CHAPTER 5

EFFECT OF CORNER MODIFICATION ON SHEAR LAG PHENOMENON IN TUBULAR BUILDINGS

5.1 INTRODUCTION

The high-rise tubular structure experiences non-uniform distribution of bending stresses subjected to the lateral load. This is a severe phenomenon that happens under lateral load and known as the shear lag effect. The shear lag anomaly is a parental problem in the tubular tall building. It generates much difficulty in design because the peripheral columns of tubular structures are under the influence of different axial forces. To mitigate the above problem modeling in terms of (1) adding additional corner column in each direction of the flange and web (Fig. 5.3) (2) placing the corner column in different ways named corner cut; corner roundness and corner recession (Fig. 5.5) have been analysed in the present chapter. The objective of the present study is to make an effort to reduce the effect of positive as well as the negative shear lag in tubular structure. The reduction in shear lag will provide regularity in the variation of bending stress. The regularity in bending stresses facilitates ease in the design of tubular tall buildings. The variation of shear lag at the different level is as shown in Fig. 5.2, (at height 0, 0.25h, 0.5h and 0.75h) in a typical example plan Fig 5.1, [Haji-Kazemi and Company 2002; Kwan 1994] for uniformly distributed lateral loading. Other analysis, for different example models, has similar findings to this example and stated that a tubular tall building consists positive shear lag in the lower quarter height and negative shear lag in the upper portion of the tubular buildings.

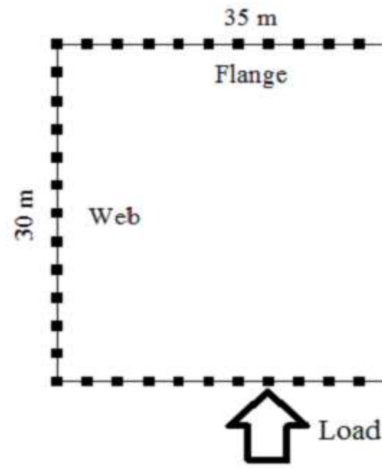


Fig. 5.1. Plan of basic tubular structure

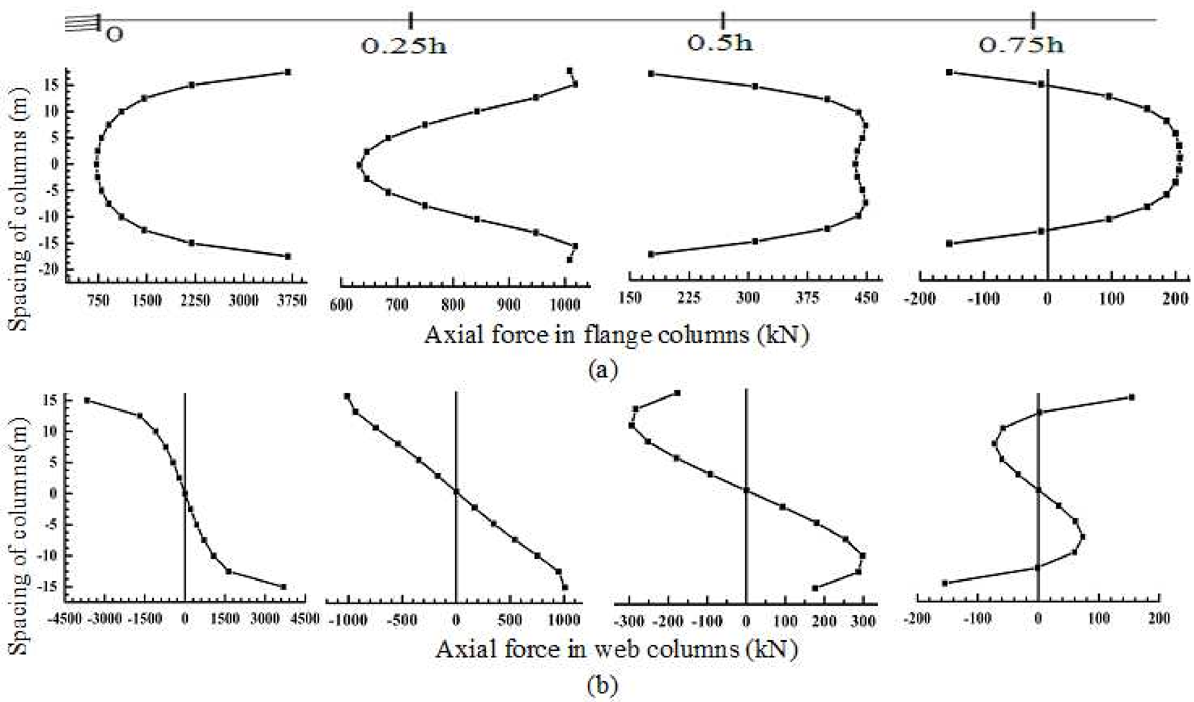


Fig. 5.2. Variation of axial forces in the flange and web columns of basic tubular structure

Although, various researchers analyzed the shear lag by analytical as well as experimental methods, unfortunately, it is lacking to develop a model that normalize and regulate the positive as well as negative shear lag. In the present chapter, an attempt to nullify the severity of the shear lag phenomenon, modeling in term of corner modifications in the plan of tubular tall building for the horizontal load are studied. These models (Fig. 5.3-5.6) analyzed by using finite element method since it is proven more reliable numerical tool. The objective of the present study is to make an effort to normalize shear lag in the tubular structure and to get a regular pattern of variation of shear lag.

5.2 PROPOSED MODELS

The basic tubular building plan modified at the corner. The following two type of modifications has been adopted.

5.2.1 Type First Modifications

The basic tubular building plan model (Fig. 5.1) modified by adding an additional column at each corner, in the direction of the flange as well as in the web (Fig. 5.3). The tube dimension preserved as adopted in the first model. The ratios ‘b/B’ and ‘b/D’ for models 2-6 are 0.07, 0.14, 0.21, 0.29, 0.36 and 0.083, 0.17, 0.25, 0.33, 0.42 respectively (Fig. 5.4).

5.2.2 Type Second Modifications

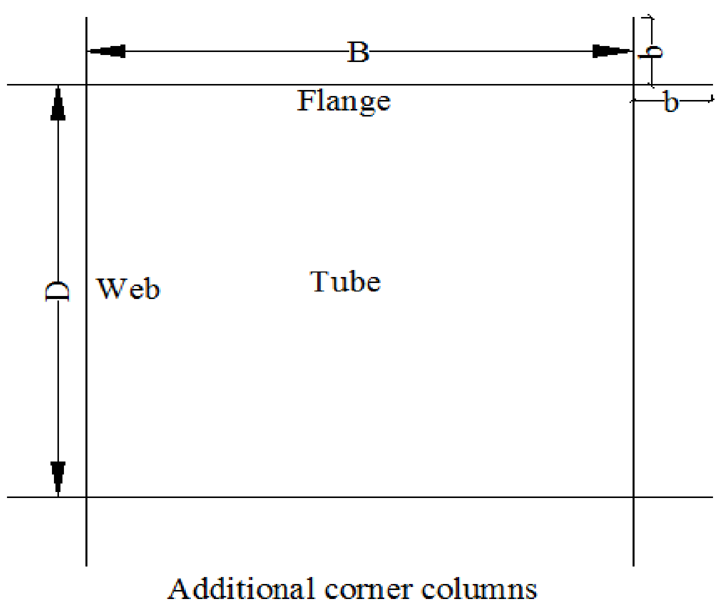


Fig. 5.3. Corner modifications: Type First

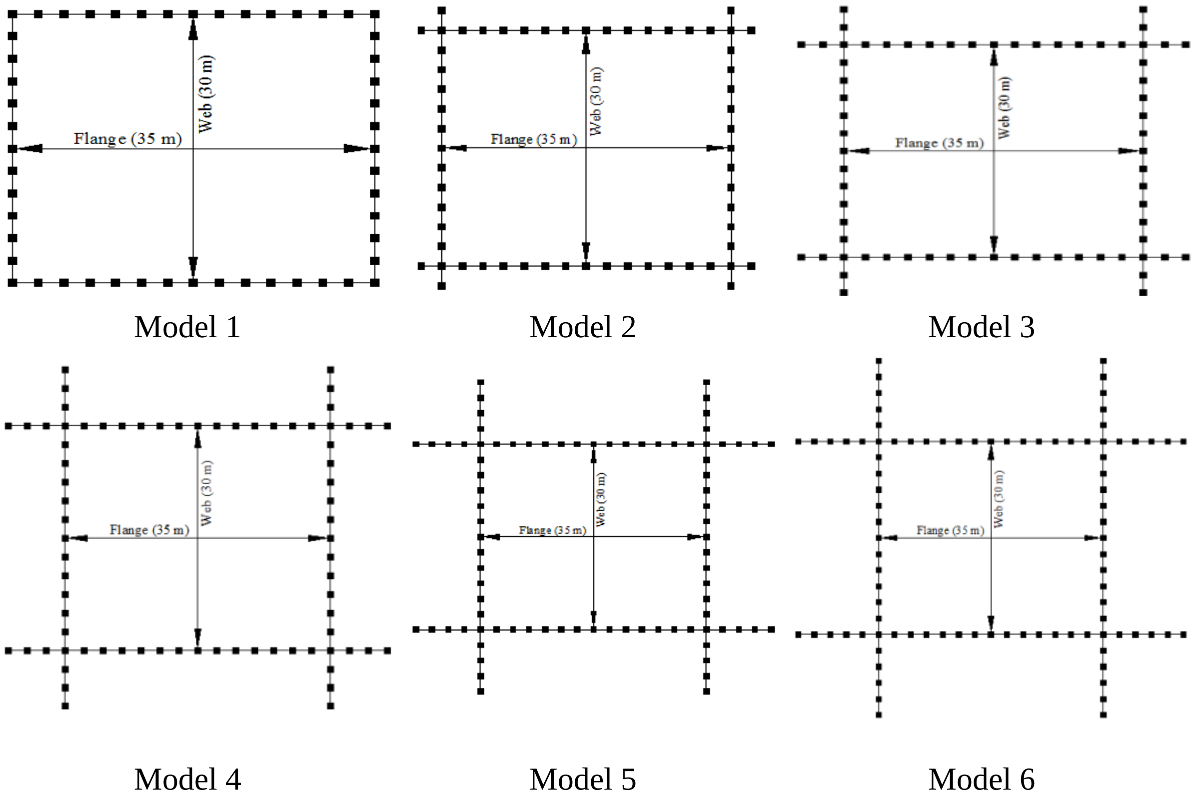
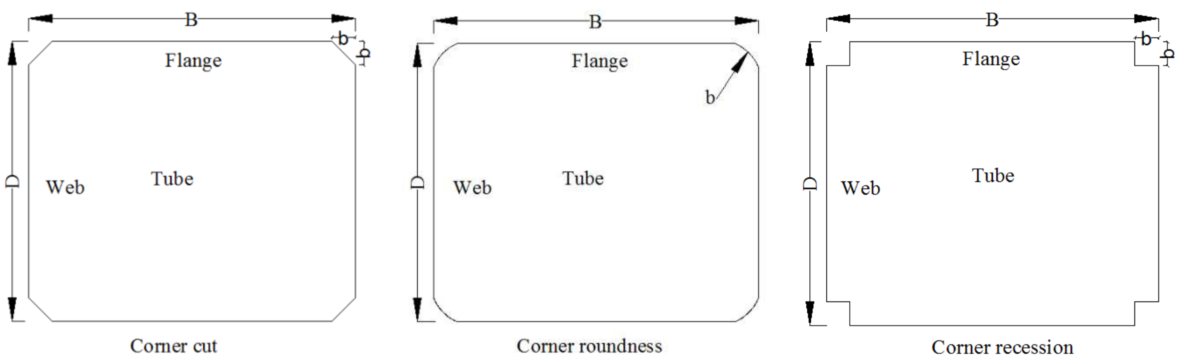


Fig. 5.4. Modified plans with basic tubular structure (Type First)



(a) (b) (c)

Fig. 5.5. Corner modifications: Type Second (After Kawai 1994)

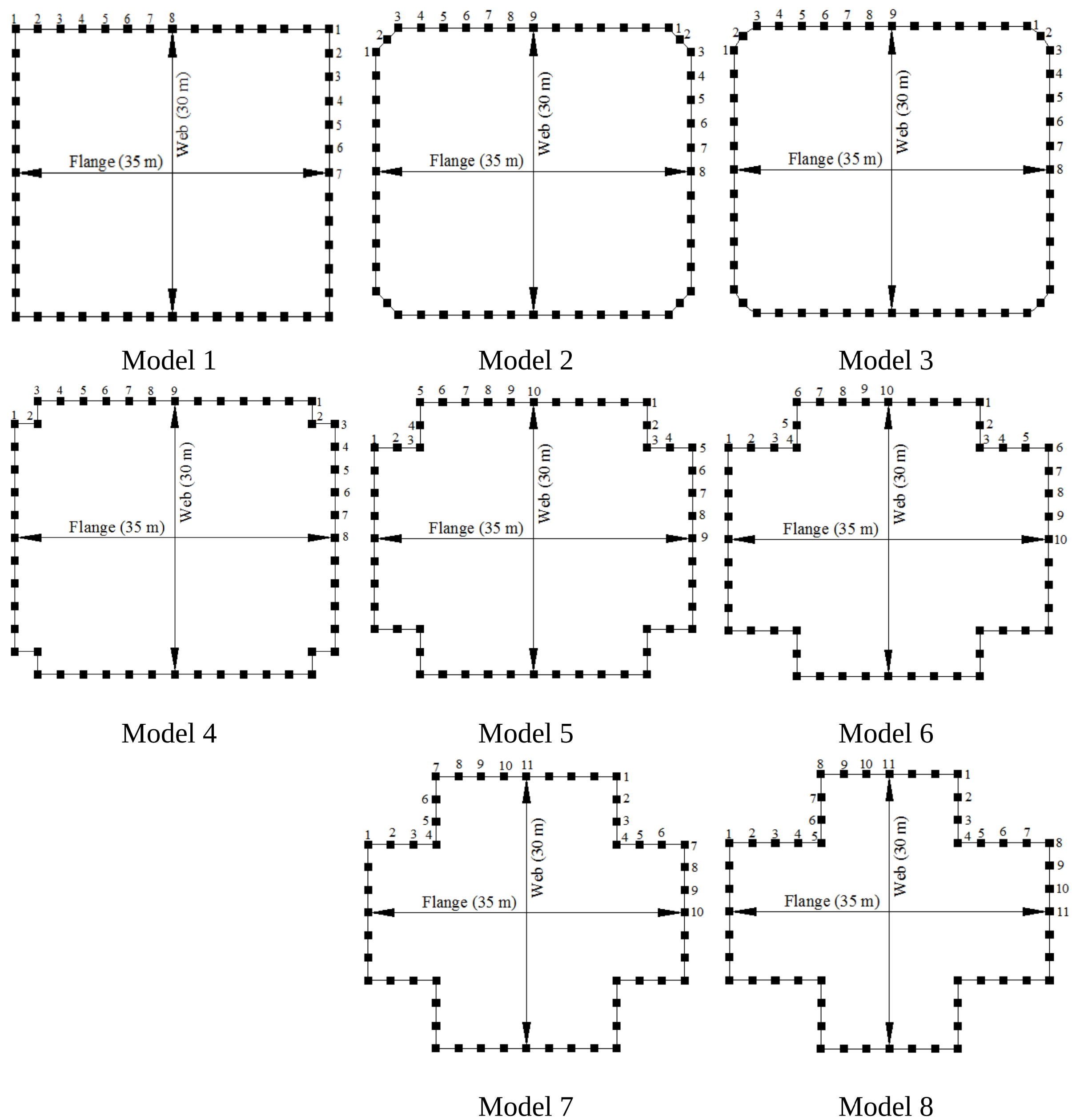


Fig. 5.6. Modified plans with basic tubular structure (Type Second)

In the second type modifications of the basic building plan as originally adopted by Kawai (1994). The tubular buildings plans modify are of three types: (i) corner cut (Fig. 5.5a) (ii) corner roundness (Fig. 5.5b) (iii) corner recession (Fig. 5.5c). Corner recession is further classified as shown in Fig. 5.6 (model 5-8) [Gu and Quan 2004]. In the second type of modification, the area of the plan of basic tubular structure is not preserved. It changes according to the variations of modifications in the plan of the basic tubular structure (Fig. 5.1). The ratio ‘b/B’ and ‘b/D’ [Kawai 1994] for models 2 to 8 are 0.07, 0.056, 0.07, 0.14, 0.14, 0.21, 0.21 and 0.08, 0.065, 0.08, 0.17, 0.25, 0.25 0.33 respectively.

5.3 METHODOLOGY

Dimensions and material properties of the framed tube buildings are: h = 120 m; dimension of tube, b = 35 m; d = 30 m; beam and column size 0.8 m × 0.8 m; story height 3 m; center-to-center spacing of the columns 2.5 m; modulus of elasticity E = 20 GPa and Poison’s ratio μ = 0.15, where h, b and d denote the height, width and depth of the tubular buildings. The beam and column dimension, spacing and material property are same for each model. A uniform load = 3.43 kN/m^2 have been considered for all models.

The proposed models demonstrated in Fig. 5.4 and Fig. 5.6, are analyzed in the following ways viz. (i) the proposed first type models are analyzed by using finite element method since its proven more reliable numerical tool. The Tubular buildings discretized with three-node beam element of moderate length and linear isotropic material in ANSYS-14.5, 2013. (ii) the proposed second type models analyzed by using STAAD Pro.v8i. (2007). The STAAD Pro is very effective in the quick calculation and applying boundary conditions, which are much difficult in other software. The result obtained closely resembled the ANSYS software. The variations of normal stress and hence axial forces examined at the different level (at the base level, 0.25h, 0.5h and 0.75h) of building with varying plans. The variations of axial forces in flange panel as well as in web panel, depicted as in Figs. 5.7-5.16.

5.4 EFFECT OF MODIFICATIONS

5.4.1 Effect of Type First Modifications

For the better understanding of the variation of the shear lag, a normalization factor (ψ) defined as the ratio of maximum normal stress in the flange, at a level, to the minimum normal stress in the flange at that level in the tubular structures. The normalization factor ψ plotted as shown in Fig. 5.7. It is clear that the basic tubular model has highest value of ψ. The normalization factors have values equals to 5.13, 1.61, 2.54 and 19.27 at height 0, 0.25h, 0.5h, and 0.75h, in the basic tubular building respectively. It is also noted that the basic tubular structure has highest normalization factor in upper part of the structure i.e. at level 0.75h. This part is negative shear lag region and represent that the stresses at the edge are much lower than the center of the flange at the upper level of the tubular building. The edge column at this level comprises tension.

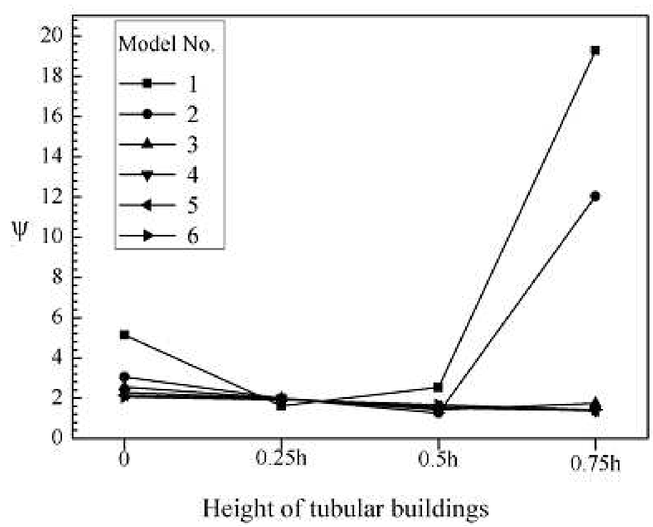


Fig.5.7. Normalization factor for model 1-6

After addition of only an extra column at each corner and in each direction the axial force at the level 0.75 h became of same nature e.g. compression in the opposite side to the loading face. Further, the addition of a column produces a drastic change in normalization factor for upper quarter height (Fig. 5.7, Model 3).

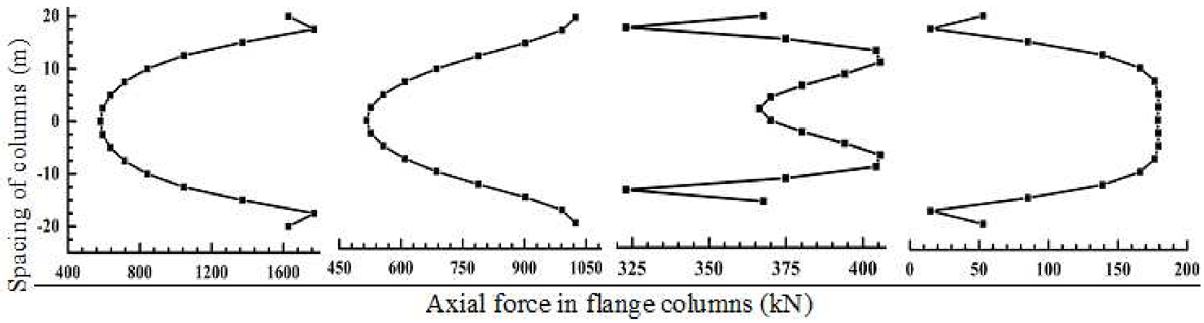


Fig. 5.8. Variation of axial forces in flange columns in model 2

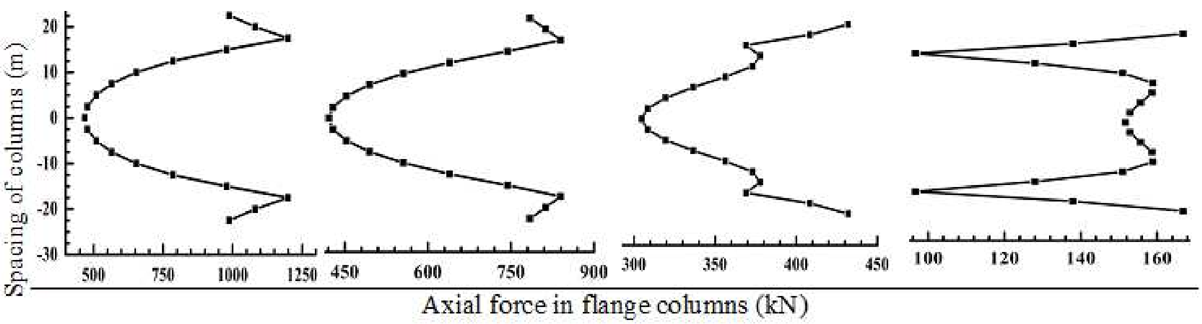


Fig. 5.9. Variation of axial forces in flange columns in model 3

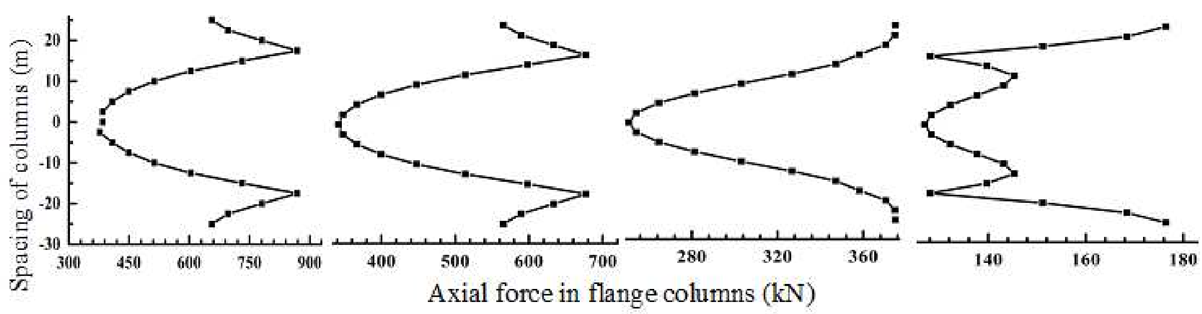


Fig. 5.10. Variation of axial forces in flange columns in model 4

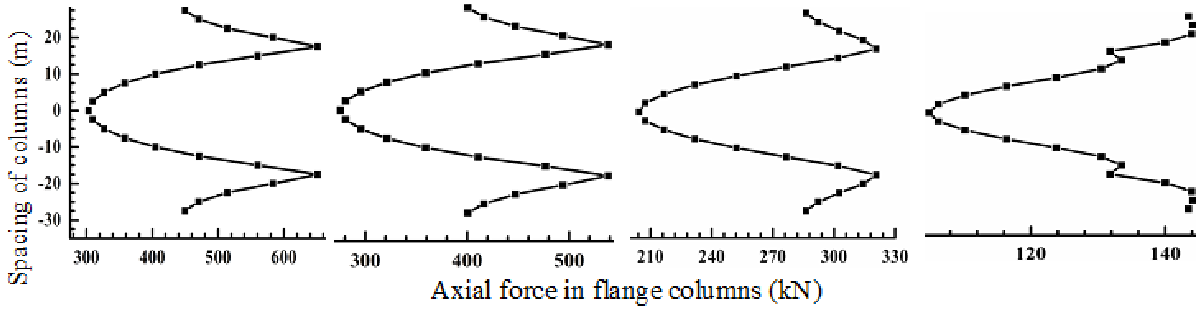


Fig. 5.11. Variation of axial forces in flange columns in model 5

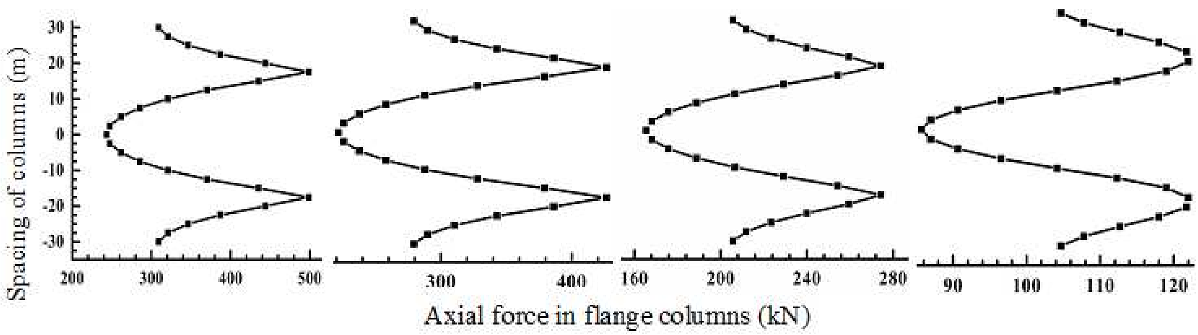


Fig. 5.12. Variation of axial forces in flange columns in model 6

The addition of extra columns in the plan of basic tubular building attributed: (i) Reduction of ψ in rapid rate for model 1-3 (ii) ψ converges of for Model 3-6 to the values 2.05, 1.92, 1.66 and 1.42, at height 0, 0.25h, 0.5h, and 0.75h respectively.

Thus, the normalization factors, finally, ranges to a value from 1.4 to 2 (Fig. 5.7.). It is major output of the study.

From Fig. 5.13, it is quite evident that shear flow does not change quantitively as much in the web at each level as in the flange. The pattern of variations in axial forces in web panel is same for every model at their corresponding level.

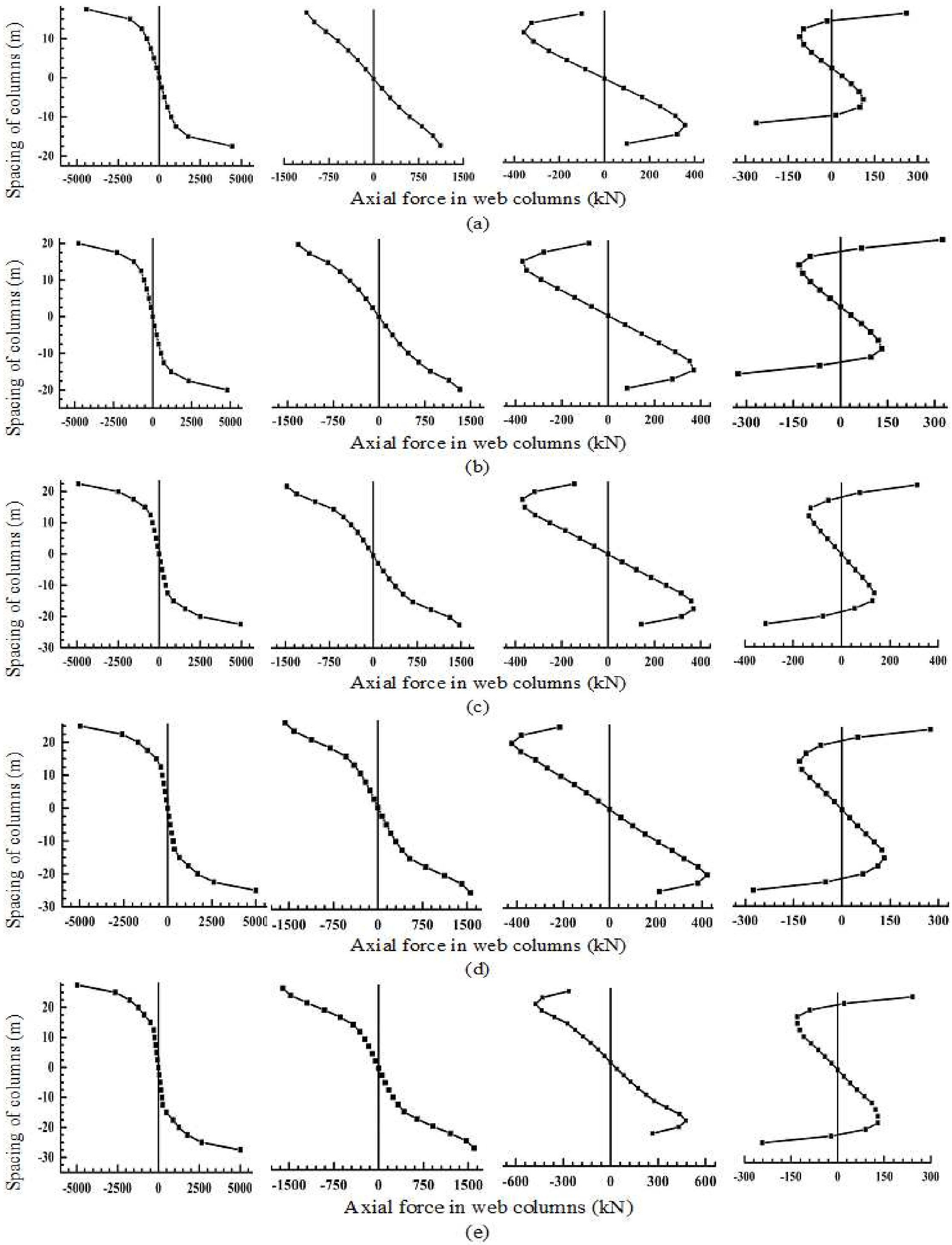
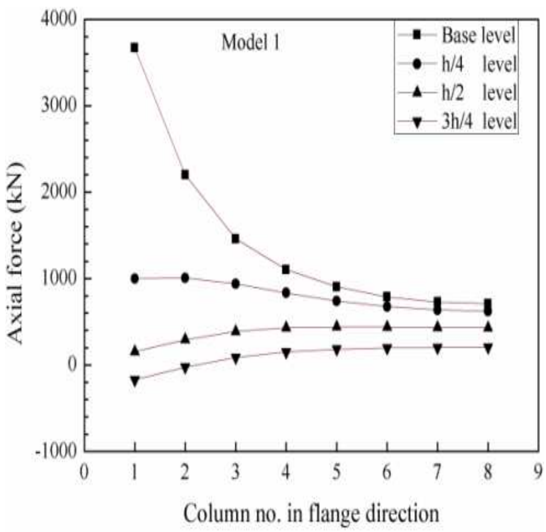


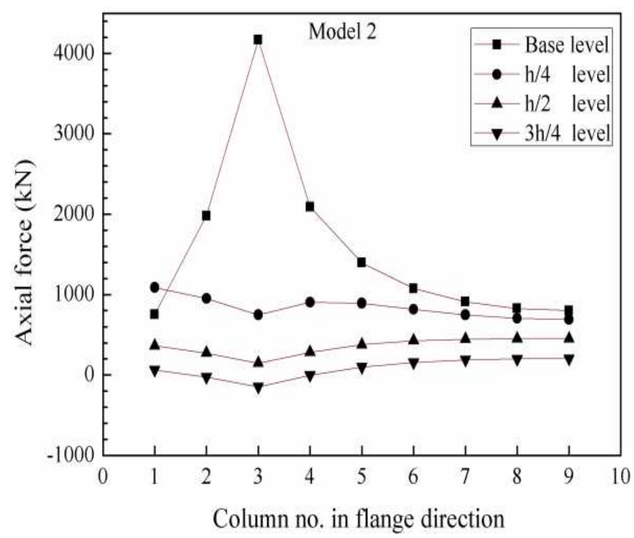
Fig. 5.13. Variation of axial forces in web columns: (a) model 2; (b) model 3; (c) model 4; (d) model 5; (e) model 6

5.4.2 Effect of Type Second Modifications

Owing the symmetry of the structures, results of only half part of the flange and web depicted in Fig 5.14-5.16. The model 1 is basic model of tubular structures. Model 2 represent the corner cut also called as corner chamfering. The variations of axial force in flange columns are as shown in fig. 5.14b for model 2. It clears that axial force in the column no. 3, which is corner column for this model, increase where as in column no. 1 and 2 decreases at the base level.



(a)



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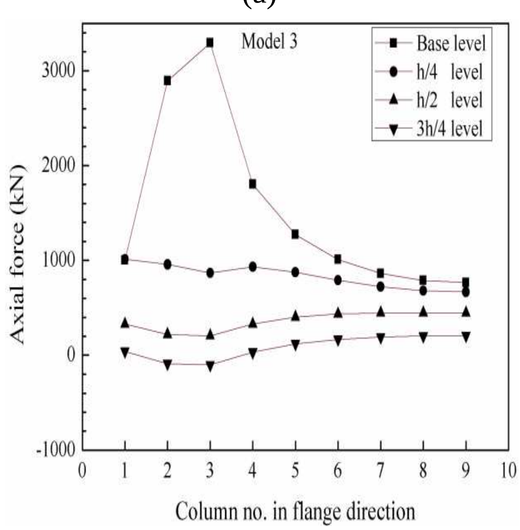

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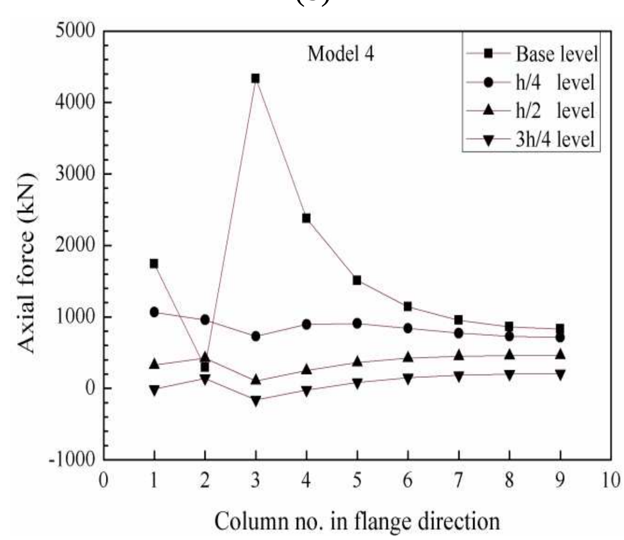
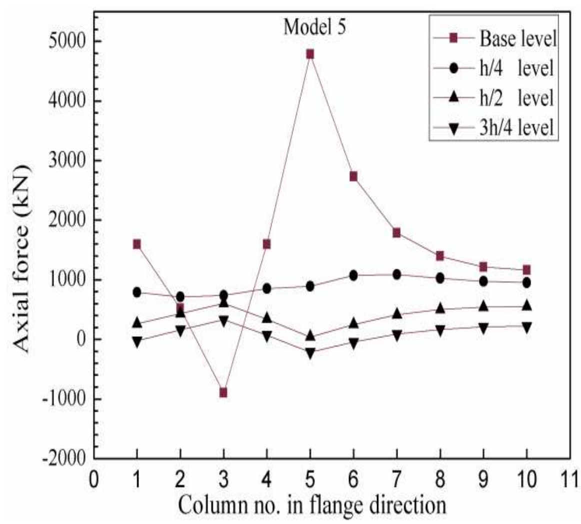
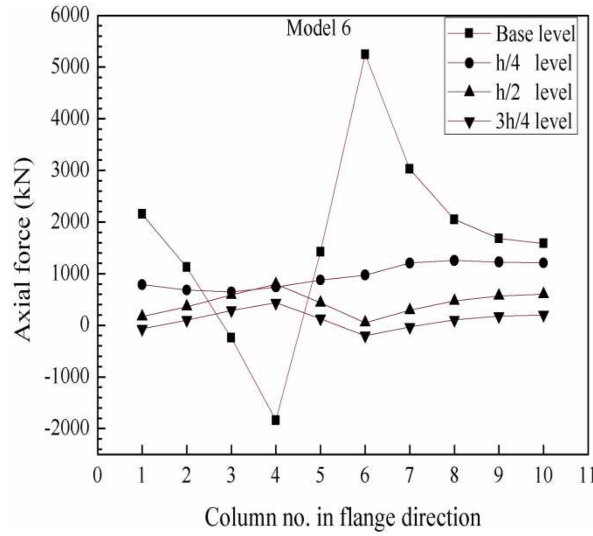
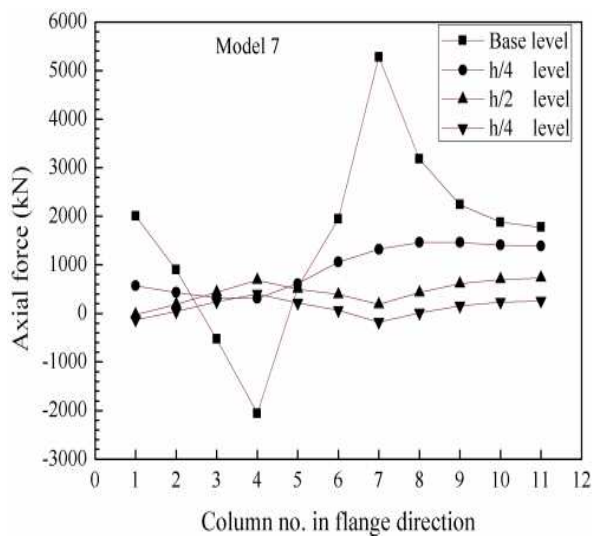


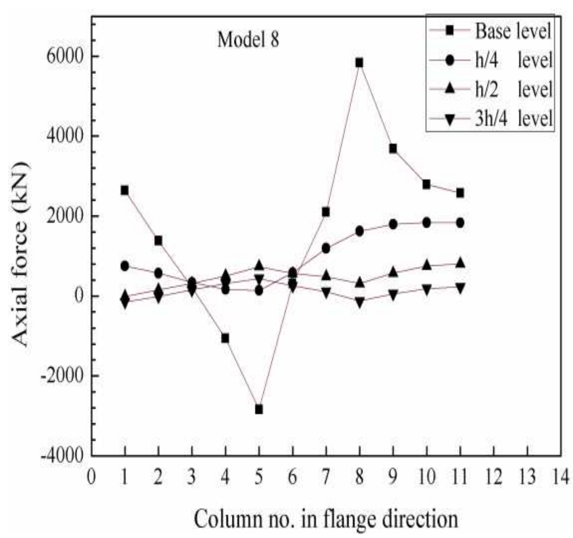
(d)





(e) (f)





(g) (h)

Fig. 5.14. Variation of axial forces in flange columns for model 1-8

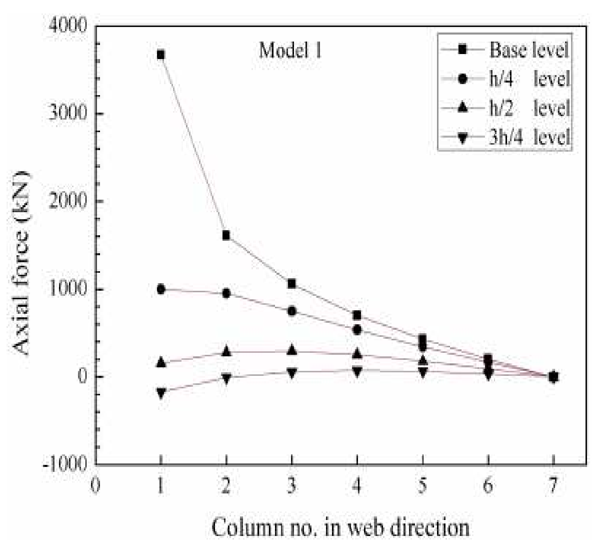
Other flange column bears approximately same axial force as in the basic model. The corner column (column 3) in the level h/2; h/2 and 3h/4 have low values of axial forces as compared to adjacent columns. It also observed that the pattern of variation of axial force at the higher level is similar to each other's. In the model 3, i.e. corner roundness, although the axial force in the corner column decreases but increases in other flange columns. The tendency of these type modifications is to normalize the axial force. The relative distribution of axial forces is being tries to be equalized as compared to the basic model. The variations of axial force in the upper storey have a nearly similar pattern of variation of axial forces to each other's (Fig. 5.14c). The corner recession (model 4), has a different pattern of variation of axial force as compared to model 2 and 3. The axial forces in column 3 increase abruptly whereas in column 2, it is very low at the base level. Further, it is increases in column 1.

The variations of axial forces in another type of corner recession are depicted (Fig. 5.14e-5.14h). The axial force in column 5, 6, 7 and 8 in the model 5, 6, 7and 8 respectively have highest axial forces whereas column 3, 4, 5 and 6 in model 5, 6, 7 and 8 have the lowest value of axial forces. The axial force decreases from corner column to the interior column and after then it increases and further decreases toward the center column in the direction of the flange. The variation of axial force in the upper level do not have similar pattern to each other's in model 5, 6, 7 and 8.

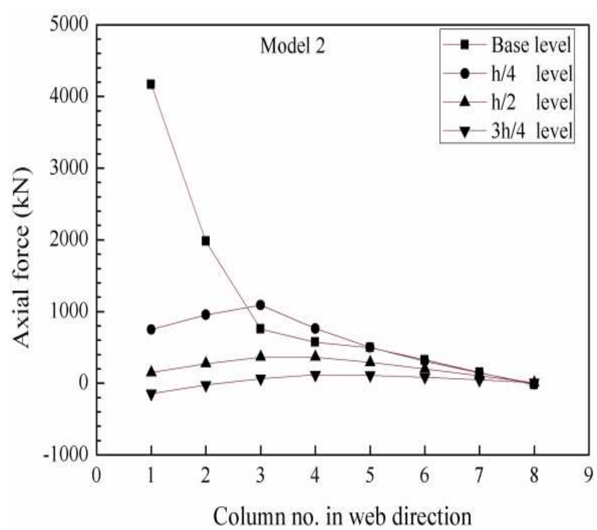
The web columns, which are in direct influence of the applied external load, have large value of axial forces as compared to the other columns (Fig. 5.15). The pattern of variations of axial forces in web column is mores affected by corner modification as compared to the flange column. It is clear from Fig. 5.15f-5.15h, the modification like model 6, 7 and 8 generate instability indeed in the web panels.

The linearity have been loosed further modification after model 4 i.e. the central web column doesn't possess zero axial stress as the axial force is not zero in models 5,6,7and 8. One of the web columns has highest positive axial force whereas other on has highest negative axial force. There is a large variation in the nature of the forces generated in the web columns (Fig.5.15g).

The lateral displacement of tubular structures has also investigated (Fig. 5.16). The lateral displacement of corner column and central column is notified and compared with the basic model. The corner column in every modification shifted toward the center of the flange as comparing with the basic model. Thus, the lateral displacement of these two columns tends to equalized as in model 7and 8. The lateral displacement increases along with the modifications in the central column whereas decreases in corner column. The lowest value of the displacement in the central column occurs in models 5, 6, 7and 8 but largest values in corner columns. The basic three modifications i.e. models 2, 3 and 4 have nearly similar values for corner column as well as for central column.



(a)



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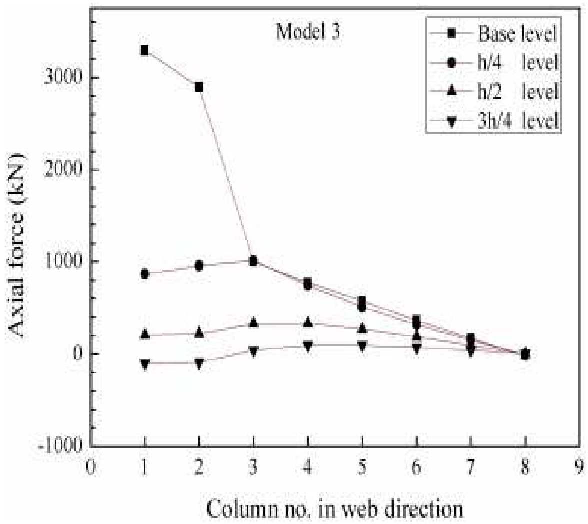
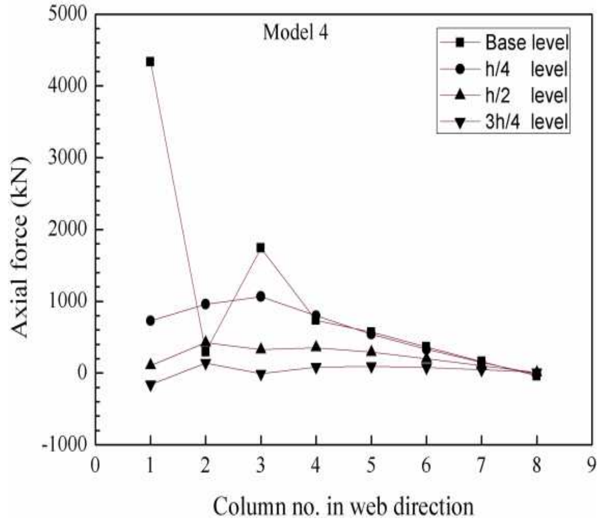
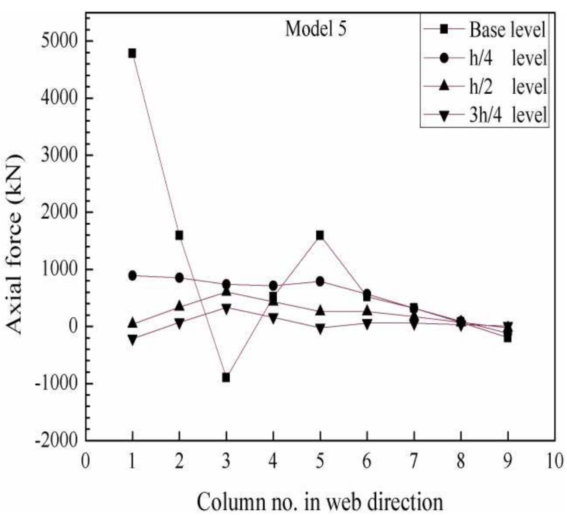

Model 3
Base level
h/4 level
h/2 level
3h/4 level
Axial force (kN)
Column no. in web direction

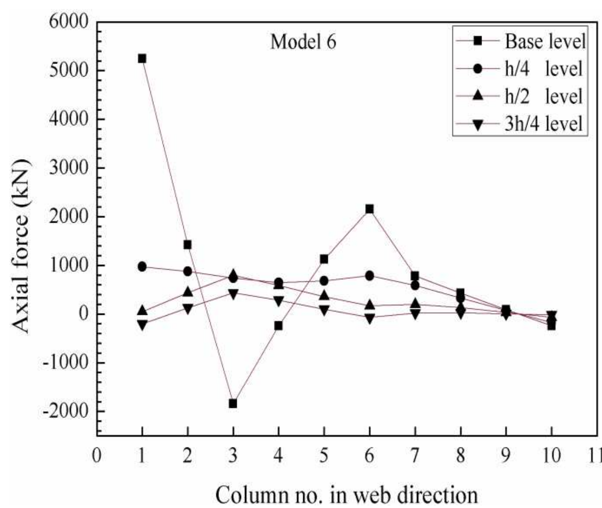
(c)


Model 4
Base level
h/4 level
h/2 level
3h/4 level
Axial force (kN)
Column no. in web direction

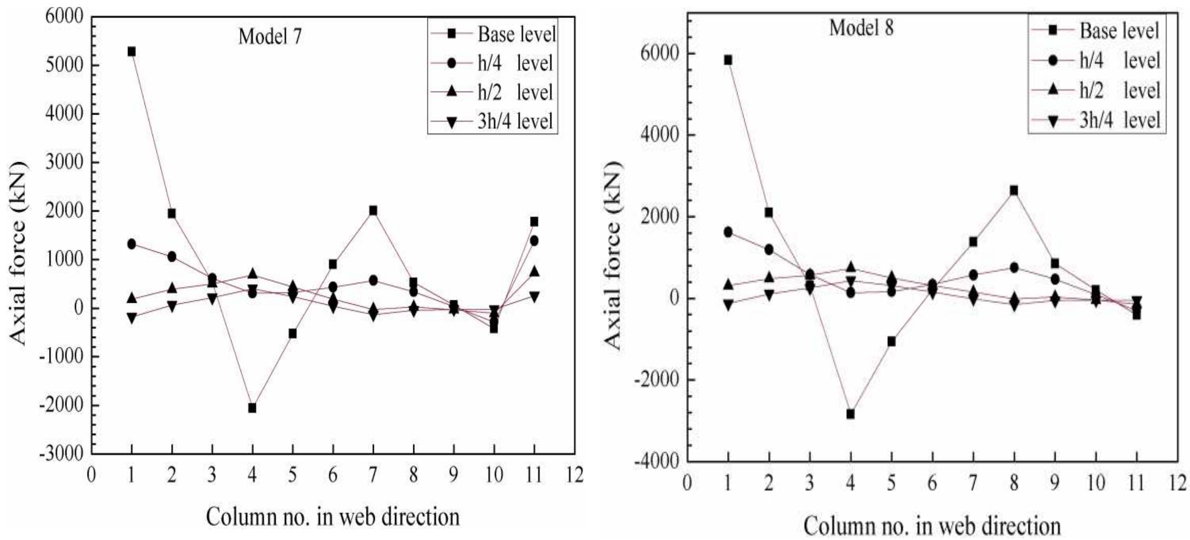
(d)


Model 5
Base level
h/4 level
h/2 level
3h/4 level
Axial force (kN)
Column no. in web direction

(e)

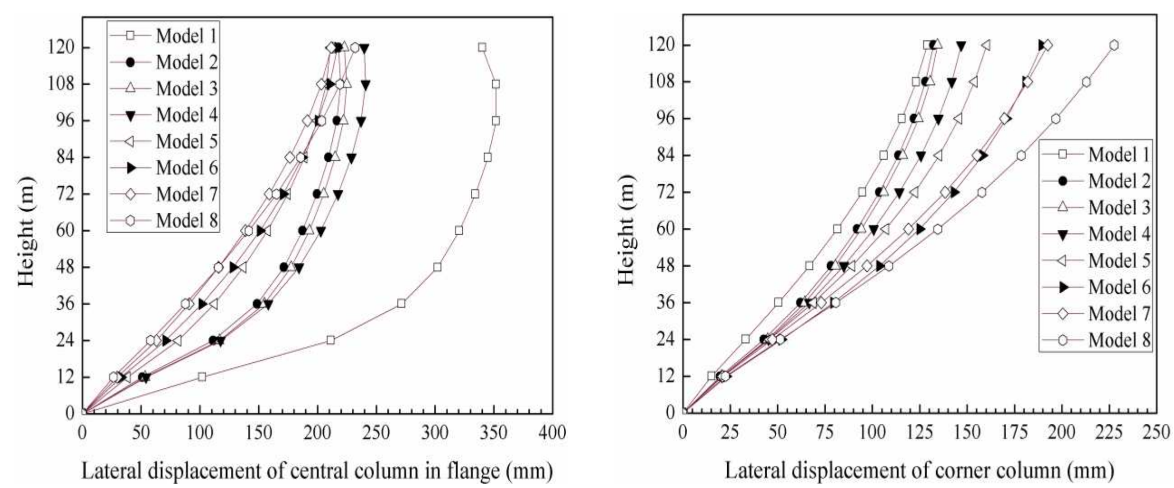

Model 6
Base level
h/4 level
h/2 level
3h/4 level
Axial force (kN)
Column no. in web direction

(f)



(g) (h)

Fig. 5.15. Variation of axial forces in web columns for model 1-8



(a) (b)

Fig. 5.16. Variation of lateral deflections for model 1-8: (a) central column of the flange (b) corner column of the flange

Comparing these three basic modifications, the lateral displacement of the central column as well as in corner column in corner roundness is least. The displacement pattern also reveals that these three basic modifications are more suitable for the tubular structure as they attributed the pattern such that lateral displacement of the upper storey do not revert as in the basic model (Fig. 5.16)

5.5 RESULTS AND DISCUSSIONS

5.5.1 Type First Modifications

The results obtained in this study can explain the following basics. In the tubular structure, the transmission of shear from the web to the center of the flange always lagged and positive shear lag appears. At a certain distance from the base of the building, fixity gradually diminished, as is the intensity of the shear. From the compatibility of deformation, the negative shear lags yields in the upper part of the tubular building. It is resembled as explain by Chang and Zheng (1987) when analyzing the negative shear lag in the Box Girder Bridge. The bending moment induced in the flange of the tubular buildings by the horizontal force consists two parts. One the normal bending moment induced according to the simple bending theory. Another one is the additional bending moment which induced by the shear deformation of the system [Chang and Zheng 1987]. The Flange panel of the basic model (Fig. 5.1) behaves as a beam in the transverse direction supported on two web panels. The additional corner columns provided in the directions of the flange make it overhanging indeterminate structure. The cantilever action of the beam attached to these additional corner columns in the flange direction results in reductions of total bending moment near the junction of flange and web. As the length of the overhang increased, subsequently the bending moment in the flange of tube get reduced accordingly.

The additional bending moment, which is the part of the total bending moment, also reduced and proportionally less normal stress mobilized. The optimum length of overhang in flange direction can be estimated by applying the equilibrium condition at the junction of web and flange. The additional corner column also stiffens the upper part of the tube and stiffness preserved through columns in the plane of the flange. Consequently, in spite of diminishing the intensity of shear, the negative shear lag not observed in any column of model six (Fig. 5.12).

In the web columns, no appreciable change in the variation of axial forces, are recognized. The extra columns provided in web direction redistributed the additional shear stresses, which are produced due to the increasing size of the flange and uniform loading.

5.5.2 Type Second Modifications

Small corner cut and recession are very effective to suppress the aeroelastic instability of a square prism when the damping is very small. Among the three corner modifications, the corner roundness is the most effective to suppress the aeroelastic instability for a square model [Kawai 1994].

The shear lag effect induced amplifications of axial forces in corner columns lowered in the case of corner roundness [Ilgin and Gunel 2007]. The corner recession has highest value of axial force in the corner column as compared with corner roundness and corner cut. The column at each corner has not directly under the influence of applied external load. The axial forces distributed in remaining flange column in this case. The Schuller (1997) has reported that certain building codes permit a reduction of wind load for circular or elliptical building by 20-40% of the usual values of the comparable size of rectangular buildings. The variations of axial forces in the continuity columns, in the case of corner recessions (model 5-8), is marked with highly irregular variation. This irregularity transmitted in the adjacent columns also. The magnitude of axial forces is significantly lower at the base level in model 4 as compared to other corner recessions. The lateral displacement of the corner and central column asserted the acceptance of corner roundness over other corner modification of type second

5.6 SUMMARY AND CONCLUDING REMARKS

It proven from results demonstrated above that, the additional columns provided at each corner, in each direction of flange and web, strengthen the web and flange panels simultaneously. Interestingly, it could be better to note that the provisions of these additional corner columns are capable of producing significant rigidity to the tubular buildings and results into the reduction of shear lag effect. Finally, it is concluded that the technique proposed is very efficient to neutralize the negative shear lag and it make the reduction in positive shear lag without changing the as much in the plan of the tubular structure since the dimension of the tube is preserved throughout in model 1 to 6.

From the different models studied for normalization of shear lag phenomenon the following major conclusions are drawn:

1. The structural efficiency against lateral loads increases significantly with additional corner columns when provided in the manner proposed in the present study.

2. The variations of the axial force found in the model 6, normalized and the value of normalization factors ranges from 1.4 - 2.

3. The variation of axial force in the columns is quite regular through the height of the building. The negative shear lag does not appear in model 6. The optimum length of the overhanging can be estimated for other tubular building plans of different width/depth.

The corner modification of type second also has a significant impact on axial forces and lateral displacement of the buildings. In this type of modification, the plan area is not preserved. The plan area changes according to the modifications. The model plan with corner roundness has highest plan area among modified plans. The suitably modified plans regarding reduction of the effect of shear lag phenomenon are as follow:

1. The corner cut, corner roundness and corner recessions (model 4) are also suitable for reduction in shear lag effect under lateral loading.

2. Among these three basic modifications, the corner roundness usually has great resistance against shear lag effect as the axial forces in the corner column reduces and the lateral displacement is nearly equal to other two basic modifications.

3. In the upper storeys, the reversal of the deflection in central column is least as compared to the basic example model (model 1). This is a healthy finding because the reversal of lateral deflections in the upper story of the building in the central columns is a reason of negative shear lag produces at the upper level. Since the reversal of the deflection in the corner column is less as compared with central column in the upper storeys of the tubular, it produces warping in the cross-sections of the tube.