Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 54(8) (2022) 581-584
DOI: 10.22060/ceej.2022.19890.7283

Experimental Study of Eccentricity and Width-to-Thickness Ratio Effects of Arched Steel Haunches on Cyclic Behavior

E. Emami, A. Kheyroddin*, O. Rezaifar

Department of Civil Engineering, Semnan University, Semnan, Iran

ABSTRACT: This paper introduces arched steel haunches (ASHs) as a novel technique in the seismic retrofitting of RC frames. In this regard, parameters such as ASH initial eccentricity and width-to-thickness ratio are evaluated as two factors affecting their cyclic behavior. A series of cyclic loading tests were performed on four specimens with single and double rectangular cross-sections and with the same nominal area and length, but with different eccentricities of 0.1 and 0.2 nominal length. Experimental results showed that the slenderness and width-to-thickness ratios play a significant role in the cyclic performance in compression and even tension, and by reducing the buckling potential and the cross-section reaching the fully plastic state, a more desirable hysteretic behavior is achieved. Therefore, with 50% reduction of these ratios simultaneously, the maximum compressive and tensile strength enhanced up to 59% and 27%, respectively, and the dissipated energy and the maximum viscosity damping ratio increased up to 152% and 14%, respectively. Also, the arched haunches showed different behavior in tension and compression for ultimate strength and plastic stiffness, which with decreasing the initial eccentricity, became more apparent. With increasing the initial eccentricity, the cross-sectional area effect on the increase of compressive strength and especially maximum tensile strength decreased. In addition, by reducing it by 50% and despite 59% reduction in cross-sectional area, the ultimate tensile plastic strength and stiffness increased up to 1.31 and 3.5 times, respectively. In addition, the obtained results will be used for further research on the experimental behavior of RC beam-column joints.

Review History:

Received: Apr. 21, 2021
Revised: Nov. 21, 2021
Accepted: Nov. 22, 2021
Available Online: Jan. 19, 2021

Keywords:

Seismic retrofitting
Arched steel haunches
Cyclic performance
Overall buckling
Chord elastic stiffness

1- Introduction

In past years, the technique of single and double straight haunches has been introduced as one of the seismic retrofitting methods of reinforced concrete (RC) moment frame. The main aim of this method is to relocate the plastic hinge from beam to column, reducing the effective shear forces in the panel zone and thus saving it from seismic loads under premature shear failure. This technique was first investigated experimentally for the seismic retrofitting of RC beam-column joints sub-assemblage by Chen [1] and Pampanin et al. [2]. Recently, researchers have evaluated the efficiency of arched steel elements for usage as dampers and knee braces in the seismic retrofitting of steel structures. According to the results of this research, it can be said that the use of these elements can have the desired structural properties such as a significant increase in energy dissipation, damping and high plastic stiffness [3-5].

This paper introduces arched steel haunches (ASHs) as a novel technique for seismic retrofitting of RC frames. In this regard, by conduction of the cyclic behavior on two groups of ASHs with double and single cross-sections, their elastic and plastic deformation capacity and strength were evaluated as well as the effect of slenderness, and width-to-thickness ratios.

2- Test specimens

According to Figure 1, in order to evaluate the effect of axial eccentricity, e and the ratio of width to thickness, d/t_f, four ASHs specimens with double and single cross-sections with 8 and 16 mm plate thickness, respectively, and in two groups with e values of equal to 0.1 and 0.2 their nominal length were subjected to cyclic loading.

3- Results and Discussion

Based on the hysteresis behavior of test specimens, it can be said that all specimens exhibited unstable and asymmetric hysteresis behavior due to overall buckling phenomena, but the cross-section specimens with lower slenderness ratio and higher plastic coefficient, γ in compression and even tension show more desirable hysteresis behavior and less pinching effects. Moreover, the post-yielding stiffness of the specimens of the first group under tension is higher than the

*Corresponding author's email: kheyroddin@semnan.ac.ir

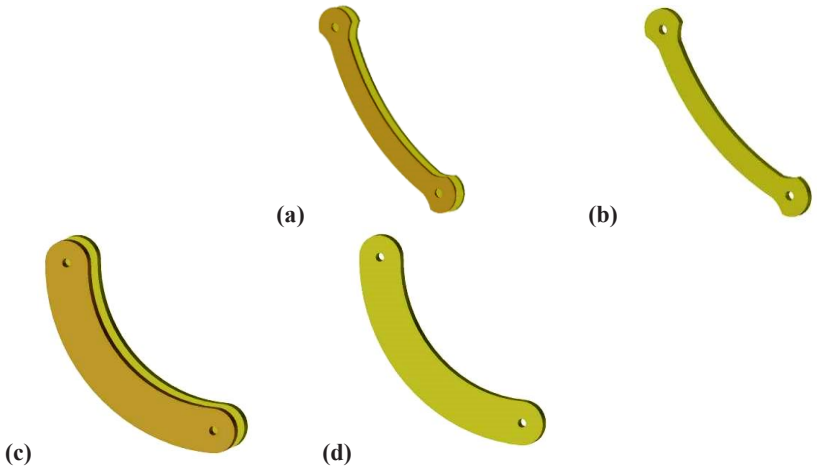

Fig. 1. Schematic configuration of the test specimens: (a) HA0.1; (b) HAS0.1; (c) HA0.2; (d) HAS0.2

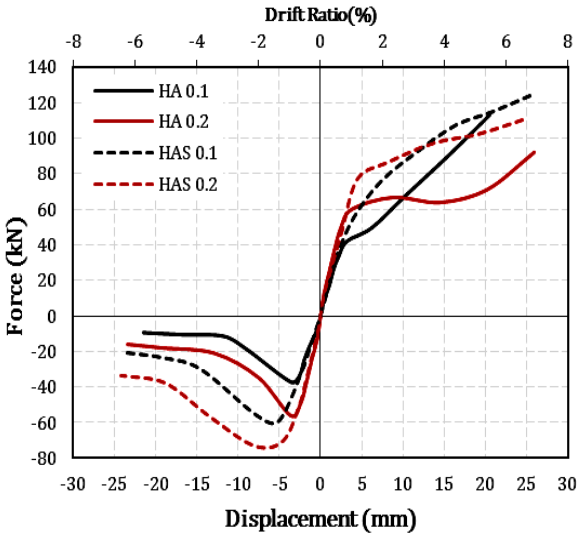

Fig. 2. Comparison of envelope curves of the specimens

second group specimens, which is mainly due to their less initial eccentricity and reaching straighter axial state; namely, their e_t/e is much higher under tension. According to Figure 2, specimens with double cross-section, HA 0.1 and HA 0.2 were subjected to overall buckling due to high slenderness (λ_y=138), consequently at low displacement after yielding and even before reaching the plastic strength, suffered a severe deterioration in compressive strength. In contrast, HAS 0.1 and HAS 0.2 specimens with a single cross-section and possessing the half ratio of λ_y (λ_y=69) and d/t_f compared to the corresponding double specimens, while reaching their plastic strength limit, the maximum compressive strength of about 1.59 and 1.32 times, respectively. They also showed almost two times ultimate compressive strength.

In tension, all specimens, especially the specimens with less value of e, by approaching their straighter state with increase of horizontal displacement and consequently decrease in initial eccentricity, are associated with a sharp increase in strength. However, it should be acknowledged that the double specimens, due to the occurrence of premature overall buckling and possessing high d/t_f ratio (d/t_f=12.5) and lower γ and consequently because of the incomplete plastic hinge at their cross-sections, after yielding exhibited a severe reduction in stiffness and reached their fully plastic strength at larger deformation.

According to Table 1, HAS specimens with single cross-section showed more desirable energy dissipation, E_d than their corresponding HA specimens with double cross-section in each group due to their fuse-like performance, so that amount of their energy dissipation compared to HA specimens in the first and second groups were about 2.52 and 2.03, respectively. The results indicate that E_d values are significantly affected by the increase in γ (or decrease in d/t_f) and especially the decrease in the λ_y ratio of the cross-section of the specimens.

To investigate the damping rate of the specimens against cyclic loads, the viscosity damping equivalent to ζ_{eq} can be calculated according to Eq. 1 [6]:

$$\xi_{eq}=\frac{E}{\pi\left(F^{+}\Delta^{+}+F^{-}\Delta^{-}\right)} \quad (1)$$

where E is the total energy dissipation in each load cycle. F^{+} and F^{-} are also the maximum and minimum forces at each cycle, respectively, which correspond to the displacement of Δ^{+} and Δ^{-}, respectively.

Table 1. Dissipated energy and equivalent viscous damping comparison

Specimen ID	Total Dissipated Energy (kN.mm)	Maximum of Equivalent Viscous Damping ($\zeta_{eq,\,Max}$)
HA 0.1	6607	0.21
HAS 0.1	16618	0.23
HA 0.2	9665	0.22
HAS 0.2	19641	0.25

The specimens with single cross-sections of HAS 0.2 and HA 0.1 with $\zeta_{eq,Max}$ equal to 0.25 and 0.21 exhibited the highest and lowest damping values, respectively. It can also be observed that the ζ_{eq} ratio in the specimens of the second group compared to the first group is larger values in all loading cycles due to the greater initial axial eccentricity.

In general, it can be said that specimens with a single cross-section under tension and compression have a lower secant stiffness degradation trend than specimens with a double cross-section. It can also be seen that the stiffness degradation of all specimens in compression than the tension due to the occurrence of overall buckling is very significant so that their ultimate compressive stiffness relative to the tension in the first and second group specimens with single cross-section were about 5.5 and 12.5 times, respectively, and with double cross-section were 3.3 and 5 times. It should also be noted that in compression the first group specimens and in tension, the second group specimens showed a relatively higher stiffness degradation rate.

4- Conclusions

The specimens with single (λ_y = 69) and double (λ_y = 138) cross-section under compression were subjected to overall buckling and compressive strength deterioration, and only single cross-section specimens reached their plastic strength theoretically due to their lower λ_y and d/t_f ratios. The maximum compressive strength in single compared to double cross-section specimens (with the same cross-sectional area) for the first and second groups were about 1.59 and 1.32 times and also their ultimate compressive strength was about twice. The dissipated energy in single compared to double cross-section specimens in the first and second groups, due to 50% reduction in λ_y and d/t_f ratios and possessing a higher γ coefficient were about 2.52 and 2.03 times, and the maximum of equal viscosity damping ratio $\zeta_{eq,Max}$, were 1.1 and 1.14 times respectively.

References

[1] Chen, T., 2006. "Retrofit strategy of non-seismically designed frame systems based on a metallic haunch system". Master of engineering thesis. Christchurch (New Zealand): University of Canterbury.

[2] Pampanin, S., Christopoulos, C., and Chen, T., 2006. "Development and validation of a metallic haunch seismic retrofit solution for existing under-designed RC frame buildings". Earthquake Engineering and Structural Dynamics, 35(14), pp.1739–1766.

[3] Hsu, H.L., and Halim, H., 2017. "Improving seismic performance of framed structures with steel curved dampers". Engineering Structures, 130, pp.99–111.

[4] Hsu, H.L., and Halim, H., 2018. "Brace performance with steel curved dampers and amplified deformation mechanisms". Engineering Structures, 175, pp.628–644.

[5] Zhou, Z., Ye, B., and Chen, Y., 2019. "Experimental investigation of curved steel knee braces with adjustable yield displacements". Journal of Constructional Steel Research, 161, pp.17–30.

[6] Chopra, A.K., 2001. "Dynamics of structures: theory and applications to earthquake engineering". 2nd ed, Englewood Cliffs: Prentice Hall.

HOW TO CITE THIS ARTICLE

E. Emami, A. Kheyroddin, O. Rezaifar, Experimental Study of Eccentricity and Width-to-Thickness Ratio Effects of Arched Steel Haunches on Cyclic Behavior, Amirkabir J. Civil Eng., 54(8) (2022) 581-584.

DOI: 10.22060/ceej.2022.19890.7283