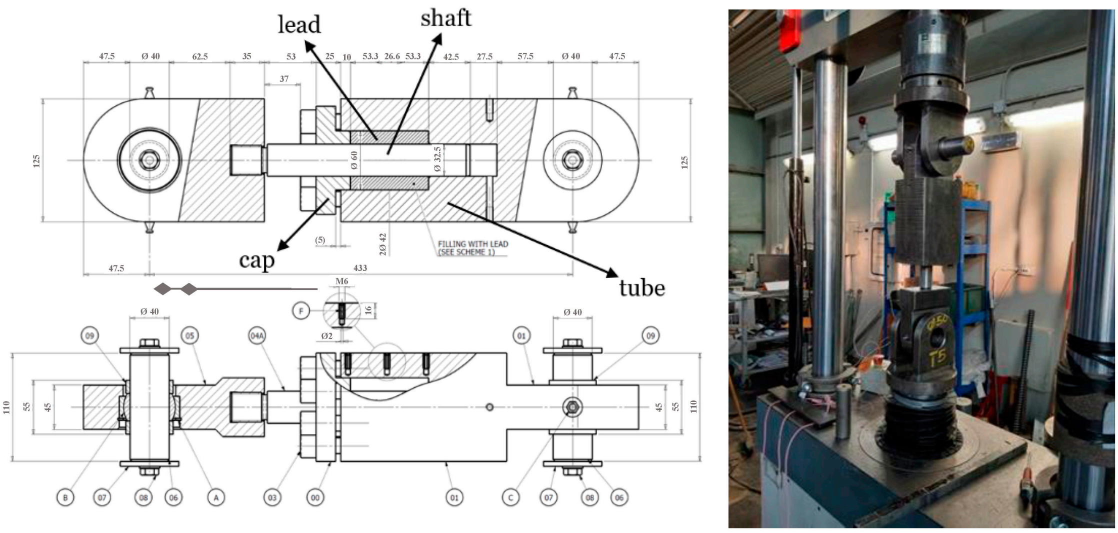
Figure 11. Construction of a buckling-restrained brace.

Improvement of BRB by adding prestressed steel tendons parallel to the internal core plate was proposed by Chou et al. [141–143] to avoid residual deformations under large seismic excitations. Furthermore, a Tube-in-Tube Damper (TTD) that keeps the advantages of BRB (it can be easily installed such as a conventional brace) has a series of strips created by cutting a series of slits through the wall, and it is welded to the inner hollow section in such a way that when the brace damper is subjected to forced displacements in the direction of its axis, the strips dissipate energy through flexural/shear yielding [144–146]. The hysteretic behavior of BRB (different configurations and its improvement) in tension and compression is very similar, and a substantial amount of energy is dissipated [147–153]. In the same field, Cao et al. [154,155] proposed the use of an external bolt-connected steel-plate reinforced concrete buckling-restrained brace frame in order to improve the seismic performance improvement of existing RC buildings. Their deep study including experimental and theoretical investigations shows the feasibility and the high efficiency of the novel external retrofitting approach. The prestressed tendons reduced the residual deformation, while the external braces enhanced the energy dissipation capacity.

4.2. Lead Dampers and SMA

A particular case of metallic devices is the extrusion dampers. The energy dissipation is produced by the rearrangement of the crystalline red of special metals (such as lead), due to the imposition of a deformation (extrusion), while maintaining, confined, the dissipative nucleus of the damper. The dampers that could be added to the steel braces belong to the category of lead extrusion dampers (LED) [156,157]. An LED consists of a thick-walled tube, on either side of which are two pistons connected by a tie rod. The space between the pistons is filled with lead, which is separated from the cylinder wall by a thin layer of lubricant kept in place by hydraulic seals around the pistons.

A new damper, called prestressed lead damper (PS-LED), proposed by Quaglini et al. [158–160], is based solely on friction and does not exploit the extrusion of lead, such as lead dampers proposed in the past [161–165], and reduces the costs of production (Figure 12). During the past few years, many researchers have tried to use the material advantages of shape memory alloys in seismic isolation, as it dissipates a significant amount of energy and can yield repeatedly without sustaining any permanent deformation [166–172]. SMA could be utilized for dampers with self-centering capabilities and undergo repeated hysteretic cycles. In addition, SMA devices are relatively insensitive to temperature changes and can sustain large loads which makes them suitable for base isolation systems, so this category is not presented in detail in this study.



(**a**) (**b**)

Figure 12. PS-LED damper proposed by Quaglini et al. able to reduce the costs of production: (**a**) description of the damper, (**b**) experimental set-up [160].

5. Viscous Dampers (VD)

5.1. Viscous Fluid Dampers

This type of VD provides a resisting force proportional to the applied velocity, it consists of a hollow cylinder filled with fluid, which is typically being silicone-based (Figure 13). As the damper piston rod and piston head are stroked, fluid is forced to flow through orifices either around or through the piston head. It was first used in the early 1980s by the military to absorb the vibrations caused by the firing of heavy weapons. The movement of the piston head within the cylinder fluid introduces kinetic energy in the damper, which is converted into heat due to friction that develops between the head and the liquid.

VDs are used alone or in conjunction with other systems' absorption of seismic energy. There are many applications in base isolation, for example, viscous dampers have been used as base isolation of a small assembly housing in Los Angeles [173,174] and also on the Millennium bridge in London [175]. There is not a huge variety of VD to steel braces, such as with FDs, but numerical studies and experimental tests on structures with the addition of viscous seismic energy absorption dampers have been reported by previous researchers [176–180]. Various structural models, with and without fluid dampers manufactured by Taylor Devices Inc., were tested on the shake table at the University at Buffalo from 1991 to 1995.

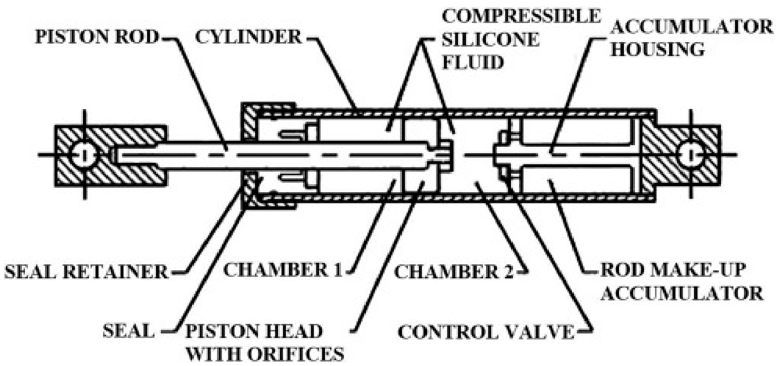


Figure 13. Longitudinal section of a typical Viscous fluid damper.

5.2. Viscoelastic Solid Dampers

Dampers with solid viscous damping material consisting of a solid elastomeric pad, with visco-elastic properties, between two steel plates. The dampers dissipate energy in the form of heat, mainly due to shear deformations in the viscoelastic material. The steel plates are attached to the structure within chevron or diagonal bracing (Figure 14). As one end of the damper displaces concerning the other, the viscoelastic material is sheared resulting in the development of heat which is dissipated to the environment. By their very nature, viscoelastic solids exhibit both elasticity and viscosity.

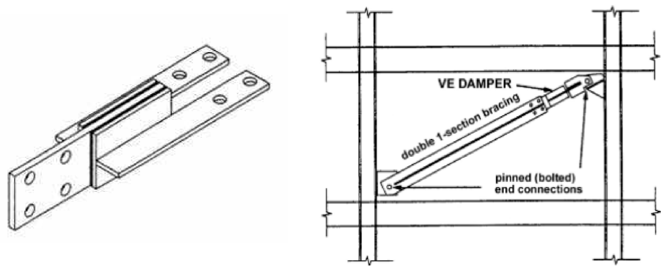


Figure 14. Longitudinal section of a typical Viscous fluid damper: (**a**) description of VDs, (**b**) one story frame with VDs.

Mahmoodi [181] described the characteristics of a viscous damping damper suitable for reducing the dynamic response of structures. Later, a standard damper with solid viscous damping material was studied by Aiken and Kelly [80]. Another damper similar to the previous one was studied by Constantinou and Symans [182] and is presented in Figure 15.

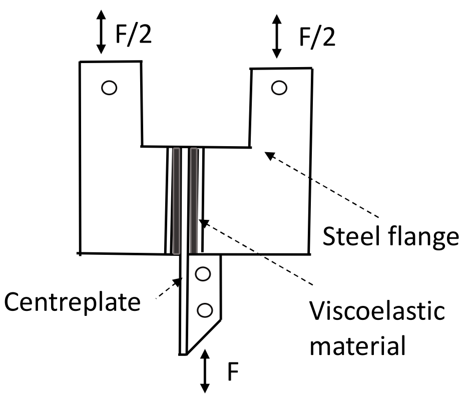


Figure 15. Improvement of Viscous Damper.

Rashid and Nicolescu [183] developed a tuned viscoelastic damper, which has high damping performance over a wide range of excitation frequencies and can effectively reduce vibration amplitudes. In addition, various researchers applied viscoelastic dampers in civil engineering to control the seismic behaviors of reinforced concrete frame structures and high-rise buildings [184–188]. In 1982, solid-material viscous dampers were incorporated into the 76-floor Columbia Center Building in Seattle, to deal with the vibrations by wind [189].

Another damper that could be included in this type of damper is the compressed rubber damper proposed by Sweeney and Michael [190]. It consists of four pieces of rubber welded to a longitudinal steel rod. The pieces of elastic material are then pre-compressed into a steel tube. The interface between the rubber and the steel pipe remains free so that it can slide and create frictional forces in long movements.

6. Evaluating Seismic Retrofitting Techniques

A preliminary assessment of the overall deficiency of existing structures and the appropriate selection of effective retrofit strategies are fundamental phases for seismic protection [17,191]. The strengthening and stiffening strategy is essentially based on the addition of shear walls, bracings, and vertical frames within the building's bays. The effects of adding steel bracings were experimentally and numerically tested [4,5,16–20,26–31]. In order for steel braces to be a reliable seismic energy absorbing system, the engineering scientific community around the world has been oriented towards seismic energy absorption dampers, such as Friction (FDs), Metallic (MDs), and Viscous (VDs).

FDs provide a large energy dissipation per cycle loading and insensitivity to ambient temperature, while the sliding interface conditions may change with time and due to their strong nonlinear behavior, may excite higher modes, and the nonlinear analysis is required. MDs provide a stable hysteretic behavior and insensitivity to ambient temperature, while the replacement of the damper after the earthquake and a nonlinear analysis is required. VDs can be activated at low displacements, and provide restoring forces, and due to their linear behavior, a simplified modeling of the damper is required. The viscoelastic solid dampers are limited in the deformation capacity and a debonding of VE material is possible, while for the viscous fluid dampers, a fluid seal leakage is possible.

Another parameter which is very important is the relation between the velocity of the excitation (earthquake or wind) and the damper force. The response of FDs and MDs is independent of the velocity and will exert a constant force in all future excitations. This characteristic makes the design of the connections and the steel bracings easier as the force of the FDs and MDs is constant and fixed. Fluid VDs are velocity dependent which means that the same damper exerts different responses in different excitation.

In terms of economic details, fabrication, installation, and repair cost, it is difficult to express the exact cost of each damper as some of them were constructed only for research reasons, some of them are still under research level, and for some of them the data were inaccessible. The most economical mechanism is the friction and the yielding of metal in dissipative devices that make the FDs and the MDs less expensive compared with the fluid material of VDs. In addition, the cost of repair is less too, as FDs/MDs just need the removal of a part of the damper and do not need to be shipped back to the factory, while the whole VDs need to be shipped back. Manufacturing time has an impact on cost. The manufacturing process of VDs is more complex than FDs or MDs, which takes up to five months.

In order to demonstrate the effectiveness of the dampers, there are either the experimental [18,35,45,71,78,88,98,112,121,131,139,143,150,160,167,176] or the numerical researches [14,42,49,73,75,80,86,127,140,142,169]. FE models play a key role in the ordinary design process of new structures and in the assessment of existing ones. The Finite Element Method (FEM) has become the most popular method in both research and industrial numerical simulations, as it takes into consideration material laws, contact interface conditions, and other parameters, which lead to the exact response of the strengthening solutions and reduce the cost of the experimental test. Without wanting to promote any software, some of the used software are Abaqus, Ansys, Comsol, Etabs, Sap2000 etc. A combination of experimental and numerical studies seems to be the ideal solution [4,74,92,115,122,127,130,150,154,159,168].

On the other hand, the efficacy of all these types of dampers has been proven as they had been used all around the world. FDs have been incorporated into existing and new buildings, with the most important being the Library of Concordia University in Montreal and the Montreal Casino in Canada [57,58,60,80]. MDs have been applied to the seismic reinforcements of the Wells Fargo Bank in San Francisco but also to many other buildings in the USA, Mexico, and Japan [11,12,99,100,109]. VDs most important applications are a group of houses in Los Angeles, the Millennium bridge in London, and the 76-floor Columbia Center Building in Seattle [173–175,185,188,189,192].

Comparing the three different categories of passive energy dissipation systems into experimental or numerical studies, applications, and optimization, it is noticed that there is no unilateral solution, as the appropriate selection of effective retrofit strategies takes into account parameters such as cost, duration, technical aspects, architectural needs, etc. In the literature, multistoried buildings are analyzed with the installation of FDs, MDs, or VDs, suggesting that all the dampers are suitable for low-rise, and mid-rise buildings, but VDs seems to be studied more for high-rise buildings [10–17,44,57–60,81,99,109,134,193–196]. It is important to notice that for further investigation, buildings' regularities or irregularities in plan and elevation, should be also examined to study their effect on dampers design optimization, and to choose the most appropriate strengthening solutions for multistoried buildings.

7. Conclusions

This article focuses on passive energy dissipation systems and more specifically the dampers that can be positioned in steel braces to increase the absorption of seismic energy and to protect them from buckling. This review paper systematically reviews/refers to 196 publications in the literature, it presents a brief overview of the steel braces frames and their problems, the seismic energy absorption dampers, such as Friction (Section 3), Metallic (Section 4), and Viscous (Section 5), that can be installed in the steel braces.

The most popular FDs is the Pall damper, published in 1981, which has been incorporated into existing and new buildings, with the most important being the Library of Concordia University in Montreal and the Montreal Casino in Canada. This type of damper provides a large energy dissipation per cycle loading and insensitivity to ambient temperature, while the sliding interface conditions may change with time and due to their strong nonlinear behavior, may excite higher modes, and the nonlinear analysis is required.

MDs provide a stable hysteretic behavior and insensitivity to ambient temperature, while the replacement of the damper after the earthquake and the nonlinear analysis is required. The most popular damper of this type is the damper ADAS which has been applied to many buildings and warehouses in the USA, Mexico, and Japan.

VDs can be activated at low displacements, and provide restoring forces, and due to their linear behavior, simplified modeling of the damper is required during numeral analysis. Fluid VDs are velocity dependent which means that the same damper exerts different responses in different excitation, which leads to more complex fabrication techniques. In addition, the viscoelastic solid dampers are limited in the deformation capacity and a debonding of VE material is possible, while for the viscous fluid dampers, a fluid seal leakage is possible.

In terms of economic details, fabrication, installation, and repair costs, FDs and MDs have the most economical mechanism. In addition, the cost of repair is also small as FDs/MDs just need the removal of a part of the damper and do not need to be shipped back to the factory, while the whole VDs need to be shipped back.

The efficacy of all these types of dampers has been proved, as they had been used all around the world, and their comparison into experimental or numerical studies, applications, and optimization shows that there is no unilateral solution, as the appropriate selection of effective retrofit strategies takes into account parameters such as cost, duration, technical aspects, architectural needs, etc. The aim of this review paper is to systematically present the overview of passive energy dampers that can be installed on steel braces (Sections 3–5), summarize the advantages and the disadvantages of each one, compare global parameters (Section 6) such as the relation of velocity and damper force, economic details, and type of study (experimental or numerical), and to facilitate future researchers working in the related field, for its better understanding and development.

From this review, it is clear that there is a huge variety of dampers that can be added to steel braces, but there is a lack of comparable applications. Future research will focus on the application to real low-rise, mid-rise, and high-rise structures (steel or concrete) as well as irregularities in plan and elevation.

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Nomenclature

The acronyms that have been followed through this review paper are presented below.

Nomenclature	Referred to
ADAS	Added Damping and Stiffness
BF	Braced Frame
BFD	Bar-Fuse Damper
BRB	Buckling-Restrained Brace
CBF	Concentrically Braced Frame
CMPD	Casting Multiplate Damper
DB	Damped Braces
EBF	Eccentric Braced Frame
EDF	Energy Dissipating Restraint
FD	Friction Damper
MD	Metallic Dampers
MYP	Metallic-Yielding Pistonic
PFD	Pall Friction Damper
PT	Post-Tensioned
RC	Reinforced Concrete
RFD	Rotational Friction Damper
SBC	Slotted Bolted Connection
SFD	Sumitomo Friction Damper
SMA	Shape Memory Alloys
TADAS	Triangular plate Added Damping and Stiffness Damper
TTD	Tube-in-Tube Damper
UMYD	U-shape Metallic Yielding Damper
VD	Viscous Damper

References

1. Daniell, J.E.; Schaefer, A.M.; Wenzel, F.; Kunz-Plapp, T. The value of life in earthquakes and other natural disasters: Historical costs and the benefits of investing in life safety. In Proceedings of the Tenth Pacific Conference on Earthquake Engineering Building an Earthquake-Resilient Pacific, Sydney, Australia, 6–8 November 2015.
2. Spencer, B.F., Jr.; Nagarajaiah, S. State of the art of structural control. *J. Struct. Eng.* **2003**, *129*, 845–856.
3. Saaed, T.E.; Nikolakopoulos, G.; Jonasson, J.-E.; Hedlund, H. A state-of-the-art review of structural control systems. *J. Vib. Control* **2013**, *21*, 919–937. [CrossRef]
4. Housner, G.W.; Bergman, L.A.; Caughey, T.K.; Chassiakos, A.G.; Claus, R.O.; Masri, S.F.; Skelton, R.E.; Soong, T.T.; Spencer, B.F.; Yao, J.T.P. Structural control: Past, present, and future. *J. Eng. Mech.* **1997**, *123*, 897–971.
5. Soong, T.T.; Spencer, B.F. Supplemental energy dissipation: State-of-the-art and state-of-the- practice. *Eng. Struct.* **2002**, *24*, 243–259. [CrossRef]

6. Soong, T.T. State-of-the-art review: Active structure control in civil engineering. *Eng. Struct.* **1988**, *10*, 74–84. [CrossRef]
7. Symans, M.D.; Charney, F.A.; Whittaker, A.S.; Constantinou, M.C.; Kircher, C.A.; Johnson, M.W.; McNamara, R.J. Energy dissipation systems for seismic applications: Current practice and recent developments. *J. Struct. Eng.* **2008**, *134*, 3–21. [CrossRef]
8. Tiwary, A.; Tiwary, A.; Kumar, A. State-of-Art in Active, Semi-Active and Hybrid Control Systems for Tall Buildings. *Int. J. Eng. Res. Appl.* **2014**, *1*, 1–5.
9. Ghaedi, K.; Ibrahim, Z.; Adeli, H.; Javanmardi, A. Invited Review: Recent developments in vibration control of building and bridge structures. *J. Vibro. Eng.* **2017**, *19*, 3564–3580. [CrossRef]
10. Titirla, M.D. Using Friction-Yielding Damper CAR1 to Seismic Retrofit a Two-Story RC Building: Numerical Application. *Appl. Sci.* **2023**, *13*, 1527. [CrossRef]
11. Shih, M.-H.; Sung, W.-P. Seismic Resistance and Parametric Study of Building under Control of Impulsive Semi-Active Mass Damper. *Appl. Sci.* **2021**, *11*, 2468. [CrossRef]
12. Javanmardi, A.; Ibrahim, Z.; Ghaedi, K.; Khan, N.B.; Ghadim, H.B. Seismic isolation retroftting solution for an existing steel cable-stayed bridge. *PLoS ONE* **2018**, *13*, e0200482. [CrossRef] [PubMed]
13. Mazza, F. Comparative study of the seismic response of RC framed buildings retrofitted using modern techniques. *Earthq. Struct.* **2015**, *9*, 29–48. [CrossRef]
14. Mamdouh, H.; Zenhom, N.; Hasabo, M.; Deifalla, A.F.; Salman, A. Performance of Strengthened, Reinforced Concrete Shear Walls with Opening. *Sustainability* **2022**, *14*, 14366. [CrossRef]
15. Choi, S.-H.; Hwang, J.-H.; Han, S.-J.; Joo, H.-E.; Yun, H.-D.; Kim, K.S. Seismic Performance Assessments of RC Frame Structures Strengthened by External Precast Wall Panel. *Appl. Sci.* **2020**, *10*, 1749. [CrossRef]
16. Unal, A.; Kaltakci, M.Y.; Wang, W.; Zhou, Q.; Chen, Y.; Tong, L.; Chan, T. Experimental and numerical investigation on full-scale tension-only concentrically braced steel beam-through frames. *J. Construct. Steel Res.* **2013**, *80*, 369–385.
17. Yoo, J.; Lehman, D.E.; Roeder, C.W. Influence of connection design parameters on the seismic performance of braced frames. *J. Construct. Steel Res.* **2008**, *64*, 607–623. [CrossRef]
18. Annan, C.D.; Youssef, M.A.; El Naggar, M.H. Experimental evaluation of the seismic performance of modular steel-braced frames. *Eng. Struct.* **2009**, *31*, 1435–1446. [CrossRef]
19. Unal, A.; Kaltakci, M.Y. Seismic behavior of concentrically steel braced frames and their use in strengthening of reinforced concrete frames by external application. *Steel Compos. Struct.* **2016**, *21*, 687–702. [CrossRef]
20. Qu, Z.; Kishiki, S.; Maida, Y.; Sakata, H.; Wada, A. Seismic responses of reinforced concrete frames with buckling restrained braces in zigzag configuration. *Eng. Struct.* **2015**, *105*, 12–21. [CrossRef]
21. British Standards Institution; European Committee for Standardization; Standards Policy and Strategy Committee. *Eurocode 8, Design of Structures for Earthquake Resistance*; British Standards Institution: London, UK, 2005.
22. American Institute of Steel Construction. *Seismic Provisions for Structural Steel Buildings*; American Institute of Steel Construction: Chicago, IL, USA, 2016.
23. Canadian Standards Association; Standards Council of Canada. *Design of Steel Structures*; CSA Group: Toronto, ON, Canada, 2019.
24. Marino, E.; Nakashima, M.; Mosalam, K.M. Comparison of European and Japanese seismic design of steel building structures. *Eng. Struct.* **2005**, *27*, 827–840. [CrossRef]
25. Federal Emergency Management Agency (FEMA). *FEMA 356 (2000): Pre-Standard and Commentary for the Seismic Rehabilitation of Buildings*; FEMA: Washington, DC, USA, 2000.
26. Brandonisio, G.; Toreno, M.; Grande, E.; Mele, E.; De Luca, A. Seismic design of concentric braced frames. *J. Construct. Steel Res.* **2012**, *78*, 22–37. [CrossRef]
27. Grande, E.; Rasulo, A. Seismic assessment of concentric X-braced steel frame. *Eng. Struct.* **2013**, *49*, 983–995. [CrossRef]
28. Hajirasouliha, I.; Doostan, A. A simplified model for seismic response prediction of concentrically braced frames. *Adv. Eng. Softw.* **2010**, *41*, 497–505. [CrossRef]
29. Jazany, R.A.; Hajirasouliha, I.; Farshchi, H. Influence of masonry infill on the seismic performance of concentrically braced frames. *J. Construct. Steel Res.* **2013**, *88*, 150–163. [CrossRef]
30. Lumpkin, E.J.; Hsiao, P.; Roeder, C.W.; Lehman, D.E.; Tsai, C.; Wu, A.; Wei, C.; Tsai, K. Investigation of the seismic response of three-story special concentrically braced frames. *J. Construct. Steel Res.* **2012**, *6477*, 131–144. [CrossRef]
31. Kawamata, S.; Ohnuma, M. Strengthening effect of eccentric steel braces to existing reinforced concrete frames. In *Proceedings of the 2nd Seminar on Repair and Retrofit of Structures Conference*; Department of Civil Engineering, The University of Michigan: Ann Arbor, MI, USA, 1981.
32. Moghaddam, H.A.; Estekanchi, H.E. Seismic behaviour of offcentre bracing systems. *J. Constr. Steel Res.* **1999**, *51*, 177–196. [CrossRef]
33. Popov, E.P.; Engelhardt, M.D. Seismic eccentrically braced frames. *J. Constr. Steel Res.* **1988**, *10*, 321–354. [CrossRef]
34. Shi, Q.; Yan, S.; Wang, X.; Sun, H.; Zhao, Y. Seismic behavior of the removable links in eccentrically braced frames with semirigid connections. *Adv. Civ. Eng.* **2020**, *2020*, 9405107. [CrossRef]
35. Shi, Y.J.; Xiong, J.; Wang, Y.Q.; Liu, G. Experimental studies on seismic performance of multi-storey steel frame with eccentric brace. *J. Build. Struct.* **2010**, *31*, 29–34.

36. Ozel, A.E.; Guneyisi, E.M. Effects of eccentric steel bracing systems on seismic fragility curves of mid-rise R/C buildings: A case study. *Struct. Saf.* **2011**, *33*, 82–95. [CrossRef]
37. Ghobarah, A.; Abou Elfath, H. Rehabilitation of a reinforced concrete frame using eccentric steel bracing. *Eng. Struct.* **2001**, *23*, 745–755. [CrossRef]
38. Jain, A.K.; Goel, S.C.; Hanson, R.D. Hysteretic cycles of axially loaded steel members. *J. Struct. Div.* **1980**, *106*, 1777–1795. [CrossRef]
39. Kahn, L.F.; Hanson, R.D. Inelastic cycles of axially loaded steel members. *J. Struct. Div.* **1976**, *102*, 947–959. [CrossRef]
40. Lee, P.S.; Noh, H.C. Inelastic buckling behavior of steel members under reversed cyclic loading. *Eng. Struct.* **2010**, *32*, 2579–2595. [CrossRef]
41. Popov, E.P.; Black, R.G. Steel struts under severe cyclic loadings. *J. Struct. Eng.* **1981**, *107*, 1857–1881. [CrossRef]
42. Salawdeh, S.; Goggins, J. Numerical simulation for steel brace members incorporating a fatigue model. *Eng. Struct.* **2013**, *46*, 332–349. [CrossRef]
43. Tremblay, R.; Archambault, M.H.; Filiatrault, A. Seismic response of concentrically braced steel frames made with rectangular hollow bracing members. *J. Struct. Eng.* **2003**, *129*, 1626–1636. [CrossRef]
44. Tremblay, R.; Lacerte, M.; Christopoulos, C. Seismic response of multistory buildings with selfcentering energy dissipative steel braces. *J. Struct. Eng.* **2008**, *134*, 108–120. [CrossRef]
45. Fell, B.V.; Kavinde, A.M.; Deierlein, G.G.; Myers, A.T. Experimental Investigation of Inelastic Cyclic Buckling and Fracture of Steel Braces. *J. Struct. Eng.* **2009**, *135*, 19–32. [CrossRef]
46. Nip, K.H.; Gardner, L.; Elghazouli, A.Y. Cyclic testing and numerical modelling of carbon steel and stainless steel tubular bracing members. *Eng. Struct.* **2010**, *32*, 424–441. [CrossRef]
47. Haddad, M.; Tremblay, R.; Chen, L.; Tirca, L. Cracking and fracture of HSS braces under cyclic loading. In Proceedings of the 5th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Crete Island, Greece, 25–27 May 2015.
48. Lotfollahi, M.; Alinia, M.M.; Taciroglu, E. Inelastic buckling simulation of steel braces through explicit dynamic analyses. *AIP Conf. Proc.* **2012**, *1389*, 2012–2015.
49. Lotfollahi, M.; Alinia, M.M.; Taciroglu, E. Validated finite element techniques for quasi-static cyclic response analyses of braced frames at sub-member scales. *Eng. Struct.* **2016**, *106*, 222–242. [CrossRef]
50. Sabouri-Ghomi, S.; Ebadi, P. Test Description of Steel X-bracing System Using Lowgrade Steel and Internal Oblique Transverse Stiffeners. *Struct. Des. Tall Spec. Build.* **2010**, *22*, 235–250. [CrossRef]
51. Ebadi, P.; Sabouri-Ghomi, S. Conceptual study of X-braced frames with different steel grades using cyclic half-scale tests. *Earthq. Eng. Eng. Vib.* **2012**, *11*, 313–329. [CrossRef]
52. Payandehjoo, B.; Sabouri-Ghomi, S.; Ebadi, P. Seismic Behavior of X-Shaped Drawer Bracing System (DBS) and X-Braced Frames with Heavy Central Core. *J. Earthq. Tsunami* **2016**, *10*, 1650004. [CrossRef]
53. Pall, A.S.; Marsh, C.; Fazio, P. Friction joints for seismic control of large panel structures. *J. Prestress. Concr. Inst.* **1980**, *25*, 38–61. [CrossRef]
54. Pall, A.S.; March, C. Seismic response of friction damped braced frames. *J. Struct. Div.* **1982**, *108*, 1313–1323. [CrossRef]
55. Colajanni, P.; Papia, M. Seismic response of braced frames with and without friction dampers. *Eng. Struct.* **1995**, *175*, 129–140. [CrossRef]
56. Pall, A.S. Friction devices for aseismic design of buildings. In *Fourth Canadian Conference on Earthquake Engineering: Proceedings*; University of British Columbia: Vancouver, BC, Canada, 1983; pp. 475–484.
57. Pall, A.S.; Verganelakis, V.; March, C. Friction-Dampers for seismic control of Concordia University Library Building. In Proceedings of the 5th Canadian Conference on Earthquake Engineering, Ottawa, ON, Canada, 6–8 July 1987; pp. 191–200.
58. Pall, A.S.; Pall, R. Friction-Dampers Used for Seismic Control of New and Existing Building in Canada. In Proceedings of the ATC-17-1 Seminar on Isolation, Energy Dissipation and Active Control, San Francisco, CA, USA, 11–12 March 1993; Volume 2, pp. 675–686.
59. Pall, A.; Vezina, S.; Proulx, P.; Pall, R. Friction-dampers for seismic control of Canadian space agency headquarters. *Earthq. Spectra* **1993**, *9*, 547–557. [CrossRef]
60. Pasquin, C.; Leboeuf, N.; Pall, R.T.; Pall, A. Friction dampers for seismic rehabilitation of Eaton's building, Montreal. In Proceedings of the 13th World Conference on Earthquake Engineering: Conference Proceedings, Vancouver, BC, Canada, 1–6 August 2004; pp. 1–2.
61. Pall, A. Performance-based design using pall friction dampers-an economical design solution. In Proceedings of the 13th World Conference on Earthquake Engineering: Conference Proceedings, Vancouver, BC, Canada, 1–6 August 2004; Volume 70, pp. 571–576.
62. Pekau, O.A.; Guimond, R. Controlling seismic response of eccentric structures by friction dampers. *Earthq. Eng. Struct. Dyn.* **1991**, *20*, 505–521. [CrossRef]
63. Filiatrault, A.; Cherry, S. Performance evaluation of friction damped braced steel frames under simulated earthquake loads. *Earthq. Spectra* **1987**, *3*, 57–78. [CrossRef]
64. Fallah, N.; Honarparast, S. NSGA-II based multi-objective optimization in design of Pall friction dampers. *J. Constr. Steel Res.* **2013**, *89*, 75–85. [CrossRef]

65. Vezina, S.; Proulx, P.; Pall, R.; Pall, A. Friction-dampers for aseismic design of Canadian Space Agency. In Proceedings of the 10th World Conference on Earthquake Engineering, Madrid, Spain, 19–24 July 1992; pp. 4123–4128.
66. Anagnostides, G.; Hargreaves, A.C.; Wyatt, T.A. Development and applications of energy absorption devices based on friction. *J. Constr. Steel Res.* **1989**, *13*, 317–336. [CrossRef]
67. Anagnostides, G.; Hargreaves, A.C. Shake table testing on an energy absorption device for steel braced frames. *Soil. Dyn. Earthq. Eng.* **1990**, *9*, 120–140. [CrossRef]
68. Anagnostides, G.; Hargreaves, A.C.; Wyatt, T.A. *Shake Table Testing of a 2-Storey Braced Frame Incorporating Friction Devices*; ESEE Research Report No. 88/2; Imperial College: London, UK, 1988.
69. Wu, B.; Zhang, J.; Williams, M.S.; Ou, J. Hysteretic behavior of improved Pall-typed frictional dampers. *Eng. Struct.* **2005**, *27*, 1258–1267. [CrossRef]
70. Papadopoulos, P. New nonlinear anti-seismic steel device for the increasing the seismic capacity of multi-storey reinforced concrete frames. *Struct. Des. Tall Spec. Build.* **2012**, *21*, 750–763. [CrossRef]
71. Papadopoulos, P.K.; Salonikios, T.N.; Dimitrakis, S.; Papadopoulos, A. Experimental investigation of a new steel friction device with link element foe seismic strengthening of structures. *Struct. Eng. Mech.* **2013**, *46*, 487–504. [CrossRef]
72. Titirla, M.; Katakalos, K.; Zuccaro, G.; Frabbrocino, F. On the mechanical response of an innovative energy dissipation device. *Ing. Sismica-Int. J. Earthq. Eng.* **2017**, *2*, 126–138.
73. Titirla, M.; Papadopoulos, P.; Doudoumis, I. Finite Element modelling of an innovative passive energy dissipation device for seismic hazard mitigation. *Eng. Struct.* **2018**, *68*, 218–228. [CrossRef]
74. Titirla, M.; Katakalos, K. Evaluation of an innovative passive mitigation device through experimental and numerical investigation. In Proceedings of the 6th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, COMPDYN 2017, Rhodes Island, Greece, 15–17 June 2017.
75. Titirla, M.; Papadopoulos, P.K. Finite element investigation of a new seismic energy absorption device through simoultaneously yield and friction. In Proceedings of the 5th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, COMPDYN 2015, Hersonissos, Crete, Greece, 25–27 May 2015.
76. Mualla, I.H.; Belev, B. Performance of steel frames with a new friction damper device under earthquake excitation. *Eng. Struct.* **2002**, *24*, 365–371. [CrossRef]
77. Mualla, I.H.; Jakupsson, E.D.; Nielsen, L.O. Structural behaviour of 5000 kN damper. In Proceedings of the 14th European Conference on Earthquake Engineering 2010, Ohrid, Republic of Macedonia, 30 August–September 2010.
78. Mualla, I.H. Experimental Evaluation of a New Friction Damper Device. In Proceedings of the 12th World Conference on Earthquake Engineering, Auckland, New Zealand, 30 January–4 February 2000.
79. Aiken, I.D.; Kelly, J.M.; Pall, A.S. Seismic Response of a Nine-Story Steel Frame with Friction Damped Cross-Bracing. In *9 WCEE: Ninth World Conference on Earthquake Engineering: 1988, Tokyo-Kyoto, Japan, Proceedings Vol. 2*; Japan Association for Earthquake Disaster Prevention: Tokyo, Japan, 1989.
80. Aiken, I.D.; Kelly, J.M. *Earthquake Simulator Testing and Analytical Studies of Two Energy-Absorbing Systems for Multistory Structures*; Report UCB/EERC-90/03; University of California: Berkeley, CA, USA, 1990.
81. Aiken, I.D.; Nims, D.K.; Kelly, J.M. Comparative Study of Four Passive Energy Dissipation Systems. *Bull. N. Z. Nat. Soc. Earthq. Eng.* **1992**, *25*, 3. [CrossRef]
82. Fitzgerald, T.F.; Anagnos, T.; Goodson, M.; Zsutty, T. Slotted bolted connections in aseismic design for concentrically braced connections. *Earthq. Spectra* **1989**, *5*, 383–391. [CrossRef]
83. Venuti, W.J. *Energy Absorption of High Strength Bolted Connections*; Department of Civil Engineering, San Jose State University: San Jose, CA, USA, 1976.
84. Roik, K.; Dorka, U.; Dechent, P. Vibration control of structures under earthquake loading by three-stage friction-grip elements. *Earthq. Eng. Struct. Dyn.* **1988**, *16*, 501–521. [CrossRef]
85. Lukkunaprasit, P.; Wanitkorkul, A.; Filiatrault, A. Performance deterioration of slotted bolted connection due to bolt impact. In Proceedings of the 13th World Conference on Earthquake Engineering: Conference Proceedings, Vancouver, BC, Canada, 1–6 August 2004.
86. Nikoukalam, M.T.; Mirghaderi, S.R.; Dolatshahi, K.M. Analytical study of moment-resisting frames retrofitted with shear slotted bolted connection. *J. Struct. Eng.* **2015**, *141*, 4015019. [CrossRef]
87. Shahini, M.; Sabbagh, A.B.; Davidson, P.; Mirghaderi, R. Development of cold-formed steel moment-resisting connections with bolting friction-slip mechanism for seismic applications. *Thin-Walled Struct.* **2019**, *141*, 217–231. [CrossRef]
88. Ormeno, M.; Geddes, M.; Larkin, T.; Chouw, N. Experimental study of slip-friction connectors for controlling the maximum seismic demand on a liquid storage tank. *Eng. Struct.* **2015**, *103*, 134–146. [CrossRef]
89. Wang, Y.B.; Wang, Y.-Z.; Chen, K.; Li, G.-Q. Slip factor between shot blasted mild steel and high strength steel surfaces. *J. Constr. Steel Res.* **2020**, *168*, 105969. [CrossRef]
90. Grigorian, C.E.; Yang, T.-S.; Popov, E.P. Slotted bolted connection energy dissipators. *Earthq. Spectra* **1993**, *9*, 491–504. [CrossRef]
91. Constantinou, M.C.; Reinhorn, A.M.; Mokha, A.; Watson, R. Displacement control device for base-isolated bridges. *Earthq. Spectra* **1991**, *7*, 179–200. [CrossRef]

92. Stefancu, A.I.; Budescu, M.; Paulet-Crainiceanu, F.; Guerreiro, L.M.C. Numerical and experimental analysis of a passive multilayer friction damper for seismic energy dissipation. In Proceedings of the 15th World Conference on Earthquake Engineering, Lisboan, Portugal, 24–28 September 2012.
93. Nims, D.K.; Richter, P.J.; Bachman, R.E. The use of the energy dissipating restraint for seismic hazard mitigation. *Earthq. Spectra* **1993**, *9*, 467–489. [CrossRef]
94. Richter, P.J.; Nims, D.K.; Kelly, J.M.; Kallenbach, R.M. The EDR Energy Dissipating Restraint, A New Device for Mitigation of Seismic Effects. In Proceedings of the 1990 Structural Engineers Association of California (SEAOC) Convention, Lake Tahoe, NV, USA, 5–8 November 1990.
95. Shrikant, M.; Praveen, J.V. Strengthening of R.C Framed Structure Using Energy Dissipating Devices. *Int. J. Recent Res. Civ. Mech. Eng.* **2015**, *2*, 303–308.
96. Nims, D.K.; Inaudi, J.A.; Richter, P.J.; Kelly, J.M. Application of the Energy Dissipating Restraint to Buildings. In Proceedings of the ATC-17-1 Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control, San Francisco, CA, USA, 11–12 March 1993; pp. 627–638.
97. Zhou, X.; Peng, L. A new type of damper with friction-variable characteristics. *Earthq. Eng. Eng. Vib.* **2009**, *8*, 507–520. [CrossRef]
98. Kim, Y.C.; Lee, H.W.; Hu, J.W. Experimental performance evaluation of elastic friction damper. *Case Stud. Constr. Mater.* **2023**, *18*, e01823. [CrossRef]
99. Li, H.N.; Li, G.; Wang, S.Y. Study and application of metallic yielding energy dissipation devices in buildings. In Proceedings of the Tenth U.S. National Conference on Earthquake Engineering Frontiers of Earthquake Engineering, Anchorage, AK, USA, 21–25 July 2014.
100. Martinez-Romero, E. Experiences on the use of supplementary energy dissipators on building structures. *Earthq. Spectra* **1993**, *9*, 581–625. [CrossRef]
101. Kelly, J.M.; Skinner, R.I.; Heine, A.J. Mechanisms of energy absorption in special devices for use in earthquake resistant structures. *Bull. N. Z. Natl. Soc. Earthq. Eng.* **1972**, *5*, 63–88. [CrossRef]
102. Skinner, R.I.; Kelly, J.M.; Heine, A.J. Hysteretic dampers for earthquake-resistant structures. *Earthq. Eng. Struct. Dyn.* **1974**, *3*, 287–296. [CrossRef]
103. Kobori, T.; Miura, Y.; Fukuzawa, E.; Yamada, T.; Arita, T.; Takenake, Y.; Miyagawa, N.; Tanaka, N.; Fukumoto, T. Development and application of hysteresis steel dampers. In Proceedings of the Tenth World Conference on Earthquake Engineering, Madrid, Spain, 19–24 July 1992; pp. 2341–2346.
104. Nakashima, M.; Saburi, K.; Tsuji, B. Energy input and dissipation behaviour of structures with hysteretic dampers. *Earthq. Eng. Struct. Dyn.* **1996**, *25*, 483–496. [CrossRef]
105. Ciampi, V. Use of energy dissipating devices, based on yielding of steel, for earthquake protection of structures. In Proceedings of the International Meeting on Earthquake Protection of Buildings, Ancona, Italy, 22 April 1991; pp. 41–58.
106. Tyler, R.G. Further Notes on Steel Energy-Absorbing Element for Braced Frameworks. *Bull. N. Z. Natl. Soc. Earthq. Eng.* **1985**, *18*, 270–279. [CrossRef]
107. Whittaker, A.S.; Bertero, V.V.; Alonso, J.L.; Thompson, C.L. *Earthquake Simulator Testing of Steel Plate Added Damping and Stiffness Elements*; Report No. UCB/EERC 89/02; University of California: Berkley, CA, USA, 1989.
108. Whittaker, A.S.; Bertero, V.V.; Thompson, C.L.; Alonso, J.L. Seismic testing of steelplate energy dissipating devices. *Earthq. Spectra* **1991**, *7*, 563–604. [CrossRef]
109. Perry, C.; Fiero, E.; Sedarat, H.; Scholl, R. Seismic retrofit in san francisco using energy dissipation devices. *Earthq. Spectra* **1993**, *9*, 559–579. [CrossRef]
110. Tsai, K.; Chen, H.; Hong, C.; Su, Y. Design of steel triangular plate energy absorbers for seismic-resistant construction. *Earthq. Spectra* **1993**, *9*, 505–528. [CrossRef]
111. Teruna, D.R.; Majid, T.A.; Budiono, B. Experimental Study of Hysteretic Steel Damper for Energy Dissipation Capacity. *Adv. Civ. Eng.* **2015**. [CrossRef]
112. Chan, R.W.K.; Albermani, F. Experimental study of steel slit damper for passive energy dissipation. *Eng. Struct.* **2008**, *30*, 1058–1066. [CrossRef]
113. Oh, S.H.; Kim, Y.J.; Ryuet, H.S. Seismic performance of steel structures with slit dampers. *Eng. Struct.* **2009**, *31*, 1997–2008. [CrossRef]
114. Bagheri, S.; Barghian, M.; Saieri, F.; Farzinfar, A. U-shaped metallic-yielding damper in building structures: Seismic behavior and comparison with a friction damper. *Structures* **2015**, *3*, 163–171. [CrossRef]
115. Ebadi Jamkhaneh, M.; Ebrahimi, A.H.; Shokri Amiri, M. Experimental and Numerical Investigation of Steel Moment Resisting Frame with U-Shaped Metallic Yielding Damper. *Int. J. Steel Struct.* **2019**, *19*, 806–818. [CrossRef]
116. Zhang, J.; Fang, C.; Yam, M.; Lin, C. Fe-Mn-Si alloy U-shaped dampers with extraordinary low-cycle fatigue resistance. *Eng. Struct.* **2022**, *264*, 114475. [CrossRef]
117. Oh, S.H.; Kim, Y.J.; Moon, T.S. Cyclic performance of existing moment connections in steel retrofitted with a reduced beam section and bottom flange reinforcements. *Canad. J. Civil. Eng.* **2007**, *34*, 199–209. [CrossRef]
118. Sahoo, D.R.; Singhal, T.; Taraithia, S.S.; Saini, A. Cyclic behavior of shear-and-flexural yielding metallic dampers. *J. Constr. Steel Res.* **2015**, *114*, 247–257. [CrossRef]

119. Wang, W.; Fang, C.; Chen, Y.; Wang, M. Seismic performance of steel H-beam to SHS column cast modular panel zone joints. *Eng. Struct.* **2016**, *117*, 145–160. [CrossRef]
120. Koetaka, Y.; Chusilp, P.; Zhang, Z.; Ando, M.; Suita, K.; Inoue, K.; Uno, N. Mechanical property of beam-to-column moment connection with hysteretic dampers for column weak axis. *Eng. Struct.* **2005**, *27*, 109–117. [CrossRef]
121. Zhu, X.; Wang, W.; Li, W.; Zhang, Q.; Du, Y.; Yin, Y. Experimental and numerical study of X-type energy dissipation device under impact loads. *J. Constr. Steel Res.* **2023**, *204*, 107876. [CrossRef]
122. Nuzzo, I.; Losanno, D.; Caterino, N.; Serino, G.; Bozzo, L.M. Experimental and analytical characterization of steel shear links for seismic energy dissipation. *Eng. Struct.* **2018**, *172*, 405–418. [CrossRef]
123. Cheraghi, A.; Zahrai, S.M. Innovative multi-level control with concentric pipes along brace to reduce seismic response of steel frames. *J. Constr. Steel Res.* **2016**, *127*, 120–135. [CrossRef]
124. Zahrai, S.M.; Cheraghi, A. Reducing seismic vibrations of typical steel buildings using new multi-level yielding pipe damper. *Int. J. Steel Struct.* **2017**, *17*, 983–998. [CrossRef]
125. Ghandil, M.; Riahi, H.T.; Behnamfar, F. Introduction of a new metallic-yielding pistonic damper for seismic control of structures. *J. Constr. Steel Res.* **2022**, *194*, 107299. [CrossRef]
126. Cheraghi, A.; Zahrai, S.M. Cyclic Testing of Multi-Level Pipe in Pipe Damper. *J. Earthq. Eng.* **2017**, *23*, 1695–1718. [CrossRef]
127. Chen, Y.; Ye, D.; Zhang, L. Analytical development and experimental investigation of the casting multi-plate damper (CMPD). *Eng. Struct.* **2022**, *250*, 113402. [CrossRef]
128. Aghlara, R.; Tahir, M. A passive metallic damper with replaceable steel bar components for earthquake protection of structures. *Eng. Struct.* **2018**, *159*, 185–197. [CrossRef]
129. Thongchom, C.; Bahrami, A.; Ghamari, A.; Benjeddou, O. Performance Improvement of Innovative Shear Damper Using Diagonal Stiffeners for Concentrically Braced Frame Systems. *Buildings* **2022**, *12*, 1794. [CrossRef]
130. Thongchom, C.; Mirzai, N.; Chang, B.; Ghamari, A. Improving the CBF brace's behavior using I-shaped dampers, numerical and experimental study. *J. Constr. Steel Res.* **2022**, *197*, 107482. [CrossRef]
131. Watanabe, A.; Hitomi, Y.; Saeki, E.; Wada, A.; Fujimoto, M. Properties of brace encased in buckling-restraining concrete and steel tube. In Proceedings of the Ninth World Conference on Earthquqke Engineering, Tokyo-Kyoto, Japan, 2–9 August 1988.
132. Clark, P.W.; Aiken, I.D.; Tajirian, F.; Kasai, K.; Ko, E.; Kimura, I. Design procedures for buildings incorporating hysteretic damping devices. In Proceedings of the International Post-SmiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures, Cheju, Republic of Korea, 23–25 August 1999.
133. Wada, A.; Huang, Y.H.; Iwata, M. Passive damping technology for buildings in Japan. *Prog. Struct. Engng Mater.* **1999**, *2*, 335–350. [CrossRef]
134. Xie, Q. State of arte of buckling-restrained braces in Asia. *J. Constr. Steel Res.* **2005**, *61*, 727–748. [CrossRef]
135. Fujimoto, M.; Wada, A.; Saeki, E.; Takeuchi, T.; Watanabe, A. Development of unbonded brace. *Q. Column* **1990**, *115*, 91–96.
136. Black, C.; Makris, N.; Aiken, I.D. Component testing, seismic evaluation and characterization of buckling restrained braces. *J. Struct. Eng.* **2004**, *130*, 880–894. [CrossRef]
137. Black, C.; Makris, N.; Aiken, I.D. *Component Testing, Stability Analysis and Characterization of Buckling-Restrained Unbonded Braces (TM)*; PEER Report 2002/08; Pacific Earthquake Engineering Research Center, College of Engineering, University of California: Berkeley, CA, USA, 2002.
138. Zhao, J.; Wu, B.; Ou, J. A novel type of angle steel buckling restrained brace: Cyclic behavior and failure mechanism. *Earthq. Eng. Struct. Dyn.* **2011**, *40*, 1083–1102. [CrossRef]
139. Hao, X.-Y.; Li, H.-N.; Li, G.; Makino, T. Experimental investigation of steel structure with innovative H-type steel unbuckling braces. *Struct. Des. Tall Spec. Build.* **2014**, *24*, 421–439. [CrossRef]
140. Bruschi, E.; Quaglini, V.; Zoccolini, L. Seismic Upgrade of Steel Frame Buildings by Using Damped Braces. *Appl. Sci.* **2023**, *13*, 2063. [CrossRef]
141. Chou, C.-C.; Chen, Y.-C.; Pham, D.H.; Truong, V.M. Steel braced frames with dual-core SCBs and sandwiched BRBs: Mechanics, modeling and seismic demands. *Eng. Struct.* **2014**, *72*, 26–40. [CrossRef]
142. Chou, C.-C.; Chen, Y.-C. Development of steel dual-core self-centering braces: Quasi-static cyclic tests and finite element analyses. *Earthq. Spectra* **2015**, *31*, 247–272. [CrossRef]
143. Chou, C.-C.; Chung, P.-T.; Cheng, Y.-T. Experimental evaluation of large-scale dual core selfcentering braces and sandwiched buckling-restrained braces. *Eng. Struct.* **2016**, *116*, 12–25. [CrossRef]
144. Benavent-Climent, A. A brace-type seismic damper based on yielding the walls of hollow structural sections. *Eng. Struct.* **2010**, *32*, 1113–1122. [CrossRef]
145. González-Sanz, G.; Escolano-Margarit, D.; Benavent-Climent, A. A New Stainless-Steel Tube-in-Tube Damper for Seismic Protection of Structures. *Appl. Sci.* **2020**, *10*, 1410. [CrossRef]
146. Benavent-Climent, A.; Gale-Lamuela, D.; Donaire-Avila, J. Energy capacity and seismic performance of RC waffle-flat plate structures under two components of far-field ground motions: Shake table tests. *Earthq. Eng. Struct. Dyn.* **2019**, *48*, 949–969. [CrossRef]
147. Usami, T.; Lu, Z.; Ge, H. A seismic upgrading method for steel arch bridges using buckling-restrained braces. *Earthq. Eng. Struct. Dyn.* **2004**, *34*, 471–496. [CrossRef]

148. Hoveidae, N.; Rafezy, B. Overall buckling behavior of all-steel buckling restrained braces. *J. Constr. Steel Res.* **2012**, *79*, 151–158. [CrossRef]
149. Nakamura, H.; Maeda, Y.; Sasaki, T.; Wada, A.; Takeuchi, T.; Nakata, Y.; Iwata, M. Fatigue properties of practical-scale unbonded braces. *Nippon Steel Tech. Rep.* **2000**, *82*, 51–57.
150. Fahnestock, L.A.; Sause, R.; Ricles, J.M. *Analytical and Large-Scale Experimental Studies of Earthquake Resistant Buckling-Restrained Braced Frame Systems*; Report ATLSS 06-01; Engineering Research Center for Advanced Technology for Large Structural Systems, Lehigh University: Bethlehem, PA, USA, 2006.
151. Iwata, M.; Kato, T.; Wada, A. Buckling-Restrained Braces as Hysteretic Dampers. In *Behavior of Steel Structures in Seismic Areas, Proceedings of the Third International Conference STESSA 2000, Montreal, QC, Canada, 21–24 August 2000*; Mazzolani, F., Tremblay, R., Eds.; CRC Press: Boca Raton, FL, USA, 2000.
152. Merritt, S.; Uang, C.M.; Benzoni, G. *Subassemblage Testing of CoreBrace Buckling-Restrained Braces*; Report No. TR-2003/01; University of California: San Diego, CA, USA, 2003.
153. Tsai, K.C.; Lin, S.L. *A Study of All Metal and Detachable Buckling Restrained Braces*; Report No. CEER/R92-08; Center for Earthquake Engineering Research, National Taiwan University: Taipei City, Taiwan, 2003.
154. Cao, X.-Y.; Feng, D.-C.; Wu, G.; Wang, Z. Experimental and theoretical investigations of the existing reinforced concrete frames retrofitted with the novel external SC-PBSPC BRBF sub-structures. *Eng. Struct.* **2022**, *256*, 113982. [CrossRef]
155. Cao, X.-Y.; Feng, D.-C.; Wu, G.; Wang, Z. Parametric investigation of the assembled bolt-connected buckling-restrained brace and performance evaluation of its application into structural retrofit. *J. Build. Eng.* **2022**, *48*, 103988. [CrossRef]
156. Robinson, W.H.; Greenbank, L.R. An extrusion energy absorber suitable for the protection of structures during an earthquake. *Earthq. Eng. Struct. Dyn.* **1976**, *4*, 251–259. [CrossRef]
157. Skinner, R.I.; Tyler, R.G.; Heine, A.J.; Robinson, W.H. Hysteretic dampers for the protection of structures from earthquakes. *Bull. N. Z. Natl. Soc. Earthq. Eng.* **1980**, *13*, 22–36. [CrossRef]
158. Pettorruso, C.; Bruschi, E.; Quaglini, V. Supplemental energy dissipation with prestressed Lead Extrusion Dampers (P-LED): Experiments and modeling. In Proceedings of the COMPDYN 2021, the 8th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Athens, Greece, 28–30 June 2021.
159. Quaglini, V.; Pettorruso, C.; Bruschi, E. Experimental and numerical assessment of prestressed lead extrusion dampers. *Int. J. Earthq. Eng.* **2021**, *38*, 46–69.
160. Quaglini, V.; Pettorruso, C.; Bruschi, E. Design and Experimental Assessment of a Prestressed Lead Damper with Straight Shaft for Seismic Protection of Structures. *Geosciences* **2022**, *12*, 182. [CrossRef]
161. Cousins, W.J.; Robinson, W.H.; McVerry, G.H. Recent developments in devices for seismic isolation. *Bull. N. Z. Natl. Soc. Earthq. Eng.* **1992**, *25*, 167–174. [CrossRef]
162. Soydan, C.; Yüksel, E.; İrtem, E. The behavior of a steel connection equipped with the lead extrusion damper. *Adv. Struct. Eng.* **2014**, *17*, 25–40. [CrossRef]
163. Soydan, C.; Yüksel, E.; İrtem, E. Retrofitting of pinned beam–column connections in RC precast frames using lead extrusion dampers. *Bull. Earthq. Eng.* **2018**, *16*, 1273–1292. [CrossRef]
164. Parulekar, Y.M.; Reddy, G.R.; Vaze, K.K.; Kushwaha, H.S. Lead extrusion dampers for reducing seismic response of coolant channel assembly. *Nucl. Eng. Des.* **2004**, *227*, 175–183. [CrossRef]
165. Patel, C.C. Response control of adjoining structures interconnected with Lead damper. *Innov. Infrastruct. Solut.* **2021**, *7*, 58. [CrossRef]
166. Alipour, A.; Kadkhodaei, M.; Safaei, M. Design, analysis, and manufacture of a tension–compression self-centering damper based on energy dissipation of pre-stretched superelastic shape memory alloy wires. *J. Intell. Mater. Syst. Struct.* **2017**, *28*, 2129–2139. [CrossRef]
167. Ma, H.; Xu, J.; Li, S. An Experimental Study of an SMA-Based Self-Centering Damper. *Int. J. Steel Struct.* **2022**, *22*, 610–621. [CrossRef]
168. Qiu, C.; Wang, H.; Liu, J.; Qi, J.; Wang, J. Experimental tests and finite element simulations of a new SMA-steel damper. *Smart Mater. Struct.* **2020**, *29*, 035016. [CrossRef]
169. Sheikhi, J.; Fathi, M.; Rahnavard, R.; Napolitano, R. Numerical analysis of natural rubber bearing equipped with steel and shape memory alloys dampers. *Structures* **2021**, *32*, 1839–1855. [CrossRef]
170. Qiu, C.; Liu, J.; Du, X. Cyclic behavior of SMA slip friction damper. *Eng. Struct.* **2022**, *250*, 113407. [CrossRef]
171. Seo, J.; Kim, Y.C.; Hu, J.W. Pilot Study for Investigating the Cyclic Behavior of Slit Damper Systems with Recentering Shape Memory Alloy (SMA) Bending Bars Used for Seismic Restrainers. *Appl. Sci.* **2015**, *5*, 187–208. [CrossRef]
172. Ocel, J.M.; DesRoches, R.; Leon, R.T.; Hess, W.G.; Krumme, R.; Hayes, J.R.; Sweeney, S. Steel beam-column connections using shape memory alloys. *J. Struct. Eng.* **2004**, *130*, 732–740. [CrossRef]
173. Makris, N.; Constantinou, M.C. Spring-Viscous Damper Systems for Combined Seismic and Vibration Isolation. *Earthq. Eng. Struct. Dyn.* **1992**, *21*, 649–664. [CrossRef]
174. Makris, N.; Deoskar, H.S. Prediction of Observed Response of Base- Isolated Structure. *J. Struct. Eng.* **1996**, *122*, 485–493. [CrossRef]
175. Taylor, D.P. Damper retrofit of the london millennium footbridge-A case study in biodynamic design. In Proceedings of the 73d Shock and Vibration Symposium, Newport, RI, USA, 18–22 November 2002.

176. Constantinou, M.C.; Symans, M.D. Experimental study of seismic response of buildings with supplemental fluid dampers. *Earthquake Eng. Struct. Dynam. Struct. Des. Tall Build.* **1993**, *2*, 93–132. [CrossRef]
177. Gluck, N.; Reinhorn, A.M.; Gluck, J.; Levy, R. Design of supplemental dampers for control of structures. *J. Struct. Eng.* **1996**, *122*, 1394–1399. [CrossRef]
178. Fu, Y.; Kasai, K. Study of frames using viscoelastic and viscous dampers. *J. Struct. Eng.* **1998**, *124*, 513–522. [CrossRef]
179. Sadek, F.; Mohraz, B.; Riley, M.A. Linear procedures for structures with velocity dependent dampers. *J. Struct. Eng.* **2000**, *126*, 887–895. [CrossRef]
180. Li, M.; Li, B. Simplified seismic design and analysis of structures with nonlinear fluid viscous dampers. In Proceedings of the 2011 Second International Conference on Mechanic Automation and Control Engineering, Hohhot, China, 15–17 July 2011. [CrossRef]
181. Mahmoodi, P. Structural Dampers. *J. Struct. Div.* **1969**, *95*, 1661–1672. [CrossRef]
182. Constantinou, M.C.; Symans, M.D. Seismic response of structures with supplemental damping. *Struct. Des. Tall Build.* **1993**, *2*, 77–92. [CrossRef]
183. Rashid, A.; Nicolescu, C.M. Design and implementation of tuned viscoelastic dampers for vibration control in milling. *Int. J. Mach. Tools Manuf.* **2008**, *48*, 1036–1053. [CrossRef]
184. Xu, Z.D. Earthquake mitigation study on viscoelastic dampers for reinforced concrete structures. *J. Vib. Control* **2007**, *13*, 29–45. [CrossRef]
185. Tsai, C.S.; Lee, H.H. Applications of viscoelastic dampers to high-rise buildings. *J. Struct. Eng.* **1993**, *120*, 1222–1233. [CrossRef]
186. Montgomery, M.; Christopoulos, C. Experimental Validation of Viscoelastic Coupling Dampers for Enhanced Dynamic Performance of High-Rise Buildings. *J. Struct. Eng.* **2014**, *141*, 04014145. [CrossRef]
187. Christopoulos, C.; Montgomery, M. Viscoelastic coupling dampers (VCDs) for enhanced wind and seismic performance of high-rise buildings. *Earthq. Eng. Struct. Dyn.* **2013**, *42*, 2217–2233. [CrossRef]
188. Nasab, M.; Guo, Y.-Q.; Kim, J. Seismic retrofit of a soft first-story building using viscoelastic dampers considering inherent uncertainties. *J. Build. Eng.* **2022**, *47*, 103866. [CrossRef]
189. Keel, C.J.; Mahmoodi, P. Designing of Viscoelastic Dampers for Columbia Center Building. In *Building Motion in Wind*; American Society of Civil Engineers: New York, NY, USA, 1986; pp. 66–82.
190. Sweeney, S.K.; Michael, R. Collaborative product realization of an innovative structural damper and application. In Proceedings of the ASME 2006 International Mechanical Engineering Congress and Exposition, Chicago, IL, USA, 5–10 November 2006.
191. Valente, M.; Milani, G. Alternative retrofitting strategies to prevent the failure of an under-designed reinforced concrete frame. *Eng. Fail. Anal.* **2018**, *89*, 271–285. [CrossRef]
192. Skilling, J.B.; Tschanz, T.; Isyumov, N.; Loh, P.; Davenport, A.G. Experimental Studies, Structural Design and Full-scale Measurements for the Columbia Sea First Center. In *Building Motion in Wind*; American Society of Civil Engineers: New York, NY, USA, 1986; pp. 1–22.
193. Elwardany, H.; Jankowski, R.; Seleemah, A. Mitigating the seismic pounding of multi-story buildings in series using linear and nonlinear fluid viscous dampers. *Archiv. Civ. Mech. Eng.* **2021**, *21*, 137. [CrossRef]
194. Arora, S. Optimization of bracing and viscous damper and comparison of fluid viscous damper and bracing system for stabilization of high rise building. *Int. J. Civ. Eng. Technol.* **2019**, *10*, 1978–1986.
195. Qiu, C.; Liu, J.; Teng, J.; Li, Z.; Du, X. Seismic performance evaluation of multi-story CBFs equipped with SMA-friction damping braces. *J. Intell. Mater. Syst. Struct.* **2021**, *32*, 1725–1743. [CrossRef]
196. Mrad, C.; Titirla, M.D.; Larbi, W. Comparison of Strengthening Solutions with Optimized Passive Energy Dissipation Systems in Symmetric Buildings. *Appl. Sci.* **2021**, *11*, 10103. [CrossRef]