EFFECT OF CORRUGATED SHEETS ON THE LATERAL STABILITY OF STEEL FRAMES

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ABSTRACT:

The theory of elastic stability is considered to be the most effective aspect which governs the safety of structures. Many studies have been developed to investigate the actual behavior of structures. The cladding which is used to cover most of the steel frames is neglected by most of the designers and is considered as a non-structural element. This research presents a comprehensive numerical method for studying the effect of cladding as a shear diaphragm and its role in maintaining lateral stability of the steel framed structures.

For most of the designers, it is a common practice to maintain the lateral stability of the steel frames by providing the classical bracing system to resist the out of plane loads (wind, earthquake, blast,...etc.), however the cladding system may be the key element in maintaining the lateral stability of these structures.

KEYWORD: Stability, Shear diaphragms, Lateral bracing, Cladding system, Drift

1. INTRODUCTION

The civil engineering community is challenged to develop the design of the traditional structures utilizing the advanced computer analysis techniques and to consider all the parameters that may affect the safety and stability of these structures. The behaviour of corrugated sheets under different combination of loads is carried out experimentally and proved using finite element models (Hofmeyer et al., 2001, 2002; Biegus et al., 2006, 2008). The influence of corrugated sheet is investigated regarding the thickness of sheeting, opening and bracing existence (Fulop et al., 2004). The behaviour of moment resisting steel frames endowed with lightweight cladding panel under dynamic and lateral loads is studied (De Matteis et al., 2007; Rogres et al., 2010).

To investigate the effect of corrugated steel sheet panels on the lateral stability, a finite element 3D-computer model is made using the finite element program ANSYS 9.0, (ANSYS

9.0, 2004). The study discusses the main factors that may affect the lateral stability of the frames which are:

- The stability of the frames in the existence of bracing with and without considering the cladding system effect.
- The effect of cladding regarding the frame height and spacing.
- The effect of cladding thickness and purlin spacing.

To examine the significance of these factors a comparative study is made and the results are discussed.

2. THE ANALYTICAL MODEL AND TECHNIQUE

The used model is a three dimensional model developed incorporating shell element using ANSYS 9.0 program definitions. The model represents a one bay frame with 10.0m span, 6.0m in height and 4.0m spacing between the frames. The frames, which are consisting of columns and girders rigidly connected to each other, are formed using shell elements connected to each other through joints at the circumference, which are called key points, as shown in Fig. (1). Purlins and side-girts are also represented in the model and connected to the frame shell elements. Corrugated sheets are also simulated in this model at the roof and sides of the frame. As shown in Fig. (2), columns and girders for the two frames have the same cross sections (HEB-500). The purlins and side-girts have the same cross section of a cold formed (C-200x100x3). The corrugated sheets are also simulated in the analytical model and they are connected to the purlins and side-girts.

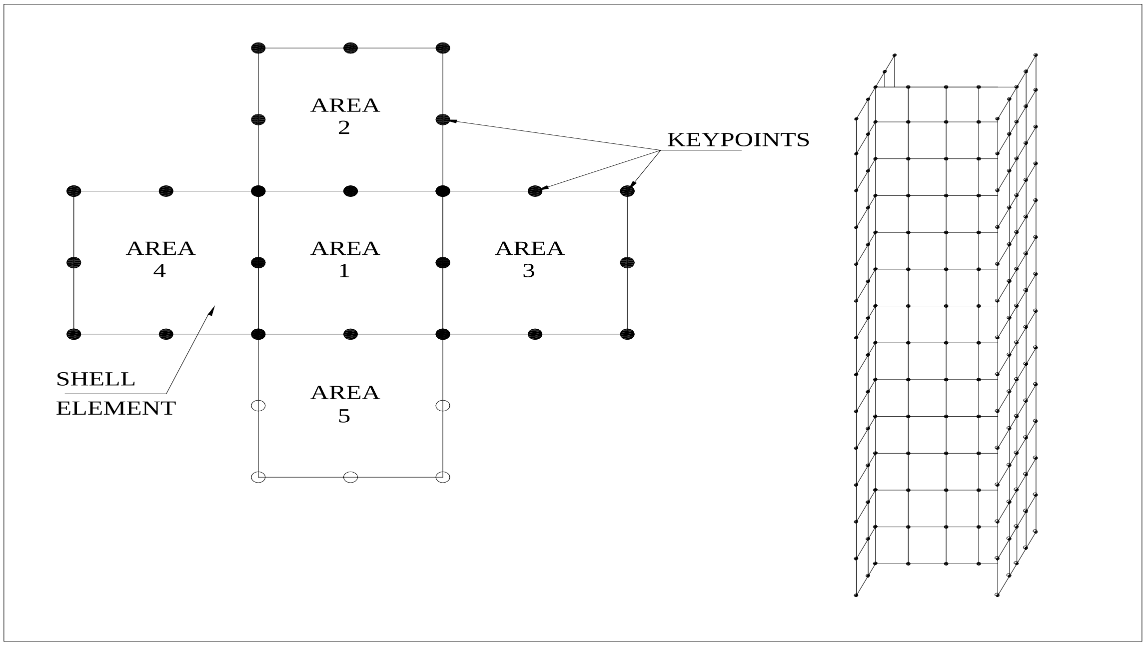

Figure 1: Formations of model and connection between shell elements

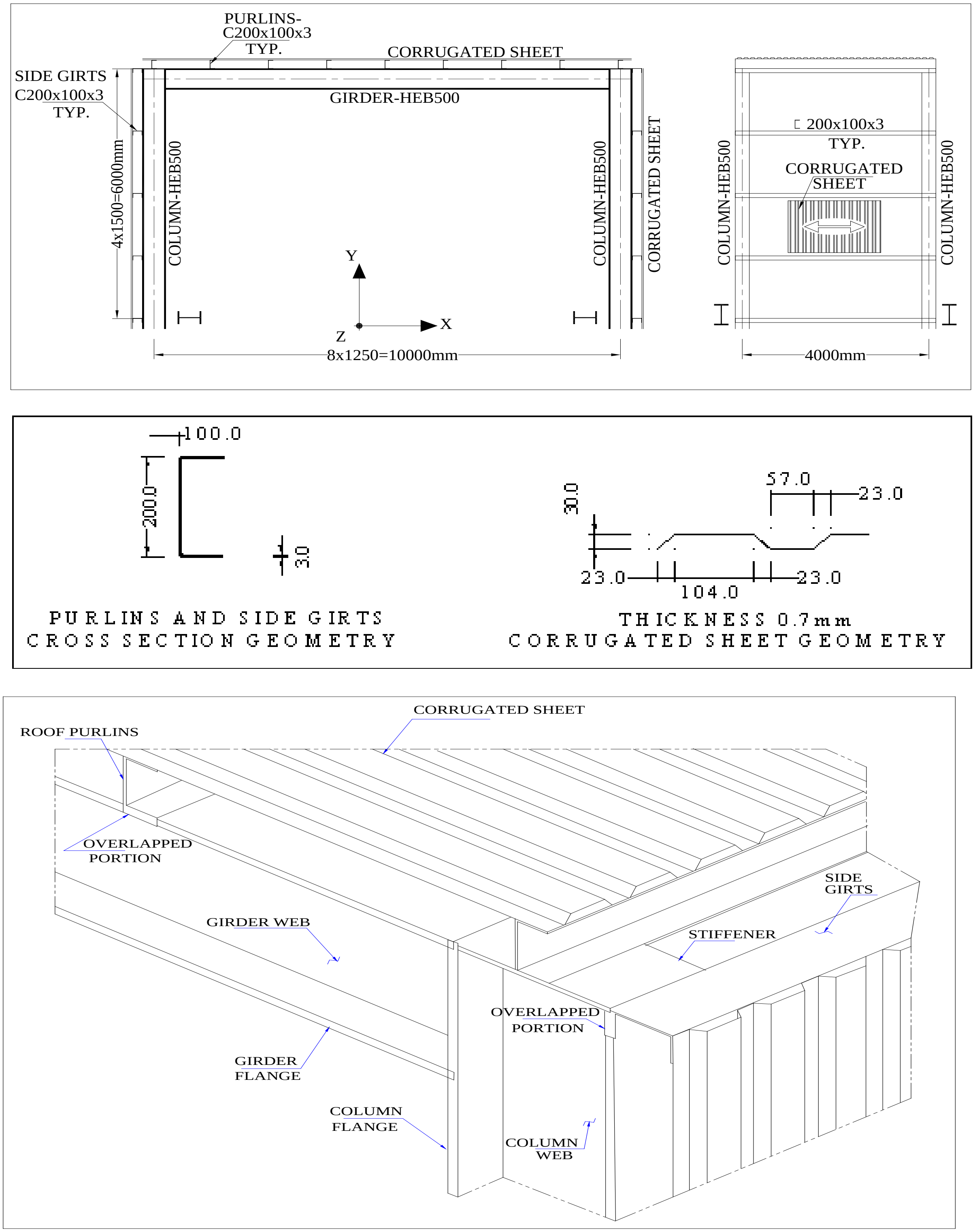

Figure 2: Reference model geometry and cross sections

3. ELEMENTS DESCRIPTION

SHELL 93 is one of the available element types in ANSYS 9.0. The element is defined as elastic and isotropic. The geometry, node locations, and the coordinate system for this element are shown in Fig. (3). The element is defined by eight nodes, and accepts four different thicknesses at the element corners. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. The deformation shapes are quadratic in both in-plane directions. The element has plasticity, stress stiffening, large deflection, and large strain capabilities.

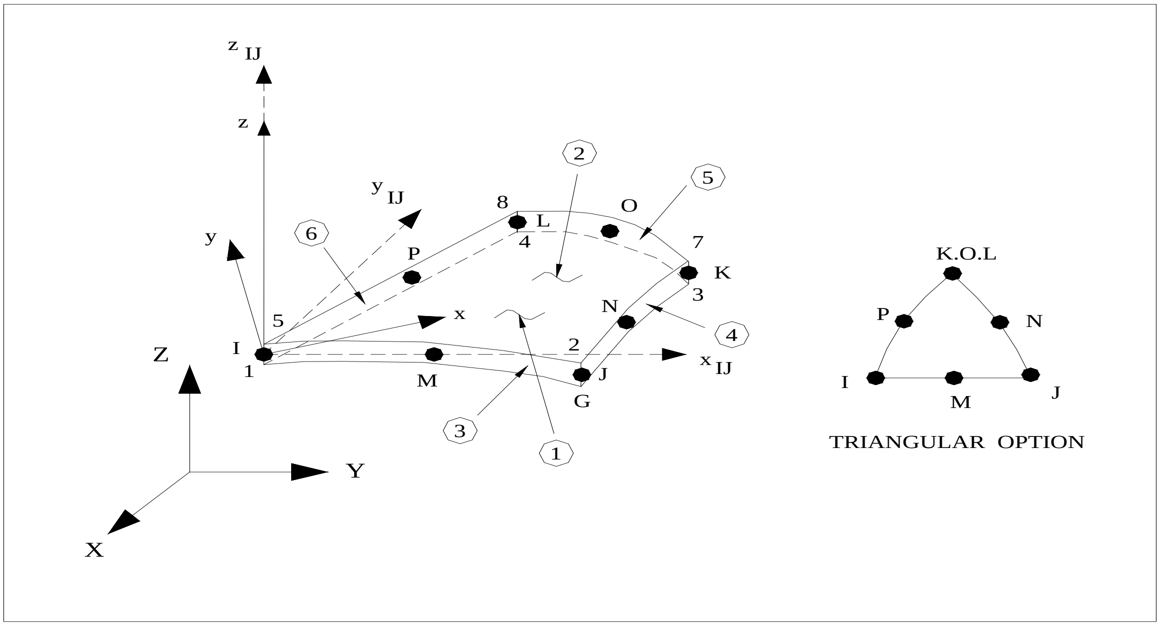

Figure 3: Element type (SHELL 93) geometry (ANSYS 9.0, 2004)

4. DEFINATION OF MATERIAL PROPERTIES

The material in use is assumed isotropic, linear and elastic. The elastic properties of steel material are defined as follows: Young’s Modulus = 2100 t/cm^2, Poisson’s Ratio = 0.3.

5. ASSIGNMENT OF LOADS AND CONSTRAINTS TO MODEL

A unit load is applied to the frame (vertical downwards) at the top of all columns parallel to Y- axis (vertically downwards), as shown in Fig (4). The program specifies a factor to be multiplied by the load intensity to determine the critical buckling load. The frame has hinged supports at its bases. This was implemented by restraining translations in all available degrees of freedom at the connection between the column and the foundation.

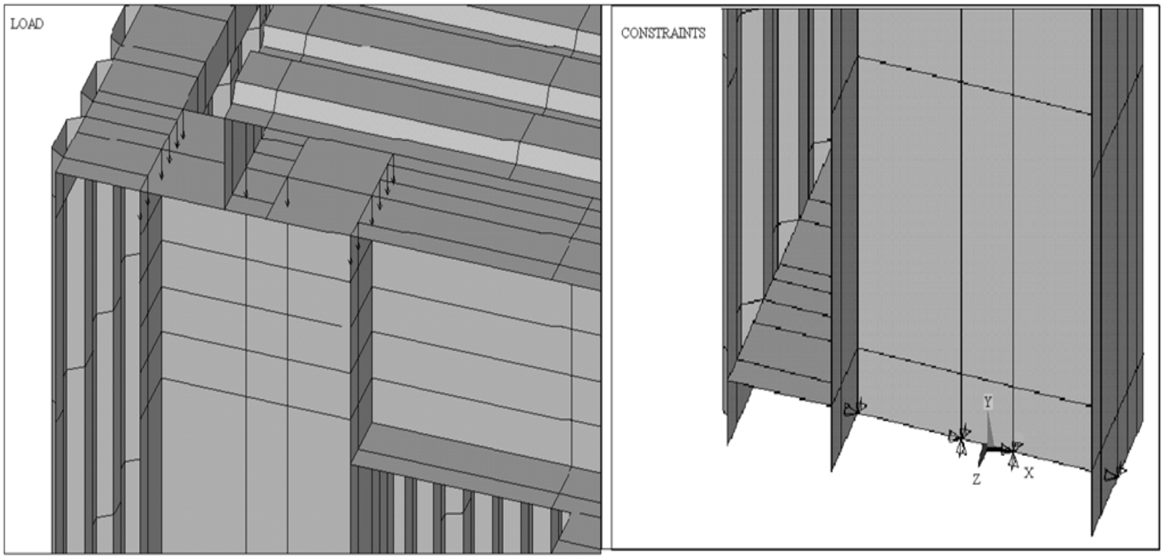

Figure 4: Assigning load and constraints to model

6. BEHAVIOUR OF FRAMES CONSIDERING SHEETING WITH AND WITHOUT BRACING AND PURLINS

The behaviour of frames is discussed and compared based on the results obtained from four models using shell element type. The four models consist of two successive frames with high 6m., spaced at 4.0m. Columns and rafter cross section is HEB-500. The frames of models 1 and 3 are attached with horizontal and vertical bracing HSS 100x100x3mms. Models 2, 3 and 4 are provided with purlins and side-girt beams arranged each 1.25m and 1.5m, respectively. Model 4 is provided with corrugated steel sheets 0.7mm thickness. The four models can be described in Table (1):

Table 1: Model description

Model no.	Horizontal and vertical bracing HSS 100x100x3	Purlins and side girts C 200x100x3	Corrugated sheet 0.7mm thickness
Model 1	●		
Model 2		●	
Model 3	●	●	
Model 4		●	●

The buckling length factor as well as the maximum drift in the out-of-plane direction (Z direction), are shown in Fig. (5). The frame deformed shape associated to P_{cr} is shown in Fig. (6). The existence of sheeting reduces the value of K_x from 5.11 as per model 2 to 2.29 as per model 4. The percentage of decreasing K_x is about 55%. However, the bracing existence in model 3 results in reducing the K_x value to less than 20% of the value given by model 2. The minimum drift takes place in models 1 and 3, while the maximum drift takes place in model 2. The sheeting existence reduces the lateral drift in model 4 by more than 55% of that in model 2.

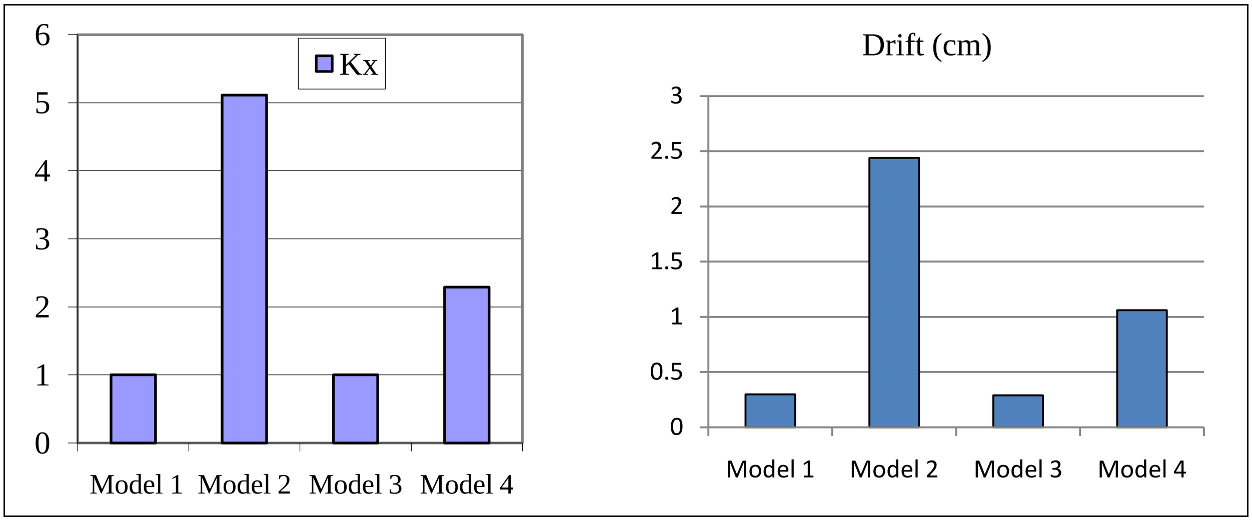

Figure 5: Buckling length factor about minor axis of bending and the corresponding lateral drift

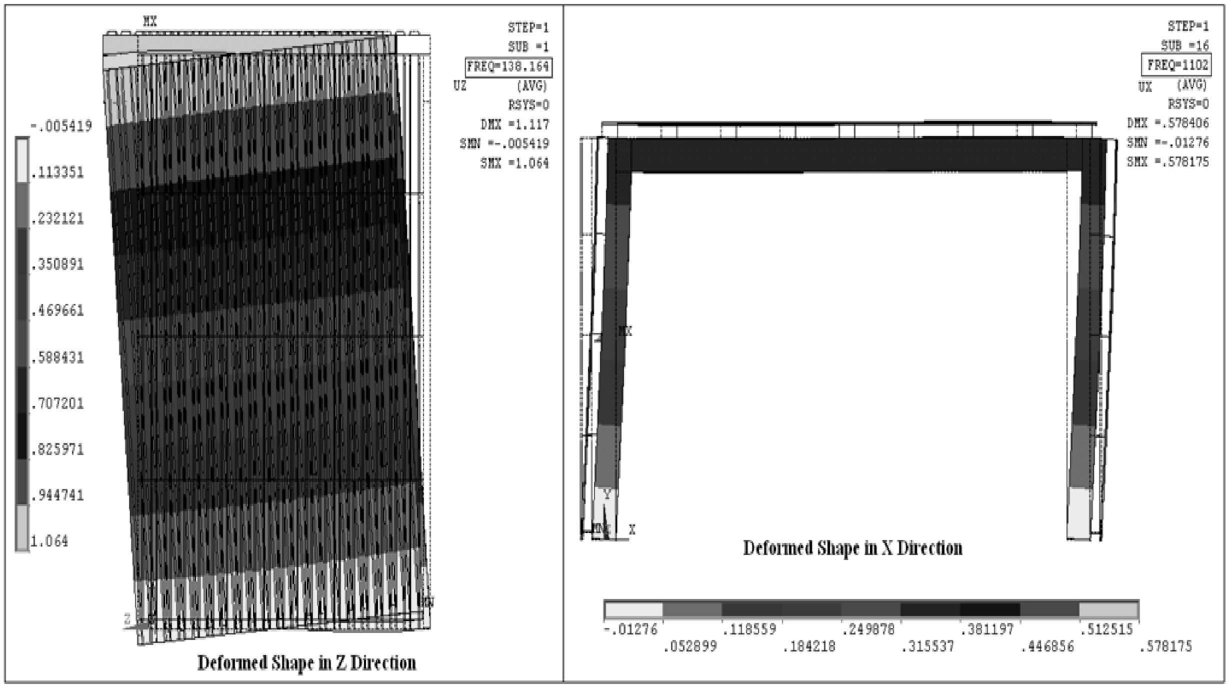

Figure 6: Mode shape (model 4) associated to P_{cr}

7. SHEETING EFFECT ON THE BEHAVIOUR OF FRAMES WITH DIFFERENT GEOMETRY DIMENSIONS

Behaviour of frames with different high, spacing between frames and spacing between side-girt is affected by the existence of sheeting. To study the effect of sheeting on frames behaviour considering the height of frames, it is necessary to determine the frames behaviour without sheeting. This parameter carried out based on three shell element models with the same properties in (cross sections, configuration, and columns end conditions, etc). The first model (Reference Model) consists of frame with 6.0m height, 10.0m span and spacing between frames is 4.0m. Purlins are 1.25m apart and side-girts are 1.5m apart. The second and third models are similar to model 1 but frame height is 9.0m and 12.0m, respectively. The three models are attached to corrugated steel sheets 0.7mm thickness. For each model there is a similar model, but without sheeting in order to compare the results and study the effect of sheeting. The buckling length factor (K_x), as well as the lateral drift are illustrated in Fig. (7). The sheeting reduces the value of K_x and the lateral drift by a percentage (50%-60%) of those values getting from models without sheeting.

The effect of sheeting on the behaviour of frames with different spacing is tested by carrying out three different models with spacing between frames 4.0m, 6.0m and 8.0m. The frames in the three models are attached to sheeting 0.7mm thickness. The span of frames is 10.0m, side-girts are arranged every 1.5m, while purlins are spaced every 1.25m. Similar models are also carried out without sheeting to evaluate the effect of corrugated sheets on various parameters such as critical buckling load, effective length factor and deformation. Fig. (8) show that the sheeting represents the main source of stiffness which results in increasing the critical buckling load about the minor axis of bending. The enhancement of frames behaviour is resulting from the magnification of frames stiffness due to sheeting resistance. Fig. (8), represents the lateral drift of frames associated with the out of plane buckling load (P_{cr}). The deformation increases as the spacing between frames without sheeting increases while decreases with the increasing of spacing between frames covered with sheeting. For frames attached with sheeting the lateral drift of frames of second and third models are equal approximately 2/3 and 1/2 of that of first model. Frames subjected to unit load in Z- direction have linear displacement variation. The stiffness of frames of the second and third models is equal to double and four times the stiffness of that of first model.

The effect of sheeting on the behaviour of frames with different spacing between side-girt is studied by analyzing three models with spacing between girt, 1.5m, 3.0m and 6.0m. Conjugate model (without sheeting) are also carried out to obtain the sheeting influence. The buckling length factor (K_x) is illustrated in Fig. (9). The sheeting has a significant effect on the effective length factor (K_x). The increasing in values of (K_x) with the increasing in spacing between side-girt reflects that the frames become weaker to resist buckling load in the corresponding direction. Fig. (9), illustrates the sway in Z-direction. The sheeting provides great resistance for sway in Z-direction might reach more than 100% compared to cases without sheeting. Side-girt spacing affects the sway in Z-direction directly.

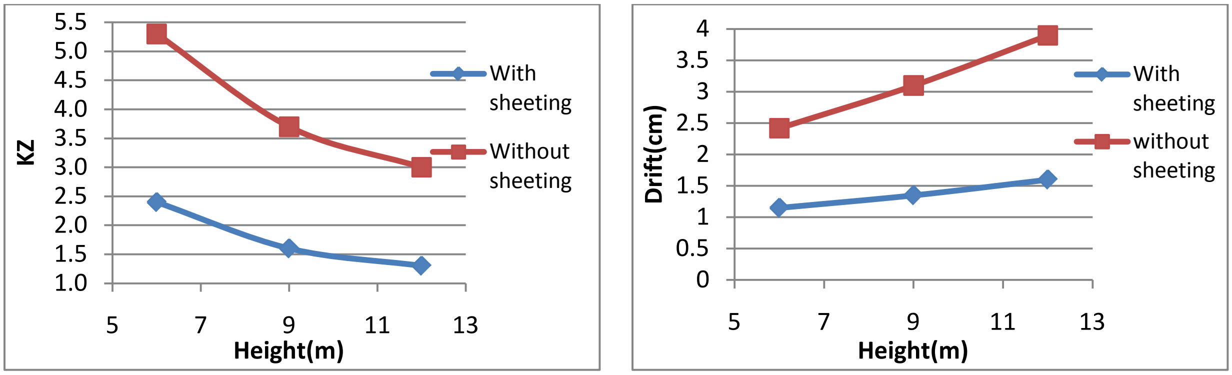

Figure 7: Variation of the buckling length factor (K_x) and the lateral drift (D_z) with the frame height, with and without the effect of sheeting

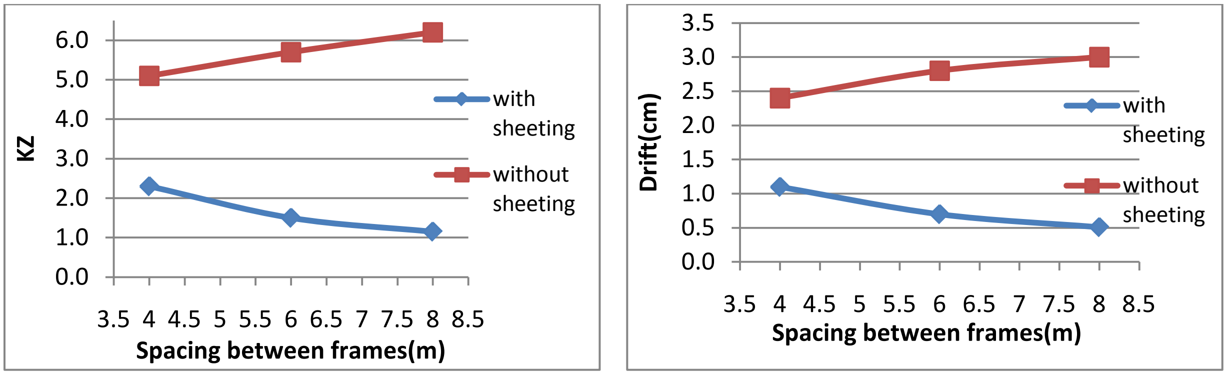

Figure 8: Variation of the buckling length factor (K_x) and the lateral drift (D_z) with the spacing between Frames, with and without sheeting

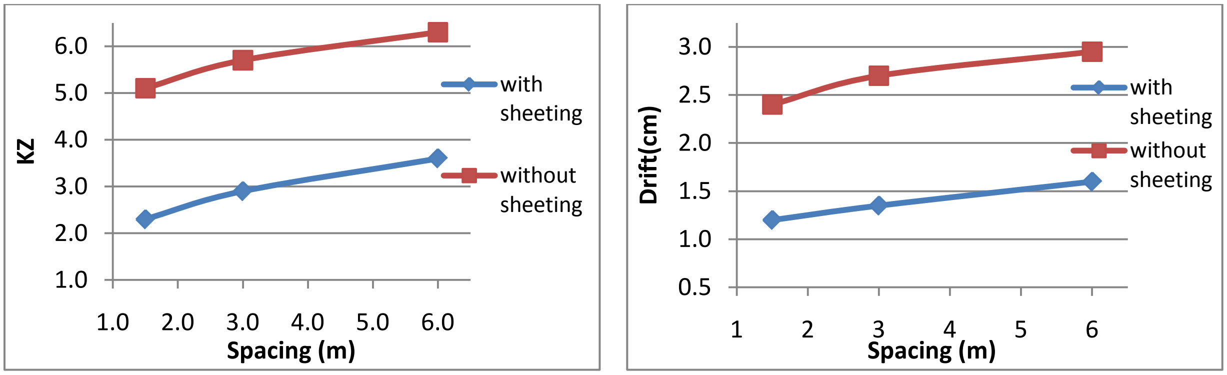

Figure 9: Variation of the buckling length factor (K_x) and the lateral drift (D_z) with the spacing side girts, with and without sheeting

8. EFFECT OF SHEETING THICKNESS ON THE BEHAVIOUR OF THE FRAMES

The effect of sheeting thickness is one of the parameters have being study in this research. To obtain the influence of this parameter on the behaviour of frames either parallel to the direction of major or minor axis of bending two additional models are carried out to be compared with the Reference Model. The three models are similar to each other in frames configurations [spacing between frames, span, height, cross sections, supports...etc.] but they are varying in sheeting thickness. The three Models are describing briefly as follows:

- Reference Model [Model 1]: Sheeting thickness 0.7mm
- Model 2: sheeting thickness 0.6mm
- Model 3: sheeting thickness 0.5mm

It is observed from Fig. (10) that the effective length factor (K_x) decreases slightly with the increase in sheet thickness, while the lateral drift of frames is reduces

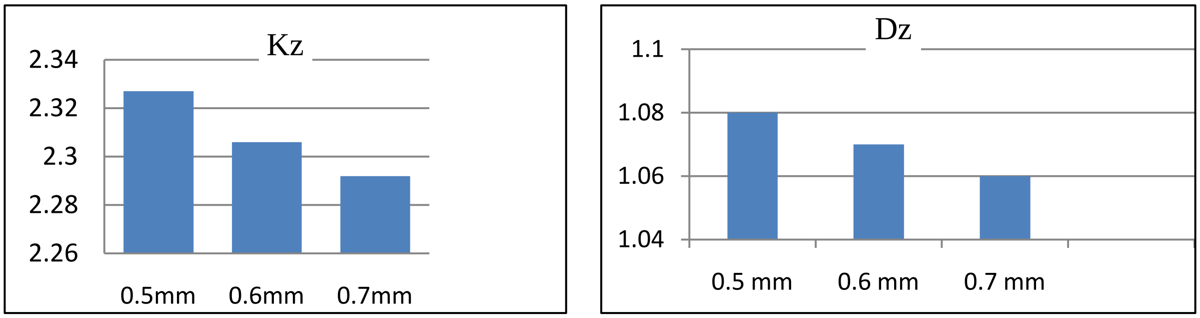

Figure 10: Variation of effective length factor K_x and lateral drift with the sheeting thickness

9. THE EFFECT OF SHEETING ON THE LATERAL STABILITY OF PORTAL AND GABLE FRAMES

Four models are carried out to study the effect of sheeting on portal and gable frames that are shown in Fig. (11):

- Models 1 and 3: are two successive Gable frames with and without sheeting.
- Models 2 and 4: are two successive Portal frames with and without sheeting.

Fig. (12) Presents the effective length factor (K_x) for portal and gable frames, with and without sheeting. The figure shows that the gable frame shape has more resistance against buckling about the minor axis of bending of frame. This can be observed by comparing the value of the buckling length factor (K_x). This may be due to the increase in stiffness of the inclined roof plane in Z-direction.

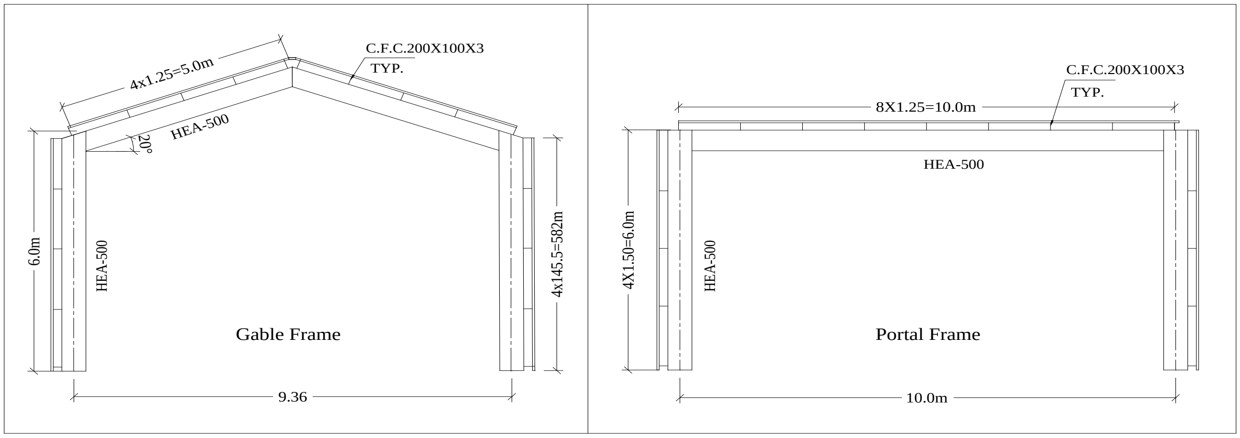

Figure 11: Geometrical models of gable and portal frames

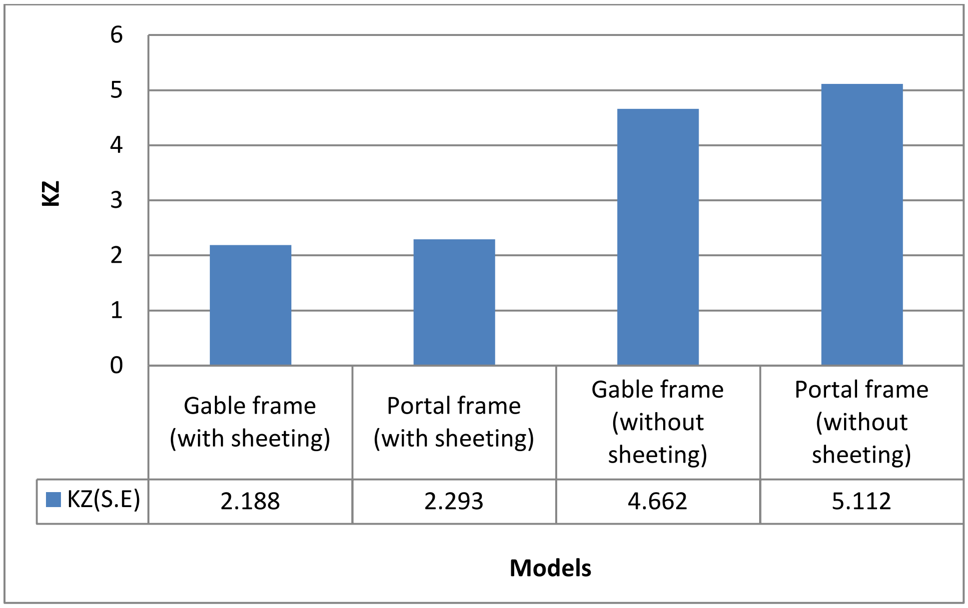

Figure (12): Effective Length Factor K_x for Gable and Portal Frames with and without sheeting

10. CONCLUSION

The effect of sheeting or bracing on the frame stiffness and critical buckling load in the plane of major axis of bending is significant, while their effect in the plane of minor axis of bending is highly significant.

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