The 2016 World Congress on
The 2016 Structures Congress (Structures16)
Jeju Island, Korea, August 28-September 1, 2016

Lateral Buckling Safety of I-shape Concrete Girders

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ABSTRACT

Three-dimensional finite elements for eigenvalue buckling problem analysis of two connected I-shape concrete girders are presented. Materials of the concrete beams are normal concrete(40MPa) and ultra high performance concrete (UHPC) which compressive strength are 150MPa and 180MPa. Ultra high performance concrete may reduce the cross sectional dimensions. Therefore stability of the UHPC beam should be evaluated. Since the references of design codes such as ACI 318 and Eurocode2 for lateral stability of concrete beam are experiments of rectangular normal concrete beam, the finite element analysis was performed to evaluate the lateral buckling stability of the girders and to compare with the design codes. From the results, it found that design codes for stability of concrete beam which are function of flange width should be revised to the function of web width to apply to I-shape concrete beam.

1. INTRODUCTION

Normal concrete beam is governed by flexure failure rather than lateral buckling failure. Due to this reason, there is not much study about stability of I-shape concrete girder. Studies about stability of concrete beam are mostly about rectangular beam and stability of I-shape beam are mostly about steel beam. Since I-shape normal concrete beam is thick and can be used in short span girder bridges, lateral buckling stability is not important, however I-shape girder with ultra high performance concrete (UHPC) which compressive strength are 150~180MPa can have slim web and more than 30m span length that can cause stability problem. But the design code is from experiment studies of rectangular normal concrete beam. Therefore finite element analysis of I-shape concrete girder should be performed to evaluate the lateral buckling stability and check the design codes validity.

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2. Design Codes

In ACI 318-14, referring to Hansell, and Winter (1959) and Sant, and Bletzacker (1961), it suggests that for the stability, the beam shall be satisfied Eq. (1).

$$l_{ot} < 50b_f \qquad (1)$$

,where l_{ot} is spacing of lateral bracing or crossbeam and b_f is width of compression flange.

In Eurocode2 (Design of concrete structures), it introduces that the beam is stable to lateral buckling if the beam is satisfied Eq. (2).

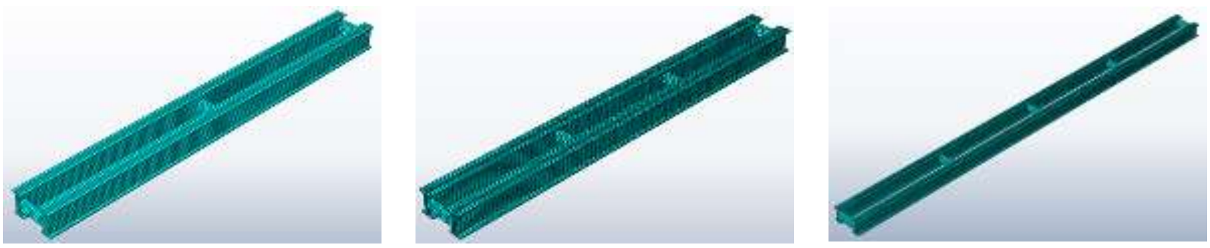
$$l_{ot} < 50b_f , d \triangleleft 2.5 | b_f \qquad (1)$$

where, d is total depth of the beam.

However ACI 318 and Eurocode2 are applicable to concrete strength less than 100MPa and it did not consider effect of web which is one of the important factor to lateral buckling behavior. Since the concrete girder have thicker web and lower elastic modulus than steel girder, the concrete girder is governed by flexure failure rather than lateral buckling failure. But in slim I shape girder using UHPC, lateral buckling failure can't be neglected. Therefore validity of the design code to UHPC should be checked by comparing the design codes with finite element analysis results of lateral buckling failure.

3. Geometric and Structural Properties

Two connected I-shape girder is designed for the finite element analysis as shown in Fig. 1. To analyze effect of the structure members to the stability, various geometric properties are chosen as shown Fig. 2. Span lengths (L) of the girder are 30m, 40m, 50m and 60m. Total depths of the girder (d) are 1.5m, 1.75m and 2m. Thickness of the flange (t_f) are 100mm, 150mm and 200mm. Thickness of the web (b_w) are 150mm, 200mm, 250mm and 300mm. Minimum flange width (b_f) is 350mm to have I-shape cross section regardless of web thickness. Flange width is increased by 50mm until buckling failure load (w_{cr}) becomes larger than flexure failure load (w_t) calculated by allowable stress design. Through this comparison, minimum flange width governed by flexure failure is computed.



(a) one cross beam (b) two cross beam (c) three cross beam

Fig. 1 Computational meshes for two connected I-shape girders

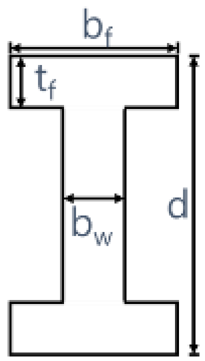


Fig. 2. Geometrical variables

Concrete properties used in the analysis are shown in the Table 1.

Table 1 Properties of concrete

Concrete compressive strength(MPa)	40	150	180
Young's Modulus(MPa)	35000	43000	45000

4. Finite Element Method

Finite element method (FEM) is used to analysis the stability of the beam with commercial finite element software, ABAUQS. Girders and crossbeam are modelled by 20 nodes solid elements (ABAQUS C3D20). Through eigenvalue buckling prediction in ABAQUS, buckling failure load (w_{cr}) is calculated.

5. Result

Fig.3 and Fig. 4 show the stable section criteria with minimum flange width. The number of the crossbeam was increases from 0 to 3 in the girder bridges with span lengths 30m, 40m, 50m, and 60m then they were analyzed to compute minimum flange width for stable girder bridge. Spacing of crossbeam (l_{ot}) over minimum flange width (b_f) plots on Fig. 3 and beam depth (d) over minimum flange width (b_f) plots on Fig. 4.

The design codes should give conservative results than the FEM results, however many cases show more conservative results which mean less values than l_{ot}/b_f = 50 and d/b_f = 2.5. Therefore, the design codes can give unstable section condition to long span slim I-shape concrete girder.

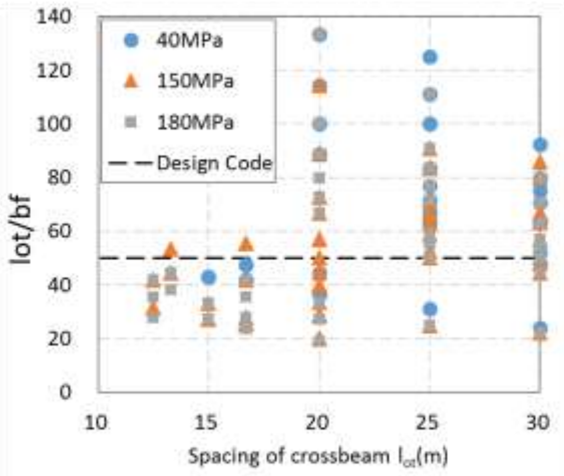


Fig. 3. Design code about spacing of crossbeam and flange width

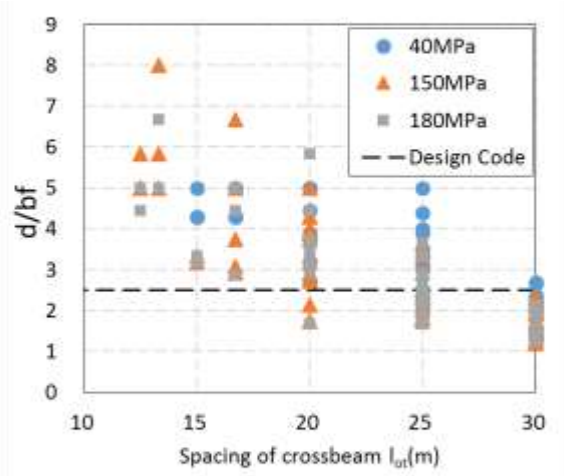


Fig. 4. Design code about beam depth and flange width

Since there is limitation of checking the stability of the I-shape girder based on flange width, the other section variable should be used for checking the stability that is web thickness (b_w). Fig.5~10 show the stable section criteria with minimum web thickness with different concrete compressive strength. Spacing of crossbeam (l_{ot}) over minimum web thickness (b_w) plot on Fig. 5, 7 and 9 and beam depth (d) over minimum web thickness (b_w) plots on Fig. 6, 8 and 10.

As shown in the graphs, the FEM results show higher value than the design codes which means that the design codes give conservative section criteria for the beam stability.

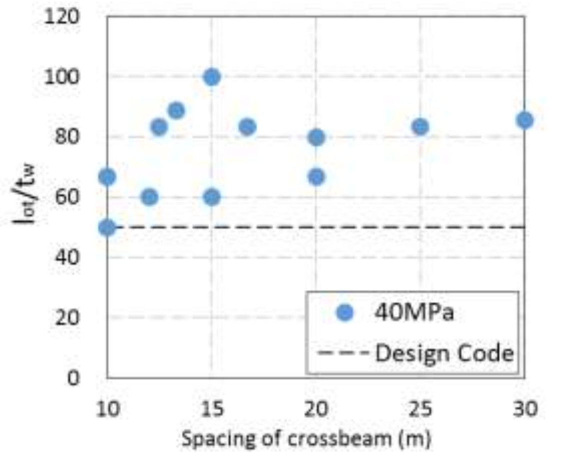


Fig. 5. Design code about spacing of crossbeam and web thickness(40MPa)

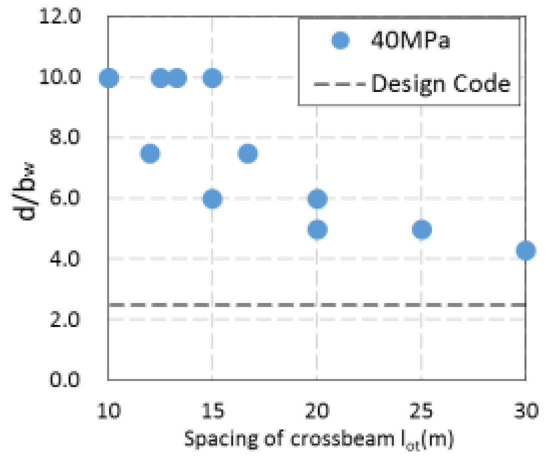


Fig. 6. Design code about beam depth and web thickness(40MPa)

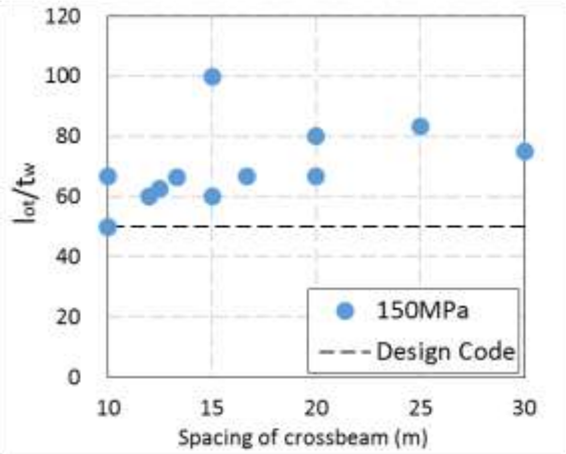


Fig. 7. Design code about spacing of crossbeam and web thickness(150MPa)

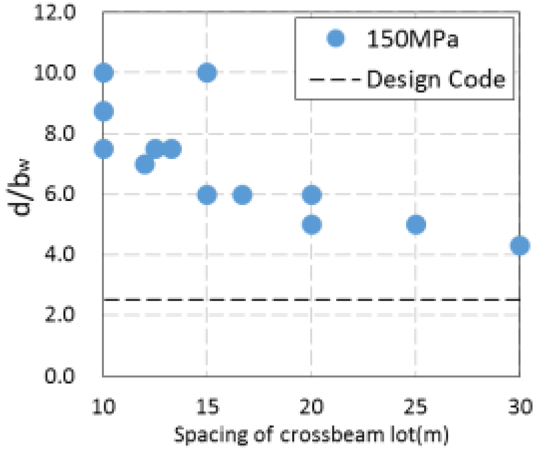


Fig. 8. Design code about beam depth and web thickness(150MPa)

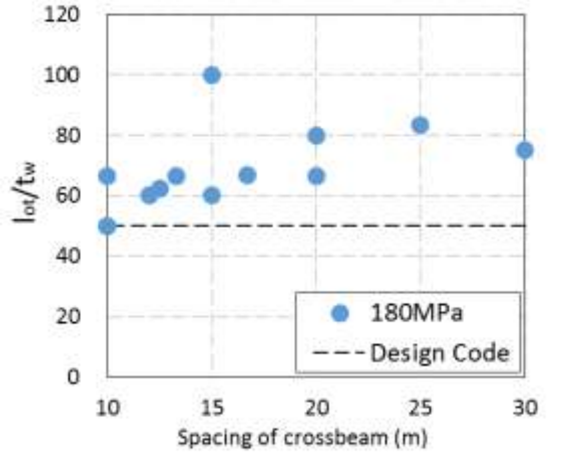


Fig. 9. Design code about spacing of crossbeam and web thickness(180MPa)

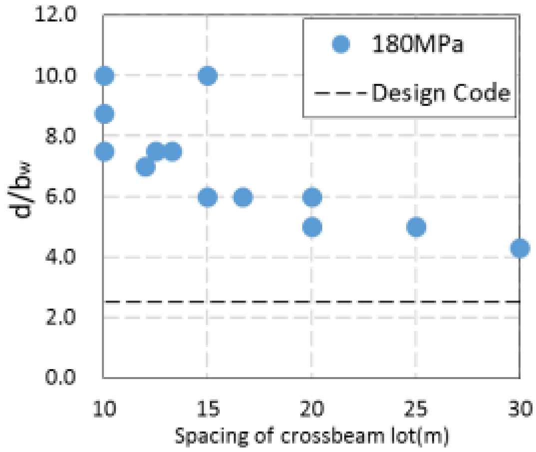


Fig. 10. Design code about beam depth and web thickness(180MPa)

The design codes are derived from the Hansell, and Winter (1959) and Sant, and Bletzacker (1961) that are studies of the stability of rectangular beam. Therefore to apply these studies to I-shape girder and T-shape girder, it is appropriate to use web thickness rather than flange width to give stable section criteria.

6. CONCLUSIONS

In this study, I-shape girders of normal concrete (40MPa) and UHPC (120MPa and 180MPa) were analyzed to check the stability condition based on ACI 318 and Eurocode2. From the comparison between FEM results and the design codes, it found that design code about flange width give unstable section criteria about beam stability due to limitation of the references which are about the rectangular shape concrete beam. Therefore considering the references, the section criteria with the function of flange width should be changed to the function of the web thickness.

Acknowledgements

This research was supported by a grant(16RDRP-B076268-03) from R&D Program funded by Ministry of Land, Infrastructure and Transport of Korean government and Korea Minister of Ministry of Land, Infrastructure and Transport (MOLIT) as 「U-City Master and Doctor Course Grant Program.

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