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Effect of Cladding and Secondary Members on the Elastic Stability of Main Columns

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Abstract**—**The corrugated steel cladding used to cover most of steel buildings is considered as non-structural element. This research will reflect the effect of cladding as a shear diaphragm in increasing the normal elastic capacity of columns. This study is important because of the lack of information of the behavior of cladding and secondary members in various codes. Mathematical models for six different cases are carried by software. The results extracted from the program have been plotted showing the effects of different variables on the ultimate load of column. The variables considered in our research are the spacing between columns and the thickness of the corrugated sheet representing the sheet stiffness.

Keywords**—**Stability of frames about minor axis, The effective length factor, Effect of secondary members on elastic buckling load column, The stiffness of sheeting.

I. Introduction

THE common practice in steel constructions is to provide a separate bracing system to maintain lateral stability of steel frames. The side girt and side wall panels are used only as a covering material although they can provide diaphragm action if they are adequately connected to each other and to the steel column. This effect can increase the elastic capacity of the column and eliminate the use of bracing elements causing a reduction in the total cost of building. So many codes of design do not give a defiantly value of the affect of secondary elements [1], [2], and [6]. Also, so many handbooks do not clear the affect of different systems of covering the roofs or sides of the constructions under construction and after construction [5]. The effect of corrugated panel has been investigated by many researchers. Reference [7] investigated the best design approach to have the least weight for this diaphragm bonded with one or two steel sheets. Reference [9] discussed the effect of corrugated sheets as shear diaphragms on the stability of steel frames. Reference [8] deduced numerical models using springs to account for the influence of sheeting on the overall behavior of purlins. In this study, the critical elastic buckling load has been deduced for six different cases, showing the effect of various elements. The spacing between columns has been considered as a variable affecting the critical buckling load. The total system has been represented by shell element to give true modeling of all elements.

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II. Cases of Study

In this research the cases of study which were taken in the consideration are as the following, a covering steel system consists of two columns (rafters) 6.0 cases as the following:-

1- Single column Fig. (6).
2- Two columns are linked by side grits Fig. (5).
3- Two columns are connected by bracing Fig. (4).
4- Two columns are connected laterally by side grits bracing Fig. (3).
5- Columns side are connected by grits and sheeting Fig. (2).
6- Total system consists of two columns, bracing, side grits, and sheeting Fig. (6).

The height of columns (rafters) are 6.0 m, the variables considered for the 6.0 cases are the spacing between columns (rafters) varied from 6.0 m to 10 m. the sheeting thickness are varied from 0.5 mm to 1.0 mm.

The columns cross sections are fixed for all systems as IPE 270. Also, the purlins cross section is a constant for all systems as C-section with web height 160 mm, flange width 40 mm, and thickness 4 mm. The bracing cross section is fixed for all system as a single angle L60X60X6 mm.

III. Finite Element Modeling

The geometry of the model consisted of a steel column (rafter) with total height 6 m and cross section IPE 270. The column was supported as a hinge at one end by restraining the displacement in the X, Y, and Z translational directions while the rotation is permitted. The other end was restrained against the displacement in X and Y translational directions, while the displacement in Z-direction is free and the rotation is also permitted. The five purlins were fixed to the top flange of column (rafter) while the sheeting is fixed to the top flange of the purlins. As well as, the bracings were connected between the two ends of column (rafter) at the top flange of columns and connected at the intersection with the lower flange of purlins in the cases where purlins exsist. In ANSYS workbench, the finite element (FE) model was formed using SHELL181 to build and shape the structure elements of covering or roofing system. The column or rafter was imperfect by the 1/500 from height of columns. This imperfection will be generated an additional moment to represent the bending stress due to eccentricity. SHELL181 is suitable for analyzing thin to moderately-thick shell structures. It is a 4-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes [3].

Regarding to the research adopted the finite element method to model the buckling problem of column or rafter without full simulation to others elements of system. The simulation of the others elements usually represents as a restrained condition along the column or rafter. This research adopts the modeling of the total system to represent a true affect.

The total system was represented by utilizing software based in the finite element method. Elastic approach was used to model the system. The software which was used to the numerical simulation was [4].

A. Material Behavior

The material properties of used steel in modeling were taken from Egyptian code of practice for steel construction and bridges allowable stress design, edition - 2007. The nominal yield stress (fy) of steel was 2400 kg/cm2 (Steel grade St 37). The modules of elasticity (Es) was 2100 ton/cm2.

B. Geometry, Meshing, and Finite Elements

The shell-181 as a shell element in numerical software (Ansys) was used to model the structure elements. The shell 181 was counted to represent the column (rafter) as steel I-beam IPE 270, the purlins as steel cold formed stiffened C-section with thickness 4 mm, height 160 mm, and flange width 40 mm, the bracing as steel angle L60X6, and cladding with variable thickness 0.5, 0.7, and 1.0 mm. as shown in Fig. (1).

Meshing the column (rafter) produced 592 elements and 1064 nodes, purlins 208 elements and 371 nodes, bracing 560 elements and 1088 nodes, cladding 399 elements and 462 nodes, as shown in Fig. (1). Figs. from (2) to (6) show the meshing of different cases of available systems which represent construction stages and probability of using elements.

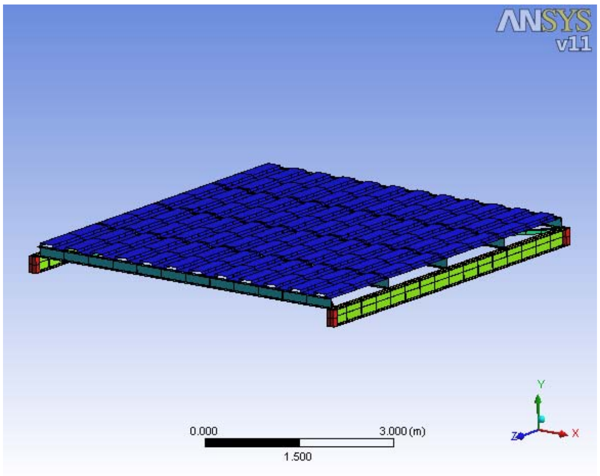

Fig. 1 The geometry of total system

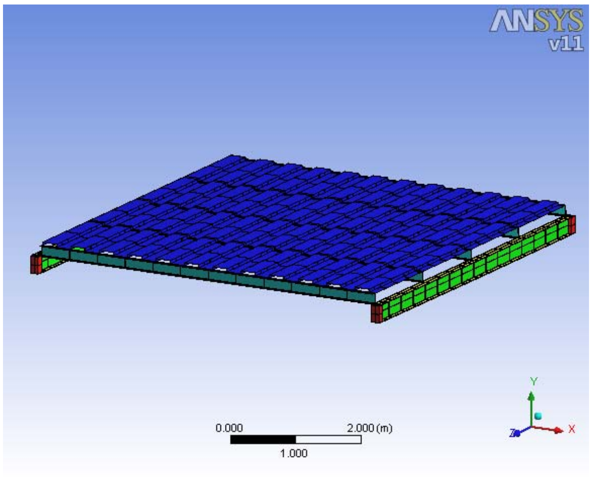

Fig. 2 The geometry of system with cladding and purlins

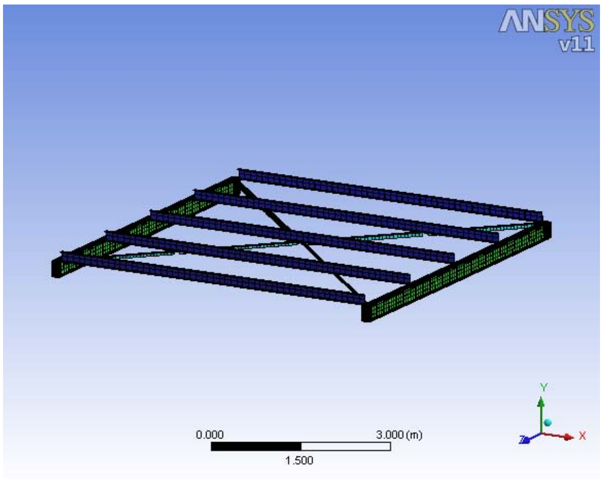

Fig. 3 The geometry of system with bracings and purlins

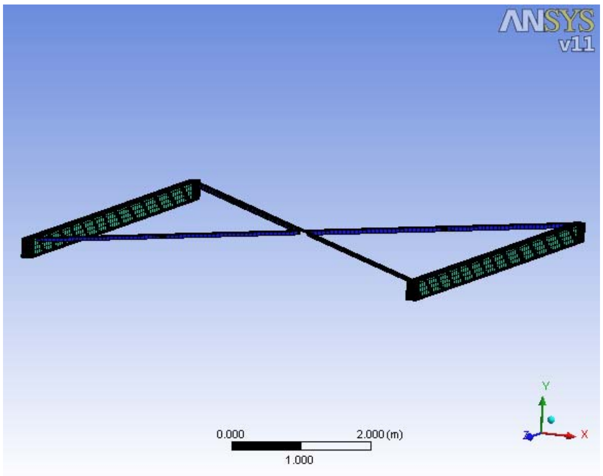

Fig. 4 The geometry of system with bracings

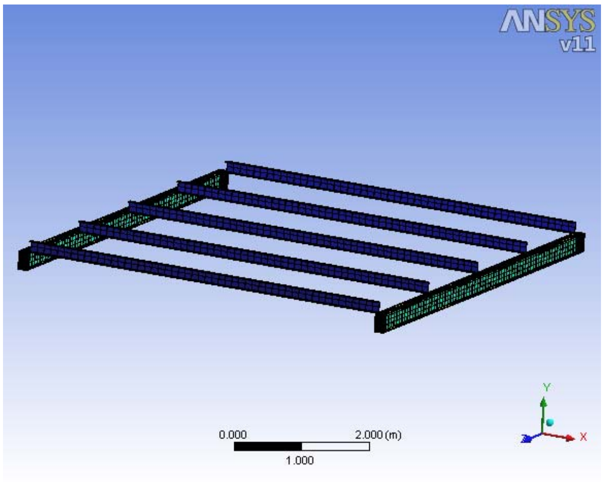

Fig. 5 The geometry of system with purlins

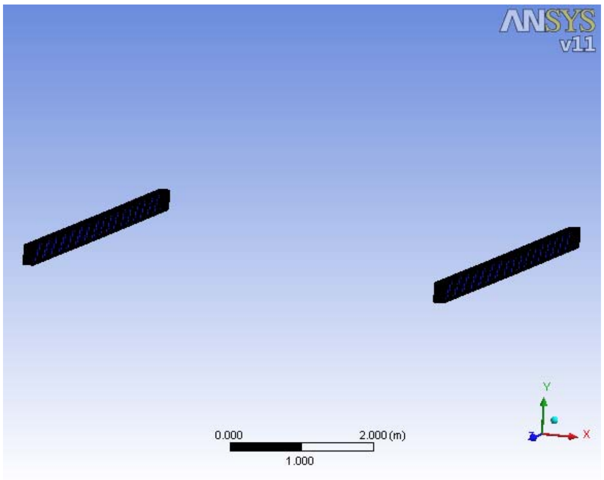

Fig. 6 The geometry of free column (rafter)

C. Loading and Boundary Condition

The boundary conditions was simulated to represent the applied force in Z – direction on one end which was restrained in X and Y - direction. The other end was restrained in X, Y, and Z – direction.

The applied load was controlled by force rating equal to 2.0, 0.5, and 5.0 ton/sec. as a normal, minimum, and maximum increment respectively. As shown in fig (7).

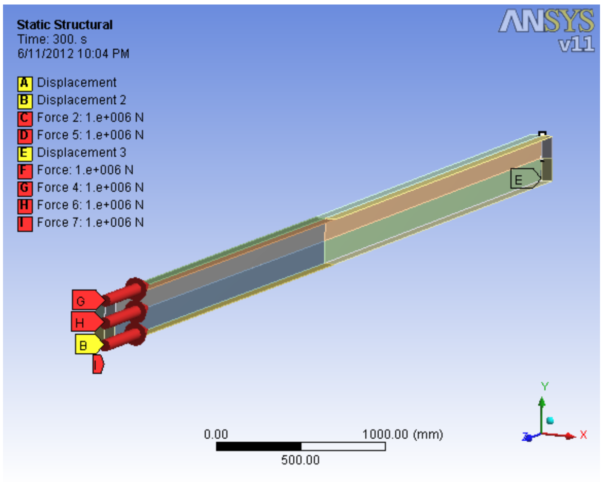

Fig. 7 The loading and boundary conditions

IV. Numerical Results and Results Analysis

The system has been analyzed using finite element (FE) model as space structure containing elements as shell (plate) elements. Ansys was used for the analysis. In the analysis, the shell element is considered to represent the addition moment which is generated due to the imperfection (1/500 length). The column (rafter) will be buckled to imperfection side to reach the ultimate capacity of section.

A. Numerical Results

Figs. from (8) to (10) represent the ultimate capacity of column (rafter) against the different system for various spacing between columns. From pervious Figs. it can be deduced that the total system increases the critical buckling load carried by each column with various magnitude according to the connected secondary members.

Fig. (11) describe the relationship between the different system and ultimate capacity for various length of column (spacing). From the chart it can be noted that all spacing do not affect significantly the critical buckling load of column for systems. As the percentage of decreasing the elastic buckling load for the same system is increased with the spacing varies form (6 m) to (10 m).

B. Results Analysis

From the previous it can be seen that, the case which has the minimum capacity occurred for free column. In this case the column (rafter) resists the external axial load without any additional stiffness to increase the column resistance. The value of critical buckling load is equal to the Euler value. Thus, the buckling mode shape for this case was single curvature (Mode 1) in the minor inertia of the section as shown in Fig. (12).

When the purlins have been used the capacity of column has increased slightly more than the case of free column. This is due to the poor flexural stiffness of the purlins, the purlins acted as link members without significant constrain of the rotation of the points of Purlin-Column Intersections. The buckling mode shape for this case was single curvature (Mode

1) as shown in Fig. (13).

The using of bracing only with columns, it increases the capacity of column more than the free column, due to the additional elastic supporting of the column ends. The additional supporting improves the capacity slightly. The buckling mode shape for this case was single curvature (Mode 1) as shown in Fig. (14).

The capacity of column was significantly increased by using purlins and bracing, as the using of purlins and bracing improves the stiffness of elastic supporting system which support the column at several point along the column and at the ends. The buckling mode shape for this case was double curvature (Mode 2) as shown in Fig. (15), because the purlins connected to the bracing intersection point acted as a strut, constraining the displacement of the Columns. In other words, the double curvature mode shape occurs due to the lateral constrain of the columns due to the existence of purlins and bracing Casing an increasing of the elastic buckling load.

The cladding with purlins increases the column capacity highly more than the previous cases. The cladding increased the total stiffness of system, due to the diaphragm-membrane action of the cladding with the purlins. That lead to the efficient constraining of the lateral displacement of the columns at all the points of purlin column intersections leading to the highest rise from the previous cases. The failure occurs at lower flange which has no connection with purlins. As shown in Fig. (16).

The total system which consists of cladding (thickness 1.0 mm), bracings, and purlins improves the column capacity slightly more than the previous case, due to the additional elastic supporting for rotation of the column ends. The mode shape occurs also at lower flange as shown in Fig. (17).

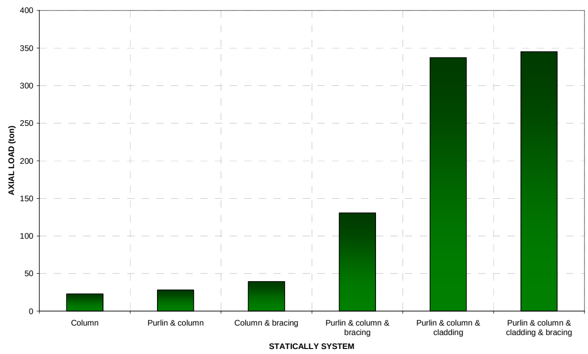

Fig. 8 The ultimate load of column with length equal to 6 m

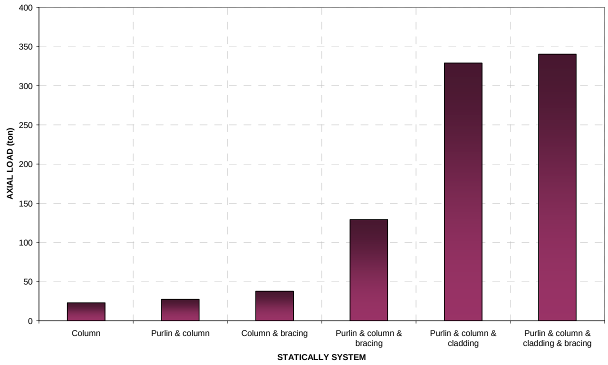

Fig. 9 The ultimate load of column with length equal to 8 m

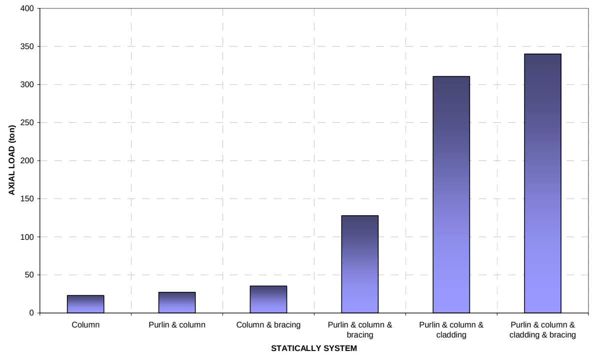

Fig. 10 The ultimate load of column with length equal to 10 m

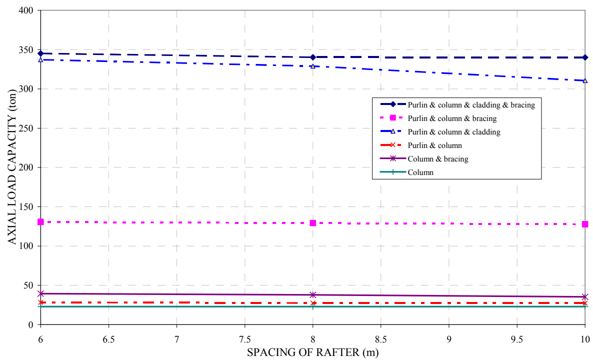

Fig. 11 The comparison of ultimate load for different systems

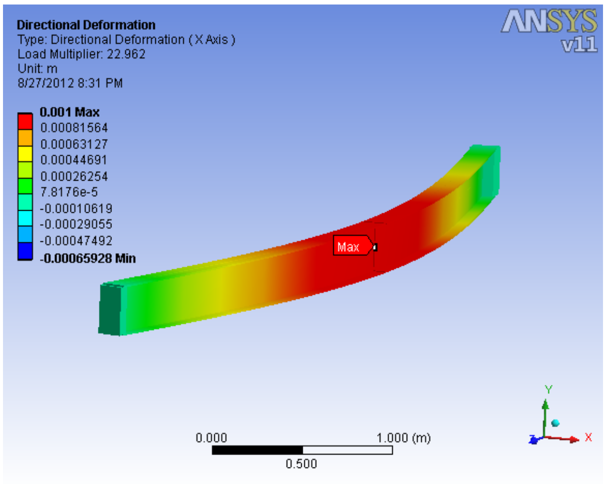

Fig. 12 The buckling mode for single column (Euler mode)

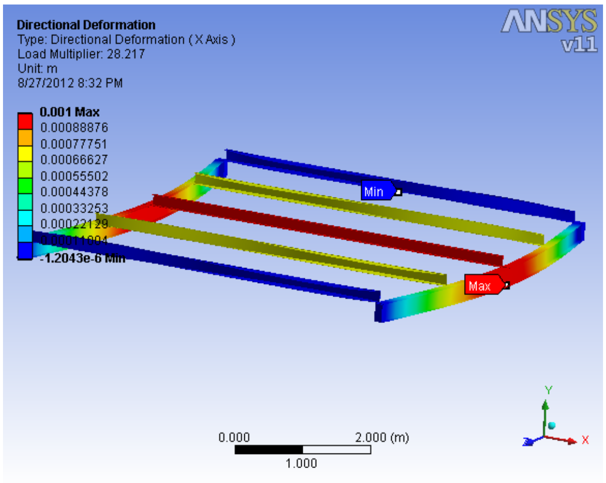

Fig. 13 The buckling mode for column with purlins (single mode)

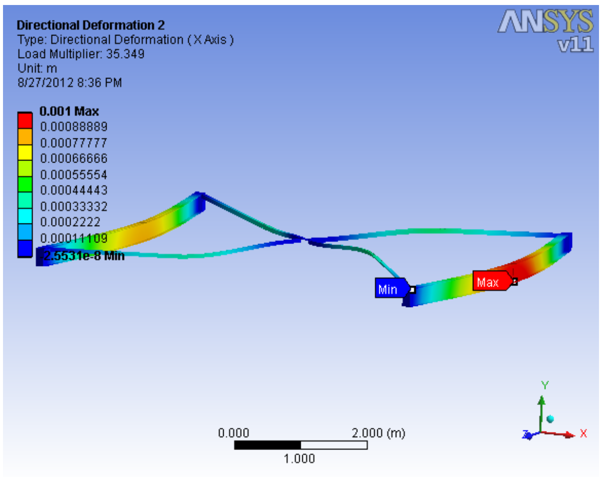

Fig. 14 The buckling mode for column with bracing (single curvature)

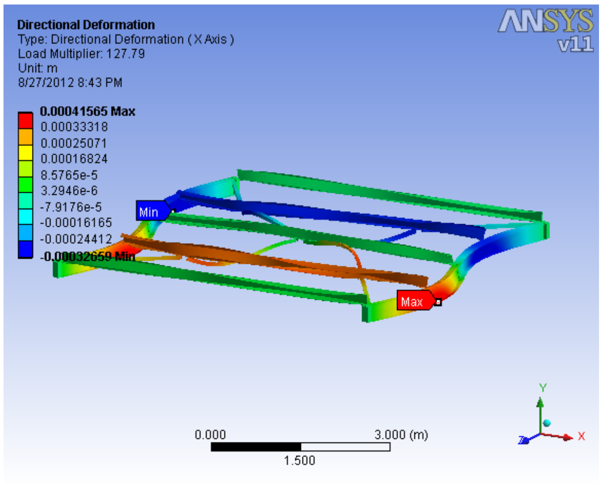

Fig. 15 The buckling mode for column with purlins and bracing (double curvature)

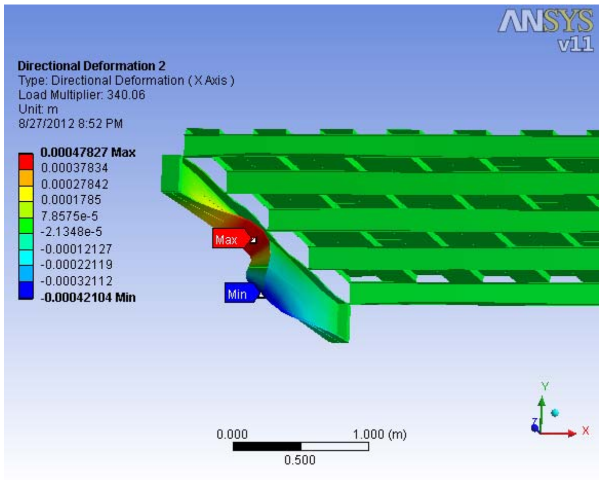

Fig. 16 The buckling mode of column purlins and cladding

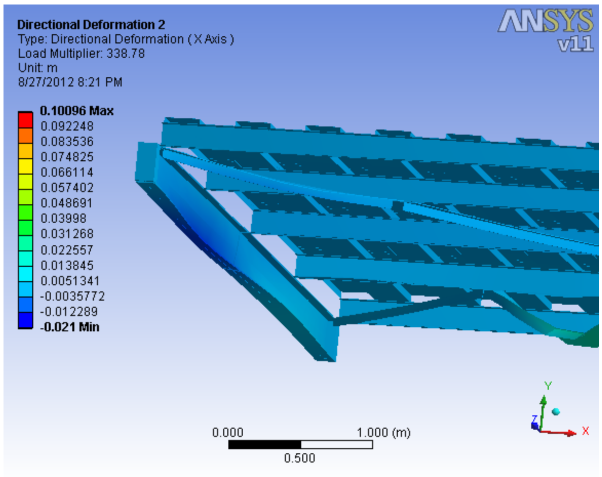

Fig. 17 The buckling mode of column for total system

V. Evaluation of Buckling Length

Euler's formula

Peu = π2 E I / (KL)2

If K= 1.0

Peu = π2 * 2100 * 420 / (600)2

Peu = 23.006 ton

Peu / Pcr = (π2 E I / (L)2) / (π2 E I / (KL)2)

Peu / Pcr = K2

K = (Peu / Pcr) 0.5

TABLE II
THE BUCKLING FACTOR VALUES AND CRITICAL LOAD

	Statically System	PCritical (KN)				Buckling Length Factor (K)			Mean Value of (K) for Each System
		From Numerical Analysis			Euler load (Peu) (KN)	Spacing			
		Spacing							
		10 m	8 m	6 m		10 m	8 m	6 m	
1	Column	229.66	229.64	229.62	230.06	1.001	1.001	1.001	1.001
2	Purlin & column	272.47	274.4	282.17	230.06	0.919	0.916	0.903	0.912
3	Column & bracing	353.49	377.55	393.78	230.06	0.807	0.781	0.764	0.784
4	Purlin & column & bracing	1277.9	1292.15	1306.4	230.06	0.424	0.422	0.420	0.422
5	Purlin & column & cladding	3105.3	3289.6	3372.4	230.06	0.272	0.264	0.261	0.266
6	Purlin & column & cladding & bracing	3400.6	3402.5	3451.4	230.06	0.260	0.260	0.258	0.259

Previous results indicate that the use of full system increase the total elastic buckling capacity of columns. In case of cladding with thickness less than 1.0mm, the effect of the diaphragm action of the cladding can be neglected due to the local buckling which occur in cladding, thus for thickness 1.0mm and greater. The cladding can be considered as a lateral diaphragm which leads to increase the elastic buckling load capacity of columns.

VI. Conclusion

From previous finite element analysis and parametric analysis we can deduce the following:-

1-The increasing of the side girt thickness has no significant effect on the buckling load of columns.

2-The secondary members (side girt, bracing) have positive effect on the critical elastic buckling load with ratio about 55 % and this effect is decreased slightly by increasing of spacing between columns.

3-The existing of cladding with thickness 1.0 mm or more increases the critical buckling loads about minor axis of bending with ratio about 70 % for different frame spacing.

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