Steel framebuckling behavior with imperfection in brace members

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1. Introduction

So far beam element model technique has beenemployed to investigate the seismic behavior as well as structural design of bridges.[1] However, it seems that using shell elements are helpful to study more details about buckling effects in thin-walled sections used in these structures. [2]In this paper a rigid frame model with braces developed to see the effect of using shell element in presence of imperfection in brace member on behavior of the steel rigid frame with brace members.

2. Numerical Model

Bridge pier in form of a rigid frame with inverted "V" shape brace members is considered in this study. 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. The constant vertical load of 5 percent of yielded force of the columns (V=56692 N) imposed on two top corners as the superstructure weight.

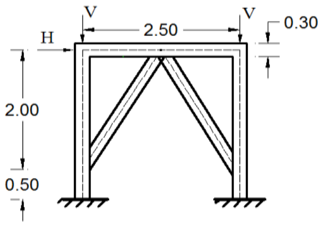

Fig. 1. Rigid frame with brace member

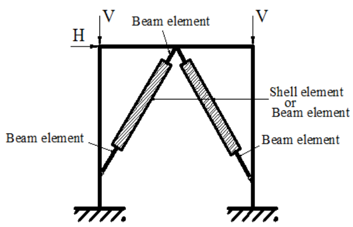

Fig.2 Numerical model using shell and beam elements

As shown in Figure 2 beam elements are also used at both ends in the case of using shell elements to model brace members. The middle part of the brace members are modeled using shell elements. The length of beam element zone at end parts is 1/12th of the total brace member length. Figure 3 shows box section profile with side length of 300mm and plate thickness of 12 mm that is employed as columns and beam of the rigid frame. Fig.4 shows I-section profile also used as brace members.

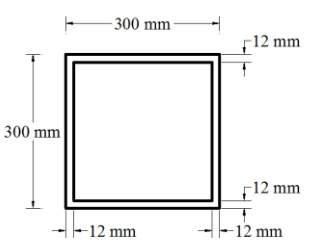

Fig. 3 Box section

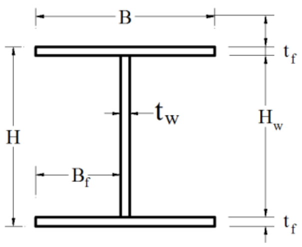

Fig. 4I-beam section

The parameters of W and H represent for total width and height of the I-section, respectively. The parameters t_w, t_f and H_w represent the thickness of the web plate and thickness of the flange plates and the height of the web plate, respectively. Steel material is assumed to be type *SS400*, bilinear stress-strain is assumed with Yang's modulus E=2.06 GPa, yield stress σ_y = 238 MPa, yield strain ε_y= 0.0012, poison ratio ν=0.3.the second incline slope is assumed to be 1/100 of the Young modulus.

3. Analysis layout

In order to capture the elasto plastic behavior of the steel structure, nonlinear pushover analysis carried out on the frame using finite element Abaqus software program.[3]As seen in Fig. 1 lateral displacement load H is applied at top corner point of the steel frame. Brace member sections were classified into three groups based on slenderness ratios 50,100 and 150.Width to thickness ratio R=0.4, R=0.6 and R=0.8 is also considered for flange and web. Therefore, 27 different cross sections are tested for brace member.

$$R_f = \frac{W_f}{t_f}\sqrt{\frac{\sigma_y}{E}\frac{12(1-\nu^2)}{k\pi^2}} \quad (1) \qquad R_w = \frac{H_w}{t_w}\sqrt{\frac{\sigma_y}{E}\frac{12(1-\nu^2)}{k\pi^2}} \quad (2)$$

R_f and R_w is width-to-thickness ratio parameter for flange and web respectively, and derived from thin plate buckling theory. Local buckling coefficient k is 0.425 and 4.0 for flange and web respectively.

4. Results and discussion

The study was also extended to discuss the effects of imposing initial in-plane imperfection equal 1/1000 compare to total length of brace member. Pushover analysis carried out in case of using beam element and shell elements in brace members. Non-dimensional maximum axial load generated in brace members in case of existence of shell elements in brace members was observed. The study shows maximum axial forces in brace member decreases as the slenderness ratio increases. Obtained analysis results indicate for slenderness ratio L/r=50 Non-dimensional axial force is around 0.92 which is the highest value compare to others. It is about 0.60 for slenderness ratio L/r=100, and around 0.32 for that of L/r=150. It was found that despite of various width-to-thickness ratios the maximum internal force in brace member is almost the same for members with similar slenderness ratios. In another word, contrary to expectations the width to thickness ratio of web or flange of bracing cross section does not have significant impact on maximum internal force generated in brace member.

Figure 4 indicates axial force history in brace member obtained from pushover analysis of a case study in which the specifications of the I-beam cross section of brace member is R_f=0.80, R_w=0.80 and L/r=100. The vertical axis in this graph represents internal axial force in brace member and the horizontal axis shows lateral displacement of the rigid frame δ during pushover analysis. As seen in case of using only beam element for brace member without imperfection, the cross yield occurs at point *B*, and after that slight gradual increase of axial force could be observed. As for using shell elements without imperfection after yielding at point *B*, there is a gradual decrease until a sharp fall at the point *C*. The possible explanation for this sudden drop might be developing local buckling deformations at both ends of the brace member causes steep decline in axial stiffness.

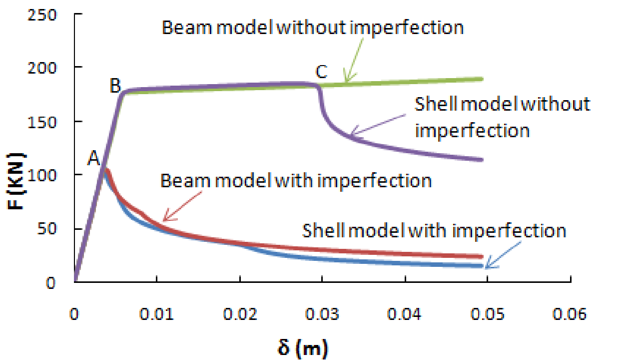

Fig. 4 Axial force histories in brace member

By considering initial global imperfection in brace member, almost similar results in terms of axial force in tow cases of using beam or shell elements are achievable. The same goes to all analysis cases. It means regardless of the width to thickness ratio parameters, beam element and shell element indicated similar results. The peak is at the point *A* which is almost half of that of without imperfection. Contrary to the case of without imperfection the axial force decline is gradual due to developing global buckling effects. As illustrated in Fig. 5 local buckling deformation also occurs in mid-length of the brace member.

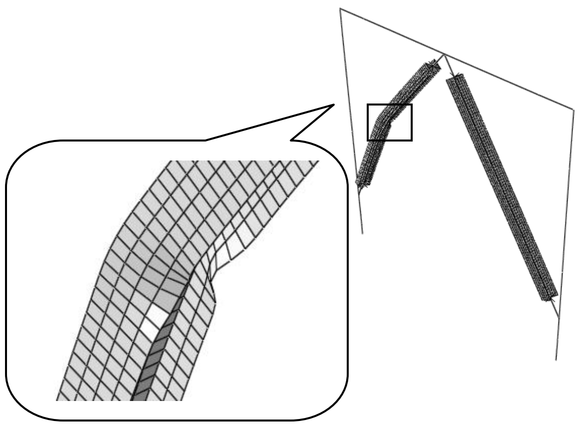

Fig. 5 Local buckling effect in case of imperfection

In case of initial curvature, as the lateral load on steel frame increases, the brace member under compressive load starts buckle by deflecting laterally out of its original longitudinal axis. This leads to concentrated tensile stress in one edge and compressive stress in the other edge of a section around middle length of brace member. As shown in Fig. 5 local buckling failure starts from the edge under compression stress. The yield zone is also around locally buckled area but not both ends. On the other hand, in situation of using shell element and without initial imperfection, during loading on the frame, at first yield stress generates at once in total length of brace members. Because of employing rigid plates to connect beam element and shell elements at end parts, brace member is more stiffened at both ends compare to middle part. Therefore the stress redistributes over end zones and local buckling occurs at both ends.

Figure 6 aims to depict effects of using shell or beam element in brace member on elastoplastic behavior of whole system. As seen in both cases of initial curvature and without initial imperfection the graph of lateral load *H* versus lateral displacement of the frame δ are coincide with each other. It means that selecting the type of element for brace members does not affected total behavior. It was also found that lateral resistance of steel frame decreases in case of applying initial imperfection.

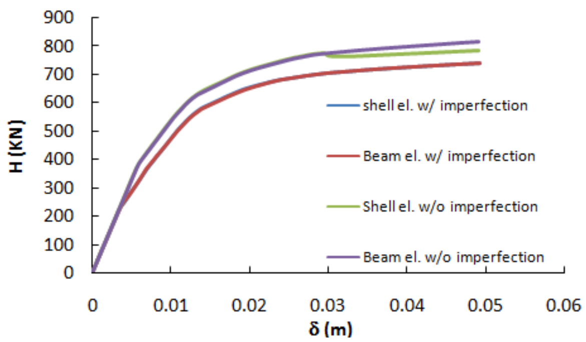

Fig. 6Lateral load vs. lateral displacement curve of steel frame

4. Conclusion

1) In case of without imperfection in bracing, only local buckling at both ends is likely to occur.
2) In case of imposing global imperfection in brace member we should use shell elements to obtain global buckling and in some cases local buckling deformation in the middle length of brace member.
3) As for behavior of the whole structural system in existence of global imperfection in brace member, it is enough to use beam model because there is not so much difference between two cases of employing beam element or shell element in presence of global imperfection.

5. References

[1]YamaoT., et al.,"3 Dimensional seismic behavior of deck type arch bridges with curved pair ribs", *Proceedings of SS06, K. Lumpur, Malaysia*, pp.213-220,2006.

[2]YamaoT., et.al. "Investigation of nonlinear dynamic analytical method of steel rigid frames taking account of effects of local buckling", *Proceedings of14th Symposium on Performance-based Seismic Design Method for Bridges, Tokyo, Japan*, pp. 41-48, 2011. (In Japanese)

[3]Dasssault Systems Simulia Corp, ABAQUS Analysis User'sManual. Version 6.11, 2011.