RESEARCH ARTICLE

Development of a divergent fluid wall damper for framed structures subjected to dynamic loads

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Summary
This study developed a new adaptive design for a divergent fluid wall damper (DFWD). This design decreases the dynamic vibration in reinforced concrete (RC) structures subjected to dynamic forces caused by earthquakes, wind, tsunamis, and explosions. The DFWD comprises a tank connected to the lower floor that is filled with a fluid and a plate with fins located inside the tank connected to the upper floor. The DFWD uses a bypass system mechanism that circulates fluid inside the wall damper tank through a divergent pipe and controls the fluid pressure during vibration using a double-acting valve. To evaluate the performance of the DFWD in RC-frame structures, we fabricated and experimentally evaluated a prototype of the device based on a new adjustable design. Two RC frames, a bare frame and a frame with DFWD, were cast with the same geometric specifications. These frames were then examined in terms of the time history of applied displacement with a maximum amplitude of 40 mm under the same conditions. The valves in the design of the DFWD were adjustable, and the fully open valve condition was examined. The results indicated that the failure capacity of the frame was significantly improved compared to that of the bare frame as the DFWD absorbed more dynamic force. The ductility of the RC-frame structure equipped with the DFWD was improved by almost 17.8% compared to that of the bare frame.

KEYWORDS
damper device, earthquake, earthquake energy dissipation, fluid damper, viscous wall damper

1 | INTRODUCTION

Designing earthquake-resistant buildings is a key challenge for structural engineers. Over the past three decades, studies have been performed to improve the seismic design of structures, and different vibration control technologies have been used to achieve safe and economical designs. Energy dissipation devices have been used extensively as external devices to absorb and release dynamic loads in earthquake engineering.

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Over the past two decades, significant improvements have been achieved in earthquake engineering. Many new technologies associated with passive energy dissipation and control have been introduced and have reached considerable maturity.\cite{1-5} Christopoulos et al.\cite{3} conducted a comprehensive study regarding passive energy dissipation systems and base-isolated buildings. These energy dissipation systems improve the seismic performance of buildings by reducing the inelastic deformation demands on the primary lateral load resisting system and by reducing the drift, velocity, and acceleration demands on nonstructural elements. Hanson and Soong\cite{5} installed different types of energy dissipation systems in actual structures for retrofitting purposes or for strengthening new structures. Furthermore, design guidelines for structures with energy dissipation devices have been developed and incorporated into design codes.

For more than two decades, scientists have theoretically and experimentally investigated the possibility of using active, hybrid, and semi-active energy dissipation systems to improve passive approaches that improve structural responses to dynamic vibrations.\cite{6-9} Housner et al.\cite{6} researched semi-active control methods, such as magneto rheological devices, for reducing structural responses. They noted that semi-active devices are characterized by their ability to dynamically vary their properties with minimal power. Takewaki\cite{10} summarized several optimal methods for smart damper placement based on inverse problem approaches, optimal criteria-based design approaches, and optimal sensitivity approaches. Furthermore, using passive dissipation systems to decrease structural responses under strong ground motion has also been studied. Suleman et al.\cite{11} used several control algorithms to examine the performance of semi-active fluid dampers for decreasing dynamic vibration.

Viscous fluid dampers are among the most widely used types of passive energy dissipation devices worldwide because of their high damping capacities, stable mechanical properties over time, simple installation procedures, and competitive costs. Viscous dampers, which operate using fluid flow through orifices, are primarily cylindrical in shape; each damper is composed of a piston with several small orifices that can contain a variety of viscous materials. Constantinou and Symans\cite{12} considered several numerical studies that modeled the fluid viscous damper and experimentally evaluated the performance of a fluid viscous damper; in addition, they compared the viscous damper to other energy dissipation systems in terms of improving the seismic resistance of structures. Their results showed that fluid viscous dampers are able to decrease the drift story and shear story by 30% to 70% and by 40% to 70%, respectively. On the other hand, energy dissipation devices were found to be incapable of achieving comparable reductions. The reason for this difference is the approximately pure linear viscous behavior of the tested fluid dampers. Lee and Taylor\cite{13} investigated several experimental and numerical studies on buildings equipped with viscous dampers and proved that viscous dampers can improve the overall damping of buildings by up to 35%. Attard\cite{14} proposed an optimal viscous damper for reducing the interstory displacement of steel structures. Liang et al.\cite{15} proposed that viscous dampers are reusable after strong earthquakes, which helps to offset the higher costs of viscous dampers compared to other passive systems that must be replaced after an earthquake. Zare and Ahmadizadeh\cite{16} developed an alternative methodology using a pole assignment active control algorithm for the design of a viscous fluid passive control system to decrease both the displacement and the acceleration responses of structures. Ahmadizadeh\cite{17} compared the performance of hydraulic fluid dampers compared to that of semi-active control systems using numerical simulations. Rama et al.\cite{18} proposed a procedure for defining an efficient distribution of viscous fluid dampers in a building structure to increase the damping effectiveness.

Lavan\cite{19} presented an optimization formulation to overcome the costs related to both the topology and the sizes of the dampers as well as an associated methodology for its solution. In their approach, dampers with similar properties were optimally allocated by the algorithm; these dampers were taken as continuous variables that were determined using the optimization algorithm and were not a priori. Their objective function minimized the direct cost of manufacturing the dampers. Constraints were adopted to limit the interstory drifts of the peripheral frames, and the frames were evaluated under a suite of realistic ground motions. Lavan\cite{20} conducted several studies on the seismic retrofitting of threedimensional structures using viscous dampers and presented a formal optimization methodology for the seismic retrofitting design of three-dimensional irregular buildings that minimizes the cost function of the dampers. Furthermore, Lavan\cite{21} presented a method for the design of nonlinear structures equipped with viscous dampers to produce the desired levels of interstory drifts while decreasing the seismic forces. Designing an energy dissipating bracing system is more difficult for seismic retrofitting that involved for new structures because of the required optimization of the system properties, which includes the uncertainty in the structural and damping properties of the existing structure.\cite{22}

For the past 30 years, viscous wall dampers (VWDs) have been considered effective energy dissipation devices that improve the responses of structures exposed to earthquakes. Miyazaki and Mitsusaka\cite{23} developed VWDs as a form of passive vibration control and proved that VWDs can improve the overall damping of structures by 5% to >20%. Arima et al.\cite{24} established VWD design formulas by conducting experimental tests that applied large dampers to actual structures. Reinhorn and Li\cite{25} evaluated the efficiency of VWDs as retrofitting devices by experimentally analyzing
a three-story model that was damaged in a previous test; their test results showed that VWDs can reduce the lateral drifts and deformations of structures by approximately 85%. Yeung and Pan\cite{26,27} experimentally assessed the performance of a VWD under a wind load at various conditions. Karunarathne\cite{28} evaluated the performance of VWDs with different types of liquids and confirmed that a high fluid viscosity results in a higher damping percentage. Lu et al.\cite{29} assessed the efficiency of VWDs in reinforced concrete (RC)-framed structures through numerical analysis and experimental tests; their results revealed that VWDs significantly improve the overall damping of RC structures. Sasaki et al.\cite{30} established the damping force formulas of VWDs in small and large earthquakes based on experimental tests with small and large dynamic vibrations. Hejazi et al.\cite{31} developed an analytical model of VWDs for RC-framed structures. Newell et al.\cite{32} assessed the seismic performance of VWDs using experiments and nonlinear response history analysis.

Previous studies have rarely improved the design of VWDs to address the drawbacks of the current technologies. Therefore, this study proposes a new adaptive design for a wall damper that functions via a bypass system mechanism. The design of this divergent fluid wall damper (DFWD) can be adjusted by controlling the fluid pressure via pipes and double-acting valves. To evaluate the efficiency of the DFWD in RC-framed structures, we fabricated and experimentally examined a prototype model using a dynamic actuator.

2 | VISCOUS WALL DAMPER

A VWD comprises a rectangular steel tank connected to the lower beam or floor, a suspended inner steel plate connected to the upper beam, and a small gap between the tank and the suspended wall that is filled with highly viscous fluid (Figure 1). The interstory drift that occurs during dynamic vibration results the suspended inner steel plate moving in the viscous fluid (Figure 2). The viscous action caused by the viscous fluid between the plates results in the damping of dynamic vibrations; thus, this fluid helps resist interstory drift. Therefore, the dynamic response of a building can be decreased by dissipating the vibration energy through viscous action. A nontoxic, odorless, and transparent fluid with a viscosity of 90,000 poise is typically used for VWDs.

The high cost of the nontoxic, high- viscosity fluid limits the use of VWDs in structures. The viscous fluid used in wall dampers is difficult to obtain except in developed countries, such as the United States and Japan. Furthermore, the
current VWD design can only be adjusted by altering the design. However, these design modifications directly affect the price and size of the VWD. An actual VWD model with dimensions of 2 m × 2 m and a 2-mm gap between the plates requires 16 L of viscous fluid, and each liter costs 100 US dollars. This study develops an adjustable wall damper that does not require highly viscous fluid to improve and adapt the seismic performance based on the structural design.

3 | DEVELOPMENT OF THE DFWD

The new design for the DFWD (PI 2016700148) is developed based on a bypass system. In this system, a double-acting valve can be adjusted to control the fluid pressure and to dampen the dynamic vibrations. DFWDs can be used to reduce the structural damage of any type of frame structure (including steel, RC, and timber) subjected to dynamic loads caused by earthquakes, wind, and tsunamis. Due to its architectural flexibility, DFWDs can be used in retrofitting.

The DFWD includes a fixed rectangular tank that is attached to the lower beam and steel plates that divide the tank into several equal-sized parallel sections to improve the damper performance (Figure 3). A suspended T-wall is attached to the upper beam inside the tank. This T-wall undergoes horizontal movement inside the container (Figure 4a). Several fins are welded to the suspended T-wall to induce fluid circulation inside the tank and bypass pipes during vibration (Figure 4b). A lid seals the tank and maintains the fluid pressure inside the tank (Figure 5). Bypass pipes with double-acting valves are connected to each part of the tank to control the fluid pressure and to maintain fluid flow between the fins (Figure 6). A rectangular bonder tie is welded around the tank to serve as a stiffener to prevent the DFWD from undergoing out-of-plane buckling due to the high fluid pressure inside the tank (Figure 7). In this design, all of the steel plates and fin edges are covered with gaskets to generate smooth movement and to seal the different damper parts (Figure 8).

Interstory drift occurs as a result of dynamic vibration. These drifts lead to lateral movement of the suspended T-wall inside the tank. Furthermore, the fins allow fluid circulation throughout the bypass pipes. In the DFWD design, fluid circulation inside the damper can be controlled by different types of double-acting valves installed in the divergent pipes. Figures 9 and 10 show the isometric view and front view of the DFWD, respectively.

The DFWD design can be adjusted by controlling the valves and is easily customizable to the specific requirements of the structure. The design concept focuses on reducing the pressure drop of the fluid to absorb the vibration energy. Hence, any type of fluid with low viscosity that can easily circulate through the bypass pipes can be used in this device. Figure 11 illustrates the position of the DFWD inside the frame.

![Figure 3](image-url) Rectangular tank and steel plate
3.1 VWD versus DFWD

The improvement of the DFWD over the conventional VWD is the development of new technology to inhibit the dynamic vibration effect using a fluid bypass system. Although both the VWD and the DFWD act as wall dampers to dissipate horizontal vibration, they have several differences in terms of mechanisms and functionality, as described below:

1. The VWD mechanism is based on the action of a high viscosity fluid material; this action limits the performance and adjustability of the wall damper and increases the manufacturing cost. In contrast, the DFWD mechanism is
based on a bypass system that controls the fluid pressure, thereby allowing any type of fluid to be used in the DFWD.

2. The performance of the VWD can only be adjusted by changing the wall size, which increases the cost of the damper. In contrast, the performance of the DFWD can be adjusted through the double-acting valves to match the requirements. As the viscosity of fluid is dependent on temperature, increased temperature in the VWD during operation can directly decrease its functionality; however, temperature changes have no effect on the fluid pressure or the DFWD performance.

3. Fabricating a VWD requires special material and facilities that are available only in a few developed countries, such as the United States and Japan. However, the design of a DFWD does not require any specific materials, so a DFWD can be easily fabricated anywhere in the world at significantly lower costs.
EXPERIMENTAL EVALUATION OF THE PERFORMANCE OF A DFWD

A prototype DFWD was fabricated based on the proposed design and was then experimentally tested to evaluate its performance and behavior. Two concrete frames were designed based on the code (BS 8110-1:1997) and then cast to assess the performance of the DFWD for RC structures. Both RC frames were cast with the same geometric specifications and were then tested under the same conditions. The frame IDs are listed as follows:

1. Bare frame (RC-B)
2. Frame equipped with DFWD (RC-D)

4.1 DFWD prototype specifications

A prototype of the DFWD was tested experimentally to assess its performance. Figures 12–14 show photographs of the DFWD prototype. The actual model included a tank with a height of 1,500 mm, a length of 1,500 mm, and a width of 150 mm. The tank was divided into three equal parts with two rectangular steel plates on each side. A suspended T-wall with a height of 1,800 mm, a length of 1,400 mm, and a width of 8 mm was used. Six fins were fixed to the suspended T-wall, and the liquid was pushed inside the tank during vibration and movement. Twelve pipes with valves were welded...
to the tank in two series at a distance of 500 mm. Four sets of pipes were prepared with equal spacing for each of the three parts of the tank to divide the fluid pressure equally among the three sections. The total length of each set of pipes with valves was 450 mm from center to center. One inch double-acting valves connected to 2-in. 90° elbows with a
A converter were used to reduce and control the fluid pressure. A 5-mm gap was added at the bottom after attaching the suspended T-wall to the upper beam to prevent device failure and to fill the tank with hydraulic oil. All of the edges were covered with gaskets. A steel lid covered the tank to maintain the fluid pressure inside, and a rectangular border tie with a thickness of 50 mm was welded to the tank as a stiffener to prevent tank buckling. Normal hydraulic oil with low viscosity was used in this experiment.

**FIGURE 12** Tank

**FIGURE 13** Suspended T-wall
4.2 | RC frame test setup and procedure

A steel box was used to locate and attach the RC columns to the basement (Figure 15). The details of RC-B and RC-D are shown in Figures 16 and 17, respectively. The section size, frame height, and span length of both frames were equal. The height and free lengths of the concrete frames were 2,000 and 1,800 mm, respectively. The sections of the beams and columns were designed as squares with dimensions of 200 mm (Figure 16). For both the beams and columns, the concrete cover was assumed to be 25 mm thick. Four longitudinal bars with 14 and 20 mm diameters were used to reinforce the beams and columns, respectively. The yield strengths of the longitudinal reinforcements and plane steel bars were 460 and 250 MPa, respectively. The suspended T-wall of the DFWD was attached to the concrete beam via 10 connector bolts.
with a 20-mm diameter embedded in the beam. The concrete was then placed in a mold. The dynamic test for the concrete frames started at 0 mm and reached a displacement of 40 mm (Figure 18). Figures 19 and 20 illustrate the prototypes of the two concrete frames subjected to dynamic loads from their top right node.
5 | EXPERIMENTAL RESULTS AND DISCUSSION

The performance of the DFWD device was examined in the concrete frame structures subjected to displacement. The concrete frame with the DFWD was evaluated in terms of the time history of the displacement with maximum displacement amplitude of 40 mm; this maximum was selected because the movement of the suspended T-wall inside the...
container was limited to within the 50-mm gap. The RC-D model was tested under fully open-valve conditions. The performance of the DFWD can be adjusted by controlling the double-acting valves. The bare concrete frame and the frame with DFWD were compared in terms of the initial crack, force and displacement relations, skeleton curve, and energy dissipation.

5.1 Comparison of the experimental results

The deformations of the bare concrete frame and the frame with DFWD are illustrated in Figures 19 and 20. In the bare frame, the initial crack occurred when the load at the column–beam joint reached 29 kN because of lateral cyclic loads. In contrast, the initial crack in the frame equipped with DFWD appeared in the connection zone at a load of 36 kN. Most of the column sections cracked, and diagonal cracks appeared and propagated at the beam–column joints because of the lateral cyclic loads. For both frames, failure occurred in the column at the beam–column connection as illustrated in Figure 21a,b.

Figures 22 and 23 depict the force–displacement relations and the skeleton curves of the bare frame and the frame with DFWD, respectively. At 40 mm of lateral displacement, the maximum force capacity of the bare frame reached 39.01 kN; in contrast, the frame with DFWD resisted up to 49.09 kN of force at the same displacement. These results confirmed the performance of the DFWD: The frame equipped with DFWD dissipated almost 28% more force at 40 mm of lateral displacement when all the valves were open.

The damping coefficient of the frame with DFWD was 6.3%, which was calculated based on the area under the maximum force–displacement relation curve. In addition, the force–velocity relation of the frame with DFWD and the net force–velocity relation were obtained by subtracting the force of the bare frame force from that of the frame with DFWD, as illustrated in Figure 24.

![Figure 21](image1)

**FIGURE 21** Crack propagation and failure in the connection zone. DFWD = divergent fluid wall damper

![Figure 22](image2)

**FIGURE 22** Bare concrete frame (RC-B)
The results in Figure 24 prove that the force–velocity relationship is nonlinear for the frame with DFWD. However, the velocity exponential coefficient (power law, $\alpha$) is considered to be 1 for the damping force in the following equation:

$$F = c \cdot v^\alpha, \quad (\alpha = 1),$$

where $F$ represents the damping force, $C$ represents the damping coefficient, and $V$ represents the velocity developed between the maximum positive and negative displacements of the frame equipped with the DFWD.

Figure 25 compares the skeleton curves of the bare concrete frame and the frame equipped with the DFWD.

The results indicate that the overall capacity and ductility of the frame equipped with the DFWD were higher than those of the bare concrete frame. These results are applicable for the 100% open-valve condition. Therefore, the performance is expected to improve by closing all the valves because more fluid pressure will be absorbed and released by the double-acting valves at the middle of the bypass pipes.

**Figure 23** Concrete frame equipped with DFWD (RC-D)

**Figure 24** Force–velocity relation. DFWD = divergent fluid wall damper

**Figure 25** Comparison of the skeleton curves for the bare frame and the frame with divergent fluid wall damper (DFWD)
Table 1 compares the ductility of the frame equipped with the DFWD and the bare frame. The results indicate that the energy dissipation in the frame with the DFWD and open valves was approximately 17.8% better than that of the bare frame.

5.2 | Comparison of the experimental results with previous studies in laboratory and commercial scales

The comparison of the performance of developed fluid wall damper with past experiences in the laboratory and commercial scales of VWD is not feasible due to difference in the wall dimensions and implemented materials properties. However, the performance of DFWD has been compared to the past study on VWD that has been done by Lu et al.\cite{29} The dimension of tested VWD was 580 mm height, 420 mm length, and 180 mm width that is almost one third of the DFWD prototype size in this study. Several frequencies and corresponding displacements were used in order to evaluate the VWD performance in different conditions. The test results related to 9.8-mm displacement and 0.2-Hz frequency as resistance force versus relative displacement graph are showed in Figure 26a. Accordingly, the force–displacement relation of the DFWD with 9.8-mm displacement also depicted in Figure 26b. As it can be seen from the figures, the results indicated that VWD was able to absorb 3.5-kN force; in contrast, the DFWD resisted up to 7 kN force for the same displacement.

The Oiles Industry Co., Ltd. Company experimentally tested the efficiency of VWDs for the commercial purposes with various sizes (with widths ranging from 1,000 to 3,950 mm and heights ranging from 1,000 to 3,000 mm) for different values of frequency, displacement, and velocity.\cite{33} The VWD with dimension of almost 1.5 times larger than the DFWD prototype under displacement of ±40 mm was able to resist around 350 kN force at the frequency of 1.0 Hz and the velocity of 150 mm/s, whereas the DFWD is able to absorb 50-kN force in 40-mm/s velocity.

5.3 | Effects of different parameters on the DFWD performance

Several parameters affect the performance and force of the developed DFWD, as described below:

Fluid type: As shown in the literature, a direct relation exists between the viscosity of the fluid and the damping capacity of viscous dampers. Therefore, using a highly viscous fluid in the DFWD increases the damping inside the container; however, because the DFWD design is based on the pressure drop of the fluid through the bypass system, the most appropriate type of fluid is a low viscosity fluid, such as a hydraulic oil. Low viscosity fluids are cost-effective and can be easily found compared to the high viscosity fluids that are required for VWDs.

| Specimens                          | Area under the curve (kN.mm) | Difference (%) |
|------------------------------------|------------------------------|----------------|
| Bare frame                         | 2,405                        | ---            |
| DFWD (with fully open valves)      | 2,835                        | 17.8           |

Note. DFWD = divergent fluid wall damper; RC = reinforced concrete.

Since the BARE FRAME is considered as the benchmark and the other models have been compared to the bare frame, therefore, the hyphens are inserted for the difference of under the curve area for bare frame.

FIGURE 26 | The performance comparison of the divergent fluid wall damper (DFWD) with viscous wall damper (VWD)
Wall dimensions: Increasing the length of the container without increasing the number of sections inside the container does not affect the DFWD performance because the structure’s interstory drift is limited. Therefore, the horizontal movement of the vane inside the container that circulates the fluid from inside the wall to the pipes is limited as well. Alternatively, adding more sections inside the wall, which requires additional bypass systems (pipes and valves), improves the damper performance by increasing the pressure drop. In addition, increasing the height and the width of the wall increases the volume of fluid circulated inside the bypass system, thus increasing the pressure drop. However, there is a limitation on the flow capacity for the valves and bypass pipes.

Valve condition: The DFWD, which is a velocity-dependent device, was tested based on displacement control in the open-valve condition; thus, it is expected to generate greater force when the valves are closed to different degrees (30°, 60°, and 90°) and with higher velocity.

5.4 Effects of different setting of valve conditions

In order to show the effects of valve conditions on the DFWD performance, a 2D fluid simulation was conducted by midas-NFX software. Only one part of the tank and pipe has been considered for this conceptual simulation for simplicity as depicted in the Figure 27. According to the experimental test, the velocity was defined as 0.04 m/s for the simulation form right side of the fin as shown in the Figure 28 by blue arrows. The pipe diameter is 2 in. according to the prototype model and has been blocked at the middle by 30%, 60%, and 90% as valve action to evaluate the fluid behavior in different conditions of control valve.

Figures 28 and 29 demonstrate the simulation results for all the models in terms of pressure (N/mm²) and velocity (mm/s) and the maximum pressure and velocity with different setting of bypass pipe blockage by control valve are compared in Table 2.

As it can be seen from the results, the pressure in the tank as well as in the pipe is increasing by increase of blocking percentage of bypass pipe via the control valve that is led to generate higher resistant force for wall damper. In the first three models which are included the fully open pipe, pipe blockage by 30% and pipe blocked by 60% the maximum

![Image](https://via.placeholder.com/150)

**FIGURE 27** 2D simulation models
(a) Fully open pipe
(b) 30% blocked pipe
(c) 60% blocked pipe
(d) 90% blocked pipe

FIGURE 28  Fluid pressure simulation results

(a) Fully open pipe
(b) 30% blocked pipe
(c) 60% blocked pipe
(d) 90% blocked pipe

FIGURE 29  Fluid velocity simulation results

TABLE 2  Comparison of maximum fluid pressure and velocity

| Specimens | Maximum pressure (N/mm²) | Pressure difference (%) | Maximum velocity (mm/s) | Velocity difference (%) |
|-----------|--------------------------|-------------------------|-------------------------|------------------------|
| 0% blockage | 0.0143                   | —                       | 38.6671                 | —                      |
| 30% blockage | 0.0226                   | 58.04                   | 37.0082                 | −4.29                 |
| 60% blockage | 0.0292                   | 104.2                   | 37.4524                 | −3.14                 |
| 90% blockage | 0.1969                   | 1,276.92                | 642.4256                | 1,561.43              |
pressure occurred at the border of the tank and pipe due to the drop pressure since a high volume of fluid is enter and pass from a smaller path which is the pipe. Therefore, although the pipe is blocked with 30% and 60%, the maximum pressure is increased by 58.04% and 104.2%, respectively, in comparison to fully open condition.

On the other hand, for the 90% blocked pipe, the critical spot with the maximum pressure occurred exactly before the blockage plate because the path is only open for 10% and a higher drop pressure happens in behind valve. Thus, the maximum pressure increment is belonging to the pipe with 90% blockage condition that is 1,276.92%. Furthermore, the fluid velocity has the maximum rate in the tank for the first three models (fully open valve, 30%, and 60% valve close) similar to the fluid pressure, but it showed a small drop by −4.29% and −3.14% in compared to the fully open condition. However, although the bypass pipe was blocked by 90%, the velocity increased to 1,561.43% due to narrower path of pipe. Hence, as it was expected, although the valve is close as certain degree, higher drop pressure occurs in the tank and bypass pipe that result more dynamic force generated by fluid pressure during movement of fins.

6 | CONCLUSION

In this study, a new adaptive and adjustable design for DFWDs using a bypass system mechanism was developed to reduce the effect of dynamic vibrations in frame structures subjected to dynamic forces. The DFWD operates by circulating fluid through divergent pipes and controls the fluid pressure via double-acting valves. The DFWD design can be adjusted by manually controlling the double-acting valves for different situations. In contrast, a VWD can only be adjusted by changing the wall size, which is the main cause of increased cost. Unlike the VWD mechanism, which is based on the friction between the high viscosity fluid material and the inner plates (which is a temperature-dependent and expensive material), the DFWD controls the fluid pressure to absorb and dissipate dynamic vibrations. As a result, any type of low viscosity fluid can be used in a DFWD. Furthermore, fabricating the DFWD does not require any special materials or facilities, and they can be easily fabricated at a global scale, with a cost savings of up to 75% compared to other types of wall dampers. A prototype of the device was fabricated and experimentally tested to assess the performance of the DFWD in RC-frame structures. During the test, the efficiency of the DFWD was evaluated for a displacement amplitude of 40 mm. The test results indicated that the frame equipped with the DFWD absorbed and dissipated approximately 28% more force than the bare frame. In addition, the DFWD improved the ductility of the RC-frame structure by almost 17.8% compared to the bare frame. Calculating the area within the force–displacement curve and using the equivalent damping constant concept, the damping coefficient of the frame with the DFWD was 6.3% for the open-valve condition; this value is expected to increase although the valves are not completely open. The results revealed that the DFWD is effective for reducing seismic structural responses in RC-frame structures, even under open-valve conditions. The proposed design can be considered an appropriate alternative to earthquake energy dissipation systems for frame structures; the DFWD provides several advantages, including cost-effectiveness, adjustable design, and strong performance.

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