



Metalik Amortisörlerle Yenilenmiş Yarı-katı Bağlantılı Çelik Çerçevelerin Doğrusal ve Doğrusal Olmayan Davranışlarının İncelenmesi ve Davranışlarının Belirlenmesi

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Özet. Binalarda sönümlenme sistemi kullanmak yapıya enerji girişini ve tepkisini azaltır ve binayı yıkılmaktan korumaktadır. Bu noktaya kadar yarı sert bağlantılı çelik çerçevelerin lineer olmayan davranışları ve histerik amortisörler ve davranış etkisini belirleme henüz araştırılmamıştır, bu çalışmada bu çerçevelerin araştırılması çalışılmıştır. Güncel çalışmada, sert, katı yarı sert, esnek yarı sert ve pim bağlantılı çelik çerçeveler ADAS amortisörleri tarafından, 4-katlı, 8-katlı, 12-katlı olmak üzere üç farklı yükseklikte, üç körfezde kolay analiz prosedürü tarafından onların davranış faktörünü kurmak için analiz edilmiştir. Dahası ADAS amortisörlü ve amortisörsüz çerçeveler arasında karşılaştırma da yapılmıştır. Bu yolla, ADAS amortisörlü çerçeveler için hesaplanmış davranış faktörü ve amortisörsüzler için 2800 kuraldan davranış faktörü kullandık ve bu çerçeveler lineer analiz ile analiz edilmiştir ve sonuçlar birinci tip periyodu, taban kesmesi, kat kaydırma ve her bir kat için toplam yer değiştirme gibi durumlarda karşılaştırılmıştır.

Anahtar Kelimeler: Histerik amortisörler; Yarı-katı bağlantılar; Doğrusal olmayan davranış; Davranış faktörü

Investigating the Linear and Non-Linear Behavior of Steel Frames with Semi-rigid Connections Retrofitted with Excurrent Metallic Dampers and Determining Their Behavior factor

Abstract. Using damping system in building frames would decrease response and entrance of energy to the structure and protects the buildings from happening collapse. By attending to this point that the non-linear behavior of the steel frames with semi-rigid connections and hysteric dampers and determining its behavior factor is not investigated yet, in this research, investigation of these frames are studied. In present work, steel frames with the rigid, hard semi-rigid, flexible semi-rigid and pin connection by ADAS dampers, in the three heights of 4story, 8story and 12story, in the three bays are analyzed by pushover analysis procedure to establish their behavior factor. And also a comparison is done between frames with ADAS damper and frames without them. In this way, we use calculated Behavior factor for frame with ADAS damper and Behavior factor from 2800 regulation for frame without them, and these frames are analyzed by linear analysis and the results are compared in different cases such as period of first mode, base shear, story drift and total displacement for each story.

Keywords: Hysteric dampers; Semi-rigid connections; Non-linear behavior; Behavior factor

1.INTRODUCTION

Among the passive energy dissipation systems, ADAS metallic dampers are of particular importance due to lack of need of sophisticated technology for manufacturing and their practical applications in structure, stable behavior against earthquake and free from the effects of

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environmental factors (temperature, humidity, etc.) in their mechanical behavior [1, 2]. Whittaker et al. have presented an analytical procedure to define the load-deformation curve of the ADAS device, assuming the equivalent X-triangular shaped geometry. [3]

Added damping and stiffness (ADAS) device has been studied by Whittaker [3]. The device consists of multiple x-steel plates of the shape shown in Figure 4 and installed as illustrated in the same Figure. The similarity of the device to that of Tyler [4] and Kelly [5] is apparent. The shape of the device is such that yielding occurs over the entire length of the device. This is accomplished by the use of rigid boundary members so that the x –plates are deformed in double curvature. Recently, a microscopic mechanist approach has been proposed for metallic dampers by Dargush & Soong [6], the applicability of which could be tested for the ADAS device. Arturo Tena-Colunga [7] presented another method to determine the global element elastic stiffness, the element capacities & the load deformation curve of the ADAS device, based upon the flexibility method & fundamental principles of mechanics. Most of the resulting integrals are solved explicitly; closed-form solutions are then made available. Shake table tests of a 3-storey steel model structure by Whittaker [3] demonstrated that the ADAS elements improved the behavior of the moment-resisting frame to which they were installed by (a) increasing its stiffness, (b) increasing its strength, and (c) increasing its ability to dissipate energy. Ratios of recorded inter-story drifts in the structure with ADAS elements to inter-story drifts in the moment-resisting frame were typically in the range of 0.3 to 0.7. This reduction is primarily an effect of the increased stiffness of the structure by the ADAS elements. ADAS elements have been very recently used in the seismic retrofitting of the Wells Fargo Bank, a 2-storey concrete building in San Francisco.

Added damping and stiffness (ADAS) elements are designed to dissipate energy through the flexural yielding deformation of mild-steel plates.

In this paper, also recent research findings on the effectiveness of using steel plate welded as the added damping and stiffness (ADAS) device for earthquake-resistant structure on an interesting type of semi-rigid steel framing connection which is commonly used in Iran (including in seismic zone) are presented.

2. DEFINITIONS AND CONCEPTS USED

In the following, the importance of using semi-rigid connections, introducing ADAS elements, evaluation the Behavior factor, capacity curve, ductility coefficient of the structure, power reduction coefficient, the overall structure Behavior factor, and yield deformation are briefly examined.

2.1. Importance of Using Semi-Rigid Connections

In steel structures two types of hinge and rigid connections are implemented in various forms. Nominal hinge connections have a percentage of moment fixity and the nominal rigid connections donot work as well as rigid; therefore, given the importance of these types of structures and the effect of flexible connections on the distribution of forces and deformation of members, these connections can be considered as semi-rigid connections with different percentage of rigidity.

In beams under uniform load with rigid end supports the highest moment is at the two ends and the lowest moment is at the midspan. In beams with end-hinged supports the highest moment is at the midspan and the lowest moment is at the two ends while in beams with semi-rigid end supports the moments at the midspan and at the ends are very close to each other. This will adjust the moments and makes the number of sections smaller. Therefore, if the connection can be implemented with certain hardness, the beam can be designed in an optimal state [8].

2.2. How to Evaluate the Behavior factor

In order to make the plan economical against the earthquake forces, the building codes have permitted the use of structures inelastic capacity in order to absorb some of the energy resulting from the earthquake.

Therefore, the current seismic design codes obtain the seismic forces to design a building through a linear range depending on the construction period and the soil condition of the building site and in order to consider the effect of inelastic behavior, energy dissipation due to hysteresis behavior, added damping and stiffness (ADAS element), it is converted to designing power via the resistance reduction factor (behavior factor). By idealizing the total behavior curve into complete elastic-plastic behavior curve according to figure (3), the seismic parameters can be obtained [6].

2.3. Added Damping and Stiffness (ADAS) Elements of Steel Plate

The ADAS (Added Damping and Stiffness) devices consist of a series of steel plates wherein the bottom of the plates are attached to the top of a chevron bracing arrangement and the top of the plates are attached to the floor level above the bracing. As the floor level above deforms laterally with respect to the chevron bracing, the steel plates are subjected to a shear force. The shear forces induce bending moments over the height of the plates, with bending occurring about the weak axis of the plate cross section. Thus, inelastic action occurs uniformly over the full height of the plates due to the geometrical configuration of the plates. To ensure that the relative deformation of the ADAS device is approximately equal to that of the story in which it is installed, the chevron bracing must be very stiff. In figure 1 braced frame with dampers element and in figure 2, the ADAS element force and displacement is shown.

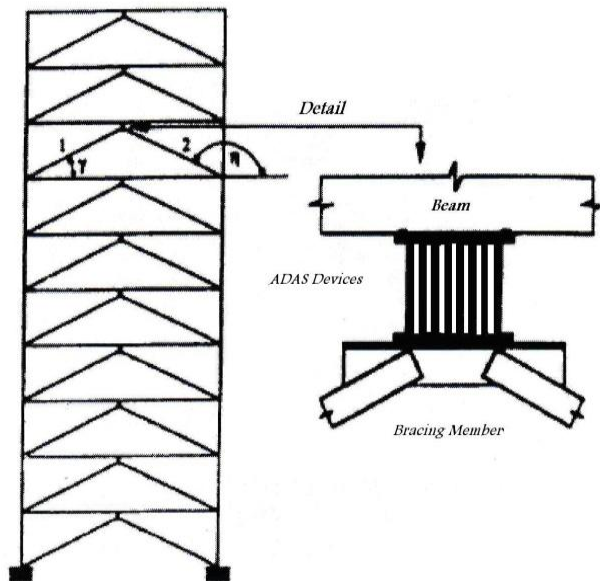


Figure 1. Shoran braced frame with dampers element

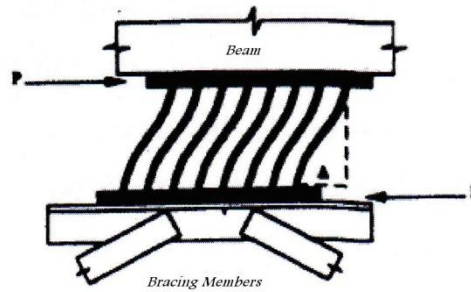


Figure 2 ADAS element force and displacement

In this research, the ADAS yielding metallic dampers are used in order to retrofit and optimize sections in structures with semi-rigid connections.

2.4. Capacity Curve

Capacity curve shows the relationship between the building base shear and the roof displacement. In order to obtain the capacity curve the nonlinear static analysis and an increasing lateral load pattern are usually used. It is possible to predict nonlinear behavior of the structures by using the capacity curve diagram. It can also be used to estimate structural ductility and hardness and to determine the structure strength against the lateral load. Moreover, the decrease or increase of strength of the structure members can be observed in it and the seismic parameters such as Δ_y and V_y can be obtained through the capacity curve. Figure (3) shows an example of capacity curve.

2.5. The Overall Structural Ductility Coefficient

The following Figure shows the general behavior of the conventional structure, and also its ideal behavior under lateral force. If the structure enters the linear region due to the seismic loading, its diagram will change as the broken line in the following figure.

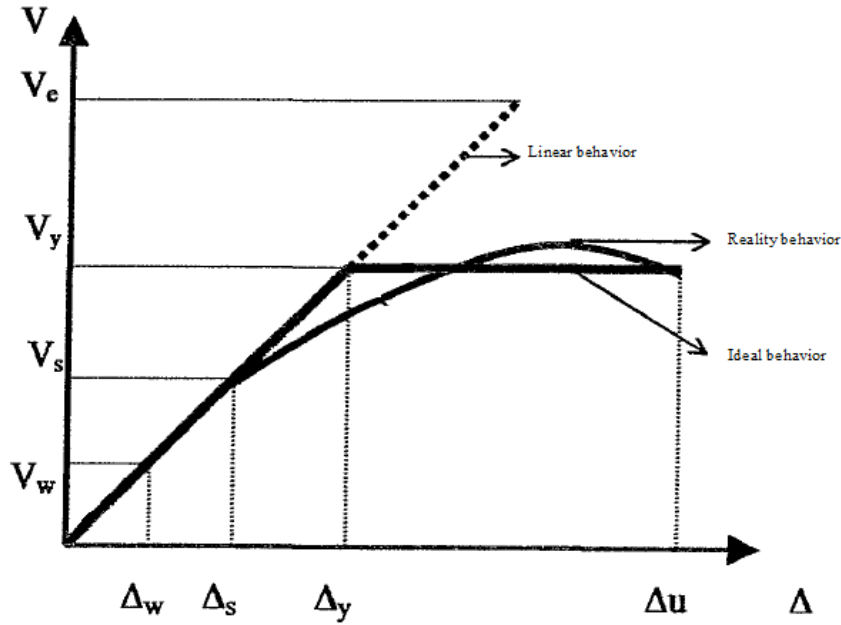


Figure 3. General and idealized behavior of structure [6]

Δ_s , Δ_y and Δ_u are respectively the displacement corresponding to the first plastic hinge in frame, displacement corresponding to the frame yield, maximum lateral displacement of the frame due to seismic loading.

V_s , V_y , V_e are respectively the shear force corresponding to the first plastic hinge in the frame, the shear force corresponding to structural failure, and the shear force corresponding to the elastic state in the frame.

The overall structural ductility factor is the ratio of maximum lateral displacement (Δ_u) to the lateral displacement corresponding to the frame yield (Δ_y) which is expressed as the following:

$$\mu = \frac{\Delta_u}{\Delta_y} \tag{1}$$

2.6. Force Reduction Coefficient (R_μ) due to Ductility

Due to ductility and nonlinear behavior of structure, the linear force of V_e can reduce to V_y which is defined as the following:

$$R_\mu = \frac{V_e}{V_y} \quad (2)$$

So far, many studies have been done on the strength reduction factor due to ductility among which three equations of Newmark and Hall, Kravincler and Nasr, and Miranda Equation can be referred to. Each one of the researchers has expressed a relationship between R_μ and μ_s . in this research, the Miranda Equation has been used which will be referred to in the following.

According to extensive studies of Miranda, the R_μ coefficient is presented as the following simple formula [9]:

$$R_\mu = \frac{\mu - 1}{\phi} + 1 \quad (3)$$

where ϕ for the rocky lands, sedimentary lands, and the lands with soft soil is obtained through (4) to (6) equations:

$$\phi = 1 + \frac{1}{12T - \mu T} - \frac{2}{5T} \exp\left[-2\left(\ln T - \frac{1}{5}\right)^2\right] \quad (4)$$

$$\phi = 1 + \frac{1}{10T - \mu T} - \frac{1}{2T} \exp\left[-1.5\left(\ln T - \frac{3}{5}\right)^2\right] \quad (5)$$

$$\phi = 1 + \frac{T_g}{3T} - \frac{3T_g}{4T} \exp\left[-3\left(\ln \frac{T}{T_g} - \frac{1}{4}\right)^2\right] \quad (6)$$

where T_g is the period considered for the ground which is changeable for each kind of soil.

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In this research, the soil of the region is assumed to be sediment which is consistent with the soil type III of the Iranian 2800 regulation which is considered for the soil of the region. Therefore, the Equation (5) is used to calculate ϕ .

2.7. Added Resistance Coefficient

When one of the structure members reaches the yielding extent and the so-called dough hinge is formed in it, the structure strength ends in terms of operation design, but in the final design mode this phenomenon is not considered as the end of the structure strength because the considered member can still absorb the input energy by inelastic transformation until it reaches the failure and destruction state and can't tolerate additional lateral load anymore. The resistance that the structure shows after the formation of the first dough joint until the instability mechanism is called the added resistance. R_s is the added resistance coefficient due to the strain hardening. The added resistance occurs since the formation of the first plastic joint until the total structure yield. In this research, the added resistance coefficient is calculated via the equation (7):

$$R_s = \frac{V_y}{V_s} \quad (7)$$

Y is the added resistance coefficient resulting from the structural uncertainty. Given that during the structure loading, after the base shear reaches the design shear and before the onset of yielding in structural members, the structure has the added resistance of y, the numerical value of Y is between 1.4 to 1.5. In this paper, equals to 1.44.

2.8. Overall Structural Behavior factor

The behavior factor of the structure according to the coefficients obtained in previous sections is determined as follows:

$$R_U = \frac{V_e}{V_y} \cdot \frac{V_y}{V_s} = R_\mu \cdot R_s \quad (8)$$

$$R_W = \frac{V_e}{V_y} \cdot \frac{V_y}{V_s} \cdot \frac{V_s}{V_d} = R_\mu \cdot R_s \cdot Y \quad (9)$$

2.9. Yield Deformation

So far, various definitions have been presented by the researchers to estimate the yield displacement Δ_y or to idealize the structures' response curve. In this research in order to determine the yield displacement Δ_y , figure (4) has been used according to the seismic rehabilitation of the existing buildings [8]. According to this figure, Δ_y is determined in such a way that the area under the two-line graph is equal to the area of the structural real behavior graph. Moreover, the first part of the two-line graph cuts the graph of the structural real behavior at $0.6V_y$. The simultaneous satisfaction of the two conditions determines the structural Behavior factor more accurately.

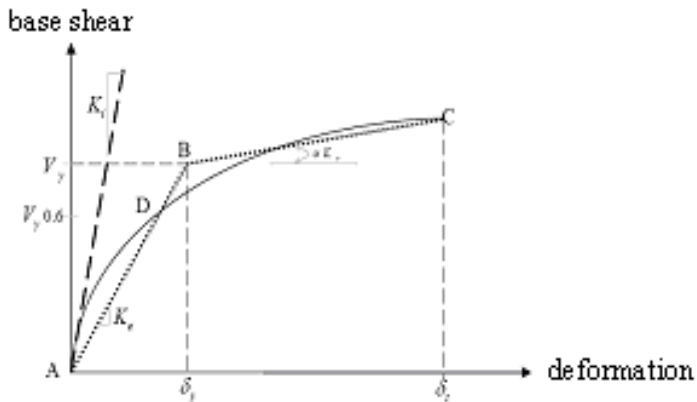


Figure 4. Determining the yield Δ_y displacement according to the instructions of seismic rehabilitation of the existing buildings [8]

3. MODELING

3.1. Studied Frames, Loading, Static Analysis

In this research in order to obtain the Behavior factor of the metal frames with semi rigid connections and metal dampers, as shown in Figure (5), yielding metallic dampers of ADAS have been installed on 12 models of frames with the heights of 4, 8, 12 stories with hinge, flexible semi-rigid, hard semi-rigid, and rigid connections. The height of the stories is 3.2 m and there are 3 openings each one as wide as 4 m. the distance between the middle frames is considered to be 4 m.

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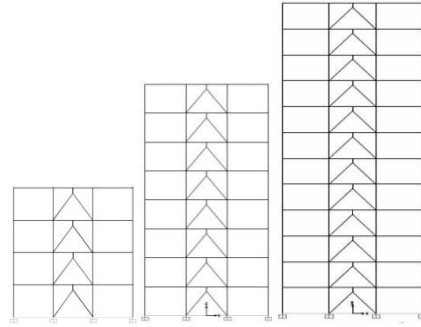


Figure 5. Frames used in the research

Loading is done based on the sixth issue of the Iranian national code [10]. The dead load of the stories is 600 kg/m^2 and the live load is considered as 200 kg/m^2 . In order to calculate the earthquake force the seismic coefficient is calculated according to the code of 2800 [11], given the relatively high risk of the zone, building with medium importance, and type III soil of the land. The Behavior factor in the bracing frames is assumed to be 7 according to the regulations of 2800. SAP 2000 [12] software is used for the equivalent static analysis and the preliminary design of the members. IPE sections are used for beams, IPB sections are used for columns and UNP sections are used for braces. The steel used in the frames is St 37.

For consider the semi-rigid connection of beam-to-column, the flexural stiffness of the connection is required.

Many studies have been done to obtain the flexural stiffness of the connection. In this paper, Astaneh and Marwan Method [13] are used. Astaneh and Marwan introduced \underline{m} parameter for the classification of connections; \underline{m} is the ratio of elastic rotational stiffness of connection to the elastic rotational stiffness of the beam connected to it.

$$m = \frac{K_{e.con}}{(EI / L)_{beam}} \quad (10)$$

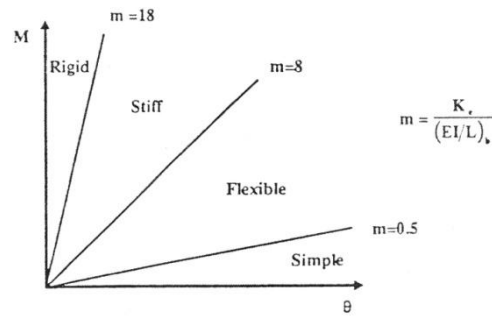


Figure 6. Classification of connections based on Astaneh-Marvan method (1989) [11]

According to Astaneh classification [8], the connections are classified as the following:

- (11) Rigid connection $m > 18$
- (12) Stiff semi-rigid connection $8 \leq m \leq 18$
- (13) Flexible semi-rigid connection $0.5 \leq m < 8$
- (14) Hinge connection $m \leq 0.5$

Since the beams used in the research are ranged from IPE140 to IPE300 and considering the flexibility of beam-to-column connection, it is possible to calculate the connection stiffness by having the parameter of m , beam length, and beam cross section characteristics. Table (1) shows the values used in the research.

Table 1. Calculating the rotational stiffness (K_θ) of stiff and flexible semi-rigid connections [11]

Section	Semi-Rigid Flexible	Semi-Rigid Hard
IPE140	11720	35849
IPE160	18825	57584
IPE180	28531	87270

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IPE200	42092	128751
IPE220	60051	183685
IPE240	84314	257900
IPE270	125431	383670
IPE300	181019	553704

To avoid the repetition of the names of frames abbreviated terms are used, so that the letter A is used at the beginning of the name of frames with metal dampers and then the name and the type of frame connection are abbreviated. In this way, H is used for hinge connection, SF is used for semi-rigid flexible connection, SH for semi-rigid hard connection, and R for the rigid connection.

3.2. Non-Linear Analysis and Determining the Behavior factor of the Studied Frames

In order to calculate the Behavior factor of the studied frames, the non-linear static analysis was done on the frames via the PERFORM software so that they were placed under the increasing lateral load and after drawing the capacity curve the seismic parameters were extracted and were used as the Behavior factor of the mentioned frames the results of which are displayed in Table (2).

Table 2. Seismic parameter characteristics of the studied models

Frame	μ	R_{μ}	R_s	R_u	R_w
AH4	8.72	4.75	1.23	5.87	8.45
ASF4	9.04	4.22	1.46	6.15	8.86
ASH4	8.83	4.61	1.38	6.38	9.19
AR4	8.81	4.59	1.41	6.46	9.30
AH8	5.29	6.16	1.08	6.67	9.61
ASF8	5.29	6.25	1.22	7.62	10.98
ASH8	5.24	6.01	1.29	7.78	11.20
AR8	6.01	6.65	1.22	8.10	11.66
AH12	4.62	5.15	1.32	6.80	9.79
ASF12	5.15	5.93	1.29	7.70	11.09
ASH12	4.80	5.54	1.43	7.93	11.42
AR12	4.89	5.63	1.48	8.36	12.04

In order to suggest an applied behavior factor for the frames with metal dampers for different states of beam-to-column connection the means of the behavior factors for each system within the frames with different stories are calculated and after making the numbers round, the following results are recommended as shown in Table (3).

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Table 3. Behavior factors of the studied frames

Behavior Factor	AP	ASF	ASH	AR
R_w	9.3	10.3	10.6	11

Figure (6) shows the structure behavior factor based on the number of structure stories for all four kinds of joint, flexible semi-rigid, stiff semi-rigid and rigid connections.

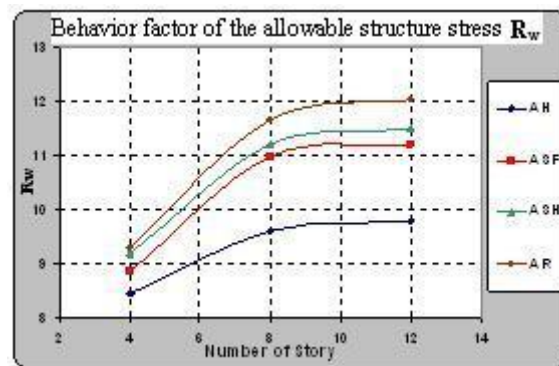


Figure 7. Behavior Factor of the allowable structure stress

According to Figure (7) and the results of Table (2) it is found that as the structure height increases from 4 to 8 and 8 to 12 stories the structure behavior factor increases so that the structure behavior factor increases 21% in average for all four connection systems through the increase of structure height from 4 to 8 stories. However, as the structure height increases from 8 to 12 stories, the structure behavior factor increases 2% in average for all four connection systems. Therefore, it can be concluded that the structure Behavior factor depends on the frame height to a certain height and then the increase of height won't have a special effect on the computed Behavior factor.

4. THE EFFECT OF ADDED DAMPING AND STIFFNESS (ADAS)

In order to investigate the effect of added metallic dampers and semi-rigid connections, the frames of the four stories studied in the previous section are compared with the frames without dampers and the results of investigation seismic parameters between the two series of frames are presented in this section. The parameters include the seismic period, base shear, relative displacement of stories (Stories drift) and the total stories displacement.

4.1. Comparison of the First Mode Seismic Period for the Studied Frames

In figure (7), the first mode seismic period for the studied frames with and without dampers in four system states with joint, flexible semi-rigid, stiff semi-rigid and rigid connections is displayed.

According to the figures, frames with dampers have greater seismic period than frames without dampers. In the studied frames added dampers increased the average seismic period about as 32% in comparison to the similar frames without dampers.

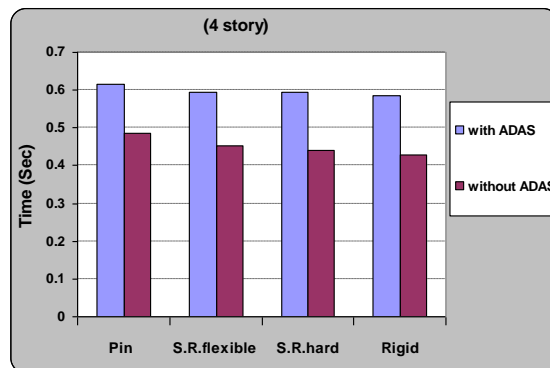


Figure 8. Comparison of the results of the first mode period for the studied frames

According to the above figures, as the rigidity increases from the joint to semi-rigid and from semi-rigid to rigid state, the seismic period of the structures decreases. The total results of seismic period changes of the studied frames in the research are displayed in Table (4).

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Table 4. Reduction percentage of seismic period of frames with dampers for different states of beam-to-column connection compared with the joint state

Fram type	Type of Beam-Column	Difference Percent
With ADAS	Hinge	-
	Flexible Semi-Rigid	3.2
	Hard Semi-Rigid	3.5
	Rigid	5
Without ADAS	Hinge	-
	Flexible Semi-Rigid	6.4
	Hard Semi-Rigid	8.9
	Rigid	11.5

4.2. Comparison of the Base Shear of the Studied Frames

In figure (9), the base shear of the studied frames with and without dampers in four system states with joint, flexible semi-rigid, stiff semi-rigid and rigid connections is displayed.

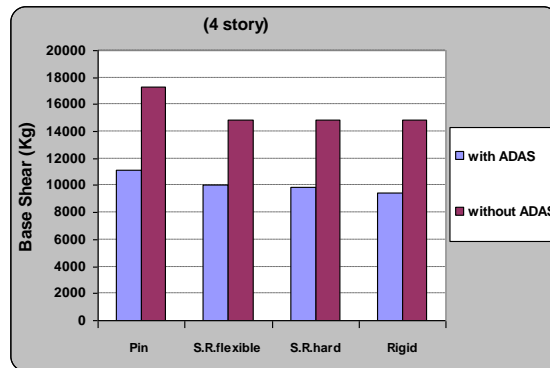


Figure 9. Comparison of the results of base shear for the studied frames

According to the above figure, frames with dampers have less base shear than the frames without dampers. As it is observed the added dampers in the studied frame decreases the base shear by 34% compared with the similar frames without dampers.

According to the above figures, as the rigidity increases from the hinge to semi-rigid and from semi-rigid to rigid state, the base shear decreases. The total results of base shear changes of the studied frames in the research are displayed in Table (5).

Table 5 Reduction percentage of the base shear of frames with dampers for different states of beam-to-column connection compared with the hinge state

Fram type	Type of Beam-Column	Difference Percent
With ADAS	Hinge	-
	Flexible Semi-Rigid	9.8
	Hard Semi-Rigid	12
	Rigid	15.2

4.3. Comparison of General and Relative Displacement of the Studied Frames Stories

In figure (10), the relative displacement of the stories (stories drift) and in Figure (11) the displacement of the stories of four-story frames with and without dampers in four system states with joint, flexible semi-rigid, stiff semi-rigid and rigid connections is displayed.

In Figure (12) the maximum displacement of the roof for four-story frames with and without dampers are compared for different states of beam-to-column connection.

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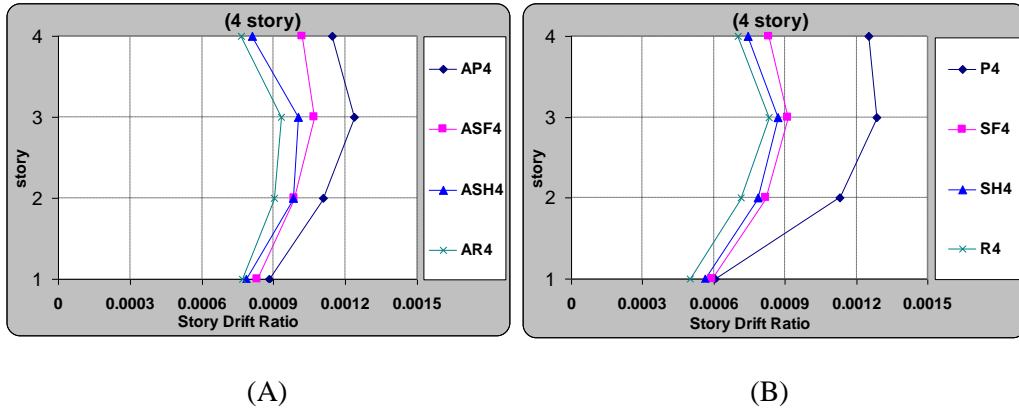


Figure 10. Comparison of the results of lateral displacement of the stories for the 4-story frame

- A. Frame with added damping and stiffness (ADAS)
- B. Frame without added damping and stiffness (ADAS)

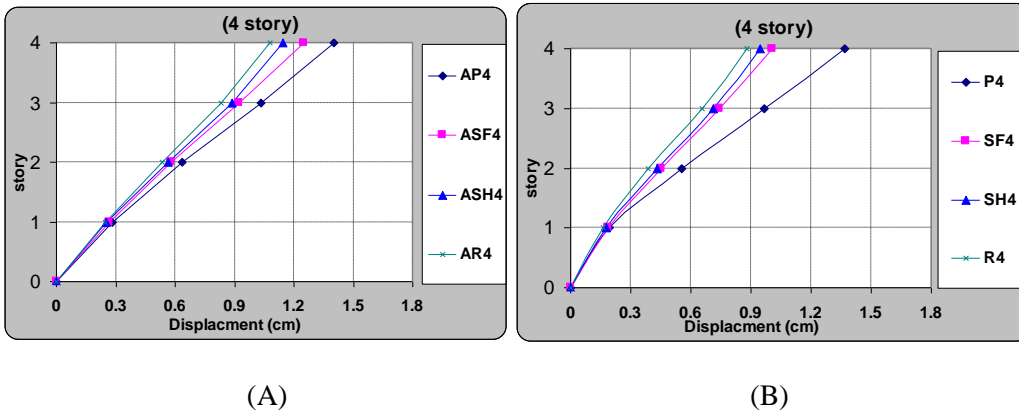


Figure 11. Comparison of the results of total lateral displacement of the stories for the 4-story frame

- A. Frame with added damping and stiffness (ADAS)
- B. Frame without added damping and stiffness (ADAS)

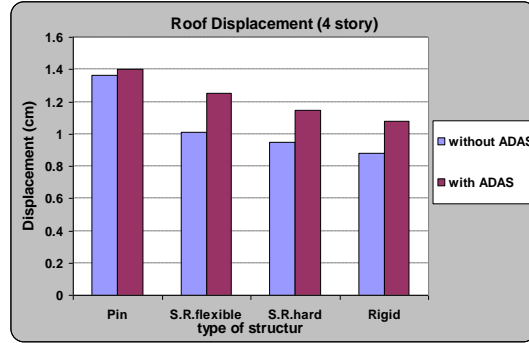


Figure 12. Comparison of the results of the roof story displacement for stories with and without dampers and different connections for the 4-story frame

According to the above figures, it is observed that the frames with dampers have more story displacement than the frames without dampers. Moreover, as the rigidity of the beam-to-column connection increases in the studied frames the displacement of the stories will decrease. In four-story frames with the connection of beam to the hinge column the added dampers will cause the increase of story displacement by 2.3% in comparison with the similar frames without dampers. The rate of story displacement for the frames with the connection of beam to flexible semi-rigid, stiff semi-rigid and rigid columns is respectively 23.8%, 20.9%, and 22.5% in comparison with similar frames without dampers. In average, the addition of dampers to four-story frames leads to the increase of story displacement by 17.4%.

Moreover, the above figures indicate that as the rigidity increases from the hinge to semi-rigid and from semi-rigid to rigid state the story displacement decreases. The total results of the seismic period of the studied frames in the research are displayed in Table (6).

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Table 6. Reduction percentage of story displacement of frames with dampers for different states of beam-to-column connection compared with the joint state

Fram type	Type of Beam-Column	Difference Percent
With ADAS	Hinge	-
	Flexible Semi-Rigid	10
	Hard Semi-Rigid	18
	Rigid	23
Without ADAS	Hinge	-
	Flexible Semi-Rigid	26
	Hard Semi-Rigid	30
	Rigid	35

4.4. Comparison of the Weights of the Studied Frames with and without Dampers

In Table (7) the weights of the systems with and without dampers are compared in four system states with hinge, flexible semi-rigid, stiff semi-rigid and rigid connections.

Table 7. Comparison of the weights of the systems with and without dampers (kg)

Fram type	Fram Weight Without ADAS	Fram Weight With ADAS	Difference Percent Fram Weight With & Without ADAS
4 Story With Hinge Joint	3420.3	3067.5	11.5
4 Story with Flexible Semi-Rigid Joint	3550.5	3130.9	13.4
4 Story with Hard Semi-Rigid Joint	3559.5	3073.9	15.8
4 Story With Rigid Joint	3486.6	2948.1	18.3
8 Story With Hinge Joint	8644.6	7684.1	12.5
8 Story with Flexible Semi-Rigid Joint	10199.4	898.3	13.5
8 Story with Hard Semi-Rigid Joint	9136.4	7822.2	16.8
8 Story With Rigid Joint	8909.5	7518.6	18.5
12 Story With Hinge Joint	15678.4	14023.6	11.8
12 Story with Flexible Semi-Rigid Joint	20914.1	18377.9	13.8
12 Story with Hard Semi-Rigid Joint	17220.9	14794.6	16.4
12 Story With Rigid Joint	16294.5	13681.3	19.1

Investigating the Linear and Non-Linear Behavior of Steel Frames

As it is observed in Table (7), the frames with dampers have lower weight than the frames without dampers. In average, the comparison of the studied frames indicates that the frames with dampers are about 15% lighter than the frames without dampers.

5. CONCLUSION

It is observed that the frames with dampers have greater seismic period than the frames without dampers. In average, the added dampers in the studied frames increase the seismic period of the structure by 14%. The results are shown in Tables (4) and figure (8).

It is also observed that the frames with dampers have less base shear than the ones without dampers which is observed in Figure (9). In the studied frames, the added dampers in average caused the decrease of base shear by 34% compared with the similar frames without dampers. Moreover, as the dampers are added to the studied frames the lateral displacement of the stories will increase.

As the connection stiffness increases, the structure behavior factor increases, too; so that as the connection rigidity increases from the hinge state to flexible semi-rigid and stiff semi-rigid and rigid state, the structure behavior factor for three different heights increases 10.7%, 13.9%, and 18.3% respectively in comparison with the hinge connection state.

The results are displayed in Tables (3) and figure (7). It is also observed that as the connection rigidity increases, the structure seismic period decreases which is displayed in Tables (4) and figure (8).

Furthermore, it is observed that as the connection rigidity increases from the joint state to the semi-rigid and rigid state and as Behavior factor increases in the frames with dampers, the base shear decreases. In average, for four different heights of the studied frames with excurrent metallic dampers, the base shear of the structure with flexible semi-rigid, stiff semi-rigid and rigid connections decreases 9%, 12% and 15% respectively in comparison with similar frames with hinge connections. Moreover, as the rigidity of beam-to-column connection increases the frame displacement decreases which is observed in Figures (10), (11), and (12).

In addition, it is observed that the frames with damper have less weight than the frames without dampers. In average, the comparison of the studied frames indicates that the frames with dampers are about 15% lighter than the ones without dampers.

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REFERENCES

- [1] Tsai, K.C., Chen, H.W., Hong, C.P., and Su, Y.F., "Design of Steel Triangular Plate Energy Absorbers for Seismic-Resistant Construction," *Earthquake Spectra*, Vol. 9, No. 3, pp. 505-528, 1993.
- [2] Powell, G.H., *Perform-3d Userguid & Element Description*, (2003), Ram International Company.
- [3] A.S. Whittaker, V.V. Bertero, J.L. Alonso and C.L. Thompson, "Earthquake Simulator Testing of Steel Plate Added Damping and Stiffness Elements," Report No. UCB/EERC- 89/02, University of California, Berkeley, 1989.
- [4] R.G. Tyler, "Tapered Steel Energy Dissipators for Earthquake Resistant Structures," *Bulletin of the New Zealand National Society for Earthquake Engineering*, 11 (4), 282- 294 (1978).
- [5] J.M. Kelly, M.S. Skinner and K.E. Beucke, "Experimental Testing of an Energyabsorbing Base Isolation System," Report No. UCB/EERC-80/35, University of California, Berkeley, 1980.
- [6] Dargush, G. F. & Soong, T. T., "Behavior of metallic plate dampers in seismic passive energy dissipation systems", *Earthquake Spectra* 1995, 11 (4), pp. 545-568
- [7] Arturo Tena-Colunga, "Mathematical modelling of the ADAS energy dissipation device", *Engineering Structures*, Vol. 19, No. 10, pp. 811-821, 1997.
- [8] Feal, C- Piluse., V "Structural Steel Semi rigid Connections", (1999) Theory, Design and Software; Published by McGraw-Hill.
- [9] Miranda, E, (1993) "Site Dependent Strength Reduction Factor ", ASCE, *Journal of Structural Engineering*, Vol. 119, No. 12.
- [10] Sixth subject of building national provisions: "incoming loads to the building, the office of gathering and promotion of building" national provisions, 2006.
- [11] Iranian code of practice for seismic resistant design of buildings, Standard no. 2800- 84, Building and Housing Research Center.
- [12] Computers and Structures. 2010; Inc., *CSI Analysis Reference Manual for SAP2000*, Computer and Structures, Inc., Berkley, California
- [13] Astaneh-asl, (1995)," Seismic design of bolted steel moment resisting frame steel tips", *Structural Steel Educational Council, Technical Information & Product Service*, Berkeley, University of California.