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IMPROVING THE PERFORMANCE OF I-SHAPED DAMPERS USING STIFFENERS

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Abstract

Research reports on the behavior of metallic dampers have confirmed that the I-shaped link, while designed under a shear mechanism, acts as a ductile fuse. The main weakness of these links is the reduction of stiffness of the system when they are connected directly to the diagonal member of the concentrically braced frame. To increase the stiffness and ultimate strength of the I-shaped links, increasing the thickness of the web plate has been proposed by researchers, which causes an increase in the imposed load on the members of the braces. An innovative idea to overcome this problem is adding diagonal stiffeners to the dampers. In this paper, the stiffening of the I-shaped links is examined numerically and parametrically using the finite element method (FEM). Numerical results reveal that the stiffeners not only prevent the buckling of the web plate (which causes improvement in its performance), but they also share the imposed loading. By adding the stiffeners, a thinner web plate can be used instead of increasing the thickness of the web plate to achieve larger ultimate strength and stiffness. The parametrical study indicated that the thickness of the stiffeners is much more important than the properties of the flange and web plate in case of the damper performance.

Keywords: Damper; Stiffness; Strength; Seismic; Ductility; Stiffener; FEM.

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1 INTRODUCTION

Since the undesirable buckling of the Concentrically Braced Frame (CBF) has been acknowledged by engineers, many researchers have tried to overcome this defect. In this regard, the use of passive energy devices as dampers has been introduced as a successful, economic, and practical solution. Several dampers have emerged to improve the behavior of CBFs up to now. The shear damper, I-shaped, directly connected to the CBFs was introduced first by Ghamari et al. [1] as a simple and practical device with desirable behavior in comparison with the other dampers. To build the mentioned damper, shear plates were surrounded by a cylinder. Ghamari et al. [1] confirmed that the bucking was prevented and the ductility and dissipating energy of CBF were enhanced.

Although this I-shaped damper was cheaper and easier to build compared to other shear dampers such as ADAS [2], TADAS [3], Shear panel [4], Slit dampers [5], and edge, longitudinal and internal stiffeners [6], it faced a problem concerning stiffness reduction. To overcome this problem, surrounding the shear plates with an octagonal-shaped instead of a cylinder-shaped was proposed by Ghamari et al. [7,8]. They accomplished several experimental tests to achieve the optimum dimension of that damper. Also, its behavior with the imposing of the shear or flexural or shear-flexural mechanism was examined. Although changing the cylinder cover into an octagon cover made it simpler to produce, the damper's weight was increased, which affected the manufacturer and installer during installation. Consequently, inspired by the suitable performance of the shear link with the shear mechanism in Eccentrically Braced Frame (EBFs) [9,10], some researchers proposed the use of an I-shaped shear link attached to CBFs. Experimental studies [11-13] approved that using the I-shaped dampers prevents CBF's buckling and improves the dissipating energy. Also, it pertains to simple manufacturing and installation than other ones.

In spite of the significant benefits of the damper, as all dampers are attached to the CBFs, it caused to reduce the stiffness and ultimate strength [14,15]. To overcome this shortcoming, two general ways can be used, which include: a) using an I-shaped section with a greater thickness, or b) adding the number of dampers (and braces) in the structure. Although increasing the thickness of the damper can increase the capacity, it does not have much effect on the stiffness. In addition, increasing the capacity increases the stresses created in elements outside the damper mainly in the brace's elements, which may cause it to buckle. In such a situation, the damper not only does not perform suitably but in addition to reducing the stiffness and strength of the system, it will also have a brittle behavior. Moreover, increasing the number of dampers to compensate for the stiffness, brings construction costs and architectural limitations. Therefore, the use of stiffeners can be a worthy solution to compensate for the weakness of stiffness and ultimate strength. Due to the number of stiffeners materials used in the damper being low and also its implementation being simple, Figure 1, accordingly can be introduced as a successful solution.

2 I-SHAPED DAMPER WITH STIFFENERS

Referring the Figure 1, the damper is attached to an end of CBFs. It is obvious to confirm the simplicity of manufacturing and installation. Also, it can be replaced after a severe earthquake. to assure the damper yield before other elements, elements outside the damper must be designed for forces larger than the capacity of the damper. It is recommended to design the mentioned element for F_{design} that is determined as:

$$F_{design} = \Omega V_{n,damper} \tag{1}$$

In this equation, the Ω is the overstrength that is investigated in the present paper and $V_{n,damper}$ is the nominal strength of the damper. The overstrength for each structure and element is defined as the nominal strength, V_n, divided by the strength corresponding to the first hinge formation, V_s.

$$\Omega = \frac{V_n}{V_s} \tag{2}$$

The AISC 341-16 [16] for shear links with I-shaped forms, is recommended to calculate the strength as $V_p = 0.6F_{yw}bt_p$ where F_{yw}, b, and t_p are yielding stress of the web plate. In this code, the shear mechanism is defined as ρ < 1.6 where the ρ is equal to $\frac{link\ length}{\frac{M_p}{V_p}}$.

For the damper with X-stiffeners, the nominal strength is determined as:

$$V_n = n(V_p + V_f + V_{st}) \tag{3}$$

where n is the number of the web plates. The V_f and V_{st} represent the shear strength of the flange plate and X-stiffeners, respectively. Researchers have confirmed that the flange plate contributes to load-resisting [17]. Using the plastic theory, the ultimate strength of the flange plate is given when the flexural hinges are formed at the two ends of the flange plates. Hence, V_f is calculated as $V_f = \frac{4M_{pf}}{h'}$ where M_{pf} is the plastic moment of the flange plate, and $M_{pf} = \frac{b_f t_f^2}{4} F_{yf}$.

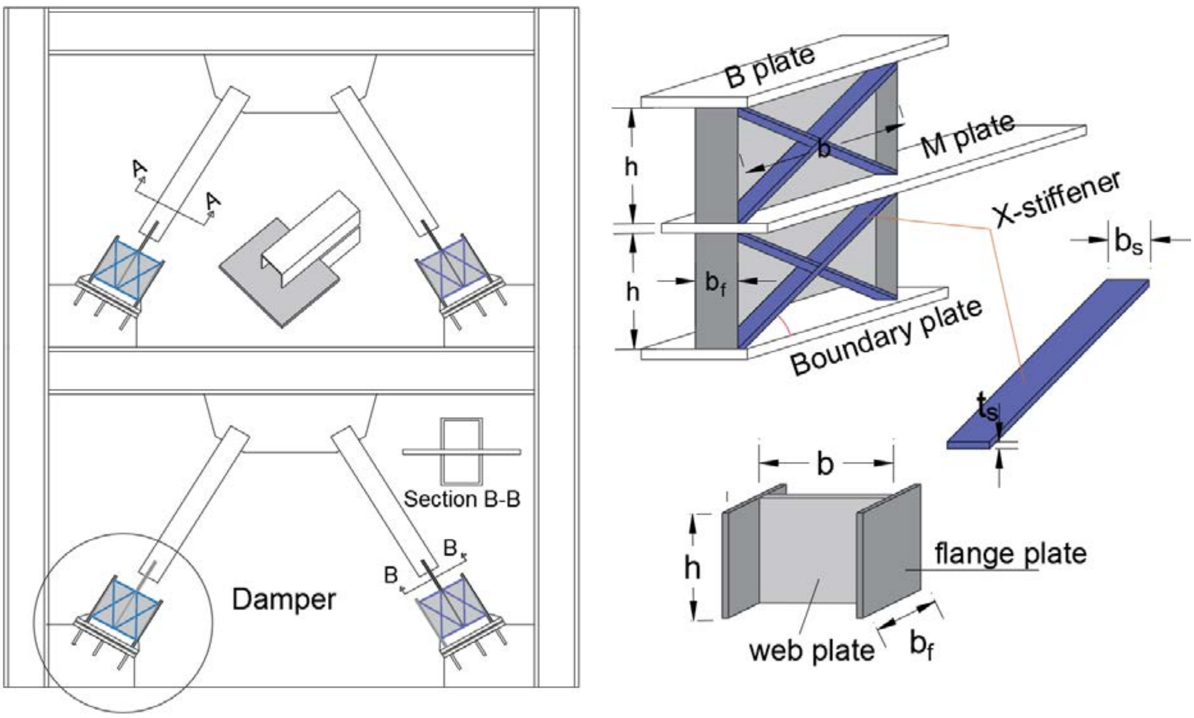

Figure 1: Strengthening of I-shaped damper with stiffeners.

Because at the beginning of the hinge formation, all components are involved, V_s is calculated as:

$$V_s = V_p + \Delta_p K_f + \Delta_p K_s \tag{4}$$

By taking $\Delta_p = \frac{V_p}{K_p}$, Equation (4) can be written as $V_s = V_p(1 + \frac{K_f + K_s}{K_p})$. Consequently, the Ω is obtained as:

$$\Omega = \frac{1 + \frac{V_s}{V_p} + \frac{V_f}{V_p}}{1 + \frac{K_f + K_s}{K_p}} \tag{5}$$

3 NUMERICAL STUDY

3.1 Numerical models

In the present paper, numerical models were simulated using ANSYS [18] software. To do so, the damper's component was modeled with the SHELL181 element. This element can account for the large displacement and buckling. All Finite Element (FE) models include h=140 mm, t_p=6 mm, b_s==160 mm, and b_f=160 mm. the variable investigated in this paper includes the t_p, t_s that they ended up with different V_p and ρ.

3.2 Verification of FE results

An experimental specimen, a shear link, reported by Tanaka and Sasaki [19] was selected for verification of FE modeling. Since the damper investigated in the paper and the test is under pure shear, their performance is the same. Accordingly, the main feature of both studies is the shear deformation. Figure 2 reveals a good agreement between the experimental test results [19] and the FE results.

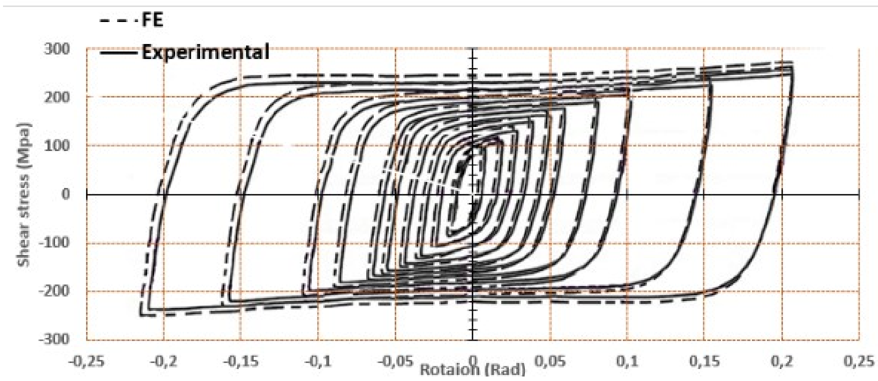

Figure 2: Comparison of the experimental test results [19] and the FE results.

4 DISCUSSION

4.1 Comparing the curves of stiffened/unstiffened dampers

Figure 3 illustrates the load-rotation of the dampers for different ρ. As shown in this figure, adding stiffeners to the damper caused it to move up the curve which ended up increasing the elastic stiffness, ultimate strength, and energy dissipation. The noticeable finding is that all damper's stiffness is coincide around the rotation of 0.005; it means, although reinforcing the I-shaped damper with stiffeners increases the elastic stiffness, it does not cause a considerable effect on the stiffness in the nonlinear zone.

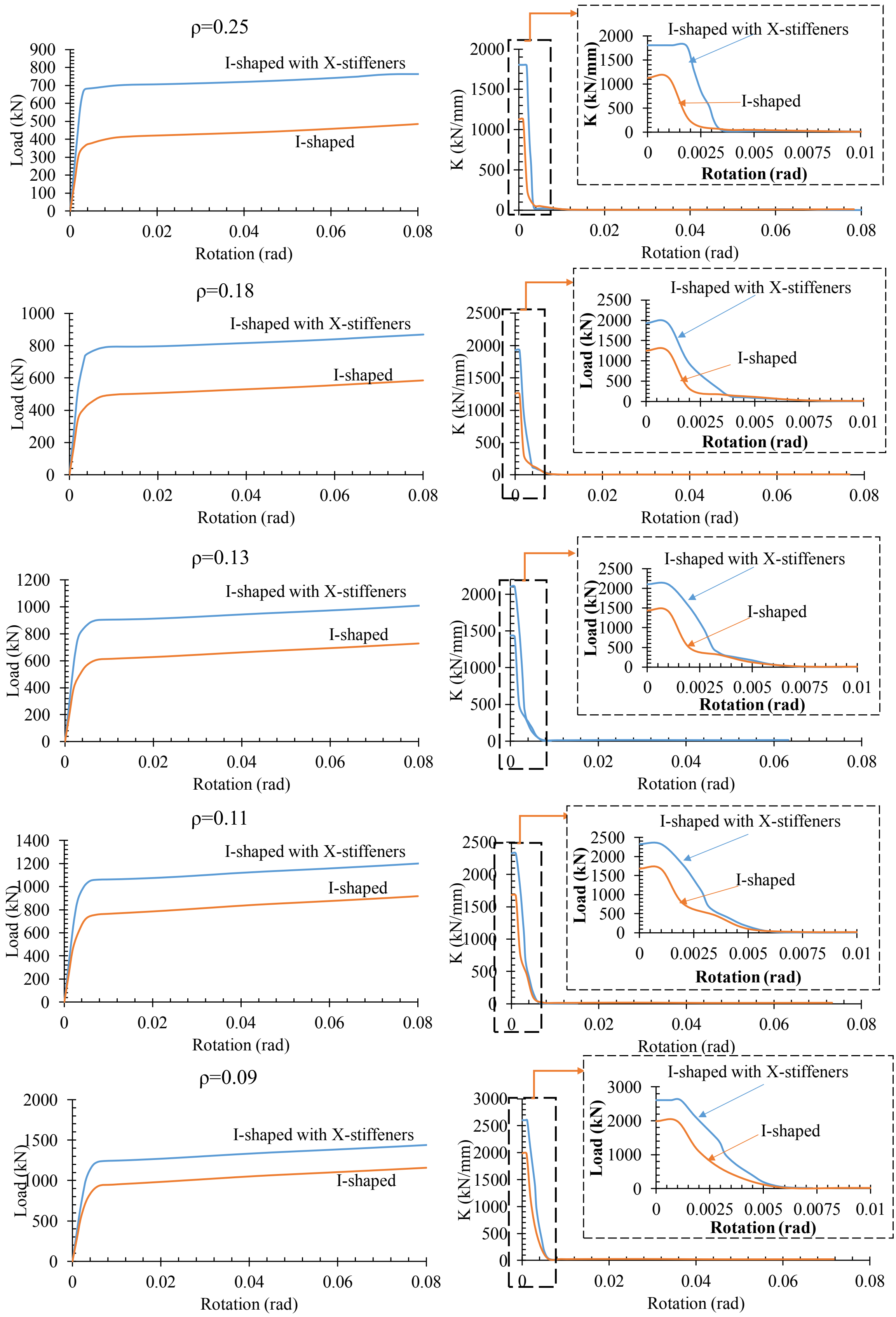

Figure 3: Comparison of the curves of the unstiffened I-shaped dampers and the I-shaped dampers reinforced with X-stiffeners.

4.2 Overstrength

Because the element outside the damper must be designed for amplitude force by Ω, the Ω of the dampers are listed in Table 1. The average amount of the Ω is 1.97 which is greater than proposed by AISC=1.5. Therefore, it is recommended to use Ω=2.0 for the damper.

In the sixth column of the table, the Ω of dampers with different flange plates are divided by the dampers with t_f=10mm. results indicated that increasing the flange plate cause to increase in the Ω. Also, in the seventh column of the table, the Ω of stiffened dampers are divided by the dampers I-shaped dampers with the same t_f. Except for the damper with ρ=0.25, the stiffeners increase the Ω between 2% to19%.

Dampers		t_f (mm)	t_s (mm)	Ω	$\frac{damper\ with\ t_f=i}{damper\ with\ t_f=10mm}$	$\frac{I-shaped\ damper}{Stiffened\ damper}$
I-shaped	ρ=0.25	10		1.54		
	ρ=0.18	15		1.67	1.08	
	ρ=0.13	20		1.82	1.18	
	ρ=0.11	25		1.95	1.27	
	ρ=0.09	30		2.08	1.35	
I-shaped with stiffeners	ρ=0.25	10	2.5	1.36		0.89
		10	5	1.63	1.20	
		10	10	2.04	1.50	
		10	20	2.38	1.75	
		15	2.5	1.51	1.11	
I-shaped with stiffeners	ρ=0.18	15	5	1.70		1.02
		15	10	2.11	1.24	
		15	20	2.42	1.42	
		20	2.5	1.64	0.96	
		20	5	1.82	1.07	
I-shaped with stiffeners	ρ=0.13	20	10	2.16		1.10
		20	20	2.44	1.13	
		25	2.5	1.75	0.81	
		25	5	1.93	0.90	
		25	10	2.23	1.03	
I-shaped with stiffeners	ρ=0.09	25	20	2.47		1.19
		30	2.5	1.90	0.77	
		30	5	2.06	0.83	
		30	10	2.31	0.94	
		30	20	2.51	1.02	

Table 1: The overstrength of the dampers.

To have a better consideration of the effect of the variable on the overstrength, in Figure 4, the overstrength versus different variables is plotted. As shown in this figure, by increasing the ratio of t_s/t_p and t_s/t_f, the Ω is increased but this increase follows a nonlinear function. Also, by increasing the slenderness of the stiffeners, the ratio of b_s/t_s and L_s/t_s, reduce Ω. Therefore, the limitation of b_s/t_s=35 and L_s/t_s=50 is proposed to prevent the high reduction of Ω.

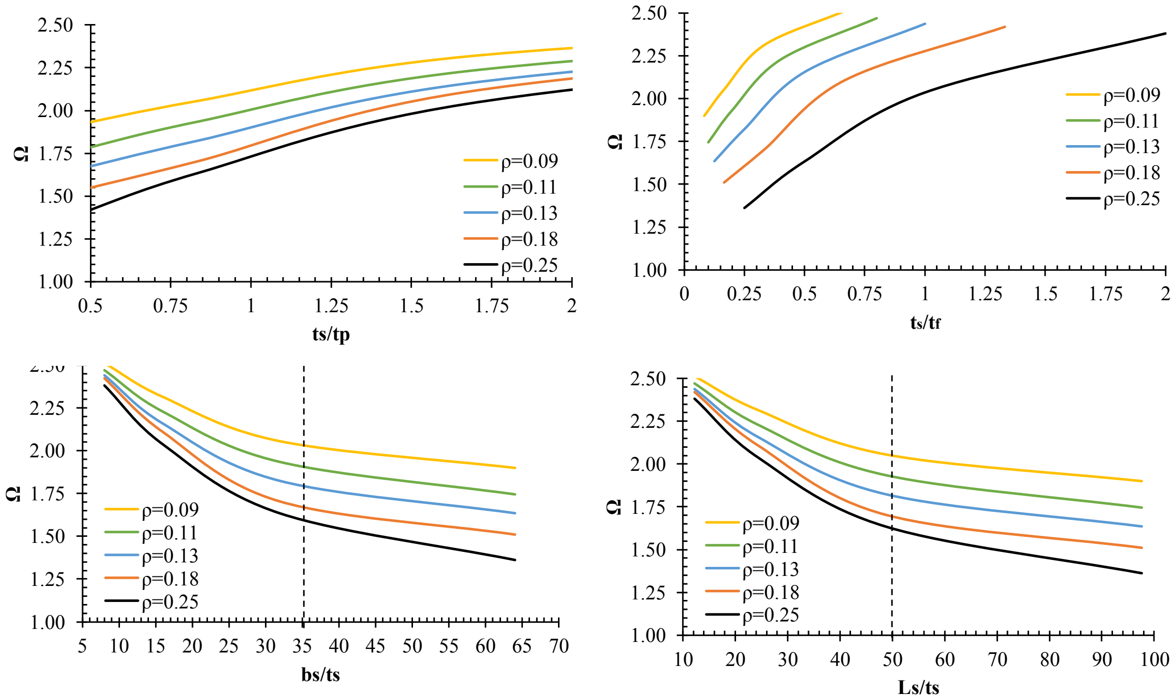

Figure 4: The overstrength.

4.3 Limitation of stiffeners' slenderness

To consider the accuracy of the limitation of b_s/t_s=35 and L_s/t_s=50, the ultimate strength and stiffness are plotted versus the variables in Figure 5. Like with the overstrength, the ultimate strength, and stiffness are reduced by increasing the slenderness. At the b_s/t_s=35 or L_s/t_s=50 the rate of reduction of the mentioned stiffness and strength tend to smooth. Subsequently, the mentioned limitation can be accounted as a suitable and capable suggestion.

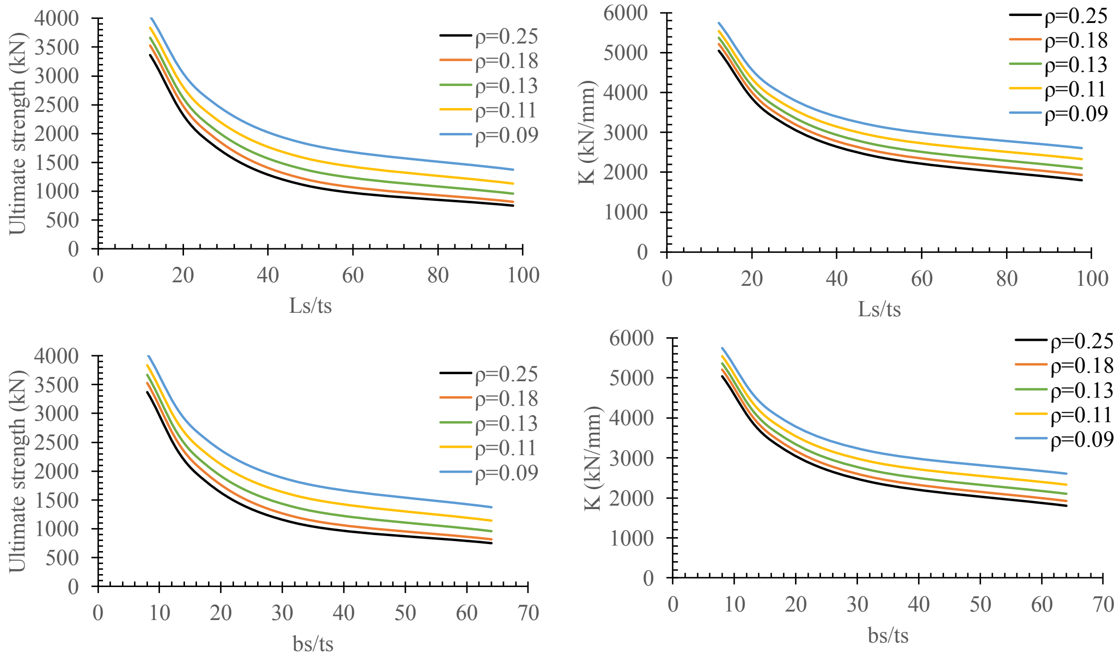

Figure 5: The ultimate strength and stiffness versus slenderness.

4.4 Yielding state of the damper

In Figure 6, the hinge formation of the damper component is shown. In this figure, only a damper with $t_s = 2.5, 20$ mm and $t_f = 10, 30$ mm as a thicker and thinner damper has been shown. Referring to Figure 6, the web plate of all the damper is yielded completely. Also, at two ends of the flange plates, hinge formation is accomplished. Moreover, in the middle of X-stiffeners, hinges are formed. This hinge formation confirms that all components of the damper contribute to the energy dissipation. The considerable notice is that thin stiffeners are subjected to buckle.

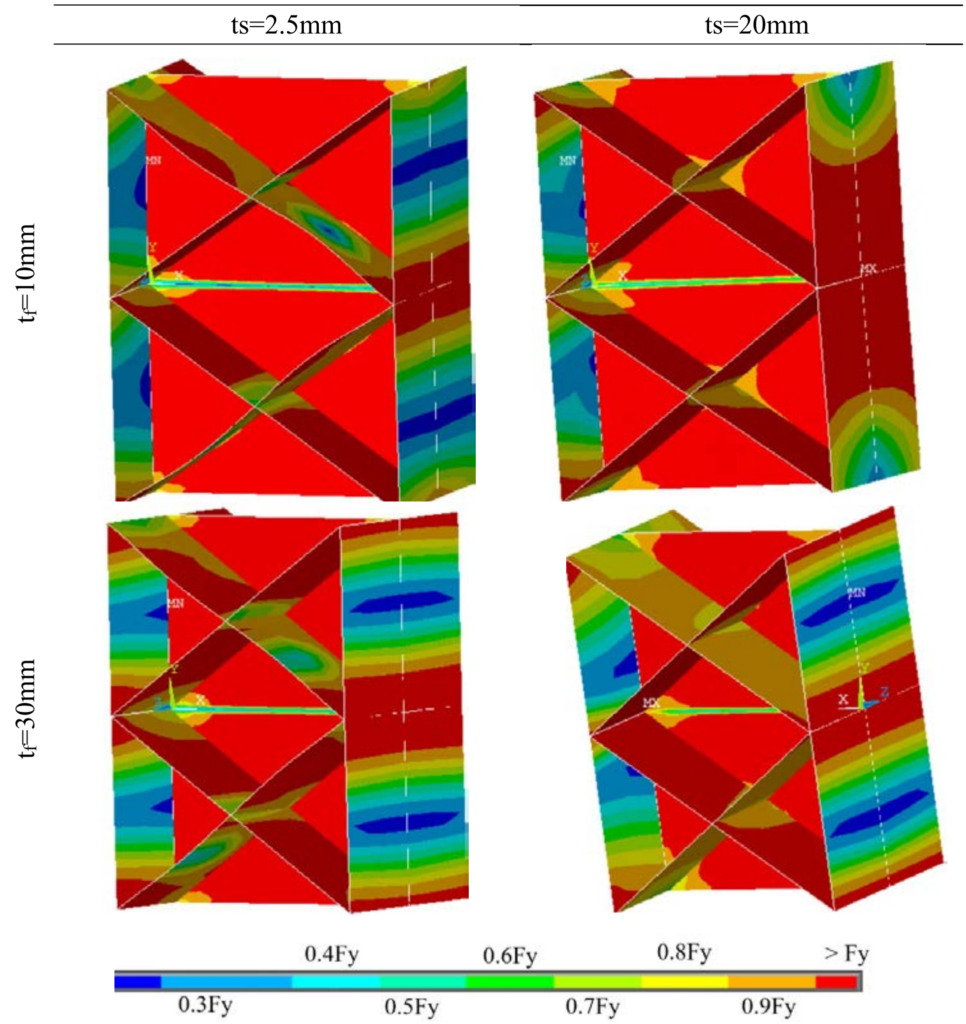

Figure 6: The yielding state of the damper for various configurations.

5 CONCLUSIONS

In this paper, the behavior of an I-shaped damper reinforced with stiffeners was investigated. The findings are summarized in the following:

- Adding stiffeners to the I-shaped damper cause to enhance the elastic stiffness, ultimate strength, and energy dissipation but it does not have a considerable effect on the stiffness in the nonlinear zone.
- The average overstrength, Ω, of the I-shaped damper with and without stiffeners was obtained equal to 1.97 which is greater than proposed by AISC=1.5. Therefore, it is recommended to use Ω=2.0 for the damper.

- The properties of flange and stiffeners affect the Ω. Increasing the flange plate increases the Ω. Also, except damper with $\rho=0.25$, the stiffeners increase the Ω between 2% to19%.
- Also, increasing the slenderness (b_s/t_s and L_s/t_s) of the stiffeners reduce Ω. Therefore, the limitation of $b_s/t_s=35$ and $L_s/t_s=50$ is proposed to prevent the high reduction of Ω.
- At the $b_s/t_s=35$ or $L_s/t_s=50$ the rate of reduction of the mentioned stiffness and strength tend to smooth. Subsequently, the mentioned limitation can be considered as a suitable and capable suggestion.

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