INVESTIGATION OF BUCKLING EFFECTS ON BEHAVIOR OF STEEL FRAME STRUCTURE

H.AFZALI[1*], T. YAMAO[2†], and A. KASAI[3]

[1]*Doctoral Student, Graduate School of Science and Technology, Kumamoto University*

[2]*Professor, Graduate School of Science and Technology, Kumamoto University*

[3]*Assistant Professor, Graduate School of Science and Technology, Kumamoto University*

ABSTRACT

As for designing earthquake resistant steel arch bridge the usual practical approach is employing beam elements in analysis procedure. Since the behavior of elements is complicated during earthquakes, this method will not present the real seismic behavior.

In this study steel rigid frame with box section in case of existence of I section brace member under global imperfection condition is used to investigate buckling effects on steel structural behavior. Shell elements are employed for modeling of brace member to take into account of the influence of local buckling effects. In brace member, various buckling parameters were considered for flange and web. Different width to thickness ratios are also assumed for plates in I section and box section. FEM analytical results are represented to show buckling failure in brace member and its impact on whole system behavior.

Keywords: Steel frame structure, steel arch bridge, seismic behavior, I-section brace member, FEM analysis.

1. INTRODUCTION

Using FEM analytical method, employing beam element model technique has been generally accepted for structural design of bridges as well as investigating of seismic behavior (Yamao et al. 2006). However; plates in thin-walled section members used in these structures are not perfectly flat. Small initial curvatures in plates of thin-walled section member cause it to deflect transversely as it is loaded. Employing shell elements in analytical model could lead in clarifying more details about deflection in built-up structural members as they buckle locally (Yamao et al. 2011). In this paper a rigid frame model with brace members developed to see the effect of using shell elements in regions in which local buckling is likely to occur. Initial imperfection in brace member is also considered to take account of global buckling effects. Steel rigid frame with brace members may be used in bridge piers. It is important to evaluate seismic horizontal strength and deformation property for

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[*]Presenter: Email:h.afzali@gmail.com

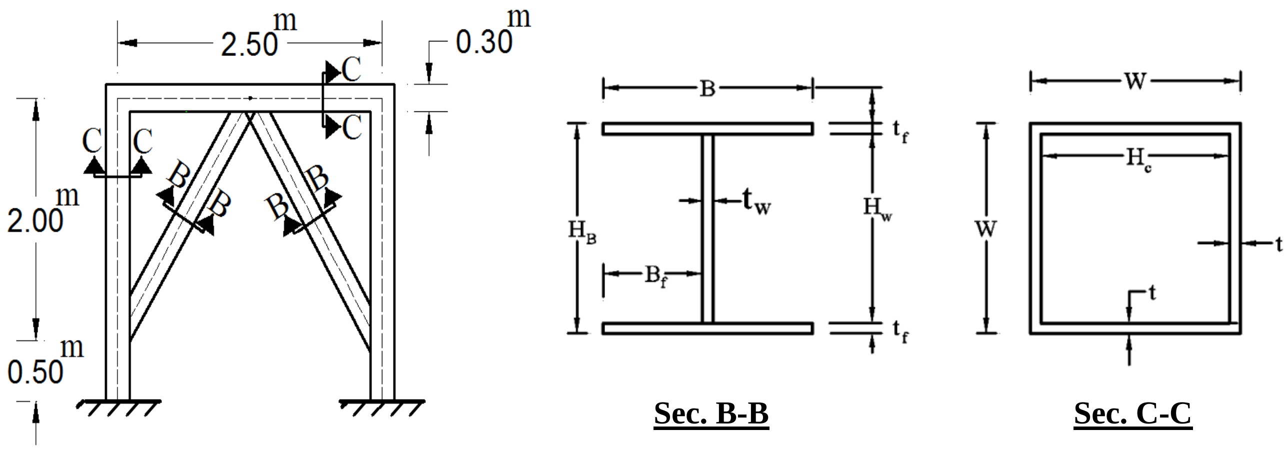
[†]Corresponding author: Email: tyamao@kumamoto-u.ac.jp

such critical structural members as piers for which seismic influence is most likely to become dominant during earthquakes. In this study use of shell element in brace members and base columns are compared with that of beam element in terms of lateral resistance of structure.

2. ANALYTICAL METHOD

2.1. Numerical model

Rigid frame with inverted "V" shape brace member is shown in Figure 1 and corresponding numerical model is illustrated in Figure 1. Structural system behavior taking account of buckling effects is shown by comparing two case of employing shell elements and beam elements for brace members in numerical model. The frame height is 2.5m and width is 2.5m. Brace members are joined to rigid frame using pin connections. The distance between the base and pin connection is assumed 0.50m. As a superstructure weight constant vertical load equals 5 percent of yield force of column sections is applied on two top corners of the frame.



(a)Rigid frame model (b) Cross sections of members

Figure 1: Specification of frame structure

As seen in Figure 1 rigid frame modeled using I-beam cross section for brace members and box cross section for columns and beams. The parameters of B and H_B represent for total width and height of the I-beam cross section, respectively. The parameters t_w, t_f and H_w represent the thickness of the web plate, thickness of the flange plates and the height of the web plate, respectively. H_c is internal side length of box section. As shown in Figure 2, steel material is assumed to be type *SS400* with bilinear stress-strain behavior. Young's modulus E=2.06 GPa, yield stress σ_y = 238 MPa, yield strain ε_y= 0.0012 and Poisson's ratio ν =0.3. The second incline slope is assumed to be 1/100 of the Young's modulus.

Shell elements are employed to determine the frame resistance taking account of local buckling effects. Therefore, to evaluate total behavior of structure, the numerical model studied in this research is made up in 4 different types shown in Figure 3. As seen shell elements are used in making brace member and base columns. The letters 'S' and 'B' stand for 'Shell' and 'Beam' elements.

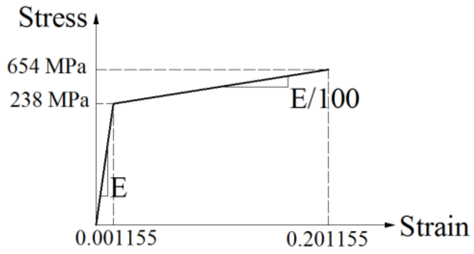


Figure2:Stress-strain curve forSS400 steel

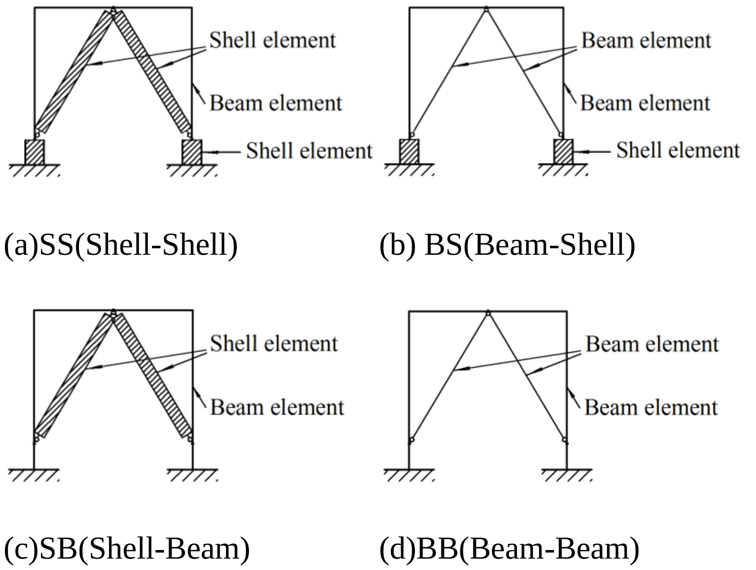


Figure3: Numerical models of the rigid frame with brace members

2.2. Buckling parameters

Buckling parameters are derived from thin plate buckling theory. Based on width-to-thickness ratio in flange and web for I-beam section and in box sections is defined as flowing.

$$R_f = \frac{B_f}{t_f}\sqrt{\frac{\sigma_y}{E}\frac{12(1-\nu^2)}{k\pi^2}} \quad \text{(For flange plate in I-beam section)} \qquad (1)$$

$$R_w = \frac{H_w}{t_w}\sqrt{\frac{\sigma_y}{E}\frac{12(1-\nu^2)}{k\pi^2}} \quad \text{(For web plate in I-beam section)} \qquad (2)$$

$$R_c = \frac{H_c}{t_c}\sqrt{\frac{\sigma_y}{E}\frac{12(1-\nu^2)}{k\pi^2}} \quad \text{(For plate in box section)} \qquad (3)$$

In above equations R_f, R_w and R_c are width-to-thickness ratio for flange, web and box section respectively. H_c represents internal dimension and t_c shows thickness for box section. Local buckling coefficient k= 0.425 for flange in I-beam section and k= 4.0 for web in I-beam section as well as box section. R_f, R_w and R_c varies between 0.4, 0.6 and 0.8. Different buckling parameters used for frame and for brace member to study elasto-plastic behavior. Dimensions of section parameters of frame and brace members used in analysis are explained in Table 1.Each specimen of study is modeled in 4 various forms as previously illustrated in Figure3.

Additionally in order to take account of global buckling effect in brace members, as seen in Figure4 global initial imperfection form equal 1/1000 of the brace member length is applied in both cases of using shell or beam elements.

Table 1: Dimensions of section parameters of frame and brace members

Specimens	Frame member		Brace member						
	W	t_c	H_B	B	t_f	t_w	R_c	R_f	R_w
1			91.5	91.5	6.0	3.6		0.4	0.4
2	300	12.3	92.4	92.4	4.1	2.5	0.4	0.6	0.6
3			92.8	92.8	3.1	1.9		0.8	0.8
4			91.5	91.5	6.0	3.6		0.4	0.4
5	300	8.5	92.4	92.4	4.1	2.5	0.6	0.6	0.6
6			92.8	92.8	3.1	1.9		0.8	0.8
7			91.5	91.5	6.0	3.6		0.4	0.4
8	300	6.4	92.4	92.4	4.1	2.5	0.8	0.6	0.6
9			92.8	92.8	3.1	1.9		0.8	0.8

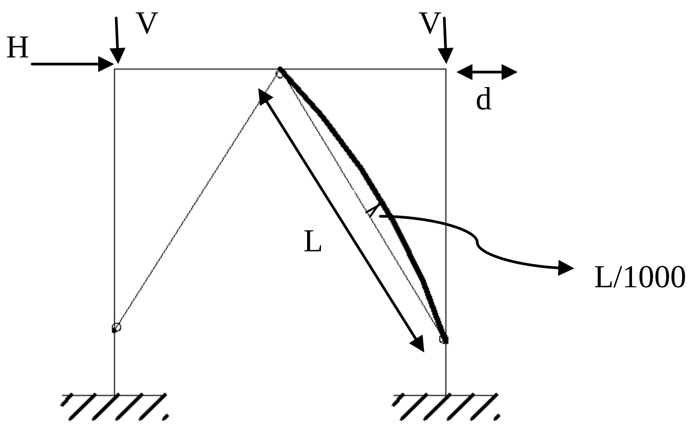


Figure 4: Applying initial imperfection in brace member in all case studies

3. RESULTS AND DISCUSSION

Displacement-based pushover analysis carried out to investigate elasto-plastic behavior of structure. The general FEM program of ABAQUS and the shell element S4R included in its package is employed to develop 3D form of the I-beam section and short column. Four node shell element (S4R) is robust and is suitable for a wide range of applications (ABAQUS 2011). It is also reliable for large displacement.

3.1. Lateral resistance

Based on the results obtain from pushover analysis, variation of lateral horizontal force *H* applied on the frame as shown in Figure 5 versus the displacement in top corner *d* is considered. As shown before in Figure3, four model types: SS, BS, SB and BB are developed to conduct nonlinear static analysis. It was found that in all case studies the lateral resistance behavior is exactly the same for types SS and BS. As mentioned before, notation SS represents using shell elements both in brace member and frame section whereas notation BS states using beam element in brace member and shell element in short column. The same goes to the cases of SB and BB. It means that lateral behavior does not depend on type of elements used in modeling of brace member. Additionally, lateral behavior is slightly different based on the type of elements used in short columns. As an example Figure 5 illustrates non-dimensional results obtained from case study using specimen 1 in which R_f=R_w=0.4 and R_c=0.4. The vertical axis represents lateral increasing force and horizontal axis shows lateral displacement of the frame in top corner.

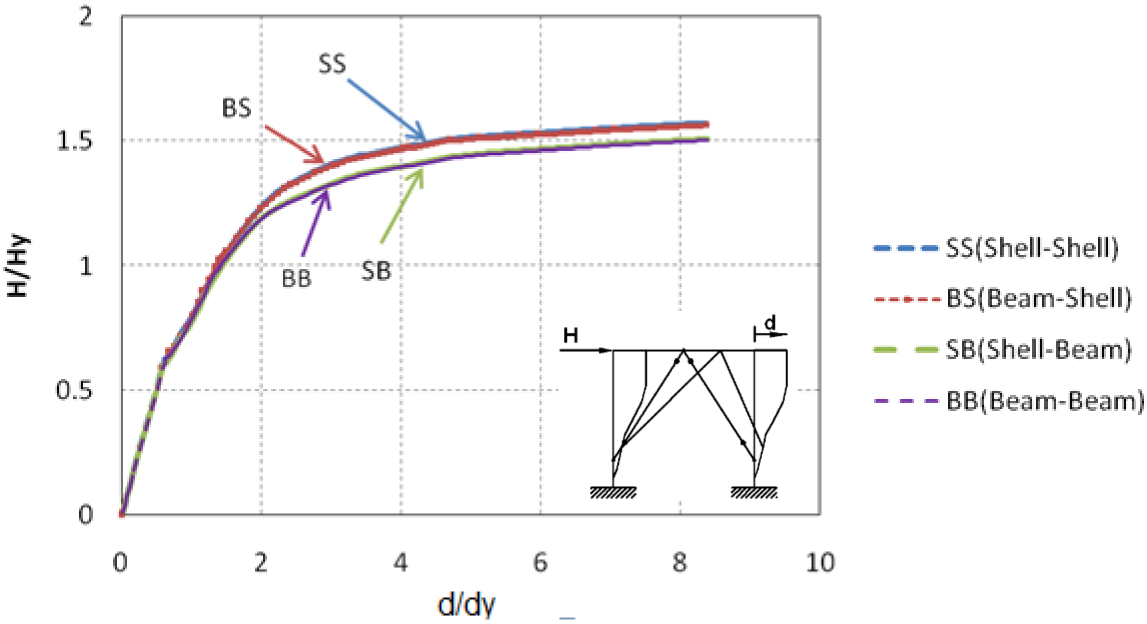
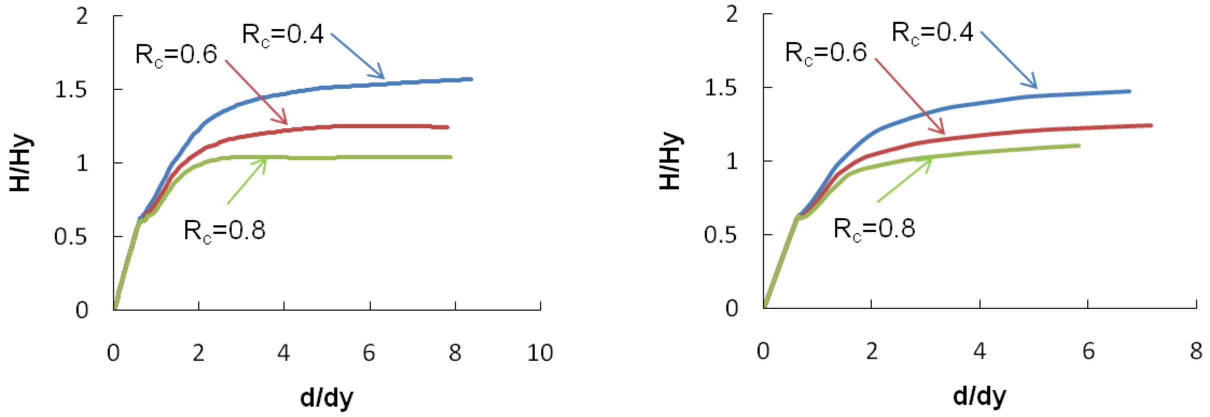


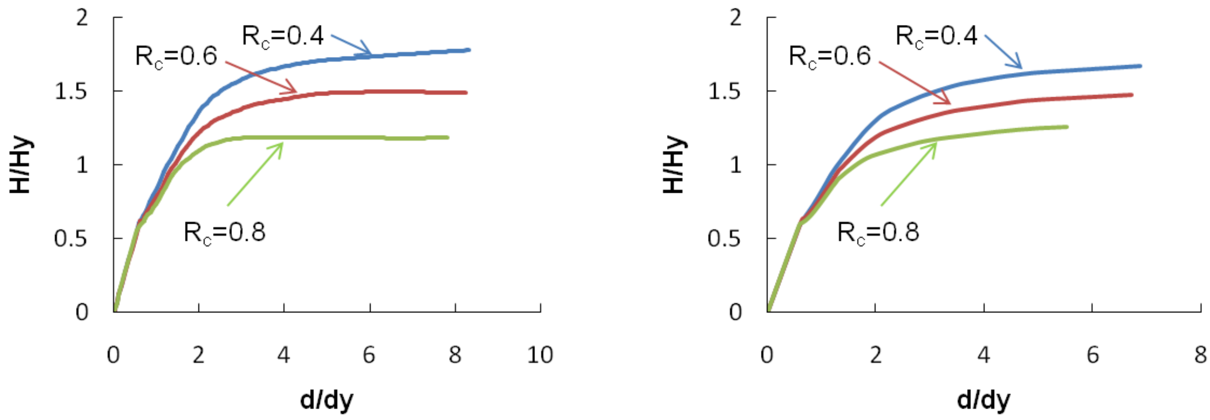
Figure 5: Lateral force versus lateral frame displacement (R_f=R_w=0.4, R_c=0.4)



(a) Model SS(Shell-Shell)

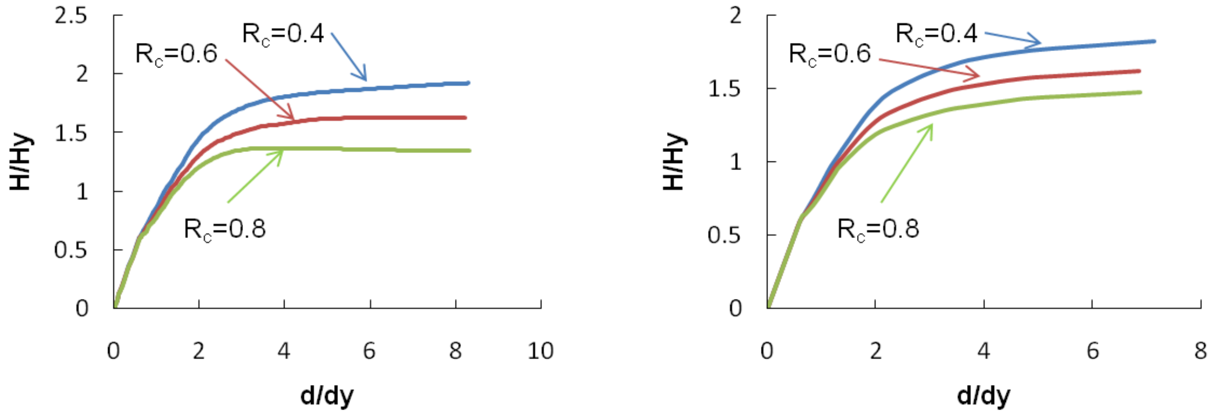
(b) Model BB(Beam-Beam)

Figure 6: Lateral behavior of structure; brace specification: R_f=R_w=0.4, L/r=100



(a) Model SS(Shell-Shell) **(b) Model BB(Beam-Beam)**

Figure 7: Lateral behavior of structure; brace specification: R_f=R_w=0.6, L/r=100



(a) Model SS(Shell-Shell) **(b) Model BB(Beam-Beam)**

Figure8: Lateral behavior of structure; brace specification: R_f=R_w=0.8, L/r=100

Lateral increasing load versus frame displacement in opposite corner (as shown in Figure 5) obtained in analysis is illustrated in Figure 6 to Figure 8 in tow case of SS and BB modeling technique. According to results it is confirmed that behavior in SS model could also represents for model BS; Behavior graph of model BB is also similar to model SB. Therefore, above mentioned diagrams could also be referred to compare between model techniques of models BS and SB. It can be inferred in case of employing beam element in frame structure like models BB or SB, after reaching yielding point the structure still can take load without any degradation in lateral strength; However, as seen in Figures 5(a), 6(a) and 7(a) in case of shell elements, model SS (or BS), degradation in lateral resistance is clear for width to thickness ratio R_c=0.8 as well as R_c=0.6 due to local buckling in column section. In case of R_c=0.4 lateral capacity extends without degradation since the failure is yielding type but not buckling type.

3.2. Buckling deformations

Calculation results of local buckling in short column and in mid span of brace member for case studies 8 and 9 mentioned in Table 1 are presented below. Maximum deformations occurred at points 1 and 2 in short column and point 3 as shown in Figure 9 is noticed.

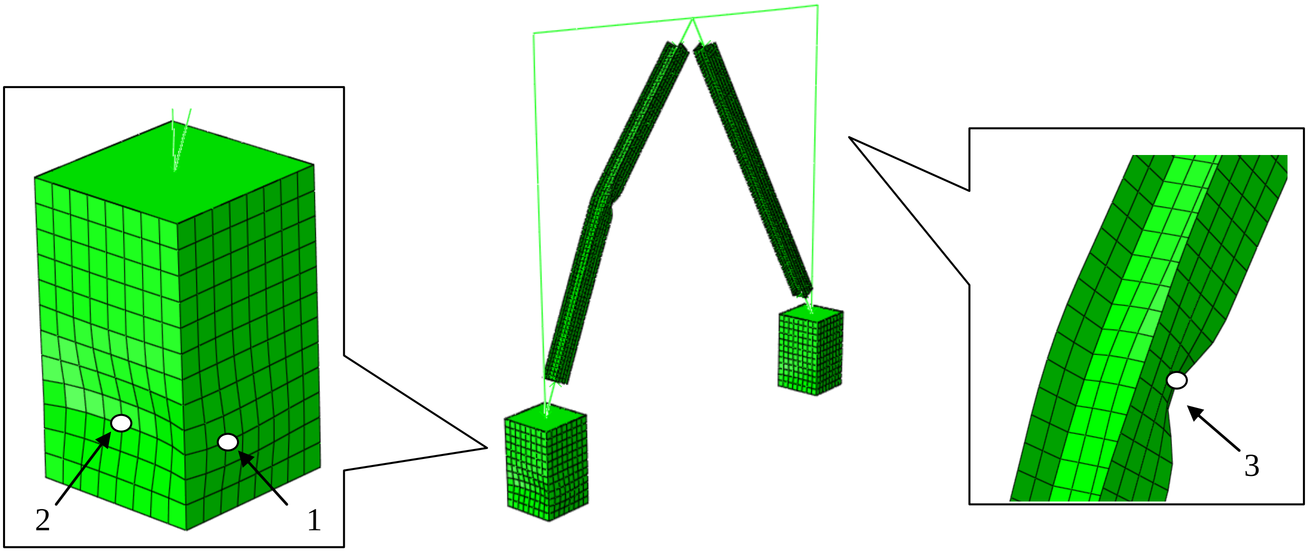


Figure 9: Local deformations; brace specification: R_f=R_w=0.8, L/r=100; short column: R_c=0.4 (H/H_y=1.35)

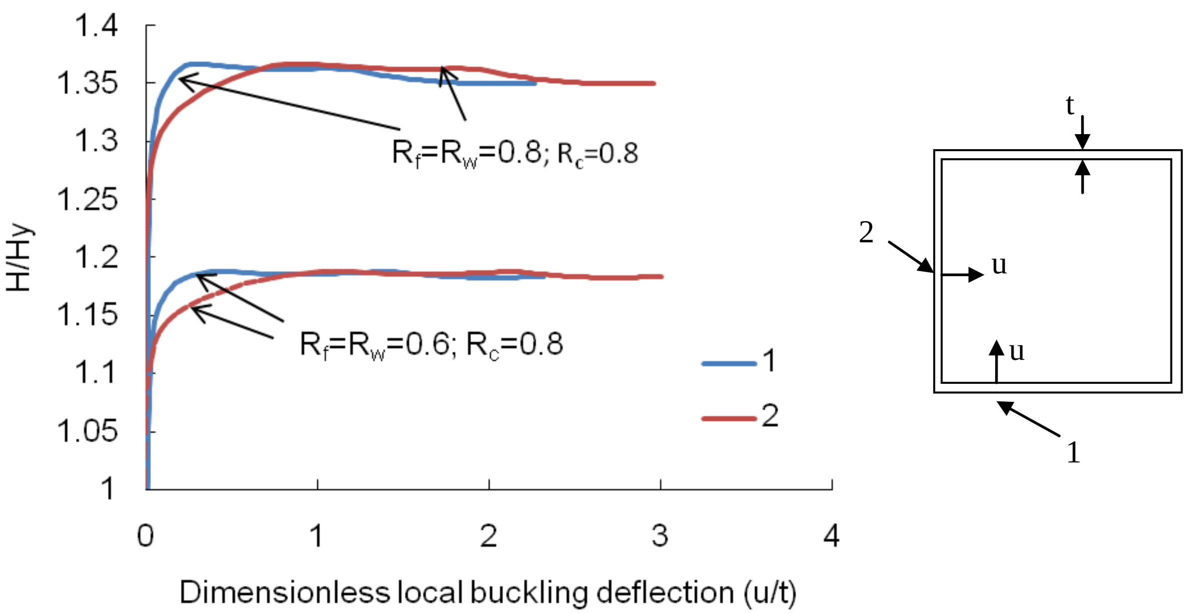


Figure 10: Lateral resistance versus local buckling dimensionless deformation in short column (model SS)

It should be noted inside deflection was observed in points 1 and 3, but in point 2 the deformation occurred towards outside of the section. Dimensionless deformation defined as displacement divided by profile thickness is presented at Figure 10. As seen in Figure 11, case of R_f=R_w=0.8; R_c=0.8 when the maximum lateral strength occurs at H/H_y=1.367, local buckling deflection in point

2 is three times more than that of point 1. In the other case study with less width to thickness ratio in brace member R_f=R_w=0.6; R_c=0.8 at maximum lateral strength H/H_y=1.187, dimensionless deflection in point 2 is 1.5 times more than that of point 1. Figure 12 shows buckling deflection in brace member. Employing relatively thin plate in brace cross section leads in high local deflection.

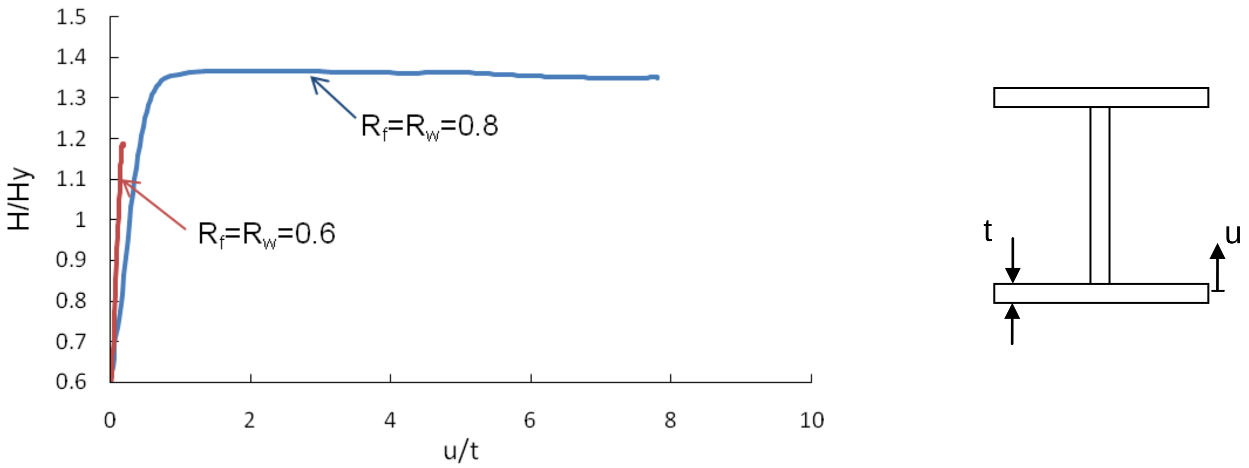


Figure12: Lateral force versus local buckling dimensionless deformation in brace member (model SS) and R_c=0.8

4. CONCLUSION

Nonlinear static analysis conducted on steel rigid frame with brace member. Frame section and brace cross section are defined to represent various buckling parameters.

1) In case of existence of initial imperfection in brace member employing shell element or beam element has the same results in terms of lateral behavior of the structure.

2) As long as capturing the local buckling deflections is concerned it is better to employ shell elements in brace member if buckling parameter is above R_f=R_w=0.6. As for short column it is better to use shell elements if the width-to-thickness ratio is more than R_c=0.4.

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