CHAPTER FIVE
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1- Summary

The objective of this research was to investigate the interactive buckling in structural elements subjected to axial force and bending moment. Strut purlins were considered as a case study for this purpose.

To implement this mission, a series of 52 free purlins was analyzed using finite element Eigen value analysis. The first half of this series (26 purlins) was subjected to axial loads, and the other half was subjected to flexural uplift.

Another series of 832 purlins through fastened to deck or sheeting was analyzed using finite element Eigen value analysis. The first half of this series (432 purlins) was analyzed under axial loads. The other half was analyzed under flexural loads. In order to study the effect of tie rods on axial or flexural buckling loads, 432 purlins were analyzed without tie rod and the other 432 purlins were analyzed with tie rods.

A series of 12 purlins through fastened to deck or sheeting was analyzed under axial load and flexural uplift simultaneously using finite element Eigen value analysis. Results of finite element for this series have been compared to the interactive curves obtained by the AISI and Eurocode3 design methods.

Results of finite element analysis for different cases have been compared to study the effects of sheeting and tie rods. Results of purlins through fastened to deck or sheeting were compared with the strength obtained by the proposed design methods of the AISI and Eurocode3 provisions for axially loaded, flexurally loaded and beam-column structural elements.

A series of 13 purlins through fastened to deck or sheeting were analyzed using finite element nonlinear analysis. The results of finite element nonlinear analysis were compared to those obtained by the finite element Eigen value analysis, AISI, and Eurocode3 in order to verify the applicability of the Eigen value analysis in investigating the interactive behavior in such structural elements.

5.2- Conclusions

From the results of the performed Eigen value and non-linear finite element analyses, and from the comparison to the different design codes, the following concluding remarks can be drawn.

a) Effect of fastening to deck or sheeting

The average increase of axial buckling load due to through fastening to deck or sheeting was in the range of 7% to 370%, while the average increase of the flexural buckling load due to through fastening to deck or sheeting was in the range of 22% to 282%. It could be concluded that through fastening to deck or sheeting have greater effect on member axial strength rather than flexural strength. It was also observed that, the roof lateral stiffness had minor effect on member axial buckling load and flexural buckling load. On the other hand, roof rotational stiffness had greater influence on member axial buckling load and flexural buckling load.

b) Effect of tie rods

The effect of tie rod on axial buckling load was also studied. It has been observed that tie rods had no effect on members subjected to local web buckling. The axial strength of these members with tie rods was nearly the same as those members without tie rods. Critical axial buckling load of overall buckling mode is strongly affected by laterally unrestrained length of the member. So that tie rods had increased axial strength of these members by a value up to 385%. The amount of increase in strength depends on web slenderness and the reduction in the laterally unrestrained length. It could be concluded that tie rods had greater effect on members with lower web slenderness ratio such that local buckling was avoided for both members without tie rods and with tie rods.

Flexural buckling load was also affected by using tie rods. Studying the effect of tie rods on flexural strength showed that tie rods had no effect on members subjected to distortional buckling. The flexural strength of these members with tie rods was nearly the same as those members without tie rods. Critical buckling load of overall flexural buckling mode is strongly affected by laterally unsupported length of the member. So that tie rods had increased flexural strength of these members by a value up to 200%. The amount of increase in flexural strength depends on flange slenderness ratio and reduction in the laterally unsupported length. It was clarified that tie rods had greater effect on members with low relatively compact flange, such that local buckling was avoided for both members with and without tie rods.

c) Comparison to the AISI and EC3 Codes

It could be concluded that the estimation of axial strength of members according to AISI is generally conservative. Non-conservative testes were for members having low web depth to thickness ratio. AISI was more conservative in the estimation of axial strength of members attached with tie rods. This may be attributed to neglecting of effect of tie rods in the AISI axial strength formula.

It was observed that some of the tested members have the same AISI axial strength, while they have different FEM strength. These members have the same cross-section dimensions, so they have got the same AISI axial strength. But these members differ in some other parameters (as span length, spacing of bolts, lateral and rotational stiffness of roof), so that they had different finite element strength. Some of other parameters affecting the members' axial strength were not considered in AISI axial strength formulas.

The estimation of flexural strength of members according to AISI may generally be considered conservative. Only few members of the tested group were non-conservative. AISI was more conservative in the estimation of flexural strength of members attached with tie rods. This may be attributed also to neglecting the effect of tie rods in the AISI flexural strength formula.

It has been observed that the strength of axially loaded members based on the Eurocode3 is generally less conservative than that based on the AISI. Eurocode3 was more conservative in the estimation of axial strength of members attached with tie rods. This may be attributed to the consideration of the effect of tie rods in the Eurocode3 axial strength formulas.

It could be concluded from the study of flexural strength according to Eurocode3 that estimation of flexural strength of members according to Eurocode3 is generally conservative. Eurocode3 was more conservative in the estimation of flexural strength of members attached with tie rods. This may be attributed to the estimation of effect of tie rods in the Eurocode3 flexural strength formulas.

d) Comparison between Eigen and Non-Linear Analyses

Comparison between Eigen value and non-linear analyses showed that, the critical buckling load obtained by the Eigen value analysis is always larger than the strength obtained by the non-linear analysis. That is due to the fact that the Eigen value analysis does not account for the material yield stress. However, it was found that for members having critical buckling stress lower than yield stress, results of nonlinear analysis are very close to Eigen value analysis. Accordingly, results of Eigen analysis could be reasonably used for estimating the members' strength particularly when elastic buckling is governing the failure mode. However, the results of Eigen analysis is generally applicable in studying the structural behavior and the interactive trend under axial and flexural loads.

e) Interactive Behavior

Interaction diagrams of finite element analysis, AISI, and Eurocode3 shows that interaction of AISI and Eurocode3 were presented by straight lines, while finite element analysis presented interaction by curves with different degrees of curvature. Eurocode3 was generally conservative with respect to AISI, except at high levels of axial forces at some cases. Both AISI and Eurocode3 may be considered more conservative at intermediate levels of axial and flexural loads. At high levels of axial loads and high levels of bending moment, AISI and Eurocode3 were less conservative.

5.3- Recommendations

To further understand the effect of interactive buckling on beam-column strength, several points need to be studied. Herein some suggestions for future work:

- Interactive buckling of different shapes for singly symmetric, doubly symmetric, and point symmetric cross-sections needs more studies

- Effect of boundary conditions on interaction between different buckling modes

- Better quantification of effect of covering roof on restraining caring purlins laterally and rotationally

- Implementation of parametric study based on nonlinear finite element analysis. This study should be extended to cover the practical range of different parameters.

- More experimental tests should be accomplished to enhance the knowledge of buckling interaction

- More studies on the effect of tie rods and its effect on buckling interaction