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ABSTRACT
In this paper, the experimental results of the new multi-stage damper and practical manufacturing details are presented. The proposed damper consists of a combination of nested pipes that could change dynamic behavior parameters like strength, stiffness and damping ratio. Cyclic quasi-static tests were performed on two samples. Results show suitable energy absorption, ductility and stable hysteresis curves in the specimens. Also, multi-level performance can dissipate energy in different input energy levels. Moreover, achieving high equivalent viscous damping ratios up to 38% is noticeable. The proposed device is light-weight and easily fabricated, demonstrating suitable cyclic performance to reduce the seismic vibrations.

1. Introduction

The low amount of inherent damping ratio of some structures has caused their poor seismic performance in past earthquakes. So, using different control methods to absorb the structural vibration and to achieve better seismic performance is inevitable. Passive and semi-active controls are among the suitable vibration control strategies that attracted several researchers such that many new tools and related calculation algorithms have been presented [Xu et al., 2003; 2004. Mehmet et al., 2014. Oliveira et al., 2015]. Simplicity, low cost, and ductile performance of passive control such as yielding dampers have been resulted in widespread applications to improve the seismic performance of structures. The scope of installing metallic energy-absorbing devices in a structure is to take advantage of the hysteretic behavior of metals to dissipate seismic input energy of a structure like fuses avoiding inelastic behavior in the other main members.

Suzuki et al. [2005] conducted studies on the behavior of U-shaped steel damper. The laboratory results showed a ductile behavior with high energy dissipation capacity. Ahmady Jazany et al. [2010] proposed new circular jagged plates as hysteretic damper. The stable hysteresis curves showed appropriate cyclic behavior of new dampers. In another study, Franco et al. [2010] suggested new yielding damper based on plastic properties of metals under torsional stresses. This device consists of a pipe with various diameters and torsional movements. Buckling prevention and high fatigue strength are its advantages.

Steel pipes are widely used to improve the seismic behavior of Concentrically Braced Frames, CBFs. Kafi [2009] conducted research on the effects of hollow steel tube to
improve the seismic behavior of CBFs. The numerical and experimental results showed main influence on the frame ductility and delay in brace buckling.

Maleki and Bagheri [2010] suggested hollow steel pipes unfilled and filled with concrete to prove the possibility of their using as hysteretic dampers under shear stresses. Their results showed that the stiffness and strength of the pipe increased linearly with increasing the length and nonlinearly with increasing the thickness and reducing the diameter. Steel pipes filled with concrete showed no ductile behavior caused by concrete failure while hollow steel pipes had stable hysteretic behavior and high equivalent viscous damping ratios. Maleki and Mahjoubi [2013] proposed dual pipe system based on using pipe bending capacity. This damper consisted of two pipes, welded to the upper part of chevron or diagonal bracing or the beam to column connections under the lateral loading to increase energy dissipation. The results of the numerical nonlinear static analysis and laboratory tests on four samples indicated stable hysteresis curves with a significant increase in ductility and energy dissipation. Also, another sample of such dampers consisting of two nested pipes was proposed [Maleki and Mahjoubi, 2014]. The space between the external and internal pipes was full of metals such as lead and zinc. The damper energy dissipation mechanism was based on plastic deformations of the concentric pipes, metal core, and internal friction between the internal and external pipes. The results of laboratory tests on six samples showed high damping ratios and stable hysteretic behaviors. The numerical modeling was also followed to determine the optimum size of the damper and design procedure. In addition, honeycomb damper and slit damper are other metallic dampers that take advantage of the in-plane shear-flexural yielding of steel plates [Kobori et al., 1996, Chan and Albermani, 2008]. Also, shear-panel damper dissipates energy using the in-plane shear yielding of stiffened steel plates [Nakashima et al., 1994].

Multilevel vibration control is one of the new methods that attracted the attention of researchers in the last two decades. Using a variable stiffness device or combining several control systems with various strength and stiffness is the philosophy of these control systems which result desirable energy dissipation in different earthquake intensity levels.

According to the first viewpoint, Fateh et al. [2016a] proposed a new Variable Stiffness Bracing (VSB) system with four nonlinear steel springs leading to nonlinear and variable stiffness capacity at different frame displacements. The main specification of the new system is its large nonlinear stiffness range that allows the springs to be used for different types of structures. Their results revealed that the VSB spring geometry, especially the horizontal-to-vertical aspect ratio, plays an important role in the dynamic structural response. Besides, in another study they suggested a Nonlinear Conical Spring Bracing (NCSB) system consisting of two solid telescopic conical springs attached to steel wire ropes to mitigate the seismic excitation. The device stiffness is not considerable in the low to medium vibration range compared to structural stiffness while NCSB stiffness increases and prevents excessive displacement in frames with large displacement values. The best geometric configuration for the NCSB system was also determined by using the proposed numerical analysis [Fateh et al., 2016b].

Based on the second viewpoint, Balendra et al. [2001] proposed a two-stage passive control system consisting of a knee brace and a slotted connection. In service loads, slit connection would create energy dissipation by friction damping, while in severe
earthquakes, energy dissipation through plastic behavior of knee member is provided. Also, Zahrai and Vosoogh [2013] conducted research on dual system using a combination of vertical link beam and knee elements. Plastic hinge on the vertical link within low forces increased energy dissipation while plastic deformation of the knee increased the ductility and energy absorption during extreme forces to improve seismic performance. Hosseini Hashemi and Alirezaei [2015] investigated the performance of a combined knee brace and eccentrically braced frame called Eccentrically Knee Brace, and tested two half-scale specimens. The knee element yields during a moderate earthquake while in large earthquakes the link gets activated as well and both systems contribute in dissipating energy. In another research, Rousta and Zahrai [2017] proposed another two-level control system consisting of knee element and vertical link beam. Their experimental and numerical results show that in moderate earthquakes knee element acts as a fuse and in severe earthquakes, vertical link beam absorbs additional input energy to increase the system ductility. Also, replacement of such fuses after severe earthquakes is easy and practical.

Innovative pipe-in-pipe multilevel damper has been recently proposed by the authors [Cheraghi and Zahrai, 2016]. Analytical study of the innovative damper was investigated in the first part of the research. Numerical analyses by ABAQUS software on the several finite element (FE) 3-D models showed that the device could act as a multilevel damper to dissipate earthquake energy in different levels from weak to severe. Moreover, it is such a fuse in structures to prevent damage to other main members of the system by deforming into plastic range. Also, a step-by-step method for finding the pipe damper optimum size and properties was introduced. Zahrai and Cheraghi [2017] studied seismic response of typical 5, 10 and 15-story steel buildings equipped with Multi-level Pipe Damper (MPD) under seven earthquake excitations using dynamic nonlinear time-history analyses and showed the effectiveness of MPD to reduce the seismic response of the structures.

In this paper, the recently proposed multilevel pipe-in-pipe damper is experimentally investigated. For this purpose, the specimen design, test setup, material properties, and loading protocol are first discussed in detail. Next, the results of cyclic quasi-static tests performed on two samples are presented. Finally, a FE model of damper considering large deformation, nonlinearity, and material damage calibrated with experimental data is introduced. It seems that the proposed damper is light weight and easy to fabricate, while demonstrating ductile behavior that is excellent in reducing the seismic vibrations. Besides, at relatively large displacements, the device shows added stiffness which is very useful against severe earthquakes particularly to reduce residual displacements. This behavior provides the structures with more additional stiffness at higher levels of displacement demand.

2. Damper Design

The main idea and components of the innovative damper were well discussed elsewhere by the authors [Cheraghi and Zahrai, 2016]. As shown in Fig. 1a, a piston is designed inside the external pipe. Besides, a cylinder is installed outside of the inner pipe (Fig. 1b) such that fixed piston is moving inside the cylinder making a composite behavior in tension and compression (Fig. 1c & d). In other words, the proposed 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.
from moderate to severe conditions. Also, to prevent the concentration of local buckling on the pipes due to earthquakes, the stiffeners are installed on both sides of the inner and outer pipes.

As shown in Fig. 1d, there is a gap between pipes determined based on the flexural stiffness of the external pipe due to its length, diameter, and thickness. By applying lateral force or displacement caused by weak or moderate earthquake, deformation of external pipe results in plastic strain and energy dissipation. With an increase in earthquake excitations and thus further distortions of external pipe, the outer and inner pipes get connected together making an increase in strength and stiffness and thereby participation in the energy dissipation. It is obvious that determining the optimal gap is one of the main concerns as choosing the gap less than its appropriate ratio causes inefficiency of outer pipe energy dissipation capacity. Participation of inner pipe before observing enough plastic strain in the outer pipe causes single level performance. On the other hand, determining the gap greater than its suitable ratio causes outer pipe failure and loss of multilevel performance too. Since the proposed gap is relatively small, any possible local damage due to dynamic loading during an earthquake is expected to be minor.

Different types of installations in the frames are applicable to this new damper. For example, it can be installed in a structural frame within a diagonal brace as shown in Fig. 2. It suggests installing the damper directly to the double gusset plate to eliminate the damper weight effects on the brace buckling possibility under axial force P-delta influences.

**Figure 1.** a) External pipe; b) internal pipe; c) assembled damper; d) cross section of the damper.
3. Experimental Study

3.1. Test Samples

To verify the cyclic behavior of dual pipe samples (D.P.S) and evaluate the amount of energy absorption capacity, cyclic tests were performed on two specimens. Numerical results of the first part of the research [Cheraghi and Zahrai, 2016] showed suitable hysteresis curves without significant strength and stiffness degradation in all eight FE models from which two samples showing better cyclic performance are selected and tested here. Table 1 lists the sizes and properties of the dampers tested. \( D_o, t_o \) and \( D_i, t_i \) are respectively the diameter and thickness values of outer and inner pipes.

St-37 steel material was used for all plate sections, pistons, cylinders, and connector pipes while main outer and inner pipe material is completely different. Pipe material especially in large size diameter has usually different chemical compounds making different mechanical properties.

Those two steel pipes used for testing are obtained from two different steel factories. To obtain the mechanical properties of these pipes, two coupon tests were performed on sub-size specimens shown in Fig. 3 extracted from two pipes made in each of the mills. The tensile test followed the ASTM-E8M standard [2002]. Figure 4 shows the stress–strain diagrams obtained from these tests. A summary of the tensile test results is presented in Table 2.

Pipe material should be mild steel with a minimum of 22–25% elongation in coupon test to guarantee ductile and stable behavior of the damper. According to the tensile test results, the Mat 2 is not suitable mild steel for which a brittle cyclic behavior is expectable. Pipe material usually has carbon more than mild steel. So, E7024 electrode that is suitable for such steel was used to decrease failure possibility in the weld.

![Figure 2. Installation scheme for new pipe in pipe damper.](image)

### Table 1. Specification of multilevel samples.

<table>
<thead>
<tr>
<th>Sample</th>
<th>( D_o ) [mm]</th>
<th>( D_i ) [mm]</th>
<th>( t_o ) [mm]</th>
<th>( t_i ) [mm]</th>
<th>Length [mm]</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
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<td>320</td>
<td>30</td>
<td>15</td>
<td>200</td>
<td>Mat 1</td>
</tr>
<tr>
<td>D.P.S. 2</td>
<td>400</td>
<td>220</td>
<td>30</td>
<td>20</td>
<td>200</td>
<td>Mat 2</td>
</tr>
</tbody>
</table>
3.2. Manufacturing Steps of the Samples

Movable piston stroke to the internal pipe may cause damage and non-ductile behavior of the damper. So, at first step, installation of the square stiffening plate on the internal pipe as observed in Fig. 5 is necessary. This plate should be ground according to the radius of inner pipe and be connected using continuous fillet weld for tight installation.
Next, the piston is placed inside the cylinder as schematically shown with black part in Fig. 6. Then, the cylinder is welded continuously to the stiffening plate. Beveling entire edge to use groove weld is recommended to achieve more strength and ductility.

<table>
<thead>
<tr>
<th>Material</th>
<th>Yield stress (MPa)</th>
<th>Ultimate stress (MPa)</th>
<th>Failure strain [%]</th>
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</thead>
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<td>561</td>
<td>25.2</td>
</tr>
<tr>
<td>Mat 2</td>
<td>415</td>
<td>727</td>
<td>20.3</td>
</tr>
</tbody>
</table>

Figure 5. First manufacturing stage for the proposed two-level control system.
Further, beveled connector pipe with suitable length is used to install the inner and outer pipes together. Continuous fillet weld is used to fix the different parts to each other (Fig. 7).

In the final stage, after fine-tuning of the piston’s place that should have equal distance from both sides of the cylinder, continuous weld is used to install the outer and inner pipes together. It should be mentioned that due to the small piston diameter, V groove weld should be used to connect it to the external pipe. Both pipes should be exactly concentric to prevent twisting and secondary stresses. Completed damper is shown in Fig. 8.

Figure 6. Second manufacturing stage for the proposed two-level control system.

Figure 7. Third manufacturing stage for the proposed two-level control system.
3.3. **Test Setup**

Test setup to apply cyclic tests is shown in Fig. 9. The test setup was designed to be very rigid so that the pipes would carry all of the applied loads without twisting. The tests were conducted at the structural laboratory of Tarbiat Modares University in Tehran.

Loading protocol is imposed to the specimens with a 1000 kN capacity actuator. The cyclic loading history was applied in displacement control. Load was applied through a cap plate to the end of samples. One side of the samples was connected to actuator and the other side was connected to the rigid frame. Three Linear Voltage Displacement...
Transducers, LVDTs, were used for each sample. One of them recorded the displacement of inner pipe and two others were installed to the top and bottom of outer pipe. Besides, two strain gauges were pasted on the outer and inner pipes of the specimens. Figures 10 and 11 show the LVDTs and strain gauges installed on the samples, respectively. Also, Figs. 12 and 13 display photos of the test setup for the first and second test specimens, respectively.

Loading history for the cyclic test is similar to that used in component test of RBS [Gharibans et al., 2003]. This is selected to achieve ultimate tolerable displacements more accurately. So, as shown in Fig. 14, the displacement history was selected according to ATC-24 [1992]; that is, 3 cycles were applied to the specimens at 0.125, 0.5, 1, 2, 3 times of yield displacement and then 2 cycles until maximum displacement. The yield displacements of the samples were evaluated previously from numerical results. The loading history imposed to each sample is presented separately in Tables 3 and 4.

Metallic dampers are not very sensitive to the rate of loading. Therefore, the rate of loading was selected between 0.3 and 1 mm/s depending on displacement amplitude. The force and displacement history was recorded by a data logger and saved in a computer.

3.4. Test Results

Both samples were loaded according to the mentioned protocol until failure. The results for initial stiffness ($K_1$), secondary stiffness ($K_2$), yield displacement ($\Delta_y$), yield force ($P_y$), maximum strength ($P_u$), and maximum ductility ($\mu$) are tabulated in Table 5. Figure 15 presents the hysteresis diagram for all specimens in cyclic loading. Both dampers yielded

![Figure 10. Three LVDTs were used for each sample: (left) sample 1; (right) sample 2.](image)
Figure 11. Two strain gauges were pasted on the outer and inner pipes of the specimens.

Figure 12. Sample 1 in testing apparatus.
at relatively small displacements; then sample 1 displayed great ductility and stable hysteresis loops for relatively large displacements while brittle failure happened in sample 2 as expected. Authors strictly suggest using seamless mild steel pipe to ensure proper cyclic behavior. Besides, it is better to increase the thickness and length or decrease the

Figure 13. Sample 2 in testing apparatus.

Figure 14. Loading protocol according to ATC-24 [1992].
diameter of the new damper in case of more strength and stiffness requirement. Also, multilevel performance as expected is visible in both samples that can dissipate energy in different energy levels. The secondary stiffness after getting contact between internal and external pipes is a combined stiffness composed of elastic stiffness of inner pipe and post-yield stiffness of outer pipe because while external pipe is in plastic range to dissipate input energy, the inner pipe is still in elastic range. It is noticeable that according to the design philosophy, secondary stiffness can be less, more, or equal to the initial stiffness related to the diameter to thickness ratio and pipe length. As observed in Fig. 15, it seems more stiffness of inner pipe in sample 2 compared to sample 1 results in more secondary strength and stiffness enhancement.

In addition, this proposed damper shows an added stiffness and strength at increasing applied deformations. This phenomenon ensures more reliability in structures subjected to severe earthquakes. In other words, the damper prevents failure of structure by stiffness amplification at large displacements. This specification is inimitable for this damper because in most metallic dampers, stiffness decreases or stays steady at displacements increment. Moreover, as a suggestion it is possible to use frictional energy dissipation in addition to the material plasticity in case of precise lathing of piston to be fit in cylinder and prevent sudden stiffness increment. Designing the inner diameter of cylinder almost with the same size of the outer diameter of movable piston results in friction enhancement between two surfaces sharply. In this case, critical slip load is required to move piston inside the cylinder. Preheating the cylinder in boiling oil to increase its diameter is a simple method to fit piston inside the cylinder such that it can act as a friction device after cooling.

Figure 16 shows test samples connected to the test setup before testing. The dual performance of the inner and outer pipes under tension and compression forces and failure of the samples are shown in Figs. 17 and 18. Shape and design of the piston results

<table>
<thead>
<tr>
<th>Number of cycles</th>
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</tr>
<tr>
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<td>7</td>
<td>496.1</td>
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<td>8</td>
<td>5.42</td>
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</table>

Table 3. Loading history applied to sample 1.

Table 4. Loading history applied to sample 2.

Table 5. Cyclic behavior of the proposed multi-stage dampers.
in symmetric behavior versus both tension and compression force that ensures suitable cyclic performance and guarantees the multilevel behavior.

The ultimate strength obtained was 471.6 kN for sample 1, while maximum strength of sample 2 reached 496.1 kN. As observed in Fig. 19, in sample 1 during the ultimate loading and at extremely high displacement (above 60 mm), cracks initiated in the pipe material and mild drop in hysteresis curve was visible. But, as shown in Fig. 20, undesirable steel material in sample 2 caused its brittle failure at 26.76 mm displacement. It appears that failure happened near the heat affected zone where welding heat had changed chemical and mechanical properties. This might have occurred for various reasons; however, authors tried to decrease the welding procedure effects by preheating and using consistent electrode and suitable welding situation. So, the material property seems to be the main reason. Maximum strain reached about 21% in sample 1 adjacent

Figure 15. Hysteresis curves for the test specimens: (a) sample 1; (b) sample 2.
**Figure 16.** Samples ready for testing: (left) sample 1; (right) sample 2.

**Figure 17.** Deflection of sample 1 under compression and tension.
Figure 18. Deflection of sample 2 under compression and tension.

Figure 19. Details of failure of the test sample 1.
to the plastic hinge and the cracked part, while it was about 19.8% near the separated part in sample 2.

### 3.5. Ductility Assessment

In general, pipes are ductile elements that can tolerate maximum displacement up to more than 30% of their diameter [Maleki and Mahjoubi, 2013]. So, it is predictable that the proposed damper shows suitable ductility with large ultimate tolerable displacement. To study the effect of the proposed damper on the structural ductility improvement, ductility amounts in different samples are evaluated. This ratio is equal to the maximum displacement to yield displacement and can be calculated using Eq. (1):

\[
\mu = \frac{\Delta_{\text{max}}}{\Delta_{y}}
\]  

(1)

The greater ductility ratio results in higher energy absorption and therefore the response modification factor \( (R) \) will be greater. Parameters of test findings are compared in Table 5. \( K_1 \) is the initial elastic stiffness related to outer part and \( K_2 \) is the secondary stiffness after having contacts between two parts. It should be mentioned when the internal pipe starts to function linearly, at the same time the external pipe has entered the plastic range. Therefore, the stiffness of the device \( (K_2) \) at this stage is a mixed property containing both elasticity and plasticity behavior.
3.6. Equivalent Viscous Damping Ratio

Equivalent viscous damping ratio is usually used for mathematical modeling of damping ratio calculated according to Eq. (2) after drawing hysteretic curves under cyclic loading:

\[ \xi_{eq} = \frac{A_h}{4\pi A_e} \]  

(2)

where \( A_h \) and \( A_e \) are respectively indicative of the energy dissipation in a cycle of loading and the amount of energy stored in a linear elastic system. Due to the low inherent damping in the conventional systems, using energy absorbing device to reduce vibrations under dynamic loading might cause increased cost. Therefore, use of the new systems with simple operation and low cost mechanism is one of the seismic design requirements.

Considering the experimental load–displacement data and hysteresis curves, the equivalent viscous damping ratio is presented in Table 6. For comparison, equivalent damping ratios at last cycle of loading are calculated for samples 1 and 2. Results showed that damping ratio for tested samples 1 and 2 respectively reached 38.27% and 18.89%. It can be seen that damper has a proper performance with great damping ratio.

To explore the damper effectiveness on absorbing the input energy, diagram of the maximum amount of the dissipated energy among each set of the cyclic loading is plotted. As shown in Figs. 21 and 22, the amount of dissipated energy in the last loop of the test (\( E_p \)) reached 69,120 and 15,011 J, respectively, for samples 1 and 2 while this amount in the last elastic loop (\( E_e \)) reached 223 and 117 J. Besides, force amount in the corresponding point in plastic range (\( F_p \)) reached 350.79 and 496.1 kN, respectively, for samples 1 and 2 while this value in elastic range (\( F_e \)) reached 180.54 and 121.76 kN, respectively.

<table>
<thead>
<tr>
<th>Sample</th>
<th>( A_h ) [J]</th>
<th>( A_e ) [J]</th>
<th>( \zeta ) [%]</th>
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<tbody>
<tr>
<td>D.O.S 1</td>
<td>69120</td>
<td>14378.6</td>
<td>38.27</td>
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<td>D.O.S 2</td>
<td>15011</td>
<td>6326.2</td>
<td>18.89</td>
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</table>

Table 6. Equivalent viscous damping ratios.

![Figure 21. Force versus number of loading cycles.](downloaded by [University of Tehran] at 06:16 04 November 2017)
Results show that force amount increased mildly from elastic to the plastic range, while the value of the dissipated energy enhanced sharply in plastic range and proved the damper ability to absorb and dissipate the earthquake energy. All related results are presented in Table 7.

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<td>4.07</td>
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4. Finite Element Analysis

Development of an analytical FE model for the proposed damper is discussed in this section using the ABAQUS [User’s manual, 2010] FE software and nonlinear static analysis on a 3-D model. The material and geometric nonlinearities are both considered in the FE models. The material properties and stress–strain curves are based on the tensile test results as explained above. Eight-node nonlinear solid element type is used and analysis is performed with respect to the effects of large deformations. Contact between pipe and piston is considered with penalty friction formulation and normal behavior of hard contact. The loading history is selected according to the cyclic test for each specimen until failure. Figure 23 compares the numerical and experimental results.

As observed in Fig. 23, there is a suitable correspondence between the numerical hysteresis curves and those obtained from experimental results. The sample 1 FE analysis was terminated at about 55 mm due to large plasticity and contact iterations, but the sample tolerated more displacements in tests up to 75 mm. However, this issue reversed on sample 2, because cyclic test ended at about 27 mm according to the outer pipe failure, while numerical model failed at about 30 mm displacement.
Also, as shown in Fig. 24, stress distribution and locations of the plastic hinges in the samples indicate the maximum stresses in the inner surface of the pipe expanded on the outer surface that is entirely consistent with the behavior theory of the pipes. The diagram of internal pipe ($F_i$) and external pipe ($F_e$) capacity is shown in Fig. 25 while related results are presented in Table 8.

5. Conclusions

In this paper, an innovative multilevel pipe in pipe passive control system was experimentally studied and its cyclic behavior was evaluated with quasi-static cyclic tests. Main results of this research can be summarized as follows:
(1) Hysteresis curves represent the stable and symmetric behavior of the proposed two-level damper in tension and compression. Moreover, they show multilevel behavior with variable strength and stiffness as expected that can dissipate seismic energy in different earthquake levels.

(2) Achieving equivalent viscous damping ratio for test specimens 1 and 2, respectively, up to 38.3% and 18.9% without use of sophisticated tools is noticeable.

Figure 24. The stress distribution in numerical models: (a) sample 1; (b) sample 2.
The ductility ratio in cyclic tests for samples 1 and 2, respectively, reached 10.2 and 5.4. Results show that accessing more ductility and equivalent viscous damping ratio in case of using mild steel is achievable.

Dissipated energy in the last loop of the test ($E_p$) reached 69,120 and 15,011 J, respectively, for samples 1 and 2 while this amount in the last elastic loop ($E_e$)
reached 223 and 117 J, respectively. So, the $E_p/E_e$ ratio increased sharply up to 309.96 and 128.3, respectively, for samples 1 and 2 that show the excellent damper ability to dissipate the input energy.

(5) Design and manufacturing of the proposed damper is fully operational and its implementation in a variety of concentric braces like diagonal and chevron braced frames is feasible.

References


