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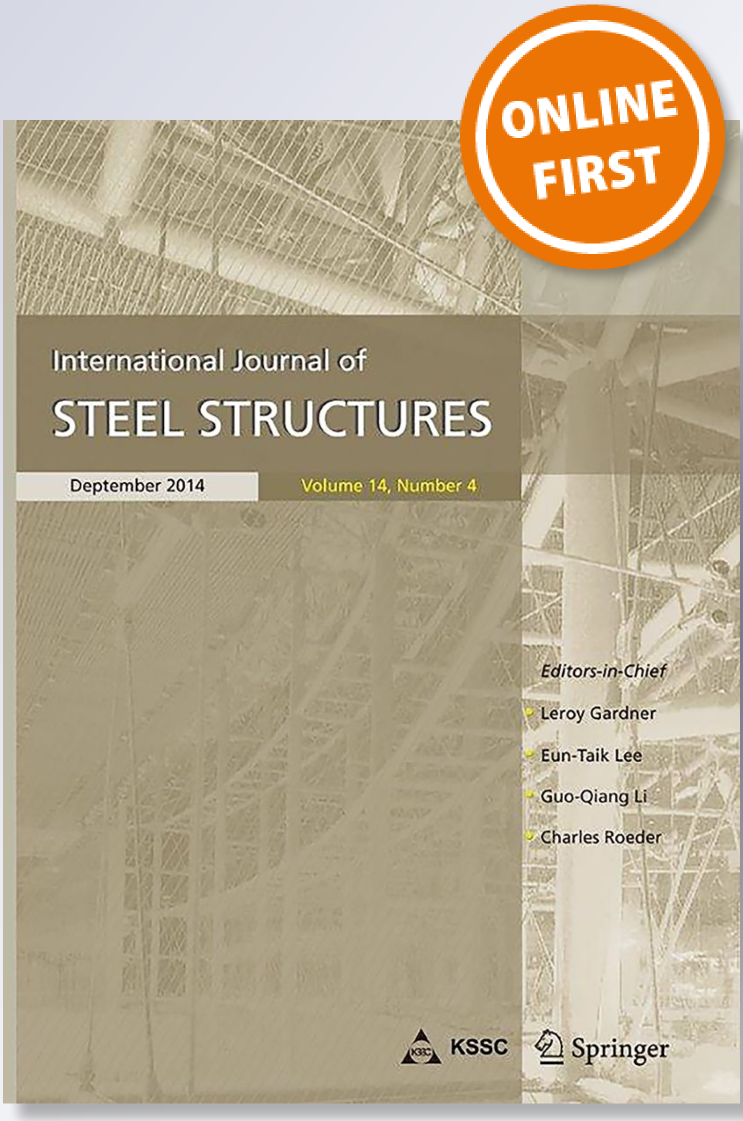

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Experimental and Numerical Investigation of Steel Moment Resisting Frame with U-Shaped Metallic Yielding Damper

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Abstract

This study introduces U-shape metallic yielding damper (UMYD) as an energy dissipation system. This damper may be used as a replaceable and cost-effective tool and fuse in structural frames to improve lateral ductility, energy absorption and damping of structural systems under earthquakes. A series of static cyclic tests were conducted in order to examine the performance of UMYD and the response of force-displacement, lateral strength, elastic stiffness and energy absorption were achieved. Finite element numerical studies were conducted through changing damper geometrical parameters. Mathematical model was presented to estimate elastic stiffness of damper and was compared with numerical specimen results, which acceptable conformity. Finite elements models indicated that UMYD abilities energy absorbability in large displacements without loss of strength and stiffness, which may be a proper complementary system for lateral load-bearing systems. The behaviour of two 4- and 8-storey steel frames with moment resisting frame system was analysed under four different earthquakes under two states of with and without damper. The seismic performance of frames was analysed with respect to floors inter-storey drift, frame base shear and floors shear. The non-linear time historey analysis results demonstrated that 8-storey frame without UMYD failed to maintain the structure performance level within life-safety level, whilst under all states using damper, performance level remained within such level and a decrease in floors shear and inter-storey drift was observed.

Keywords U-shaped damper · Elastic stiffness · Dissipated energy · Steel moment resisting frame · Life safe level · Base shear

1 Introduction

Seismic design of building structures is based on inelastic behaviour of some of structural elements due to earthquakes. Using of dampers in pre-determined locations of building may concentrate and dissipate the input energy there, which results in prevention of inelastic behaviour in the main load bearing elements. Dampers absorb imposed energy and in some cases, which yielded under severe quakes, may easily be replaceable (Ebadi Jamkhaneh et al. 2018; Ebadi Jamkhaneh and Kafi 2018a, b; Ahadi koloo et al. 2018). Metallic-yielding damper (MYD) is one of the effective energy dissipating systems. The idea of using these dampers in structures commenced by experimental work by Kelly et al. (1972) and Skinner et al. (1974). They tested and introduced simple steel tools as energy absorption tools. U-shaped steel strips were from amongst these tools. The results of the tests demonstrated that U-shaped strips may act within high deformation range and enable energy absorption through steel strip plastic deformation. After a couple of years, studies were conducted on U-shaped tools behaviour by Aguirre and Sanchez (1992) through cyclic tests. Complementary studies on these dampers were conducted by Dolce et al. (1996) to make practical. They fulfilled experimental and numerical works on U-shaped tools by circular arrangement as tools for inactive control purposes of structures. Deng et al. (2013) tests dampers composed of two U-shaped plates usable as isolator in bridge. Appropriate

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behaviour of these tools together with simple design and easy implement of these U-shaped strips as seismic isolator was one of their important results. Bagheri et al. (2015) comparatively studied the seismic behaviour of braced frames with yielding and friction dampers. The results of the study showed that friction damper performance is a little better than the yielding damper in decreasing maximum base shear of frames.

Another type of yielding damper is steel ring. Steel rings also are innovatively utilized in the off-center braces and their performance are assessed in terms of ductility and energy dissipation. Bazzaz (2010), Bazzaz et al. (2011a, b, 2012, 2014, 2015a, b) and Andalib et al. (2010,2011,2014,2018) studied the performance of steel ring as an energy dissipator member.

The aim of this study is to assess the performance of U-shaped MYD in steel frames in numerical and experimental states. U-shaped MYDs are subject to cyclic loading and fatigue tests through experimental case and further parametric study is conducted by taking benefit from finite element method (FEM). Then, these dampers are used in two 4- and 8-storey moment frame and seismic behaviours of these frames are compared with each other using with and without damper under non-linear time historey analysis.

2 Experimental Studies

An experimental study was conducted to examine the behaviour of U-shape yielding dampers under cyclic loading. The purpose of this experimental study includes determining cycles bearable by damper, determining mechanical characteristics of damper and collecting data for numerical models validation.

The main purpose of these experiments is to determine the behaviour of the behaviour of dampers under cyclic loading. Also, according to the maximum lateral displacement of the damper, determine the number of cycles and failure of the material. Other purposes of this research are seismic performance evaluation and determination of the capacity of the moment frames equipped with a passive control system.

2.1 Material Properties and Specimen Features

Two dampers (UD1 and UD2) with the details given in Fig. 1a have been used to determine the behaviour of metal yielding dampers hysteretic behaviour. Specimen UD1 have a thickness equal with 10 mm and specimen UD2 have a thickness equal with 12 mm. The length (L) of UD1 and UD2 are 100 and 150 mm. The parameters of B and D are 190 and 113 mm for both specimens. The radius of the curved portions used in the specimens UD1 and UD2 is 56.5 mm. The plates were made of structural steel material conforming to ASTM A653 (ASTM International

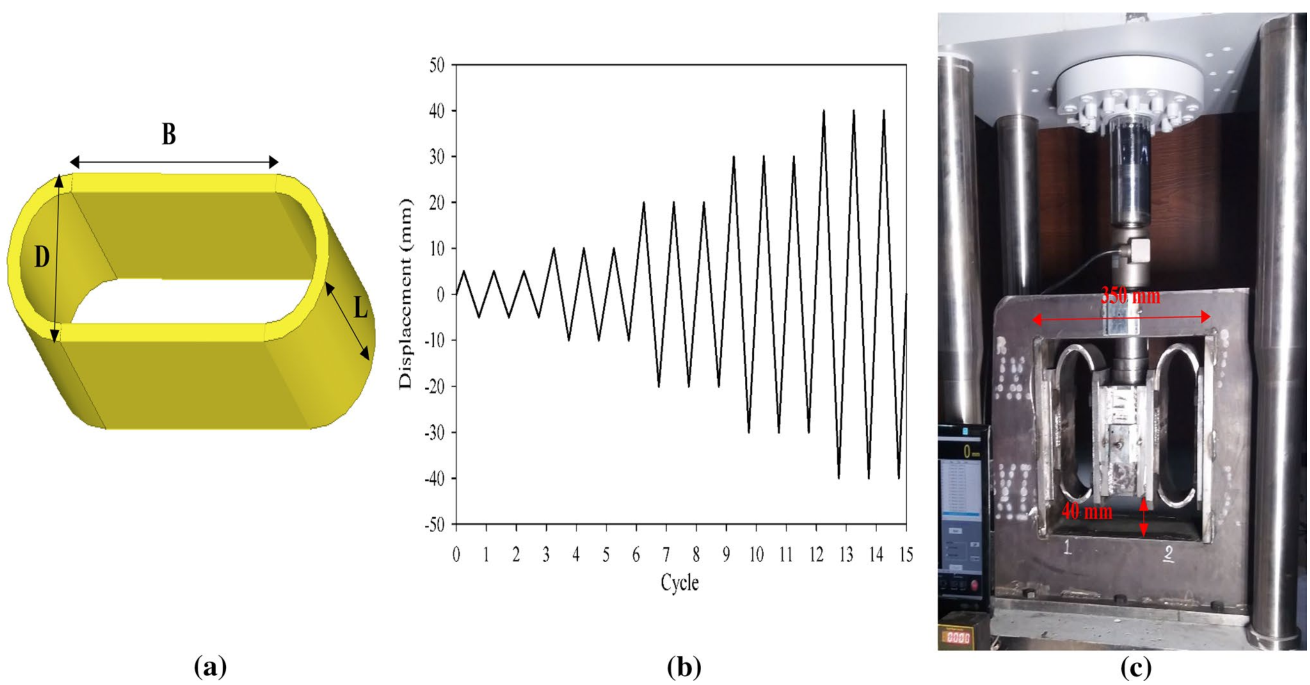

Fig. 1 Schematic view of the damper: **a** geometrical parameters, **b** loading protocol, and **c** experimental test setup using uni-axial testing machine

Table 1 Material properties of steel plates

Coupon test no.	Yield stress (MPa)	Ultimate stress (MPa)	Modulus of elasticity (GPa)	Yield strain (με)	Hardening strain (με)	Rupture strain (με)
1	257	389	201	1951	18,900	370,000
2	249	373	199	1868	23,200	340,000
3	256	369	202	1903	19,200	333,000

2008) (Grade 255) with a galvanized coating for all sheet thicknesses. Three tensile coupon tests were conducted for 10 mm thick sheet used for the specimens based on ASTM A370-97a (1997) Standard. The base metal material properties are given in Table 1 that obtained from tensile material tests.

In order to construct each damper, two sheets with length of 367.5 mm were used that each sheet being converted to a U-shaped sheet after cold bending method. Thus, the total length of the sheet used for each damper is 735 mm and with a width of 100 mm and 150 mm. After co-inserting two U-shaped sheets, 30 mm of the direct-sided parts of the two sheets were connected to the support by weld.

The applications of these dampers are in moment resisting, bracing and dual frame systems with shear walls. These dampers are used at the intersection of braces with a beam (in the Chevron braces) and at the intersection of the brackets by connecting the beam to the column (in diagonal braces). Also available in concrete and steel shear walls. In these systems, it is installed at the corner of the wall and the beam or on top of the wall to act as a passive control system along with the main lateral load-bearing system.

2.2 Test Setup and Loading Protocol

In Fig. 1c, the method to establish dampers' system and test has been shown. Two U-shaped sheets were placed and welded to two lateral plates (length = 60 mm) for preventing the out of deformation and twisting of plates. The specimens were exposed to cyclic loading through applying axial displacement without any outward deformation. Two U-shaped sheets are placed in front of each other by means of a rigid part and connected to the hydraulic jack to apply the cyclic loading pattern. One side of each damper is connected to the middle rigid link and the other side is attached to the body of the device with weld method. Maximum displacement is 40 mm. The loading protocol shown in Fig. 1b was used for specimens' cyclic non-linear static testing. This pattern was designed to control displacement and includes big cycles with increasing amplitude from 5 to 40 mm. Also, fatigue test was conducted on specimens with an amplitude of 40 mm and for 80 cycles to determine the position of fracture on sheets and maximum cycles.

3 Test Results and Discussion

Figure 1b indicates UD1 specimen during the test. The specimen is subjected to compressive and tension loading as displacement control method by testing machine to apply deformation of specimen. The sheet is deformed through rolling upon exerting force along the damper plane. Due to the loading, the failure of the damper sheet occurs in the area of the curvature of the sheet from the direct part that is in contact with the support. This can be attributed to the creation of a cold sheet bending method and a local weakness of the sheet in that section.

Figure 2 shows force-displacement response of two UD1 and UD2 specimens under cyclic loading model with respect to Fig. 1. These specimens showed sustainable behaviour with symmetric hysteretic loops with strain hardening behaviour after yielding. Additionally, the specimens did not show any loss in strength and stiffness within the entire loading process. The pinching effect was not seen in hysteretic loops and the general shape of loops expresses the fact that the U-shaped damper tool is completely proper as energy absorption system. It may be understood the cyclic curves that the maximum force and initial elastic stiffness of UD1 damper are equal to 65.8 kN and 10 kN/mm, respectively. Meanwhile, values of maximum force and initial elastic stiffness for UD2 were resulted as 91.3 kN and 9.8 kN/mm, respectively.

In Fig. 2c,d, the hysteretic curve resulted from the fatigue test on the specimens has been shown. It was known upon conducting fatigue test on the two specimens and exerting various cycles with 40 mm amplitude for UD1 and UD2 dampers, respectively, that the first and second specimens took 84 and 38 cycles, respectively. The mechanism of yielding and fracture of specimens was in 19th cycle a minor displacement occurred in the left bolt and then accompanied with sheet being torn at the beginning of camber in right damper and in further cycles, the weld of left damper was torn (Fig. 2e).

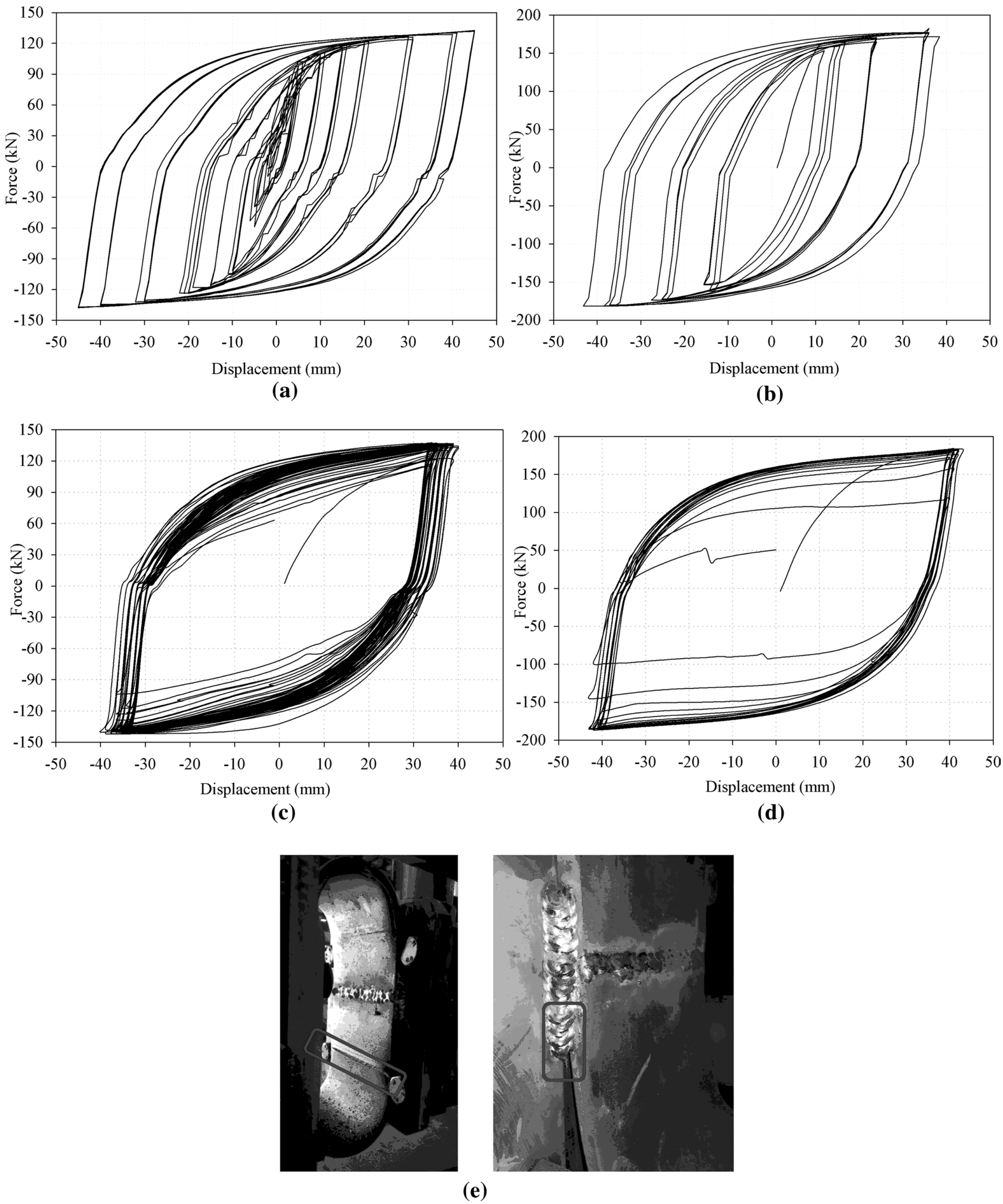

Fig. 2 Hysteresis loops of **a** UD1, **b** UD2 and fatigue test of, **c** UD1, **d** UD2, and **e** failure mode

4 Analytical Studies

Parametric studies were conducted to examine the UMYD performance, stress distribution along damper sheet and suggesting a practical formula to predict damper capacity. The effect of geometrical parameters on elastic stiffness, load-bearing capacity and energy absorption was studied, as well.

4.1 Numerical Models

A 3D model was generated based on finite element method in Abaqus (ABAQUS v6.14.2-2014) software for analytical studies. The material property and non-linear geometry were considered in numerical models. S4R element was utilized for damper numerical models. S4R element is a 4-node doubly curved thin or thick shell, reduced integration, hourglass control and finite membrane strains. Non-linear static analysis was conducted considering effect of large deformations. The real characteristics of steel material were obtained from tensile material tests. The von Mises yield criterion was considered as materials yield criterion. According to Fig. 3a, the bottom nods were constrained in all transmission and rotation degrees of freedom and the top nods of damper were constrained in all directions except for the direction of applying force. In this figure, used render shell thickness (scale 5) for idealization of original model that was form S4R shell elements.

Displacement control loading model was applied for cyclic tests in numerical models to simulate experimental models. On the other hand, quadratic elements with 30 mm dimensions in supporting areas and 5 mm in other areas were used for elements meshing. The comparison between

Table 2 Comparison of experimental results and computational analysis in specimen UD2

	Axial stiffness (kN/mm)	Ultimate compression strength (kN)	Dissipated energy (kJ)
Experimental model	10	87.3	6.4
FEM model	11.3	78.9	5.8
Variation (%)	+13	−9.6	−9.4

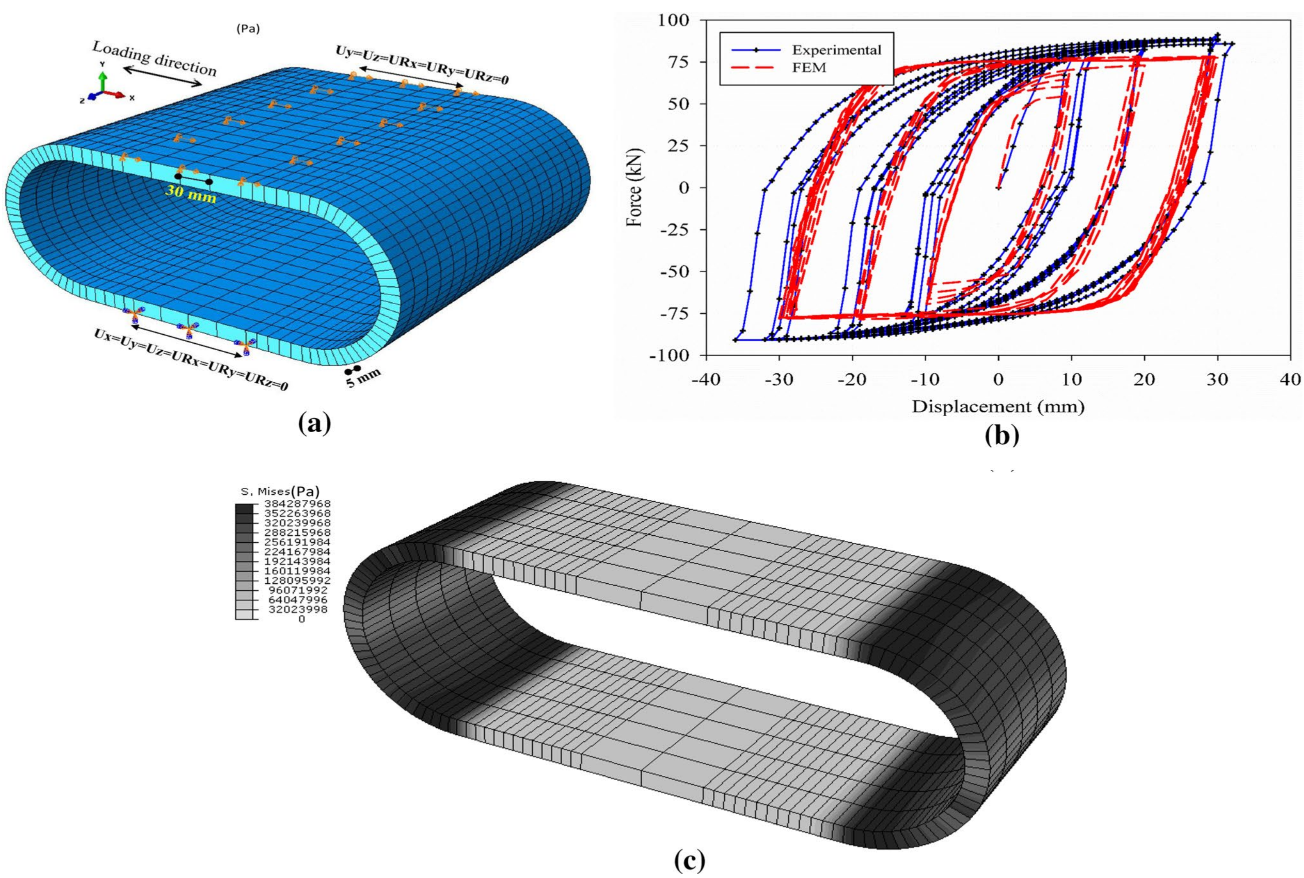

Fig. 3 **a** FEM model with boundary conditions and mesh sizing, **b** comparison of FEM and experimental model UD2, and **c** stress distribution of specimen UD2 under cyclic loading

numerical and experimental models results has been given in Table 2.

In Table 2, variation means the different between the results of FE and experimental models, indicated using positive and negative signs. Meanwhile, Fig. 3b shows that FE model hysteretic loops had a good accuracy with experimental result, which confirms the accuracy of numerical model for parametric studies. Figure 3c shows stress distribution due to von Mises criterion on damper plate. This figure indicates stress ratio in initial area of plate camber has achieved the yielding stress area. The yield area develops through applying further deformations across damper plate, to achieve its yield plastic strain and the plate is torn. This case approves high energy absorption in tested U-shaped damper deformation.

4.2 Parametric Studies

An extensive parametric study conducted on U-shaped dampers to examine the effect of geometrical parameters on mechanical features. The effect of thickness, width and length of damper on load bearing capacity, elastic stiffness and energy absorption were studied. In Table 3 the geometrical features of 12 numerical models have been given. In Fig. 4 the cyclic response of force-displacement of numerical models has been shown.

In Table 3 a comparison between the responses of numerical models has been completed. In Table 3, the changes of maximum force may be drawn with respect to length. According to these, such changes are linear and trend sustains linear trough entering materials into non-linear area. Therefore, the two following Eqs. (1) and (2) are suggested to predict maximum damper capacity for 10 mm and 12 mm thicknesses, respectively.

$$P = 0.04L - 0.1 \quad \mathrm{t} = 10\mathrm{mm} \tag{1}$$

$$P = 0.057L - 0.22 \quad \mathrm{t} = 12\mathrm{mm} \tag{2}$$

L denoted for length of damper in mm unit and unit of damper capacity (P) is Newton. These equations are for tensile strength of steel with a range between 250 and 280 MPa.

It may be expressed the results that through increasing the thickness from 10 to 12 mm, the maximum durable force by damper in all models increased 46% on average. On the other hand, energy absorption by damper with 12 mm thickness was roughly higher for 50% in comparison with damper with 10 mm thickness. Through increasing damper width from 100 to 150 mm, load bearing capacity has increased up to 50%. This is while by increasing width from 150 to 200 mm, such increase does not exceed 35%. This trend is also correct for energy absorption.

4.3 U-Shaped Damper Characteristic Formulation

Elastic stiffness is one of the most characteristics of dampers which are needed in the process of designing energy absorption systems. A mathematical model was applied to determine such characteristic based on materials mechanical principles. A semi-circular strip is suggested as per Fig. 5. By dispensing with effects of axial, shear and circumferential forces on stiffness and presuming small displacement, the displacement at the location to apply P force using unit load approach is found using Eq. (3):

$$\delta = \int \frac{Mm}{EI} dx \tag{3}$$

where M and m are bending moment under actual and unit load, respectively; also E is elasticity module and I is section moment of inertia. Therefore:

Table 3 Geometrical characteristics of numerical models

Specimen	t (mm)	L (mm)	D (mm)	B (mm)	Internal radius (mm)	Elastic stiffness (kN/mm)	Maximum strength (kN)	Yield displacement (mm)	Dissipated energy (kJ)
UD3	10	100	113	135	46.5	7.44	38	3.36	2
UD4	12	100	113	135	44.5	11.92	55.5	3.16	3
UD5	10	150	113	135	46.5	9.77	57.3	3.36	3
UD6	12	150	113	135	44.5	20.45	83.7	2.76	4.5
UD7	10	200	113	135	46.5	13.89	76.5	3.16	4
UD8	12	200	113	135	44.5	26.73	112.4	2.76	6
UD9	10	100	113	195	46.5	5.31	37	3.68	1.9
UD10	12	100	113	195	44.5	8.28	54.2	3.16	2.9
UD11	10	150	113	195	46.5	7.73	56.4	3.68	3
UD12	12	150	113	195	44.5	16.27	82.6	2.52	4.4
UD13	10	200	113	195	46.5	59.56	75.6	2.76	3.8
UD14	12	200	113	195	44.5	32.15	111.3	2.60	5.9

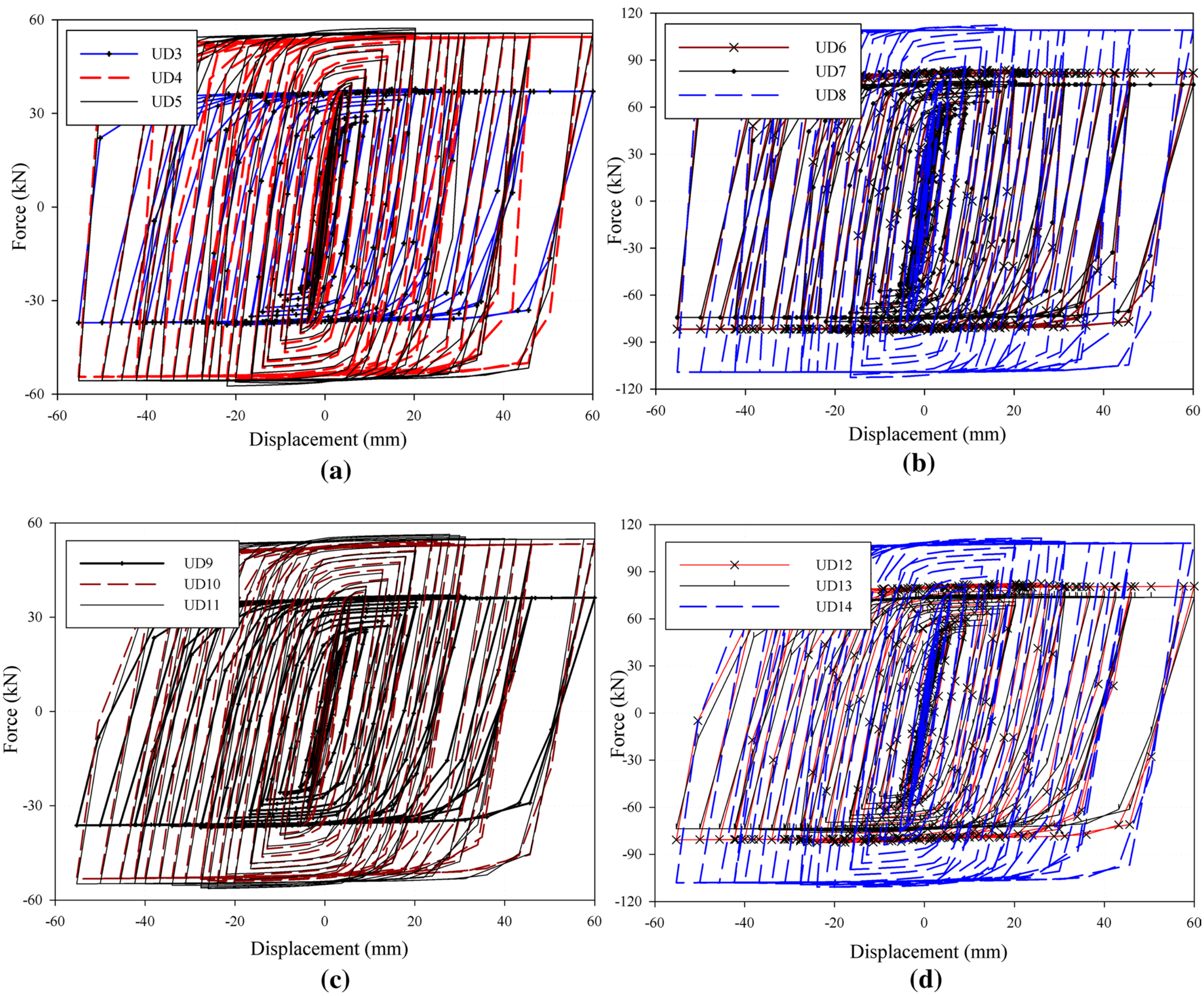

Fig. 4 Force-displacement response of dampers: **a** B135 mm; **b** B = 195 mm

$$\delta = \frac{PR^2}{EI}\int_0^{\pi}(1-\cos\theta)^2\,ds = \frac{PR^3}{EI}\left[\theta - 2\sin\theta + \frac{\theta}{2} + \frac{\sin 2\theta}{4}\right]_0^{\pi} = \frac{3\pi PR^3}{2EI} \quad (4)$$

R is internal radius of damper. Therefore, elastic stiffness is:

$$K = \frac{P}{\delta} = \frac{2EI}{3\pi R^3} \quad (5)$$

Considering geometrical characteristics, stiffness may be written as Eq. (6):

$$K = \frac{ELt^3}{18\pi R^3} \quad (6)$$

where L is damper width. In Fig. 5b, a comparison between figures of elastic stiffness found from mathematical and numerical models have been presented. As it is seen, there is a proper accuracy between the results of elastic stiffness found from mathematical and numerical models. The maximum and minimum differences between these two were 11% for UD3 specimen and 1.4% for UD5 specimen, respectively. Also, stiffness of UD1 and UD2 specimens based on Eq (6) are 3.5 and 9.2 (kN/mm) that there were 6% and 8% differences with test specimens.

5 Non-Linear Time Historey Analysis

Non-linear dynamic analysis was conducted in SAP 2000 (2014) software to examine the behaviour of relevant yield damper system. In order to do so, two 4- and 8-storey moment frame symmetric structures with the intermediate ductility were studied using three 7-m spans. The height of

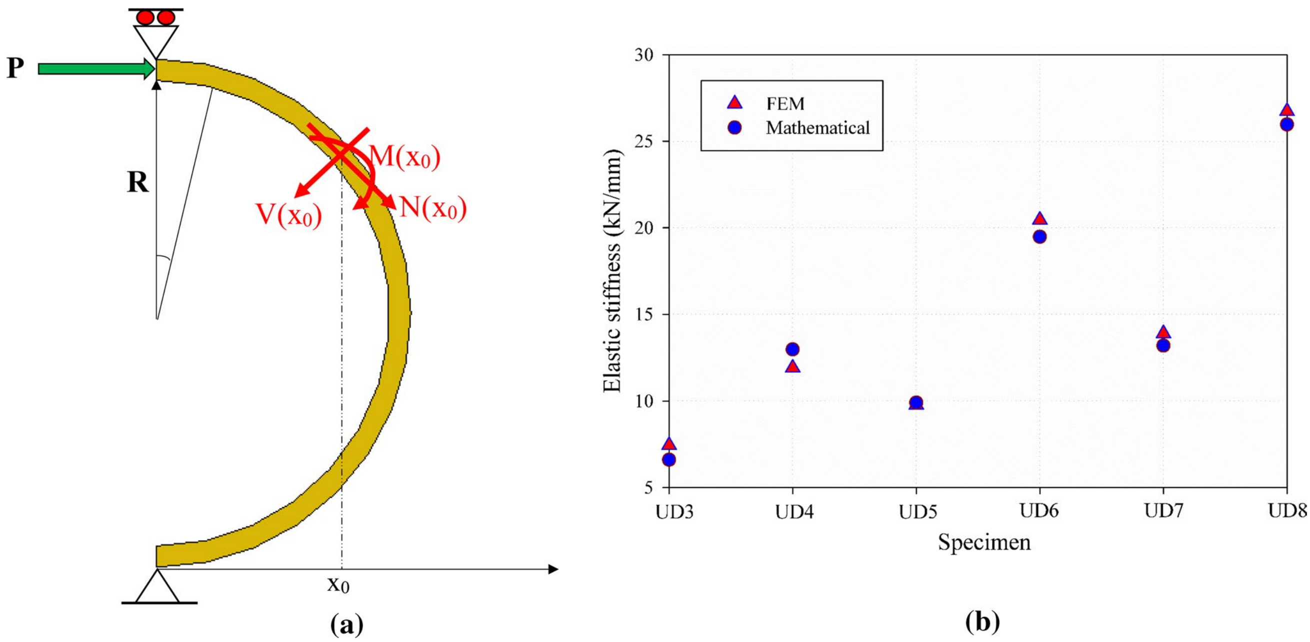

Fig. 5 **a** Mathematical model for a semi-circular strip and **b** comparison between elastic stiffness of FEM and mathematical results

all floors is equal to 3.5 m. In order to decrease analysis time, the models were analysed using 2D manner. After analysing and designing according to the AISC 360-10 (2010) guideline, the sections of two moment frame structures were achieved as per Table 4. In this table, C indicates to the first letter of column. Desingning of MYDs is based on a simple design method which is proposed based on the elastic–plastic response reduction curve by Shen et al. (2017). The detailed design procedures are given as follows:

Step 1: Obtain the capacity spectrum and the storey stiffness of the primary structure. A pushover analysis of the primary structure is carried out, and the relationship curves of the storey shear force and the storey drift are obtained.

Table 4 Column, beam and damper dimensions (Unit: mm)

Number of story	Story level	Column	Beam ($b_f \times h_w \times t_f \times t_w$)	Damper
4 story	1	C400-8	110×220×10×8	UD5
	2	C400-8	110×220×10×8	UD4
	3	C350-8	110×220×10×8	UD3
	4	C350-8	110×220×10×8	UD7
8 story	1	C500-15	140×300×12×8	UD8
	2	C500-15	140×300×12×8	UD8
	3	C500-12	140×300×12×8	UD14
	4	C500-12	140×300×12×8	UD14
	5	C500-12	120×240×10×8	UD6
	6	C500-12	120×240×10×8	UD12
	7	C300-10	100×200×10×8	–
	8	C300-10	100×200×10×8	–

Step 2: Determine the stories where the MYDs should be installed. The target structural performance point (TSPP) can be obtained according to the capacity spectrum and the design response spectrum, and then, the storey drift distribution di can be determined using the TSPP and the curve.

Step 3: Determine the parameters of the EPRRC. By using the energy equivalent method, the equivalent bilinear representation of the capacity spectrum associated with the TSPP is plotted, and the yielding point can be determined.

Step 4: Determine the yielding force of the MYDs.

Plastic hinges were assigned to the structural elements to allow for nonlinear behaviour of frame members. The nonlinear behaviour of the U-shaped damper was modelled with a bi-linear elasto-plastic shear spring with hardening. For this purpose, a nonlinear link element called Plastic Wen was used. This element has six degrees of freedom and for each degree of freedom one can specify independent uniaxial plasticity properties. Four earthquakes were selected for models non-linear dynamic analyses (Table 5).

The selected ground motions have different frequency contents and intensities and encompass a range from design basis earthquake (DBE) to maximum credible earthquake (MCE) for a site. The acceleration time histories of the mentioned earthquakes for 5% of critical damping are shown in Fig. 6. As it is further seen, the frames without yielding damper failed to bear severe quakes (Kobe and Northridge) and were further yielded. In fact, yielding in these frames occurred due to formation of plastic hinges in structural members and further frame non-stability occurred. However, adding dampers could assure frames stable. Two states

Table 5 Earthquake data for the parametric analysis

Earthquake motion parameters	Northridge (USA)	Kobe (Japan)	El Centro (USA)	Hachinohe (Japan)
Date of occurrence	1994	1995	1940	1968
Magnitude of earthquake, M_w	6.7	6.8	6.9	7.5
Maximum horizontal acceleration, (g)	0.843	0.834	0.349	0.231
Predominant period, T_p (sec)	0.36	0.36	0.56	0.22
Significant duration, $D_{5\text{–}95}$ (sec)	5.32	8.4	24.58	27.79
Time of MHA [t_p (sec)]	4.2	8.52	4.1	4.18
$^{PGV}/_{PGA}$ (sec)	0.157	0.112	0.102	0.146
Arias intensity (m/sec)	5.004	8.389	1.758	0.899
SIR (m/sec/sec)	1.903	1.407	0.117	0.037
Energy flux (J.m^{-2}.sec^{-1})	8560.187	7649.179	2144.177	2409.691
Type	Near field	Near field	Far field	Far field
Hypocentral distance (km)	9.2	7.4	15.69	14.1

$SIR = I_{a(5-75)}/D_{(5-75)}$

of ordinary frames with and without yielding dampers were exposed to ground motions and the responses of structure were compared with each other.

5.1 Lateral Displacements

In Fig. 7, a comparison is shown between the floor drift ratios in all the models without and with U-shaped damper under earthquakes of both near and far fields. Considering the results, the floor drift ratio for the strengthened frames was a little less than it was for the frames with intermediate moment resisting frame.

Performance levels were used to describe the state of the structures after being subjected to a certain hazard level, and those based on FEMA 273 (1997) were classified as fully operational, operational, life safe, near collapse, and collapse. Overall lateral deflection, ductility demand, and inter-storey drifts were the most commonly used damage parameters. Each of the five qualitative levels was related to a corresponding quantitative maximum inter-storey drift (as a damage parameter) as follows: $< 0.2\%$, $< 0.5\%$, $< 1.5\%$, $< 2.5\%$, and $> 2.5\%$, respectively.

The floor drift ratio charts show that the moment resisting frame system in a 4- storey low building managed to keep the structure within the life-safety region under both the near-field and far-field types of time histories. However, when the number of floors was increased from 4 to 8, it was seen that the structure with the moment frame system shown in the Kobe earthquake failed to remain in the life-safety region. By adding the U-shaped damper to the frames, the structure performance level was kept in the life-safety region. Considering these results, it can be inferred that the maximum storey drift ratio was generated with the near-field ground motion, and that such an effect was seen more often in mid-rise structures. Under Kobe earthquake, the maximum inter-storey drift ratio in 4- and 8-storey frame equipped with UMYD decreased for 22% and 16%, respectively. Also, the results of the analyses confirm that the application of U-shaped metallic dampers reduces not only roof displacements but also all storey displacements. The reduction was observed for almost all frames under four used earthquakes.

5.2 Base Shear and Storey Shear Forces

The analyses results demonstrated that 8-storey frame without damper yielded under two near fault ground motions, and they further managed to withstand all four earthquakes through adding U-shaped yielding dampers to frames and absorb entering energy through dampers. The maximum base shear forces for frames have been given in Table 6. Considering these tables, it is understood that the frames base shears for all frames equipped with U-shaped dampers decreased. Such reductions are between 18% and 35%. The chart of shear distribution of 4- and 8-storey normal structures equipped with damper has been given in Fig. 8 under Kobe earthquake. As it is seen in this figure, the floor shear forces in frames with yielding damper has decreased in comparison with normal frames. Such reduction has been observed for floor shear forces in all other models under various earthquakes. Therefore, U-shaped yielding damper is suitable in reducing base shear and floors shear forces.

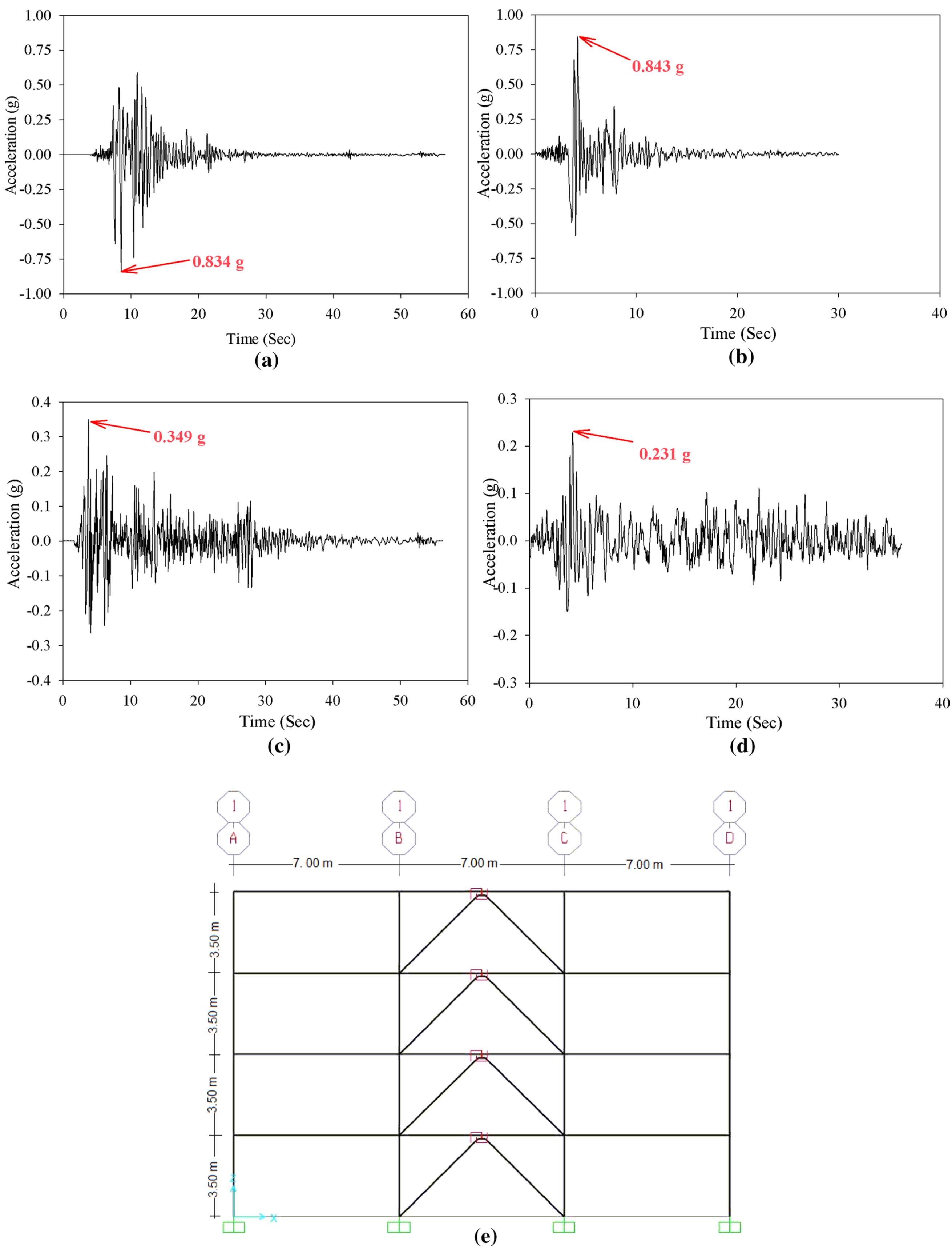

Fig. 6 Earthquake records: **a** Kobe, **b** Northridge, **c** El Centro, **d** Hachinohe and **e** MYD arrangements

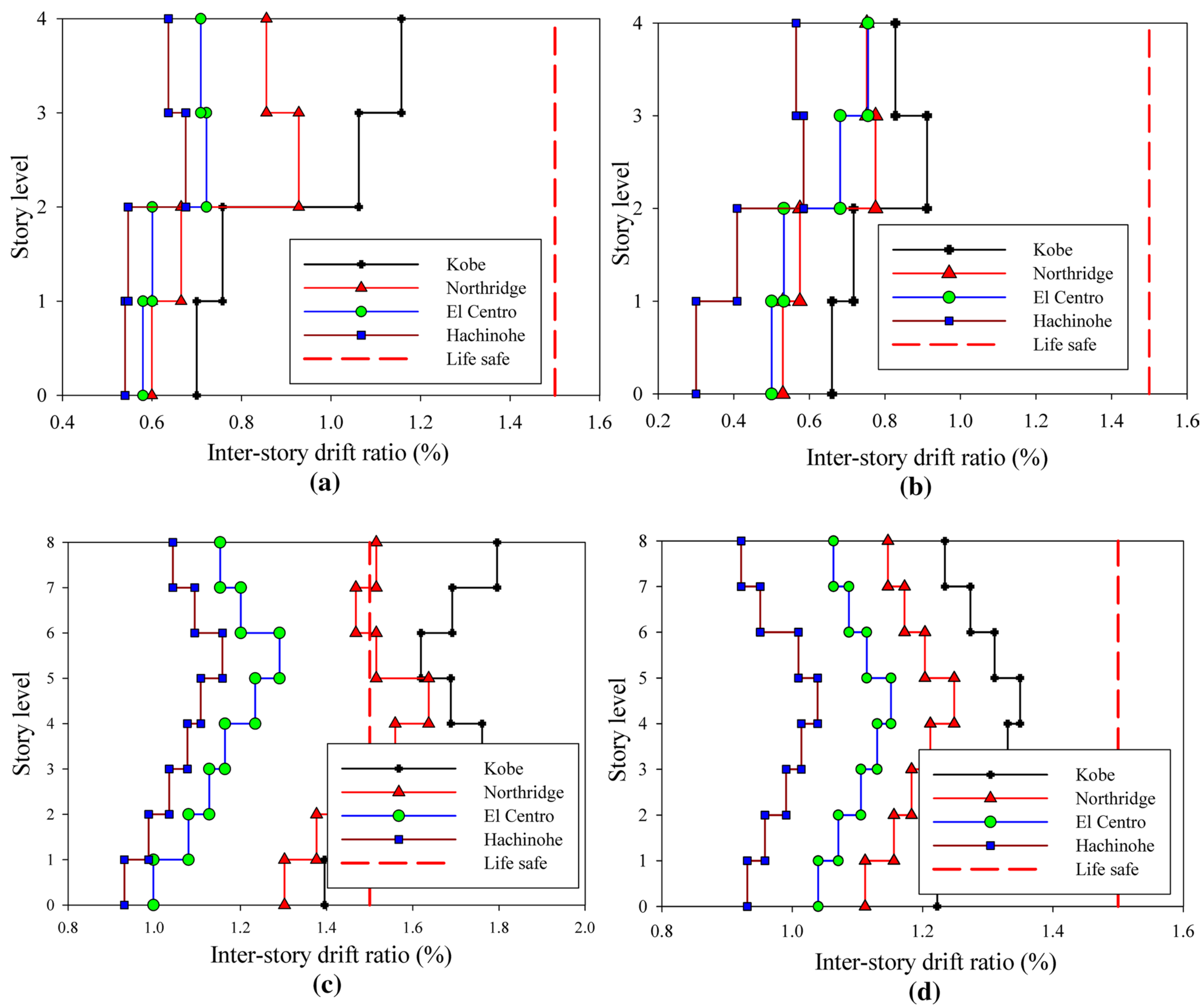

Fig. 7 Inter-storey drift of frames under earthquakes: **a** normal 4-storey, **b** retrofitted 4-storey; **c** normal 8-storey and **d** retrofitted 8-storey

Table 6 Maximum base shear forces in 4- and 8-storey frames (Unit: kN)

Storey	Earthquake	Kobe	Northridge	El Centro	Hachinohe
4-Storey	Normal	593	674	335	168
	With U-damper	486	515	226	117
	Reduction (%)	18	24	33	30
8-Storey	Normal	775	896	493	386
	With U-damper	632	693	384	301
	Reduction (%)	18	23	22	22

5.3 Hysteretic Responses of Damper Devices

In order to better application of damper energy absorption features, each of dampers shall have inelastic behaviour under severe excitations. Nevertheless, their plastic deformations shall not exceed permitted range, which results in damper yielding. This range for U-shaped damper is roughly 15 times its yielding displacement. Figure 9 shows the hysteretic responses of U-shaped dampers on 2nd and 8th floors of 8-storey frame equipped with yielding damper under Kobe earthquake. It is observed that the dampers yielded but their maximum displacement is less than allowable limitation.

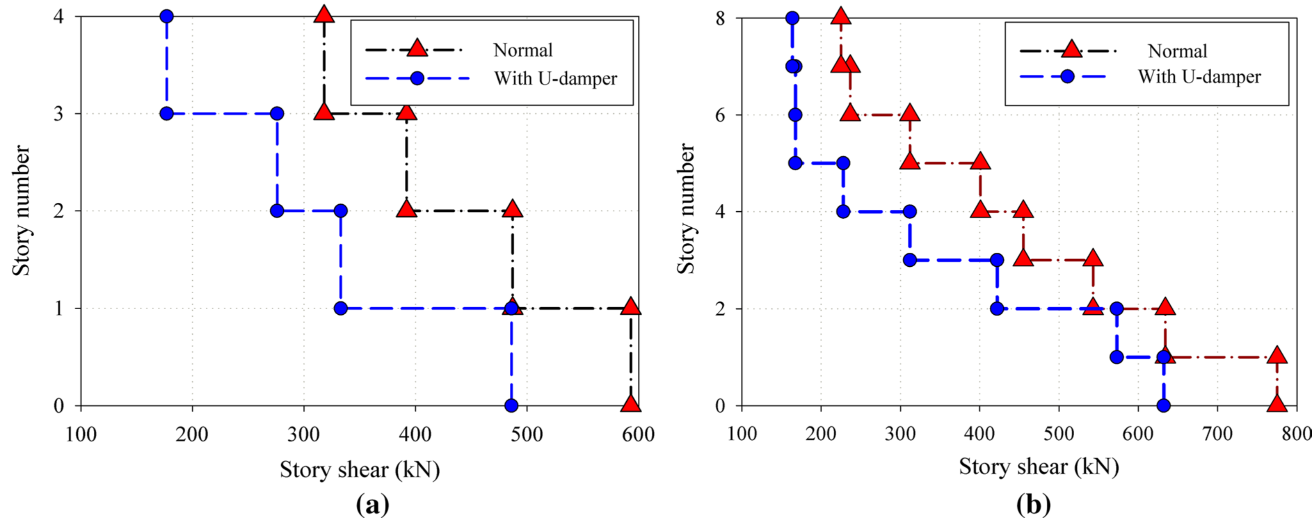

Fig. 8 Shear distribution of **a** 4- storey and **b** 8-storey normal structures equipped with damper under Kobe earthquake

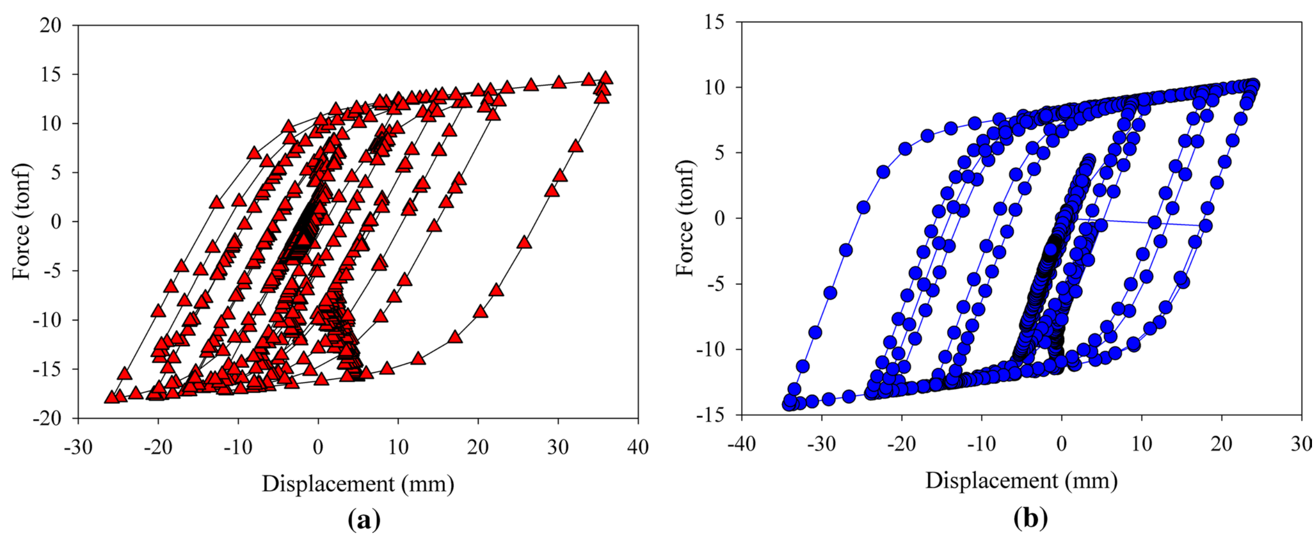

Fig. 9 Hysteretic responses of U-shaped dampers on **a** 2nd floor and **b** 8th floor of 8-storey frame equipped with yielding damper under Kobe earthquake

6 Concluding Remarks

In this study, experimental, parametric and finite element numerical study were conducted on U-shape metallic yielding dampers under cyclic loading. Further, these dampers were used to examine the behaviour of 4- and 8-storey steel moment frames under various ground motions and a comparison was conducted between normal frames and frames equipped with U-shape yielding dampers. The system as the structure lateral load-bearing complementary system, has certain advantages such as being cost-effective, simple implementation, easy installation, and simple replacing after being yielded under severe earthquakes. The most important findings of these studies are as follows:

1. Experimental studies on U-shape yielding dampers demonstrated that this system has the ability for large deformation with high energy absorbability. Energy dissipation in this system is based on plastic deformation of plate camber section in bending moment due to deformation resulted from cyclic loading. The tested damper managed to bear up to 84 cycles with 40 mm deformation amplitude with 25% strength loss.
2. Analytical studies on calibrated models showed that damper deformation results in stress distribution in camber section and starting point of damper plate curve. U-shape yielding damper models had fat hysteretic loops with high deformation.

3. The absorbed energy, load-bearing capacity and elastic stiffness were controlled through geometrical parametric study on dampers and linear and practical formulas to estimate load-bearing capacity in proportion to the damper width were introduced.
4. It was known through changing the thickness, width and diameter of damper that the effect of damper width is the most important parameter in increasing load-bearing capacity in comparison to other geometric parameters. On the other hand, elastic stiffness of damper was calculated which was in agree with the result of FEM analysis.
5. It was understood through non-linear time historey analyses that 8-storey frame with steel moment resisting frame system failed to bear near fault earthquakes. Seismic performance of frames improved through adding U-shape yielding dampers to 4- and 8-storey frames and the structure response with respect to inter-storey drift and base shear of structure and shear force of the floors were decreased. The floors shear decrease was between 18 and 35%.

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