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Numerical and Experimental Behavior of Moment Concrete Frame Retrofitted with ADAS Metal Yielding Damper Under Lateral Loading

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Abstract: Many concrete structures need to be retrofitted, repaired, strengthened, and improved due to various reasons, such as errors during design or construction, changing the use of the structure, and losing part of the structure's capacity due to the corrosion of steel rebars. Since the use of dampers in the structure can increase the useful life of the structure, this advantage causes sustainable development in the environment and less damage to the environment, because less materials will be used to destroy and rebuild the structure. In this study, the behavior of concrete frames with bracing and dampers was experimental and numerically studied using ABAQUS software. The difference value of strength for the concrete frame, concrete frame with steel brace, and concrete frame with damper was 4.6, 0.4, and 3.9%, respectively. By utilizing the verification results, it is possible to save both cost and time for the experimental study. In the following, a parametric study was conducted on the behavior of the frame equipped with a damper and the number of bending plates in various thicknesses. Results indicate that when the thickness is increased from 1 to 2, 1 to 3, and 1 to 4 mm, the strength is increased by about 2.6, 16.83, and 27%, respectively. Also, by increasing the number of plates from 6 to 8, 6 to 10, and 6 to 12, the strength has increased by 9.33, 26.30, and 54%, respectively.

Keywords: Yielding damper ADAS; Cycle loading; Ductility; Moment concrete frame.

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1. Introduction

One of the ways to reuse structures is retrofitting. Retrofitting includes the process of finding the problem, removing the damaged parts, as well as selecting and performing appropriate retrofitting to increase the life of the structure. On the other hand, retrofitting is the process of improving the structural system of an existing structure to improve its performance under existing loads or to increase the resistance of structural components to carry additional loads. Therefore, this causes sustainable development and is effective in reducing damage to the environment.

Using dissipated energy systems in the structure leads to dissipating a considerable part of the internal energy due to wind or earthquake. It minimizes the damage to the structure. In conventional methods, the structure resists earthquakes by combining stiffness and ductility. The damping value is negligible in these structures. Thus, in the region of elastic behavior, the dissipated energy of the structure is insignificant. These structures bear large displacements during severe earthquakes and remain stable only by their non-elastic deformation manner. These large displacements cause the creation of local plastic hinges at some points of the structure, which increase ductility and energy adsorption. These damages occur in the main structural members of the structure, such as columns and beams, resulting in a high repair cost. Using dampers reduces the earthquake force and damage to the buildings.

Every earthquake affects the structure with three factors: displacement, speed and acceleration. The controlling factor for displacement, speed and acceleration is hardness, damping and mass, respectively. Dampers are sometimes used to control damping. Dampers based on damping mechanism are divided into different categories including mass dampers, viscous dampers, yield dampers and friction dampers. Yielding dampers act like a structural fuse and absorb earthquake energy as the steel yields. In the meantime, yielding dampers, such as buckling braces, create relatively high stiffness in the structure. So that this system can be used as the main lateral bearing system of the structure. In the use of yielding dampers, in addition to yielding, it is also very important to keep them yielding so that energy can be absorbed throughout the entire length of the earthquake.

Tsai et al. (1993) were the first persons, to use ADAS and TADAS dampers to reduce the seismic response of the structure. They examined the cyclic behavior of the damper and the structure. Based on their findings, structures with dampers reduce drift and damage [1]. A numerical investigation of Abulfaz and Qobara was conducted on concentric and eccentric straight internal braces in non-ductile concrete frames. The results showed desired seismic performance of these buildings when using eccentric braces [2-3]. Tehranizadeh (2001) has investigated the ADAS damper effect numerically and experimentally for a steel building. The effect of yielding damper on the seismic response of the structure has been studied. According to the results, if the stiffness of the brace is almost twice that of the damper, the response of the

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structure is reduced to the optimum level [4]. Mahri et al. (2003) conducted experimental studies to evaluate the seismic performance parameters of different bracing frame systems for bracing-frame connections [5]. Mahri and Hajipour (2003) investigated the direct connection of cross braces to the frame corners experimentally [6]. In this research, the connection plates were welded to concrete members and beam and column connection plates in three ways. When using novel structural elements for seismic retrofitting of available concrete structures, in which the connected ductile member of the seismic retrofitting system is the available weak concrete structures, several experimental and numerical studies [7-8]. Show weaknesses, such as dimensional mismatch of new structural members with available concrete members, high force requirement in the joint of the link to the concrete elements of the story, and requirement of a large number of occupied spans.

Zahraei and Rad (2007) in a study using TADAS dampers in the consumption of seismic energy in concrete structures and also analyzed the behavior of the structure with these dampers. First, they examined TADAS dampers and the structure's behavior with these dampers. Then, they used one type of damper in four concrete buildings with different properties [9].
Alhashem et al. (2008) numerically investigated ADAS and TADAS yield dampers with CBF, Chevron, and EBD bracing systems under seismic loading. The yield period of the system with a damper was higher than other bracing systems. Also, the base shear of structures with dampers in the considered earthquakes was lower than the base shear of structures with bracing systems [10]. Vargas and Bruno (2009) proposed a design method for structures equipped with yield dampers based on ductility and required stiffness ratio [11]. Yen and Chin (2010) installed several internal connections with steel plates to the webs of connecting beams and measured their performance under cyclic loading by defining two indices of strength and ductility [12]. Ghobraei et al. (2010) and Lee et al. (2015) used numerical and experimental methods to optimize the shape of the yielding damper. The optimal shape increased the dissipated energy and made the stress distribution uniform in the damper [13-14].

Bayat and Abdullahzadeh (2011) compared the behavior of moment steel frame with ADAS damper and CBF bracing system during an earthquake. According to their findings, the height of the structure and the geometric characteristics of the damper have played a significant role in reducing the earthquake response [15]. In addition, the drift profile of the structure with the damper was not affected by the earthquake intensity, but only increased the input energy [15]. Mahmoudi and Abdi (2012) investigated the behavior coefficient of the structure with TADAS type yielding damper in a numerical study. They subjected a moment-resisting steel frame and a frame with a TADAS yielding damper to earthquake loading [16].

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Sharbatdar et al. (2012) studied the effect of shear walls and steel brace in retrofitting existing moment-resistant concrete frame and their triple interaction. The results showed that the use of steel braces reduced the drift of the structure by about 50% [17]. By modifying the ADAS damper system stiffness value as a percentage of the total structure stiffness, Rise et al. (2013) investigated the dynamic behavior of short-period structures [18]. The research titled nonlinear dynamic analysis of steel frames with Steel damper has been conducted by Khazaei (2013) in this field. As part of this research, steel structures with 4, 7, and 12 floors with ADAS dampers were analyzed [19].

Mahmoudi et al. (2014) calculated the factor of the behavior of the intermediate and special moment-resistant frame equipped with TADAS and extracted their hysteretic curve. To do this, they performed the ascending nonlinear analysis of official buildings with different floors (3-5-7-10-15) using OPENSEES software and calculated the behavior factor for the intermediate and special moment-resisting frame in two states of bare frame and frame equipped with the damper in life safety performance level [20].
Sahoo et al. (2015) combined the ADAS damper with a plate damper and devised a shear-flexural yielding damper. According to their findings, the carrying capacity and energy dissipation in these dampers are 20 to 30 tons greater than ADAS dampers [20]. Ince et al. (2015) retrofitted and reinforced a concrete frame with a yielding damper and steel brace [22]. Based on the results of recent studies on the energy adsorption capacity of yielding steel dampers in TADAS [23-24], the usage of these dampers overcomes the noted weaknesses and has benefits such as those of increasing ductility, stiffness, and lateral strength, adaptability to architecture, adding minimal weight to the main structure, and that of incorporating a steel braced frame system within the concrete building with the slightest interruption to its structural performance.

Tahamoli Roodsari et al. (2018) investigated the effect of using ADAS and TADAS dampers along with Chevron brace in reinforced concrete frames. They created 7 reinforced concrete frames and retrofitted them with Chevron brace and ADAS and TADAS dampers with a different numbers of splitter blades [25]. Saghafi et al. (2019) investigated the seismic response of three reinforced concrete frames with 4, 7, and 10 stories equipped with yielding steel dampers (TADAS). They used OPENSEES software to perform nonlinear time history analysis using seven earthquake records to determine the structural response [26].
Hemti et al. (2020) conducted an experimental study on three samples of the reinforced concrete frames. Experimental specimens consisted of a reinforced concrete frame, a reinforced concrete concentric braced frame (CBF), and a reinforced concrete eccentric braced frame (EBF), and their cyclic behavior was studied and compared [27]. Khoshkalam and colleagues.

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(2021) proposed a new type of ADAS damper that minimizes the effect of axial load on the damper. In this innovative damper, the plastic strain in the ADAS damper is 50% less than the normal ADAS damper [28].

Building retrofitting refers to measures that increase the useful life and resistance of concrete and metal buildings against earthquakes. Improving the performance of building components leads to improvement and the seismic resistance of buildings. Earthquake is one of the natural disasters that have caused many damages so far. In the last few decades, the use of energy dissipation systems in order to absorb and concentrate most of the input energy in the intended devices during an earthquake has been noticed. These systems can be used in the design or retrofitting of structures. There are different methods to strengthen the structure against earthquakes. Using seismic dampers is one of the methods of strengthening the building against earthquakes. It is one of the inherent characteristics of damping materials. Thermal effects and fatigue phenomena change the internal damping of solids. As a result, in order to know the damping of the materials, we must minimize the effects of these factors in the materials. Seismic absorbers prevent the transfer of all earthquake energy from the ground to the structure. The best advantage of using this method compared to other methods of strengthening the structure is that a small percentage of the earthquake force enters the building or it does not enter at all. In this study, it has been tried to strengthen the concrete structure by using yielding damper and brace. In the following, the research method and its results will be described. There are many concrete structures that need to be retrofitted due to changes in regulations, changes in use, and other reasons. Reinforcement of concrete structures is done using different methods. One of these methods is using a damper. In this study, the concrete structure has been strengthened by using the yielding damper. The method of conducting this research is laboratory and numerical. Abaqus software was used for numerical analysis. In this article, the use of yielding damper in the concrete frame and its strengthening is one of the main goals. The innovation of this research is the investigation of the proposed yield damper and the evaluation of the behavior of the reinforced concrete frame.

Figure 1 shows the flowchart of the research process.

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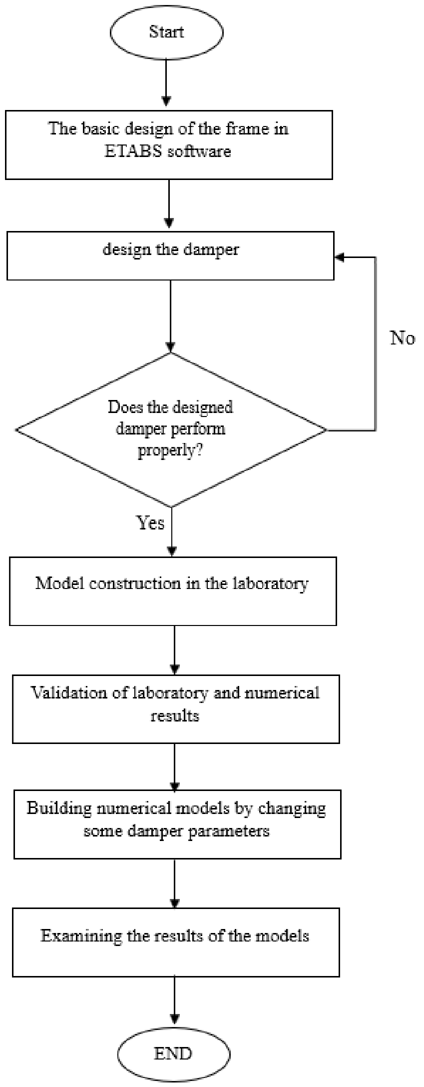

Figure 1. Flowchart of the research process

2. Experimental Samples

An investigation of the behavior of concrete frames and concrete frames with yielding dampers has been conducted in the laboratory using nine concrete frames. A preliminary experiment was conducted on three samples, and some modifications were made afterward to other samples. The concrete used in these samples was from the conventional type created in the workshop, with the mix design according to Table 1. Before concrete pouring, three cubic samples were provided. Under the environmental and temperature conditions of the laboratory, cubic samples were cured for 28 days in the water reservoir. After curing cubic samples, the

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compressive strength of the samples was determined using the hydraulic jack of the laboratory of the Ferdowsi University of Mashhad. The results of the cubic samples experiment are shown in Table 1.

Table 1. Compressive strength of 28-day cubic samples taken from concrete according to the 1608-3 standard

	Dimension (cm)	Sample-1	Sample-2	Sample-3	Average	Standard Deviation
Cubic Concrete Sample	15×15×15	26.4	23.6	25.3	25.1	1.33

The concrete moment frame is designed based on the ACI 318-14 regulations in Etabs software [29]. The sections obtained based on the design are shown in the table 2. The concrete frame considered is a one-story, one-span frame. There are four φ19 longitudinal reinforcements on the beam, six φ 10 longitudinal reinforcements on the column, and 12 φ 16 reinforcements on the foundation. Table 2 shows the number of stirrups and geometric properties of samples. In moment-resisting frames, the only different thing is the distance between transversal reinforcements. In these samples, Conc-F shows the concrete moment-resisting frame, BR represents the sample with steel bracing, and ADAS shows the sample with the ADAS damper.

Table 2. Properties of the beam, column, and foundation rebars

Sample		**Conc-F-1**	**Conc-F-2**	**Conc-F-3**	**F-1-BR**	**F-2-BR**	**F-3-BR**	**F-1-ADAS**	**F-2-ADAS**	**F-3-ADAS**
Column	Dimension (cm)	20×20								
	Longitudinal reinforcement	6φ10								
	ρ	1.18								
	transversal reinforcement	7φ8	9φ8	11φ8	7φ8	9φ8	11φ8	7φ8	9φ8	11φ8

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Beam	Dimension (cm)	20×15								
	Longitudinal reinforcement	4φ8								
	ρ	1.05								
	transversal reinforcement	8φ8	8φ8	10φ8	8φ8	8φ8	10φ8	8φ8	8φ8	10φ8
Foundation	Dimension (cm)	60×40								
	Longitudinal reinforcement	12φ16								
	transversal reinforcement	20φ10								

Fig. 2 shows the geometric plan of the concrete frames subjected to the experiment. In moment-resisting frames, the only different thing is the distance between transversal reinforcements. In these samples, Conc-F shows the concrete moment-resisting frame, BR represents the sample with steel bracing, and ADAS shows the sample with the ADAS damper.

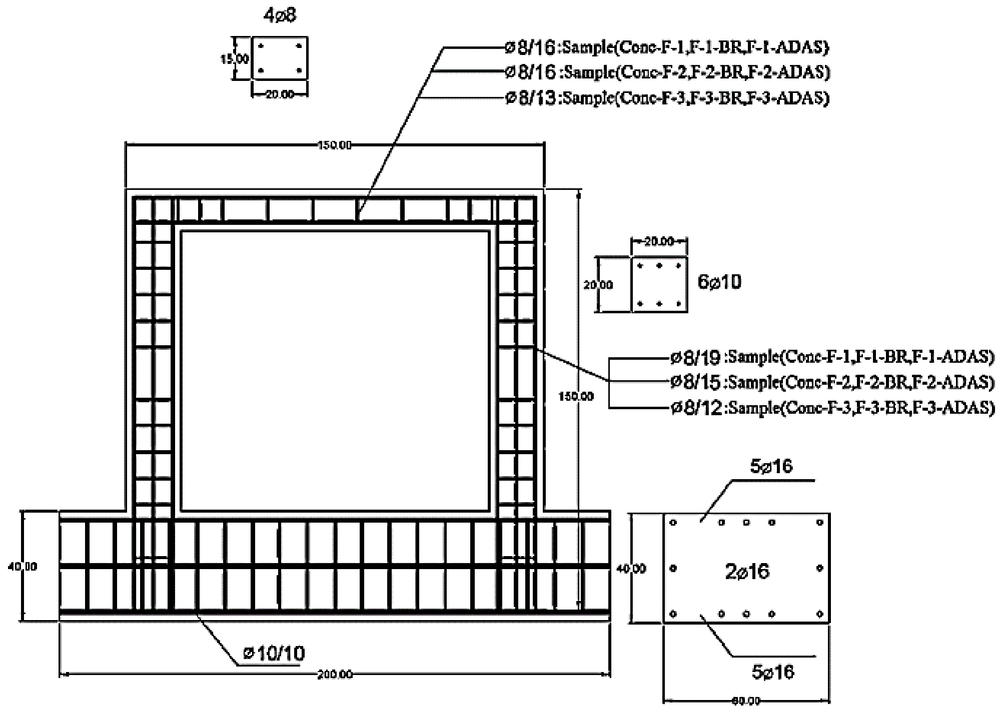

Figure 2. Geometric plan of concrete frames

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After creating concrete frames of Conc-F-1, Conc-F-2, and Conc-F-3 and conducting experiments, examining cracks, and comparing their details, the damper was created according to Fig. 3 because dampers and braces retrofit frames.

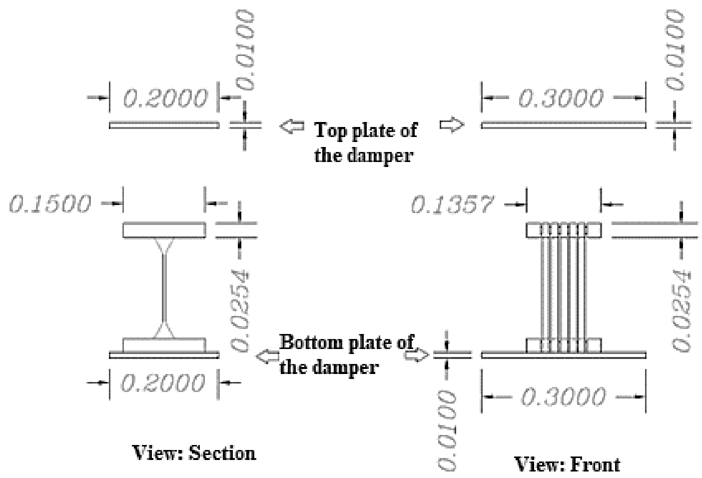

Figure 3. Extended plane of the subjected ADAS damper (units are in meters)

The utilized steel is St37, and geometric properties and the created ADAS damper plan are shown in Fig.s 3 and 4, respectively. This damper is characterized by the thick top and bottom plates that do not change as a result of tensile and shear forces in the damper. CNC machines were used to cut the damper's plates, which minimized errors during the manufacturing process. Fig. 5 showed geometric view of the F-3-BR braced concrete frame and Fig. 6 geometric view of the concrete moment-resisting frame and placing manner of the brace and the F-3-ADAS yielding damper.

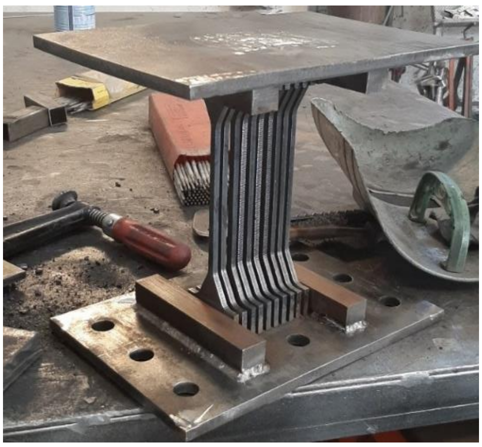

Figure 4. Prepared yielding damper to be installed in the concrete moment-resisting frame

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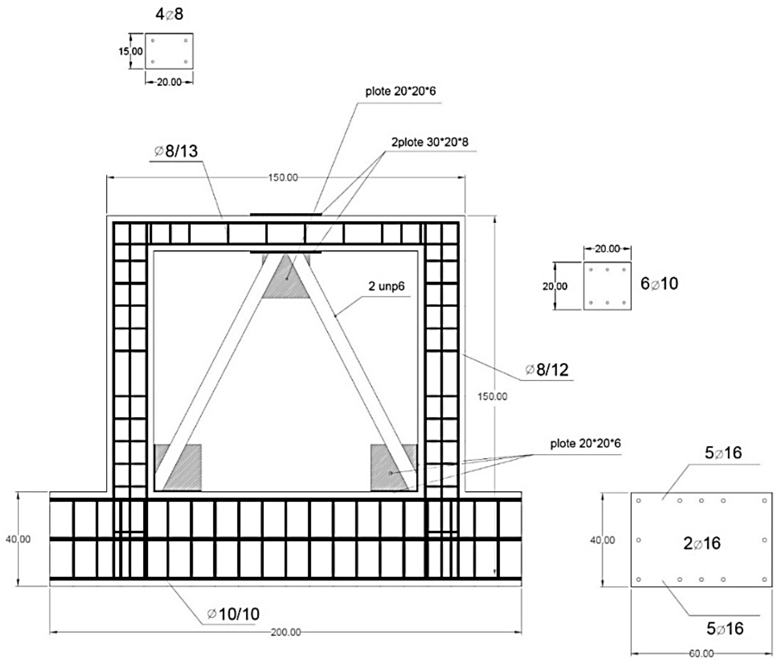

Figure 5. Geometric view of the F-3-BR braced concrete frame

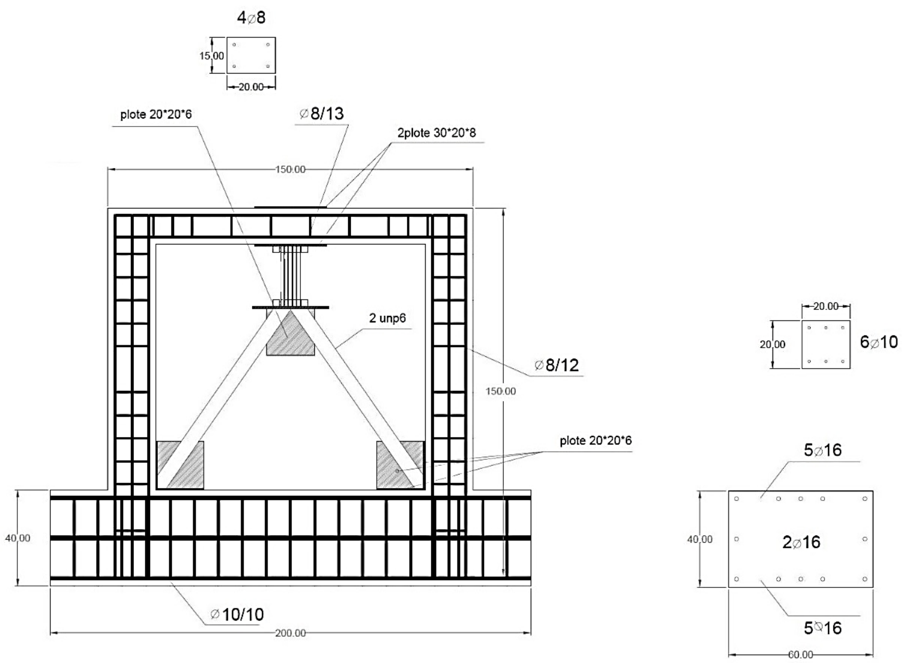

Figure 6. Geometric view of the concrete moment-resisting frame and placing manner of the brace and the F-3-ADAS yielding damper

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3. Test Layout

Fig. 7 illustrates the loading method, laser gauge location, angles, and through bolt in the sample. In the structural laboratory of the Ferdowsi University of Mashhad, the hydraulic jack has a capacity of 800 kilograms. To measure frame displacement under cyclic loading, a displacement record sensor (laser gauge with 0.1 mm accuracy) was used. The foundation was also anchored to the solid laboratory floor using four IPE140 double-welded profiles. Prior to the concrete pouring, a buried plate was installed in the beam-to-column connection. This plate was then connected to the load cell jack, and the load was applied. In other samples, two L100x10 angles were attached to the stem of the angle with a through bolt. Following this, four other bolts were used to connect the angle to the load cell plate. Experimental work was performed in the structural laboratory of the Ferdowsi University of Mashhad on a solid concrete floor.

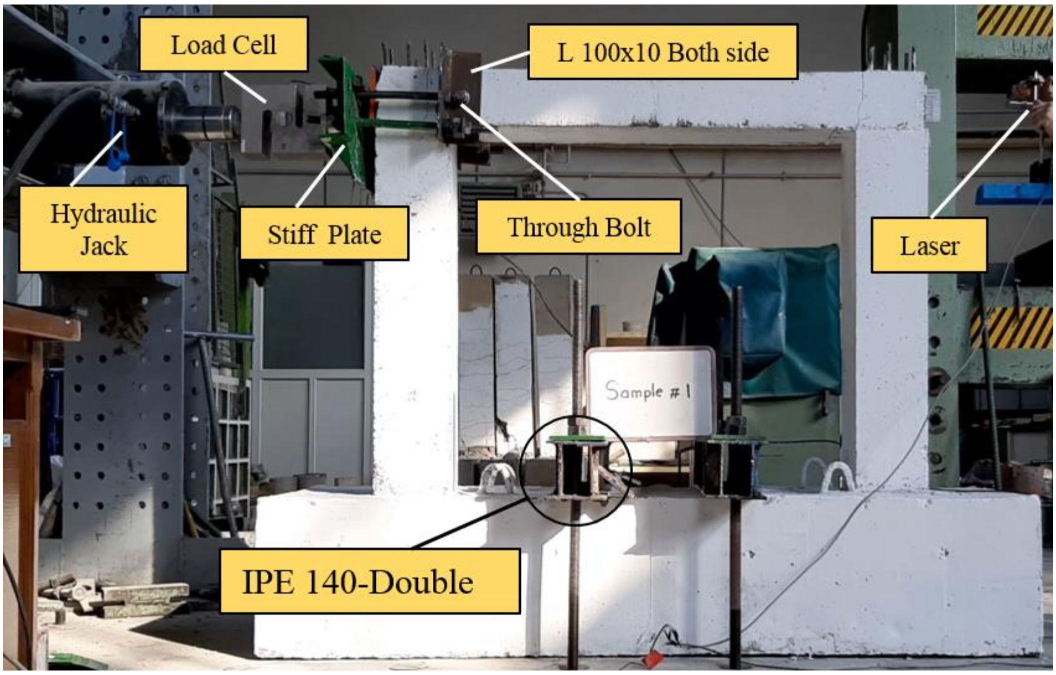

Figure 7. Layout of the experiment of concrete moment-resisting frame

4. Numerical Modeling Of Samples

In this research, for modeling concrete, Concrete Damage Plasticity material was used. It also has properties such as the use of uniform loading, vibration, dynamic, sensitivity to the strain rate, the impact of elastic stiffness recovery in cyclic loading, and the use of viscoelasticity in behavior equations to improve convergence. Fig. 8 shows the compressive strain, and Fig. 9 shows the tensile strain used in this model.

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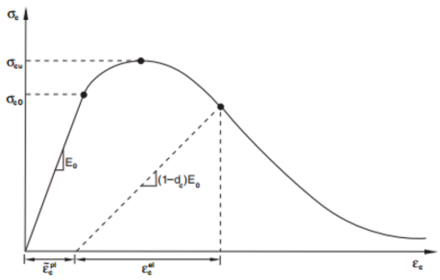

Figure 8. Compressive stress-strain curve of the CDP model[30]

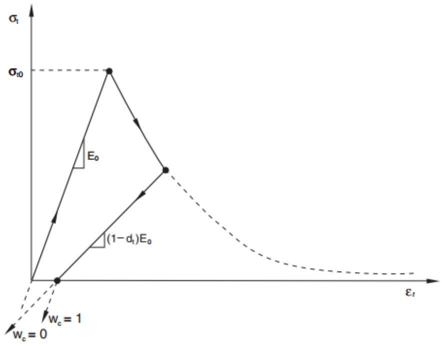

Figure 9. Tensile stress-strain curve of the CDP model[30]

The concrete used in this model has characteristic strength of 25 MPa, and the column and beam cover is 25 mm. The elasticity modulus of steel is 200 GPa, and Poisson's ratio is 0.3. The yield stress of steel is 300 MPa, its ultimate stress is 520 MPa, and the ultimate strain is 0.09. The ideal bilinear stress-strain curve for steel is shown in Fig. 10.

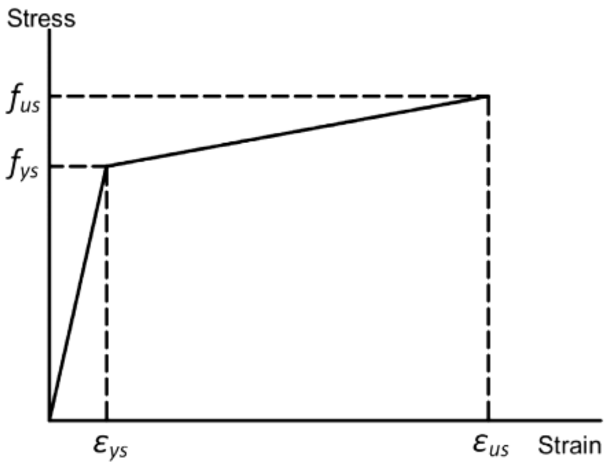

Figure 10. The stress-strain curve of the hardened steel

Table 3 shows the concrete properties, and Table 4 shows the steel properties.

Table 3. Concrete frame properties

Elasticity modulus	Poisson's ratio	Dilation angle	Eccentricity
25744.1	0.2	35	0.1

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Fb0/fc0 Ratio	K Coefficient	Viscosity parameter
1.16	0.667	0.01

Table 4. Steel properties in the analysis

Elasticity modulus	**Poisson's ratio**	**Yielding stress**
200000	0.3	300
Ultimate stress	Ultimate strain	
520	0.09	

The element type considered for rebar was from the truss element named T3D2, which is a two-nodes linear element. The element used for modeling the concrete frame is from the brick type named C3D8R. Fig.s 11 and 12 show hexagonal and continuum brick elements.

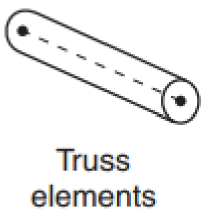

Figure 11. Two-nodes truss element

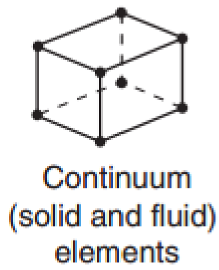

Figure 12. Hexagonal 3D element

After modeling longitudinal and transversal reinforcements of the concrete frame, these parts are assembled in the assembly module based on their location, and the model is created. The nonlinear static analysis method was used by considering the nonlinear parameters of material and geometry. The frames were subjected to pushover loading. Similar to the experimental sample, displacement was applied on top of the frame, and base shear was calculated at each increment. The displacement on the frame is measured during the process. The interaction type between rebars and concrete is Embedded Region. The couple behavior between concrete and rebar can be observed in this state, as well as the compatibility between the strains. The connection between the steel brace and gussets, and each connection that cannot displace, is the Tie connection.

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4.1 Reinforced Concrete Frames

Fig. 13 shows the Conc-F-3 sampled after the test. The distance between the stirrups of the beam and column was simultaneously reduced in this sample. In the observation, cracks were observed only in the beam, and no significant cracking was observed in the columns.
The structure’s support only has two horizontal cracks, which occurred after the beam’s crack appeared. As a result, crack formation near the beam-to-column connection has been reduced and has been transferred to the middle of the beam. The software simulation of the model is shown in Fig. 14.

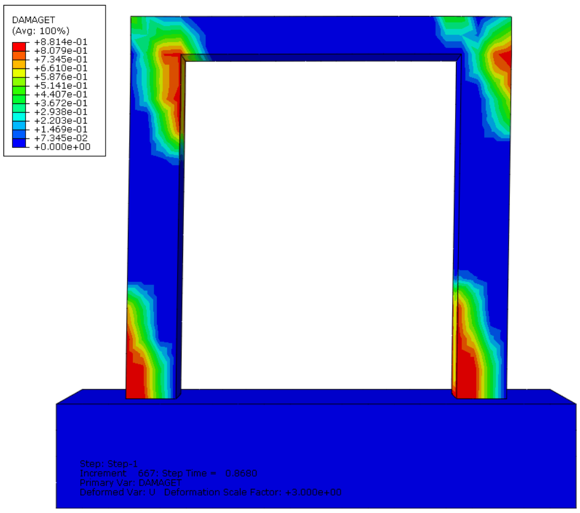

Figure 13. Cracking way of the ConcF-3 after the experiment **Figure 14.** Cracking concrete frame in numerical modeling

The structure's support only has two horizontal cracks, which occurred after the beam's crack appeared. As a result, crack formation near the beam-to-column connection has been reduced and has been transferred to the middle of the beam. The software simulation of the model is shown in Fig. 14.
Created cracks in the columns support and panel zones are observable in the finite element image. The tensile cracks are observable in one direction due to the unilateral loading manner. However, the crack distribution is proper regarding the loading direction.

4.2 Reinforced Concrete Frames With Steel Bracing

Fig. 15 shows the cracking of the concrete frame with steel brace in the F-3-BR after the experiment. Through bolts and steel plates were used to connect the brace to the concrete beam. Therefore, beam cracks are formed between the connection and the brace connection plate. A significant increase in flexural stiffness can be observed in this part of the beam. These cracks

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started to grow from the beam-to-column connection joint. Also, horizontal cracks are observable in the concrete frame's column. There is a lower crack in the right column than in the left. Fig. 16 shows the Von Mises stress distribution in the steel brace and other elements.

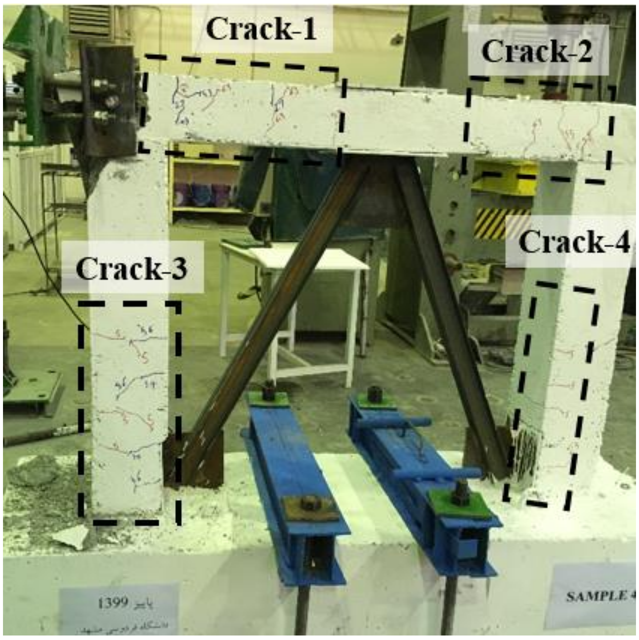

Figure 15. Deformation and cracking of the concrete frame with steel bracing

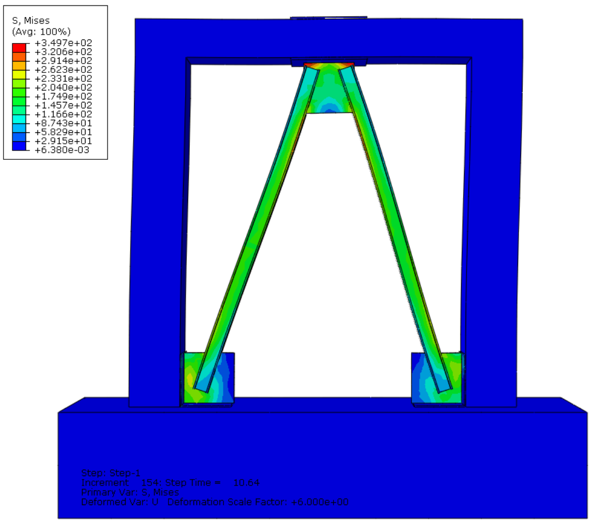

Figure 16. Numerical modeling of the concrete frame with the steel bracing

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As shown in the numerical model, all stresses were created in the bracing element because when the lateral load is applied, the steel bracing system adsorbs a considerable share of the lateral load with its high stiffness. As a result, most stresses were created in braces in this model. Similar to the experimental sample, some distortion is observed in the middle of the right brace.

4.3 Reinforced Concrete Frames With The ADAS Yielding Damper

Fig. 17 shows the concrete frame with the ADAS damper in the F-3-ADAS damper after cyclic loading. Some cracks are observed in the connection joint of the jack to the left side angles. There are no horizontal cracks in the concrete frame's column, and the beam has few cracks. In the connection joint between the plate under the beam and the damper, there are some vertical cracks. Most of the frame deformations were transferred to the damper region. The damper deformation shows that shear deformations dominate in the damper. Fig. 18 illustrates the modeling of the concrete frame with the ADAS damper. This Fig. shows the tensile cracks in the concrete frame. Also, the ADAS damper deformation in the frame has been shown separately.

Figure 17. Concrete frame with the yielding ADAS damper of the F-3-ADAS sample

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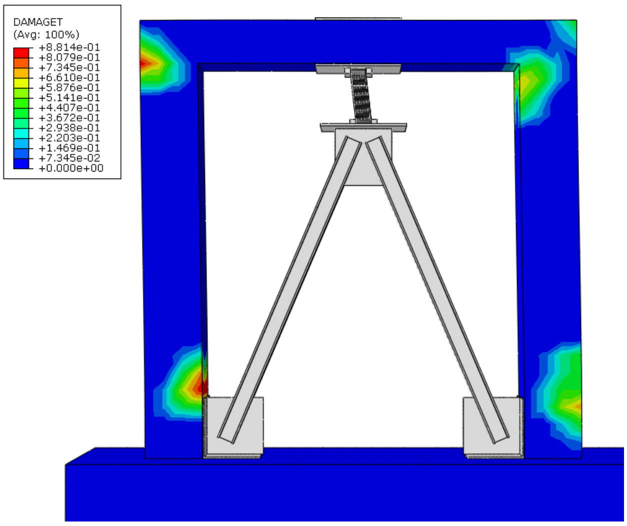

Figure 18. Tensile cracks of the numerical modeling in the concrete frame with the ADAS damper

Formed cracks in the columns' supports and on top of the gusset plates of the Inverted-V-bracing are evident in Fig. 18. There are also some cracks in the corners of the frame, where the tensile stress is significant. Fig. 18 the ADAS damper deformation that is illustrated individually.

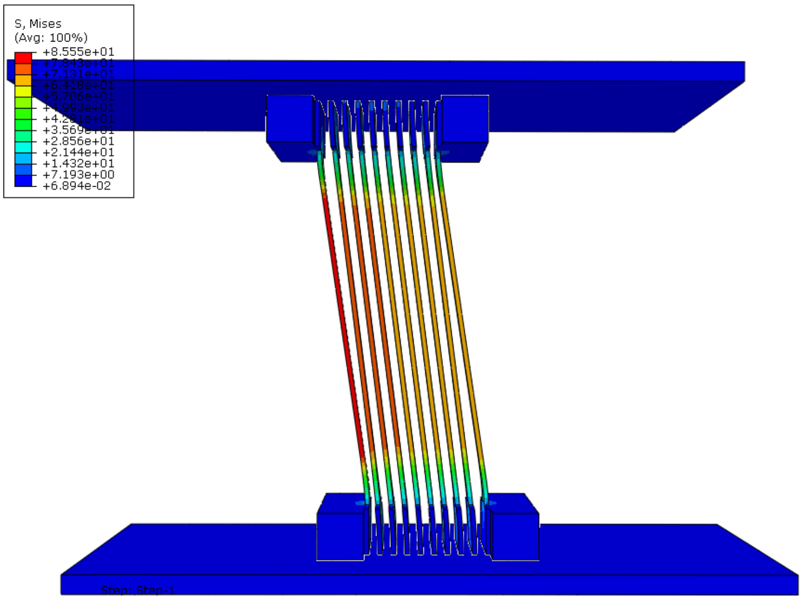

Figure 19. The ADAS damper deformation that is illustrated individually

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According to Fig. 19, it is concluded that the damper deformation manner is anticlastic because two ends of the bending plates are fixed. A concave inflection point was formed in the middle of the plates. The deformation manner of the damper is similar to that of the experimental sample. There is good agreement between numerical and experimental results.

4.4 Comparison Between The Experimental And Numerical Pushover Curve

A comparison was made between the pushover curves of experimental samples and those of numerical samples in this section. For the comparison of pushover curves, the samples explained in the previous section were selected. Fig.s 20 to 22 show the pushover curve of the concrete frame, concrete frame with the brace, and concrete frame with the ADAS damper.

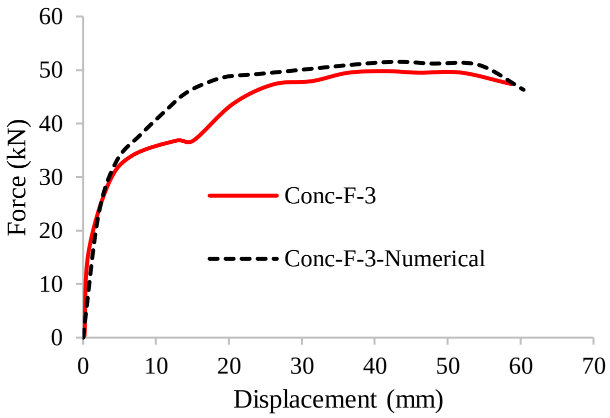

Figure 20. Pushover curve of the concrete frame

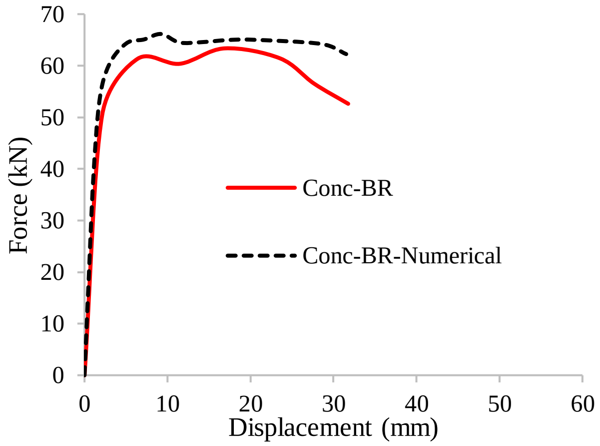

Figure 21. Pushover curve of the concrete frame with the brace

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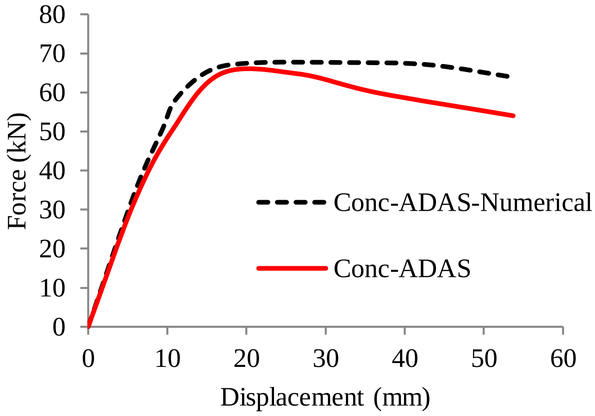

Figure 22. Pushover curve of the concrete frame with the ADAS damper

The concrete samples after the maximum strength show softening behavior with strength and stiffness drop. Due to the presence of hair cracks and wide cracks, the strength drop is higher in the upper cycle. Compared to other samples, retrofitted samples with bracing have a higher strength because they have a higher yielding threshold. This strength is reduced due to local buckling of the brace and cracks in the connection joint between the gusset and beam. The damper yielded at lower displacements and forces in samples with the ADAS damper, and the force increased as displacement was increased. The hardening behavior was caused by the activation of the damper and the use of steel strain hardening. The curve behavior with the damper has sufficient strength and stiffness. Table 5 shows all the specifications of the models.

Table 5. shows all the specifications of the models

sample	Yield displacement (mm)	Maximum displacement (mm)	yield strength (kN)	Maximum strength (kN)	stiffnes (kN/mm)
Conc-F-1	11.1	57.93	29.12	40.88	2.62
Conc-F-2	10.6	57.9	32.13	47.59	3.03
Conc-F-3	9.03	56.62	34.23	49.17	3.79
F-1-BR	9.3	31.81	66.43	60.75	7.14
F-2-BR	9.8	33.11	61.33	63.91	6.26
F-3-BR	9	30.08	62.55	65.85	6.95

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F-1-ADAS	9.13	48.82	42.21	57.31	4.62
F-2-ADAS	8.5	51.89	45.67	60.85	5.37
F-3-ADAS	8.6	63.4	57.21	63.72	6.65

According to Table 5, it can be seen that the structure reinforced with braces as well as the structures with braces and yielding dampers have increased hardness and strength characteristics. The highest increase is for models with braces and dampers. The stiffness of the F-1-BR brace structure is 2.72 times higher than the similar sample, i.e. Conc-F-1. In general, the stiffness of structures with braces has increased by 1.83 to 2.72 times compared to models without braces. In structures with braces and dampers, the highest level of stiffness in the F-2-ADAS model has increased by 1.76 compared to the unreinforced model. The hardness of structures with braces and dampers is 1.75 to 1.77 times higher than the similar model. Regarding the yield stress and final stress, it can be seen that the structure sample reinforced with braces in the F-1-BR model had the highest yield stress and, in the F-3-BR model, the final stress was higher than the control sample. The range of the yield stress ratio for the model reinforced with braces is 1.83 to 2.28 times that of the control sample, and the ultimate stress for the model reinforced with braces is 1.33 to 1.49 times that of the control sample. The range of the yield stress ratio for the model reinforced with braces and dampers is 1.42 to 1.67 times that of the control sample, and the ultimate stress for the model reinforced with braces is 1.29 to 1.4 times that of the control sample.

Table 6 shows the maximum strength of numerical and experimental samples. As shown in the table, the difference between the strength of the sample is negligible.

Table 6. Comparison between the maximum strength of experimental and numerical samples

Sample	**Maximum** (**kN**) **experimental strength**	(**kN**) **Maximum numerical strength**	**Difference** (%)
Conc-F-3	49.17	51.46	4.6
F-3-BR	65.85	66.14	0.4
F-3-ADAS	63.76	66.23	3.9

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4.5 Parametric Study Of The Numerical Samples

In the following, the behavior of the frame with the damper under some parameters of the damper is investigated. In this section, the thickness of the damper's plates is 1, 2, 3, and 4 mm, and the number of the damper's plates is 6, 8, 10, and 12. Samples were compared based on the results of pushover analyses. In the comparison process, the concrete frame and reinforcement are similar in all states. Ten plates with 2-mm thickness were verified for the sample before deformations, and their curves were investigated.

4.5.1 The Impact Of Damper's Plates

Fig.s 23 up 25 show the Von Mises stress distribution in the frame with 1-, 3-, and 4-mm thicknesses. The deformation of the thickness of the plates does not affect the general stress distribution in the frame. Fig.s 26 up 28 show the ADAS damper deformation incorporated in the frame.

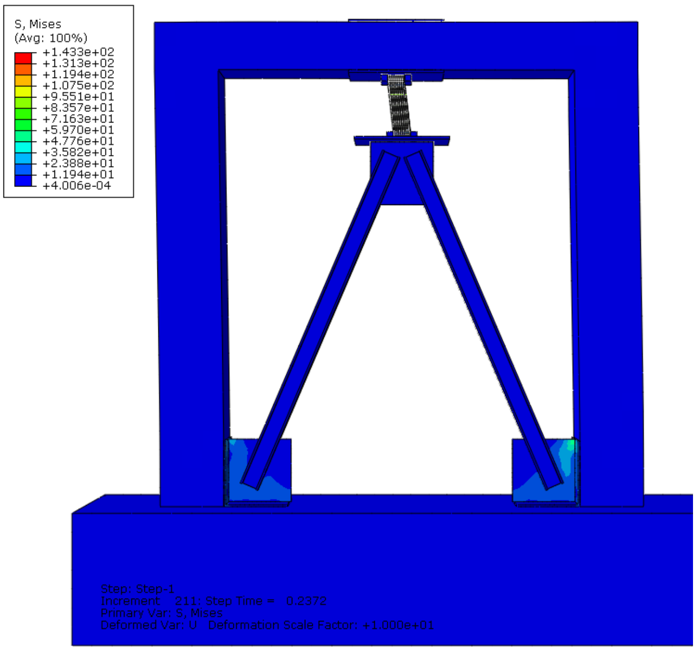

Figure 23. Tensile cracks in the frame with damper with 1 mm of thickness

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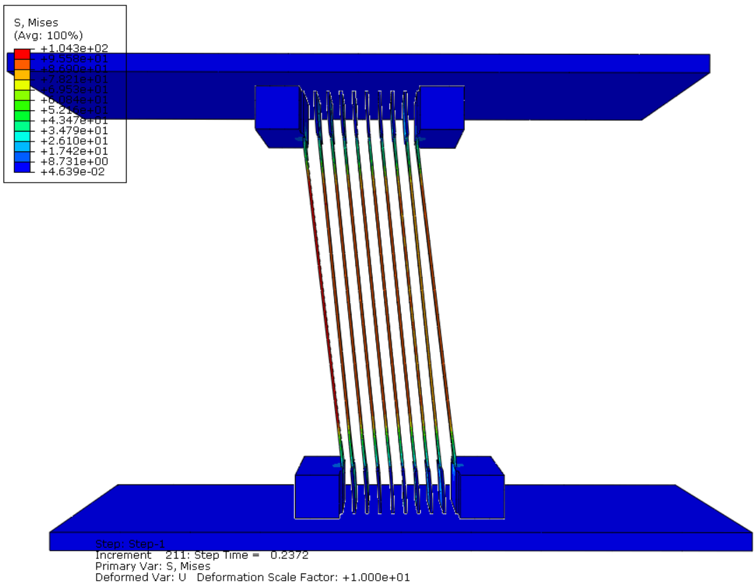

Figure 24. The ADAS damper deformation with 1 mm of thickness

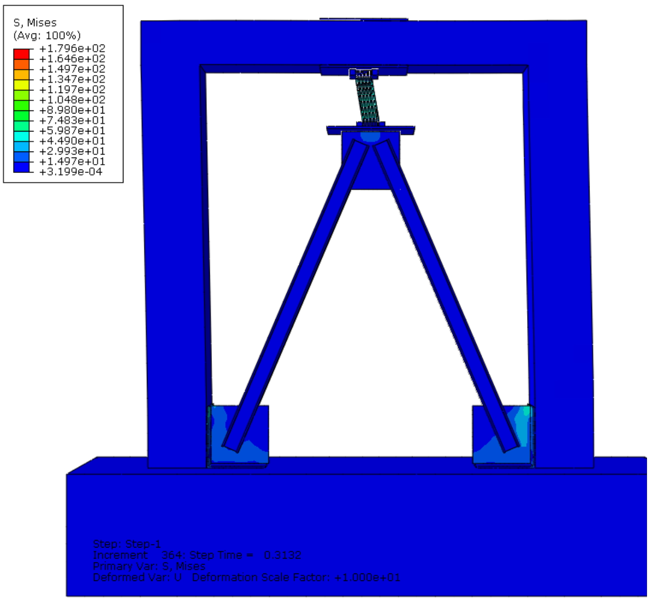

Figure 25. *Tensile cracks in the frame with damper with 3 mm of thickness*

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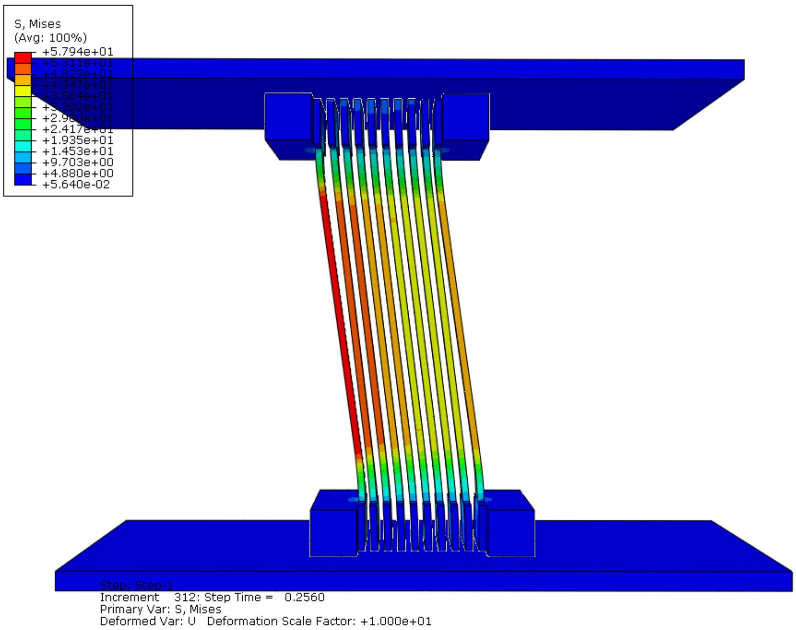

Figure 26. The ADAS damper deformation with 3 mm of thickness

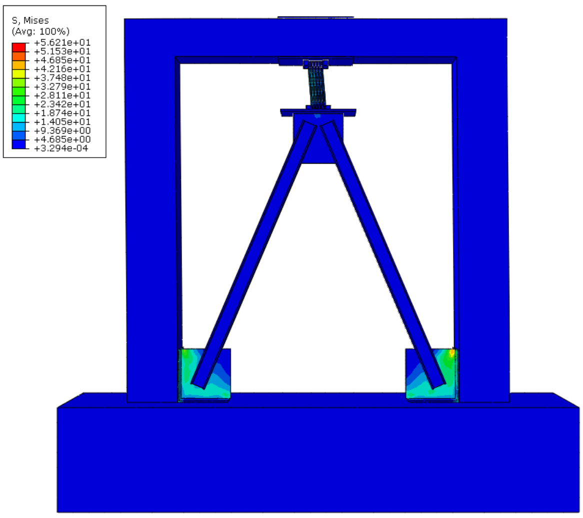

Figure 27. Tensile cracks in the frame with damper with 4 mm of thickness

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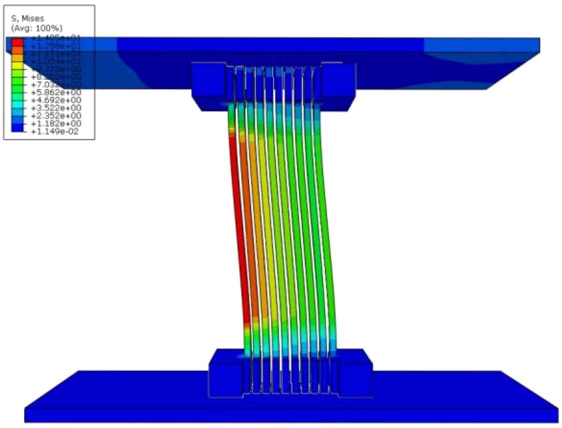

Figure 28. The ADAS damper deformation with 4 mm of thickness

The plate's deformation manner is double-curved because both ends of the damper are fixed, and plates cannot rotate. Fig. 29 shows the pushover curve of dampers with different thicknesses.

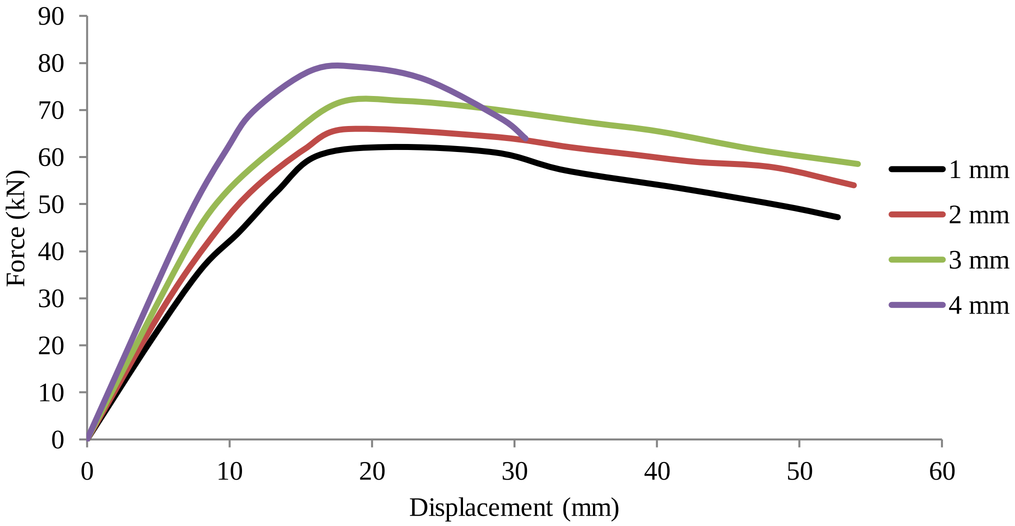

Figure 29. The pushover curve of the frame with the ADAS damper and different plate thicknesses

According to the push-over diagram in Fig. 29, it can be seen that in the displacement of 10 mm the force applied to the frame with a different plate thickness of 1 to 4 mm is 40, 45, 50 and 60 kN, respectively. According to these results, it observed that frames with 4 mm

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thickness at a displacement of 10 mm by 50%, a plate with a thickness of 3 mm by 25% and a plate with a thickness of 2 mm by 12.5% more than the concrete frame with the plate is 1 mm thick. This ratio for the displacement of 20 mm, the force applied to different frames with different plate thicknesses has been obtained as 62, 66, 71.5 and 79 kN, therefore, in this amount of displacement from the studied frames, respectively, for the frame with thickness 4, 3, and 2 mm plates are 28, 16, and 7 percent more than a frame with 1 mm plate thickness, respectively. In displacement of 30 mm, this percentage for frames with thickness of 4, 3, and 2 mm is 3, 7, and 3 percent, respectively, compared to the frame with a plate thickness of 1 mm.

According to Fig. 29, the plate thickness variations affect the stiffness and strength of the frame with the damper directly. The strengths of the frame are 62.16, 63.76, and 72.6 KN with 1-, 2-, and 3-mm thicknesses, respectively. Increasing the thickness from 1 to 2, from 1 to 3, and from 1 to 4 mm, has increased the strength by about 2.6, 16.83, and 27%, respectively. As shown in the Fig., the strength of the sample with a 4-mm plate is 79 KN. However, its behavior is not appropriate because it experiences a large strength decline after a slight deformation following the maximum strength.

4.5.2 The Impact Of Damper's Plates Numbers

Fig. 30 up 32 show the stress distribution in concrete frames with the ADAS damper with 6, 8, and 12 plates. Fig.s 33 up 35 show the deformation of the ADAS damper.

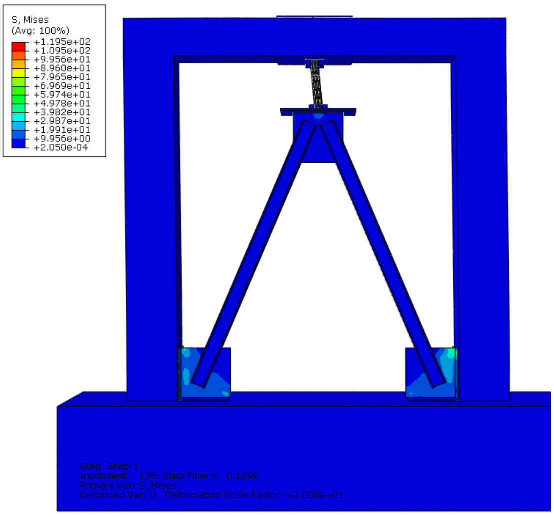

Figure 30. Tensile cracks in the frame with damper with 6 bending plates

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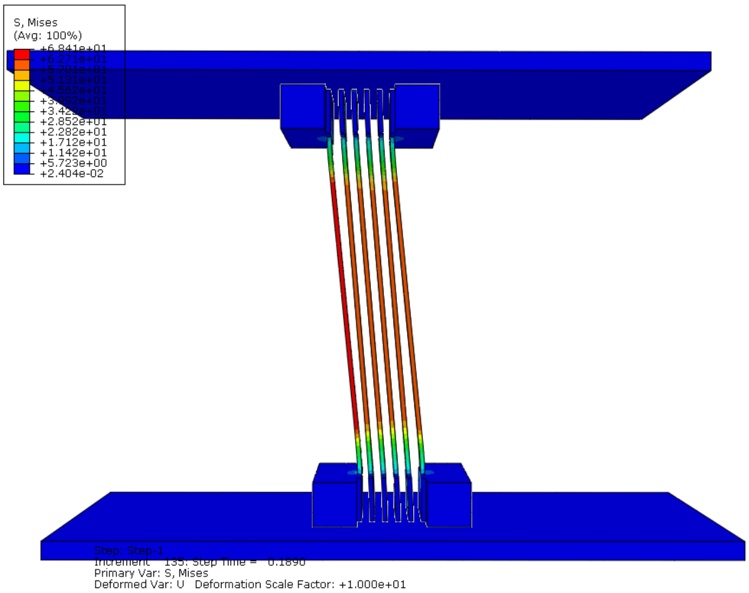

Figure 31. Deformation of the ADAS damper with 6 bending plates

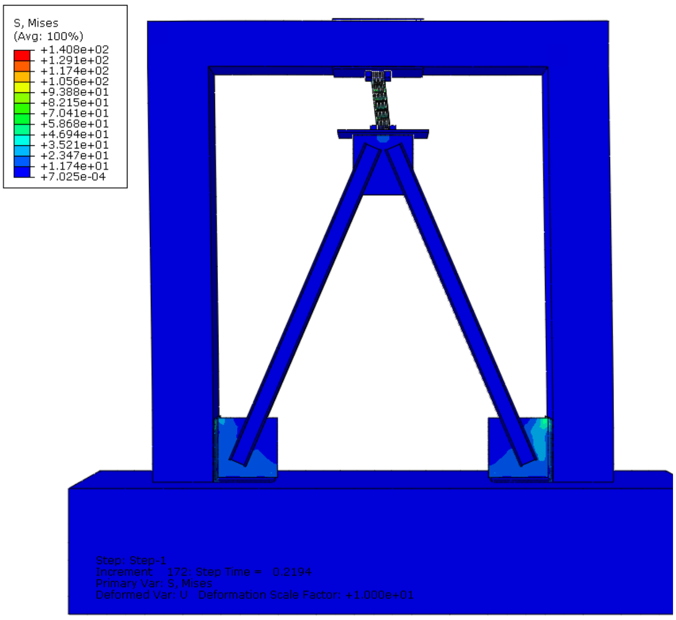

Figure 32. Tensile cracks in the frame with damper with 8 bending plates

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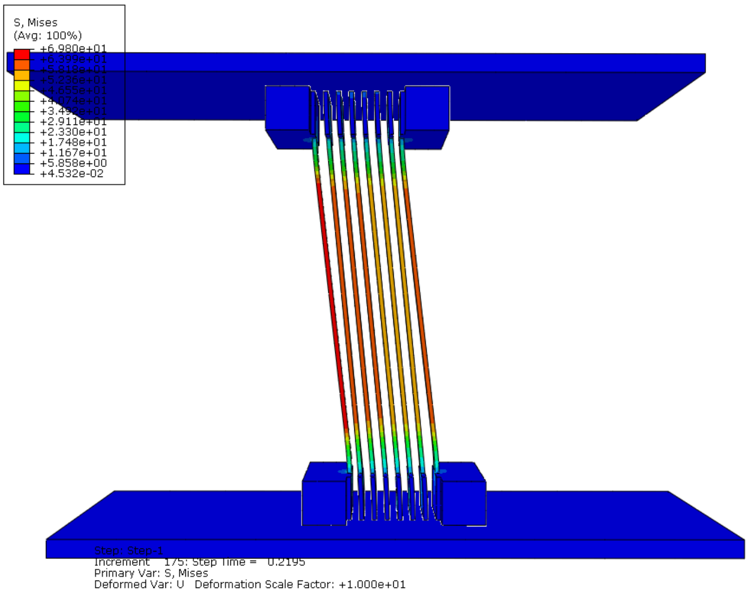

Figure 33. Deformation of the ADAS damper with 8 bending plates

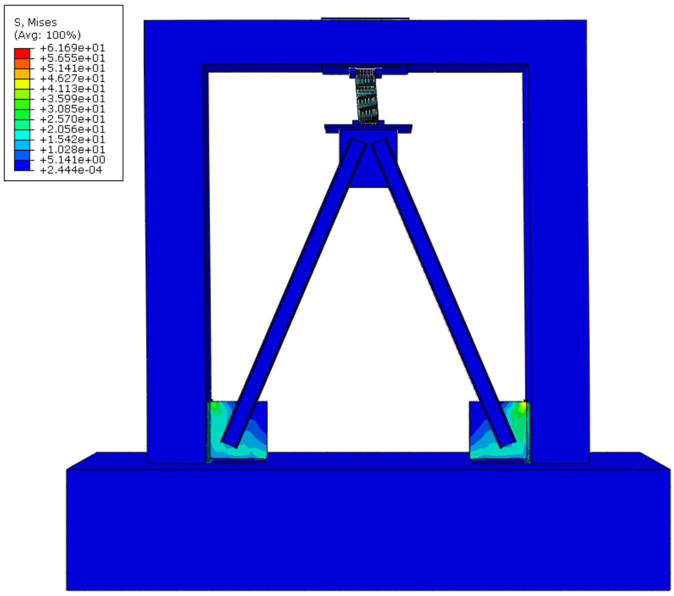

Figure 34. Tensile cracks in the frame with damper with 12 bending plates

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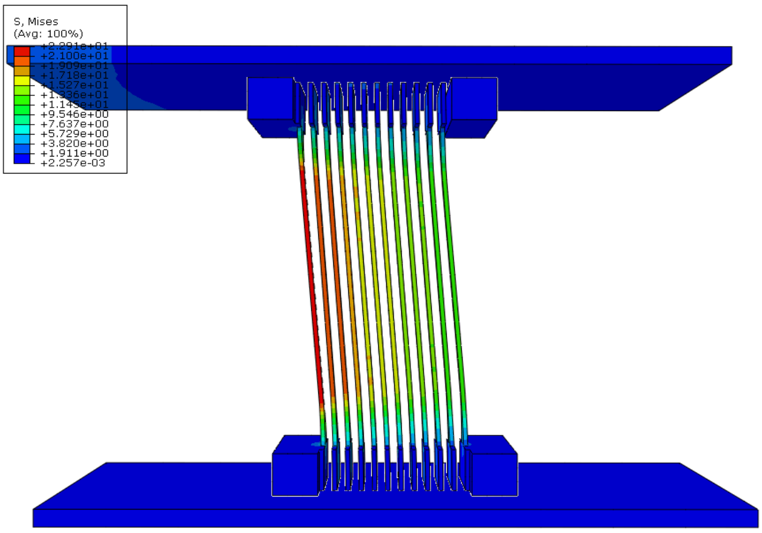

Figure 35. Deformation of the ADAS damper with 12 bending plates

In this case, the thickness of the plates remained at 2 mm, and only their numbers varied. The damper deformation manner and the stress distribution do not affect the damper and concrete frame. Fig. 36 shows the pushover curve of the concrete frame with different numbers of the damper's plate.

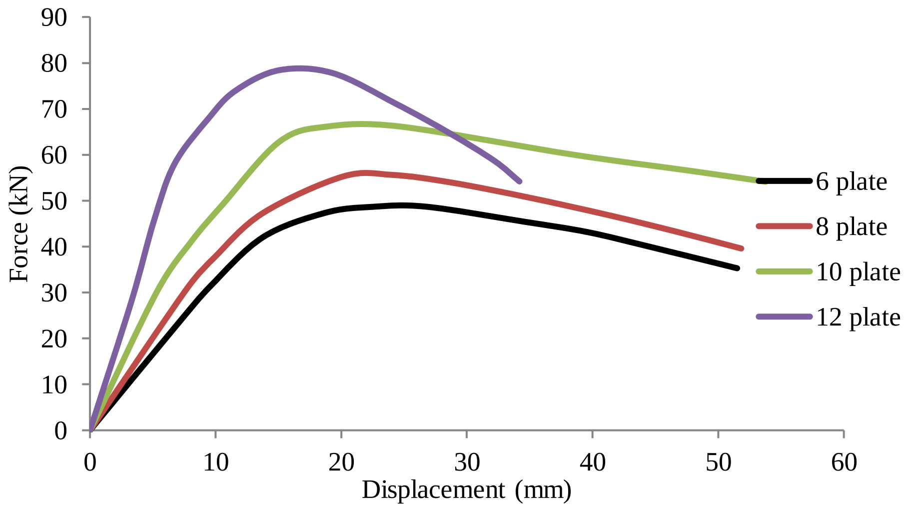

Figure 36. The pushover curve of the concrete frame with the ADAS damper with different numbers of bending plates

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According to the push-over diagram in Fig. 36, it can be seen that in the displacement of 10 mm the force applied to the frame with a different plate thickness of 1 to 4 mm is 31, 38, 49 and 68 kN, respectively. According to these results, it observed that frames with 4 mm thickness at a displacement of 10 mm by 119%, a plate with a thickness of 3 mm by 58% and a plate with a thickness of 2 mm by 22.5% more than the concrete frame with the plate is 1 mm thick. This ratio for the displacement of 20 mm, the force applied to different frames with different plate thicknesses has been obtained as 47, 55, 66 and 78 kN, therefore, in this amount of displacement from the studied frames, respectively, for the frame with thickness 4, 3, and 2 mm plates are 66, 40, and 17 percent more than a frame with 1 mm plate thickness, respectively. In displacement of 30 mm, this percentage for frames with thickness of 4, 3, and 2 mm is 38, 38, and 11 percent, respectively, compared to the frame with a plate thickness of 1 mm.
Increasing the number of bending plates results in increasing the stiffness and strength of the concrete frame with the damper. The strength of the frame with 6, 8, and 10 bending plates is equal to 50.59, 55.31, and 63.76 KN, respectively. The increasing number of plates from 6 to 8, 6 to 10, and 6 to 12 increased the strength by about 9.33, 26.30, and 54%, respectively. The frame equipped with the damper with 12 plates has 78 KN strength, which is significantly larger than other samples. However, a significant loss occurred in samples after the maximum strength. The ductility of these models makes them unsuitable for usage in modeling.

5. Conclusion

In this research, a numerical study was conducted on the behavior of concrete frames, frames with steel bracing, and concrete frames with the ADAS damper. Also, frame cracking, Von Mises stresses in the brace and damper, and their pushover behavior was studied. Modeling was conducted in ABAQUS software. In this software, the results of experimental studies were verified by using modeling tools.
Based on the results:
1- In order to approximate the cracking behaviors of samples to an acceptable level, numerical modeling can be used. It is achieved by trial and error in the modeling, material module, meshing, interactions, and constraints on the sample. It can reduce experimental costs significantly.
2- The verification showed that the difference value for the concrete frame, frame with steel bracing, and frame with the ADAS damper was 4.6, 0.4, and 3.9%, respectively.
3- Changing plate thickness directly affects the stiffness and strength of the damper with damper. The strengths of the frame are 62.16, 63.76, and 72.6 KN with dampers with 1-, 2-, and 3-mm thicknesses, respectively. Increasing the thickness from 1 to 2, from 1 to 3, and from 1 to 4 mm, has increased the strength by about 2.6, 16.83, and 27%, respectively.

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4- Increasing the number of bending plates results in increasing the stiffness and strength of the concrete frame with the damper. The strength of the frame with 6, 8, 10, and 12 bending plates is equal to 50.59, 55.31, 63.76, and 78 KN, respectively. The increasing number of plates from 6 to 8, 6 to 10, and 6 to 12 increased the strength by about 9.33, 26.30, and 54%, respectively.
5- The range of the yield stress ratio for the model reinforced with braces is 1.83 to 2.28 times that of the control sample, and the ultimate stress for the model reinforced with braces is 1.33 to 1.49 times that of the control sample. The range of the yield stress ratio for the model reinforced with braces and dampers is 1.42 to 1.67 times that of the control sample, and the ultimate stress for the model reinforced with braces is 1.29 to 1.4 times that of the control sample.
6- The owner can clearly know the economic benefits of the retrofitting under different earthquake intensities. The retrofitting also causes the frame to have reduced environmental problems (such as carbon emission) compared to the original frame in the repair process after a rare earthquake happens.

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