Cyclic Performance Evaluation of Hollow Structural Section (HSS) and Concrete-Filled Tube (CFT) Braces

Samira Ebrahimi*, Seyed Mehdi Zahrai†‡ and Seyed Rasoul Mirghaderi‡||

*School of Civil Engineering, College of Engineering
University of Tehran, Iran

†Center of Excellence for Engineering and Management of Civil Infrastructures
School of Civil Engineering, College of Engineering
University of Tehran, Iran

‡School of Civil Engineering, College of Engineering
University of Tehran, Iran

§samira.ebrahimi@ut.ac.ir
¶mzahrai@ut.ac.ir
||rmirghaderi@ut.ac.ir

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Hollow structural sections (HSS) are widely used as braces because they have inherent axial, flexural, and torsional capacities. Delaying or preventing local buckling is accomplished by concrete infill in HSS braces to improve their cyclic response heavily relying upon three key parameters: (1) presence of concrete infill, (2) width (diameter)-to-thickness ratio, and (3) length-to-width (diameter) ratio impress the cyclic response of HSS braces. Nevertheless, it is not clear that based on which parameter, concrete infill can significantly enhance the peak compressive strength and energy dissipation capacity of HSS braces. This paper aims to investigate this concern while presenting a numerical study on the cyclic response of 120 HSS and Concrete-Filled Tubes (CFT) braces with various geometric characteristics. Square and circular cross-sections, 10, 12, 13.33, 20, 30, 33.33, and 50 width (diameter)-to-thickness ratios and 10, 15, 20, 25, 30, 37.5, 45, 50, 75, and 112.5 length-to-width (diameter) ratios are selected for the numerical investigation. Obtained results indicated that concrete infill can increase peak compressive and post-buckling strengths and energy dissipation capacity of HSS braces around 81%, 43%, and 73%, respectively. It was found that concrete infill and parameters of width (diameter)-to-thickness ratio and length-to-width (diameter) ratio influence the cyclic response of HSS braces differently. On the other hand, concrete infill noticeably enhances the peak compressive strength of HSS braces with larger values of width (diameter)-to-thickness ratio and energy dissipation capacity of such braces with lower values of length-to-width (diameter) ratio.

Keywords: Braces; Hollow Structural Section (HSS); Concrete-Filled Tube (CFT); width (diameter)-to-thickness ratio; length-to-width (diameter) ratio.

*Corresponding author.
1. Introduction

Hollow Structural Section (HSS) and Concrete-Filled Tube (CFT) have been widely used as braces, as indicated in extensive numerical and experimental research studies.\textsuperscript{1–6} Schneider,\textsuperscript{7} Shams and Saadeghvaziri,\textsuperscript{8} Huang \textit{et al.}\textsuperscript{9} have investigated the effect of the cross-section shape and thickness on the ultimate strength of CFT columns under axial load. The results have shown that the short circular CFT columns loaded axially convey an elastic-perfectly plastic behavior and also have more post-yield axial ductility compared to square or rectangular CFT columns. Research conducted by Knowles and Park\textsuperscript{10} on the effect of slenderness ratio on the ultimate strength of CFT columns under axial load, has shown that slenderness ratio is an important factor in concrete confinement, such that a slenderness ratio of less than 35 will ensure concrete confinement. Numerous tests have illustrated that concrete infill increases the compressive strength for circular CFTs and the ductility for rectangular CFTs, and also delays or prevents local buckling of the steel tube.\textsuperscript{11,12}

Hajjar\textsuperscript{13} has shown that in CFT braces, outward-buckling mode with the longer buckle-wavelength leads to reduced strain demands in comparison with HSS braces that illustrate short wavelength inward-buckling. Broderick \textit{et al.}\textsuperscript{14} have experimentally investigated the response of HSS and CFT bracing members under monotonic and cyclic axial loading. Based on experimental observations, they have concluded that the CFT specimens have relatively higher ductility and larger post-buckling strength than those of the equivalent HSS specimens improving ductility capacity by delaying or limiting local buckling. They have indicated that tension strengths of HSS and CFT specimens were equal. Liu and Goel\textsuperscript{15} have tested nine full-scale, one-bay, one-story braced frames with rectangular CFT and HSS braces under quasi-static cyclic loading. They have found that the presence of concrete infill can increase energy dissipate capacity and failure ductility and also can change the mode of the local buckling. Li \textit{et al.}\textsuperscript{16} have investigated, experimentally and numerically, CFTs behavior under eccentric tensile loading. They have indicated that conventional design equations predict safely and conservatively the tension and flexural strength of CFTs loaded eccentrically.

Tao \textit{et al.}\textsuperscript{17} have used a database including test results of 484 circular CFST stub columns and 445 rectangular CFST stub columns to investigate the applicability of design codes such as AIJ, AISC, DBJ 13-51-2003, and EN1994, in computing the compressive strength. Wang \textit{et al.}\textsuperscript{18} have considered a wide range of parameters for circular and rectangular CFST stub columns to determine the compressive strength, the compressive stiffness, and the compressive strain.

Trica and Chen\textsuperscript{19} conducted a regression analysis to anticipate the failure strain for a single reversal value in simulating brace fracture. Their predicted value for failure strain depends on parameters of slenderness ratio, width-to-thickness ratio and steel yield strength. Also, they proposed an empirical regression equation for square HSS braces with slenderness ratio between 50 and 150 using data from 14 experimental tests. Ebrahimi \textit{et al.}\textsuperscript{20} investigated the gusset plate behavior in
Special Concentrically Braced Frames (SCBFs) and proposed a new method for calculating the force distribution at the gusset plate-to-column and beam interfaces. They also presented a new procedure to determine the gusset plate dimensions. Ebrahimi et al.\textsuperscript{21} proposed through gusset plate connections to improve connection responses and numerically studied the behavior of HSS braces, gusset plate and connections in SCBFs with HSS columns and beams.

Improving cyclic response of HSS braces is accomplished by concrete infill. The effect of concrete infill on cyclic response of HSS braces severely relies upon essential parameters such as: (1) presence of concrete infill, (2) width (diameter)-to-thickness ratio, and (3) length-to-width (diameter) ratio, however, there is limited information that in which kind of HSS braces the concrete infill significantly enhances the peak compressive strength and energy dissipation capacity. This study investigates these essential parameters to conclude which one leads to more effective impact of concrete infill performance in improving the peak compressive strength and energy dissipation capacity of HSS braces.

This paper presents an extensive numerical study on the cyclic behavior of 120 HSS and CFT braces with two different shapes (square and circular) under cyclic axial loading. A comprehensive finite element (FE) model is first established and verified by the experimental results; then, parametric studies are performed by using this FE model to investigate the influence of those key parameters. The objectives of this study are as follows:

1. To evaluate the influences of various parameters such as presence of concrete infill, width (diameter)-to-thickness ratio and length-to-width (diameter) ratio on the peak compressive strength, the post-buckling strength and the energy dissipation capacity of HSS braces.
2. To identify in which kind of HSS braces, concrete infill significantly enhances the peak compressive strength and the energy dissipation capacity.

2. Numerical Modeling of HSS and CFT Braces

In this investigation, 120 braces with four types of cross-section (consisting of square HSS, circular HSS, square CFT, and circular CFT) in three different lengths (3000, 6000 and 9000 mm) are considered. The dimensions, the length ($L$), width (diameter)-to-thickness ratio ($\frac{D}{t}$ or $\frac{D}{T}$) and length-to-width (diameter) ratio ($\frac{L}{B}$ or $\frac{L}{D}$) of these specimens are given in Table 1.

3. Loading Protocol

Specimens are subjected to a cyclic axial loading protocol outlined by ATC-24 loading protocol\textsuperscript{22} as displacement-control. Defining $\Delta_y$ (brace yielding or buckling displacement) that is a key factor in ATC-24 loading protocol, is accomplished by applying an increasing axial displacement to brace specimens. The values for $\Delta_y$ are
### Table 1. Geometric characteristics of HSS and CFT braces.

<table>
<thead>
<tr>
<th>Name</th>
<th>Dimensions (mm)</th>
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<th>$L = 6000$ mm</th>
<th>$L = 9000$ mm</th>
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<td>13.33</td>
<td>37.5</td>
<td>13.33</td>
</tr>
<tr>
<td>Circular 80 x 6</td>
<td>14.33 11.25</td>
<td>7</td>
<td>20.5</td>
<td>11.25</td>
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<td>10</td>
<td>37.5</td>
<td>10</td>
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<td>14.33 11.25</td>
<td>7</td>
<td>20.5</td>
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<td>7</td>
<td>20.5</td>
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<td>7</td>
<td>20.5</td>
<td>11.25</td>
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### Table 2. Calculating $\Delta_y$ for different brace specimens.

<table>
<thead>
<tr>
<th>Name</th>
<th>$\Delta_y$ (brace yielding or buckling displacement) (mm)</th>
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<td>$L = 3000$ mm</td>
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<td>4 6</td>
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<tr>
<td>Circular 80 x 6</td>
<td>4 6</td>
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<td>4 6</td>
</tr>
<tr>
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<td>4.8 8</td>
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<td>4.8 8</td>
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<td>5.8 10</td>
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<tr>
<td>Circular 300 x 10</td>
<td>5.8 10</td>
</tr>
<tr>
<td>Square 300 x 300 x 15</td>
<td>5.8 10</td>
</tr>
</tbody>
</table>
calculated with respect to the brace displacement at the initial of yielding or buckling and determined by illustration brace axial force versus brace axial deformation. Table 2 gives the values of $\Delta_y$ for different brace specimens.

Table 2 indicates that concrete infill increases $\Delta_y$ by up to 34%. From Table 2, it can be concluded that the concrete infill in HSS specimens with lower length-to-width (diameter) ratio exhibits a significant effect on increasing $\Delta_y$, while the concrete infill makes a lesser contribution to increase $\Delta_y$ in HSS specimens with larger length-to-width (diameter) ratios. In this study, displacement ductility, $\mu_\Delta$, of brace specimens is defined as the ratio of maximum axial displacement to yielding or buckling displacement, considered to be 10.

4. FE Models of Specimens with ABAQUS

A three-dimensional nonlinear simulation of all the HSS and CFT specimens is performed in ABAQUS program. Due to the presence of two materials, the ductile steel and the brittle concrete in CFT specimens, their modeling is complex. The key components are steel, concrete and their interaction. A deformable, homogeneous shell element (S4R a 4-node doubly curved thin or thick shell, reduced integration type) is used to model steel elements. S4R elements possess: (1) six degrees of freedom per node, (2) three section points in order to calculate the strain and stress conversions through the thickness, and (3) reduced integration in the elements plan. The steel selected in the specimens is St37 and steel material is considered as the bilinear elastic–plastic model. Modulus of elasticity, Poisson’s ratio, yield strength, and ultimate strength values are assumed to be $E_s = 2 \times 10^5$ MPa, $\nu_s = 0.3$, $F_y = 240$ MPa, and $F_u = 370$ MPa, respectively. The material model of nonlinear kinematic hardening plasticity is used for the steel elements.

Three-dimensional, deformable and solid element (C3D8R eight-node brick element with reduced integration type) is used to simulate concrete. C3D8R elements possess: (1) three degrees of freedom per node and (2) reduced integration in order to compute the stress and strain. The compressive cylinder strength and Poisson’s ratio values are assumed to be $f_c = 30$ MPa, and $\nu_c = 0.2$, respectively. The concrete-damaged plasticity model is used to simulate the plastic behavior of concrete. The concrete-damaged plasticity model assumes a nonassociated potential plastic flow rule and isotropic damage and this model is useful for cyclic loading conditions.

In this study, the stress–strain relationships proposed by Velasco for the concrete in tension and compression are used (Figs. 1 and 2).

Velasco defined the tension behavior of concrete by two steps. The first step is related to stress–strain curve before crack nucleation and the second step is related to post-failure stress-cracking displacement curve. In the first step, the stress–strain relationship is determined as $\sigma(t) = E_0 \epsilon(t) \leq \epsilon_0$ and in the second step, the trilinear model is used for stress-cracking displacement defined by four points, $(0, \sigma_0)$, $(w_1, \sigma_1)$, $(w_2, \sigma_2)$, and $(w_0, 0)$, where $\sigma_1 = k_1 \sigma_0$, $\sigma_2 = k_2 \sigma_0$, $w_1 = w_0/c_1$, and $w_2 = w_0/c_2$. $k_1$ and $k_2$ are the empirical parameters that can better describe the
behavior of post-failure softening in uniaxial tension test. \(c_1\) and \(c_2\) are the constants and their values 20 and 5 are proposed by Velasco, respectively. He considered the ideal stress–strain relationships for compression behavior of concrete by three parts: (1) initial elastic branch, (2) damage-based plastic rising branch, and (3) damage-based plastic declining branch (Eq. (1)),

\[
\sigma_c(\varepsilon_c) = \begin{cases} 
E_0 \varepsilon_c, & \varepsilon_c \leq \varepsilon_{c0} \\
\sigma_{cu} \left[ 1 - \left( 1 - \frac{\varepsilon_c}{\varepsilon_{cu}} \right)^{\eta_1} \right], & \varepsilon_{c0} < \varepsilon_c \leq \varepsilon_{cu}, \\
\sigma_{cu} \left[ 1 - \left( \frac{\varepsilon_c - \varepsilon_{cu}}{\varepsilon_{cm} - \varepsilon_{cu}} \right)^{\eta_2} \right], & \varepsilon_{cu} < \varepsilon_c \leq \varepsilon_{cm},
\end{cases}
\]  

(1)

![Ideal stress–strain curve for uniaxial tension of concrete](image1)

![Ideal stress–strain curve for uniaxial compression of concrete](image2)

Fig. 1. Ideal stress–strain curve for uniaxial tension of concrete \(22\) (a) before beginning of crack and (b) post-failure.

Fig. 2. Ideal stress–strain curve for uniaxial compression of concrete \(22\)
where $\varepsilon_{cu}$ is the strain according to the ultimate compression stress, $\varepsilon_{cm}$ is the maximum strain equal to $\varepsilon_{cm} = k_c \varepsilon_{cu}$, $k_c$ is the empirical parameter and is calculated from the compression tests. From the experimental data utilizing the Statistical “Nonlinear Fit” package of Mathematica, values of $\eta_1$ and $\eta_2$ can be estimated $7.0, 26$

The most important factor in behavior of the CFT members is the interaction between concrete infill and steel tube. In ABAQUS, “contact pair” consisting of master-steel and slave-concrete surfaces is considered for the interaction between concrete infill and steel tube. Tangential behavior is defined as “Penalty” and the coefficient of friction concrete infill and steel tube is selected as 0.3, but in the studies, it is considered from 0.2 to 0.4. Normal behavior is defined as “Hard Contact” which allows for separation after contact but avoids over closure.

Figure 3 shows the boundary conditions of brace specimens. The vertical displacements at both ends of specimens are constrained ($U_X = U_Y = 0$) while the horizontal displacement at one end is constrained ($U_Z = 0$) but it is allowed at the other end. Meanwhile, a reverse axial displacement is imposed at the other end of the specimens.

5. The Verification of FM Results

In this study, the experimental study by Broderick et al.$^{14}$ is used to validate the FE results. They carried out the experimental studies on the response of HSS and CFT members subjected to monotonic and cyclic axial loading and considered steel with a nominal yield strength 235 MPa and an ultimate strength of between 360 and 510 MPa. The compressive and tensile strengths of concrete were considered 24 and 2.53 MPa, respectively. The length of the HSS and CFT specimens was considered 1100 mm. The loading protocol used in their studies was according to the provisions of the ECCS.$^{27}$ CFT specimen of $20 \times 20 \times 2.0$ SHS tested under cyclic axial loading by Broderick et al., considered to validate specimens modeled in ABAQUS. The results obtained from ABAQUS are compared to those obtained by Broderick et al. (Fig. 4).
The similarity between the CFT specimen tested by Broderick et al. and the developed model in ABAQUS is illustrated in Fig. 5. From Figs. 4 and 5, it can be concluded that the FE results have reasonable accuracy.

6. Numerical Results of HSS and CFT Braces

The brace behavior is related to many variables, such as the presence of concrete infill, width (diameter)-to-thickness ratio and length-to-width (diameter) ratio. In this research, 120 HSS and CFT braces with different geometric characteristics are investigated to study the influence of those parameters on the braces behavior.
6.1. Failure modes

This section investigates the effect of parameters: (1) presence of concrete infill, (2) width (diameter)-to-thickness ratio, and (3) length-to-width (diameter) ratio on severity of local buckling of braces. The obtained results show that all HSS and CFT braces experienced global buckling almost when the compressive force achieved buckling load \( P_{cr} \). The plastic hinges appeared at the mid-length of braces. The behavior of CFT braces is fundamentally different from that of HSS braces. In compression loading, HSS braces experienced both inward and outward local buckling, whereas the concrete infill in the CFT braces eliminated inward local buckling and only outward local buckling occurred increasing the bending capacity of cross-section, and also delaying the onset of local buckling.

Local buckling in CFT braces was observed at larger longitudinal deformations in comparison with the equivalent HSS braces (Fig. 6). From Fig. 6 and comparison of Figs. 6(a-1), 6(b-1), 6(c-1) with Figs. 6(a-2), 6(b-2), 6(c-2), it can be concluded that in HSS braces, width (diameter)-to-thickness ratio is the key parameter in severity of

![Diagram](image1.png)

(a-1): Square HSS 200 × 200 × 6 \( L = 3000 \)  
(a-2): Square HSS 200 × 200 × 15 \( L = 3000 \)

(b-1): Square HSS 200 × 200 × 6 \( L = 6000 \)  
(b-2): Square HSS 200 × 200 × 15 \( L = 6000 \)

Fig. 6. The severity of local buckling in different HSS and CFT brace specimens.
Fig. 6. (Continued)
local buckling. On the other hand, HSS braces with larger width (diameter)-to-thickness ratio show more severe local buckling in comparison with the equivalent HSS braces with lower width (diameter)-to-thickness ratio. Also, the presence of concrete infill in CFT braces reduces the severity of local buckling in comparison with the equivalent HSS braces. However, from comparison of Figs. 6(a-1), 6(a-2), 6(d-1), 6(e-1) with Figs. 6(b-1), 6(b-2), 6(d-2),6(e-2), it can be concluded that length-to-width (diameter) ratio does not have significant effect in severity of local buckling. On the other hand, the severity of local buckling in the equivalent HSS and CFT braces with different length-to-width (diameter) ratios is approximately similar. Due to the occurrence of steel tube local buckling, most design codes specify limits for width (diameter)-to-thickness ratio of HSS and CFT members.28–31

6.2. Compression strength (buckling capacity)

Previous studies showed that concrete infill increases the compressive strength of HSS members2,14 but none of these studies specifies which parameter, namely width (diameter)-to-thickness ratio and length-to-width (diameter) ratio, has more significant effect on the contribution of concrete infill in increasing the compressive strength of HSS members.

In Table 3, the peak compressive strengths of HSS braces are compared with those of equivalent CFT braces and their percentage increase rates are calculated.

### Table 3. Peak compressive strength of HSS and CFT braces and calculating percentage increase.

<table>
<thead>
<tr>
<th>Name</th>
<th>Peak compressive strength (buckling capacity) (kN)</th>
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<td></td>
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<td>CFT</td>
<td>% Increase</td>
<td>HSS</td>
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<td>695</td>
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<td>3285</td>
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<td>3206</td>
<td>5884</td>
<td>84</td>
<td>3147</td>
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</table>
From Table 3, it is clear that for HSS and CFT braces with constant width or diameter, there is a general tendency of decrease in the peak compressive strength with increasing width (diameter)-to-thickness and length-to-width (diameter) ratios and also, the peak compressive strength in CFT braces is approximately 81% greater than equivalent HSS braces. Table 3 shows that there is no distinct relationship between percentage increase of the peak compressive strength of equivalent HSS and CFT braces and length-to-width (diameter) ratio while the relationship between percentage increase of the peak compressive strength of equivalent HSS and CFT braces and the width (diameter)-to-thickness ratio is obvious. As a result, parameter of width (diameter)-to-thickness ratio has a significant effect on the contribution of concrete infill in increasing peak compressive strength of HSS braces. Figure 7 depicts the variation of the percentage increase of the peak compression strength of equivalent HSS and CFT braces corresponding to the width (diameter)-to-thickness ratio.

From Fig. 7, it can be concluded that concrete infill in HSS braces with larger width (diameter)-to-thickness ratio has more significant effect on increasing the peak compressive strength.

6.3. The post-buckling strength

The compressive strength decreases upon increasing compressive deformations. The degradation in compression strength of braces is a significant parameter in Chevron configuration SCBFs since the compressive strength degradation induces a net vertical force on the connecting beam. Table 4 presents the post-buckling strength of brace specimens for displacement ductility (μΔ) of 5. Tremblay\textsuperscript{32} presented an expression for post-buckling strength of braces according to results of 76 specimens. He selected displacement ductility of 2, 3 and 5 to cover the range of anticipated axial deformations for braces in tension–compression curves.

From Table 4, it can be calculated that for HSS and CFT braces with constant width or diameter, the post-buckling strength decreases with the increasing width.
(diameter)-to-thickness and length-to-width (diameter) ratios and also the post-buckling strength in CFT braces is approximately 43% greater than those in equivalent HSS braces. Figure 8 compares hysteresis curves of HSS and CFT braces for some brace specimens. From Fig. 8, it is clear that the post-buckling strength is greater for CFT braces in comparison with equivalent HSS braces but the percentage of compressive strength degradation of CFT braces is greater than those of equivalent HSS braces.  

6.4. Energy dissipation

Energy dissipation controls the dynamic behavior of the SCBFs during severe earthquakes. In this study, the energy dissipation is defined as external work and is equal to the area enclosed via brace axial force–brace axial deformation hysteresis curves, similar to the definition used by Sheehan and Chan. Previous studies showed that the energy dissipation of HSS members is increased by concrete infill but none of these studies specify which parameters, namely width (diameter)-to-thickness ratio and length-to-width (diameter) ratio, have more significant effect on the contribution of concrete infill in increasing the energy dissipation of HSS members. In Table 5, the energy dissipation of HSS braces is compared to those of equivalent CFT braces and their increase in percentages are calculated.
Table 5 indicates that for HSS and CFT braces with constant width or diameter, brace specimens with lower width (diameter)-to-thickness ratio enclose a greater area per hysteresis loop in comparison with larger width (diameter)-to-thickness ratio and also, it is clear that CFT braces dissipate more energy than equivalent HSS braces (approximately 73%). Table 5 indicates that there is not a distinct relationship between percentage increase of the energy dissipation of equivalent HSS and CFT braces and the width (diameter)-to-thickness ratio while the relationship between percentage increase of the energy dissipation of equivalent HSS and CFT braces and the length-to-width (diameter) ratio is obvious. As a result, parameter of the length-to-width (diameter) ratio has a significant effect on the contribution of concrete infill in increasing the energy dissipation of HSS braces. Figure 9 depicts the variation of the increase percentages of the energy dissipation of equivalent HSS and CFT braces corresponding to the length-to-width (diameter) ratio.

From Fig. 9, it can be concluded that concrete infill in HSS braces with lower length-to-width (diameter) ratio has more significant effect on increasing the energy dissipation.
<table>
<thead>
<tr>
<th>Name</th>
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<td>L = 3000 mm</td>
<td>HSS</td>
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<td>Square 80 × 80 × 6</td>
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<td>Circular 300 × 15</td>
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</table>

| L = 6000 mm     | HSS | CFT | % Increase |
|-----------------|-------------------|
| Square 80 × 80 × 6 | 8963 | 9124 | 2 |
| Square 80 × 80 × 8 | 12281 | 13329 | 8 |
| Square 120 × 120 × 6 | 26359 | 28186 | 7 |
| Square 120 × 120 × 10 | 32415 | 33375 | 3 |
| Square 200 × 200 × 6 | 54224 | 112172 | 107 |
| Square 200 × 200 × 10 | 86394 | 158643 | 84 |
| Square 300 × 300 × 6 | 136125 | 200233 | 47 |
| Square 300 × 300 × 10 | 198385 | 189163 | 74 |
| Square 300 × 300 × 15 | 237296 | 340493 | 43 |
| Square 300 × 300 × 15 | 342654 | 416159 | 21 |
| Circular 80 × 6 | 7641 | 10053 | 32 |
| Circular 80 × 8 | 10188 | 12913 | 27 |
| Circular 120 × 6 | 22333 | 25753 | 15 |
| Circular 120 × 10 | 28020 | 37224 | 33 |
| Circular 200 × 6 | 32013 | 116125 | 263 |
| Circular 200 × 10 | 57320 | 166154 | 190 |
| Circular 200 × 15 | 73429 | 227238 | 209 |
| Circular 300 × 6 | 70878 | 150672 | 113 |
| Circular 300 × 10 | 117473 | 216141 | 84 |
| Circular 300 × 15 | 168301 | 298711 | 77 |

| L = 9000 mm     | HSS | CFT | % Increase |
|-----------------|-------------------|
| Square 80 × 80 × 6 | 9203 | 9306 | 1 |
| Square 80 × 80 × 8 | 18235 | 18709 | 2 |
| Square 120 × 120 × 6 | 28046 | 28128 | 0.3 |
| Square 120 × 120 × 10 | 48309 | 49166 | 2 |
| Square 200 × 200 × 6 | 50319 | 83552 | 66 |
| Square 200 × 200 × 10 | 57193 | 92075 | 61 |
| Square 300 × 300 × 6 | 83989 | 133904 | 59 |
| Square 300 × 300 × 10 | 125188 | 175037 | 40 |
| Square 300 × 300 × 15 | 242812 | 306096 | 26 |
| Square 300 × 300 × 15 | 329262 | 350712 | 7 |
| Circular 80 × 6 | 11042 | 11551 | 5 |
| Circular 80 × 8 | 14588 | 14992 | 3 |
| Circular 120 × 6 | 19775 | 27758 | 40 |
| Circular 120 × 10 | 31401 | 32958 | 5 |
| Circular 200 × 6 | 26918 | 78583 | 12 |
| Circular 200 × 10 | 46129 | 114238 | 148 |
| Circular 200 × 15 | 61980 | 154837 | 149 |
| Circular 300 × 6 | 53052 | 112742 | 113 |
| Circular 300 × 10 | 108208 | 145131 | 34 |
| Circular 300 × 15 | 168029 | 220231 | 31 |
7. Conclusion

In this paper, the effects of three main parameters: (1) presence of concrete infill, (2) width (diameter)-to-thickness ratio, and (3) length-to-width (diameter) ratio on the cyclic response of HSS braces were studied. This study investigated which parameters, namely width (diameter)-to-thickness ratio and length-to-width (diameter) ratio, have more significant effect on the contribution of concrete infill in improving the compression strength and the energy dissipation capacity of HSS members.

120 HSS and CFT braces with square and circular cross-sections and three different lengths (3000 mm, 6000 mm, and 9000 mm) were considered. 10, 12, 13.33, 20, 30, 33.33, and 50 width (diameter)-to-thickness ratios and 10, 15, 20, 25, 30, 37.5, 45, 50, 75, and 112.5 length-to-width (diameter) ratios were selected for the numerical study. The following can be concluded:

Based on the parametric study on HSS and CFT braces, local buckling in HSS braces with larger width (diameter)-to-thickness ratio is more severe than the case for equivalent HSS braces with lower width (diameter)-to-thickness ratio, while the presence of concrete infill in CFT braces reduces the severity of local buckling.

The peak compressive strength in HSS and CFT braces having constant width or diameter, decreases with increasing width (diameter)-to-thickness and length-to-width (diameter) ratios. Also, the peak compressive strength in CFT braces is approximately 81% greater than those in equivalent HSS braces. While increased rate of the peak compressive strength of equivalent HSS and CFT braces does not show a distinct relationship to length-to-width (diameter) ratio, it obviously depends on the width (diameter)-to-thickness ratio. The results obtained from numerical study showed that concrete infill in HSS braces with larger width (diameter)-to-thickness ratio has more significant effect on increasing the peak compressive strength.

The post-buckling strength in HSS and CFT braces having constant width or diameter decreases with increasing width (diameter)-to-thickness and length-to-width (diameter) ratios. The post-buckling strength of CFT braces is approximately
43% greater than that of equivalent HSS braces but the compressive strength degradation of CFT braces is greater than that of equivalent HSS braces.

HSS and CFT braces with constant width or diameter having lower width (diameter)-to-thickness ratio enclose a greater area per hysteresis curve compared to larger width (diameter)-to-thickness ratio. Also, CFT braces dissipate approximately 73% more energy than equivalent HSS braces. While increase rate of the energy dissipation of equivalent HSS and CFT braces does not show a distinct relationship to width (diameter)-to-thickness ratio, it obviously depends on the length-to-width (diameter) ratio. The parametric studies showed that, concrete infill in HSS braces with lower length-to-width (diameter) ratio has more significant effect on increasing the energy dissipation.

References

11. M. D. O’Shea and R. Q. Bridge, Tests on circular thin-walled steel tubes filled with medium and high strength concrete, Department of Civil Engineering, Centre for Advanced Structural Engineering, University of Sydney (1997).


