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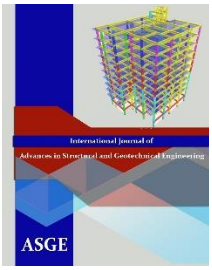

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NUMERICAL INVESTIGATION OF DEFLECTION PREDICTION OF COLD FORMED C- SECTION ROOF PURLINS

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Numerical Investigation of Deflection Prediction of Cold Formed C- Section Roof Purlins

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ABSTRACT

This paper aims to develop equations to ease the calculation of the deformation of C-shaped purlins loaded with live, dead and wind loads. A theoretical research model is created to simulate the behavior of part of a roof steel structure. The model is loaded after connecting its parts with connections similar to that in a steel roof, and the results are extracted using the finite element method (FEM). These results are then used in statistical equations to develop new equations that calculate the values of deformation for the C-shaped sections; the values of vertical, horizontal and rotational displacement are calculated [1], and the results are compared to those in reality. One equation is developed to calculate the value of the horizontal displacement with a total number of specimens of 1055, all of different dimensions, with a degree of confidence of 92%. The specimens are then increased to 2016 specimens with different dimensions, and 3 detailed equations are developed each for a different type of displacement; horizontal, vertical and rotational, with a degree of confidence of 95%. A detailed explanation is provided for how to calculate the deformation in the purlins and how to obtain its value statistically for each different type of displacement, with high accuracy, enabling it to be used in the stage of preliminary design.

Keywords: Deformation, C-shape cold formed section, Connection, Finite element method, Proposed equation.

1. PARAMETERS USED

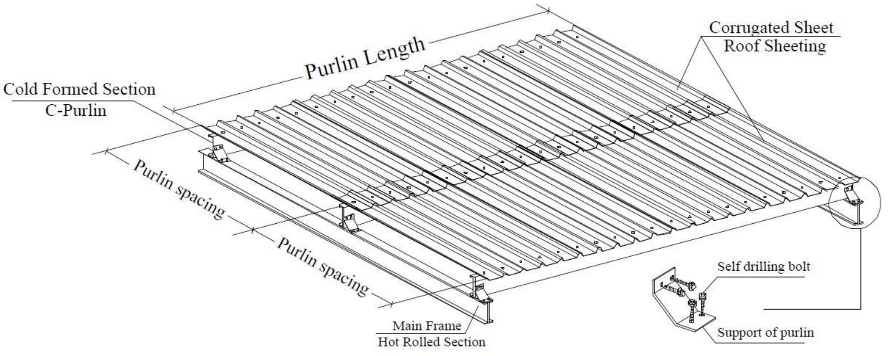

Figure 1. Typical roof with purlins and cover.

For the models that have a thickness ranging from 1.3 to 3 mm and a height ranging from 120 to 265 mm, it is obvious that the stiffness and the ultimate load increase by raising the cold formed C-section`s thickness. Moreover, the load-deformation relation is nonlinear for all the different tested cold formed C-sections with 3 mm thickness, as shown in Figure 1.
C-Purlins are loaded according to the Egyptian load code [2]., mainly wind loads and gravity loads. The gravity and wind loads are gradually increased to obtain the maximum vertical deflection value. The load - deflection relationships are plotted for several models with variable thicknesses, to study the effect of the cold formed C-sections thickness on the behavior of the clip beam connections. The maximum deflection is located at mid span. Mostly, the load-deflection relationship is nonlinear.

2. DEFLECTION PREDICTION USING A PROPOSED FORMULA

2.1. INTRODUCTION

This paper discusses and presents results of parametric analyses of the deformation of cold formed steel sections subjected to horizontal and vertical loads using COMSOL Multiphysics [3], 3d FEA modeling tools. Finite element model was applied including geometric and material nonlinearities because the reliability of results is based on how accurately the ideal model simulates the previous experiments. In Finite Element Analysis [FEA] shell elements can be utilized for effective results. It can lead to huge computational time savings since they allow modeling of thin features with fewer mesh elements. The analytical model took into account geometrical nonlinearities. A number of equations are proposed simple equations to predict vertical displacement, horizontal displacement and rotation under vertical and horizontal load.

After analysis the results, a multiple nonlinear regression analyses performed by the statistical software package, SPSS, in order to develop a deformation and it is vertical displacement (Δ Ver), horizontal displacement (Δ Hor.) and rotation (∳) formula for CFS subjected to vertical and horizontal loads which is the objective of the thesis.

As usual day-to-day design office operation, the extensive use of the FEA method for the purlin sections analysis is not possible. Instead of, a parametric equation cleared in the form of dimensionless geometrical parameters is helpful and desired for the torsional buckling. The present study attempts to show an individual parametric equation for determining the purlin deflections. an equations are based on the previous 2016 generated models.

When singly symmetric and nonsymmetrical open sections are used as beam these members may be subjected to torsional – flexural buckling. The differential equations of equilibrium governing the behavior of open thin walled cross sections.

2.2. PROPOSED EQUATION GENERAL FORM

For the deformations of the different displacement and rotations we use the equations in the form.

$\Delta_{xx} = A_{xx} + B_{xx} + C_{xx}$ Equ. (1)

$\oint = A_{Rotation} + B_{Rotation} + C_{Rotaion}$ Equ. (2)

The formula proposed depends on multiplied nonlinear regression analysis executed by the statistical software package, SPSS. Constant of calculated are obtained from the (Δ Ver , Δ Hor, . ∮) values calculated in the given parametric study.
The values of vertical applied loads are very close to those of the deflection. Values of (R2) indicate the degree of confidence used for determination of the given constants. This value was R2 = 95% for all the parameters.
The value of the horizontal applied loads and rotational applied loads are also close to those of deflection, while values of R2 indicate the degree of confidence used for determining the given constants, and these values of R2 proved to be 95% for all the parameters.

2.2.1. A: TORSIONAL BUCKLING EFFECT

$A_{xx} = B1*(G*J/L)$ Equ. (3)

where:
B1=Constant , G =shear modulus, (GPa), J= Venant torsion constant of cross section, (cm^4), L= Length of Purlins (mm).

The pure tension of thin walled open cross section is twisted by couples applied at the ends and acting in plans normal to the axis of the cross section, and if the ends of the member are free to warp, we have the case of pure torsion. The only stress produced are the shearing stress at each section. The distribution of these stress depends on the shape of cross section and is the same for all sections [4].
For a beam of thin walled open section, it can be assumed with reasonable that the shearing stress at any point is parallel to the corresponding tangent to the middle line of the cross section and is proportional to the distance from the line.

2.2.2. B: AXIAL LOAD DEFLECTION EFFECT (PART.2)

$$B_{xx} = B2*(P/Area) \qquad \text{Equ. (4)}$$

where:
B2=Constant, P= the applied load of the purlin (N), A= Area of the cross section (m^2)

Channels sections are some of singly symmetric open shapes. If these members are subjected to bending moments in the plan of symmetry, they may be fail in one of the following two ways:

1- The member deflects gradually in the plane of symmetry without twisting and finally fails by yielding or local buckling at the location of maximum moment.
2- The member starts with a gradual flexure bending in the plan of symmetry, but when the load reaches a critical value, the member will suddenly buckle by torsional – flexural buckling.

The type of failure mode, which will govern the maximum strength of the member, depends on the shape and dimensions of the cross section, the eccentricity of applied load [5].

2.2.3. C: LATERAL SUPPORT EFFECT (PART.2)

$$C_{xx} = B3*\left[\left(\frac{PL^4}{EI_x}\right) * \left(\frac{f*Cos(\Phi)}{t^n}\right)\right] \qquad \text{Equ. (5)}$$

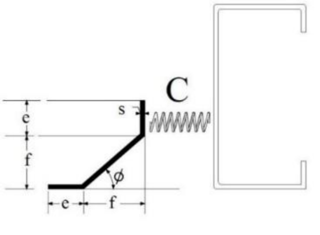

Figure 2. Mechanical model used.

We solve this part of equation by virtual work method according to:

1- In determining the resistance of a cross section, the effective width of a compression element should be based on compressive stress $\sigma_{com,Ed}$ in the element when the cross section resistance is reached;
2- The cross sections are used in design: gross cross section and effective cross section of which the function of loading (compression, major axis bending).
3- For serviceability verifications, the effective width of a compression element should be based on the compressive stress $\sigma_{com,Ed,ser}$ in the element under the serviceability limit state loading;
4- Distortional buckling shall be taken into account where it constitutes the critical failure mode [6].

In this case analysis can provide with different types, taking into consideration that the flexible support and flexibility was given in consideration to determine the type of support.

2.3. DERIVING CFS DESIGN EQUATION USING REGRESSION ANALYSIS

Thus, the form of the final equation with all variables will be as follows:

Vertical displacement:

$$\Delta_{Ver.} = B1*(G*J/L) + B2*(P_{ver.}/Area) + B3*\left[\left(\frac{PL^4}{EI_x}\right)*\left(\frac{f*Cos(\Phi)}{t^n}\right)\right] \quad \text{Equ. (6)}$$

Horizontal displacement:

$$\Delta_{Hor.} = C1*(G*J/L) + C2*(P_{Hor.}/Area) + C3*\left[\left(\frac{PL^4}{EI_y}\right)*\left(\frac{f*Cos(\Phi)}{t^n}\right)\right] \quad \text{Equ. (7)}$$

Rotation:

$$\oint = D1*(G*J/L) + D2*(P_{ver.}/Area) + D3*\left[\left(\frac{PL^6}{EC_w}\right)\right] \quad \text{Equ. (8)}$$

Table 1. Constant of the proposed equations.

B1	B2	B3	C1	C2	C3	D1	D2	D3
0.115	0.143	0.411	0.001	0.677	0.103	0.408	0.363	0.128

These constants were calculated using statistical analysis software, by entering the value of the different parameters as finite elements.

Those parameters were then entered as functions to obtain the same results from the software, and the constants values were a result of studying 2016 samples by using the try and error method to get to results close to those generated by the software with a degree of confidence 95%.

Comparison between horizontal applied loads against deflection shows close agreement as presented in.

2.4. VALIDATE OF THE PROPOSED EQUATION (ΔVER)

The proposed equation is validated using results extracted from 2016 finite elements models, that the values obtained from the proposed equation are fitting with the analytical results with some under estimated values.

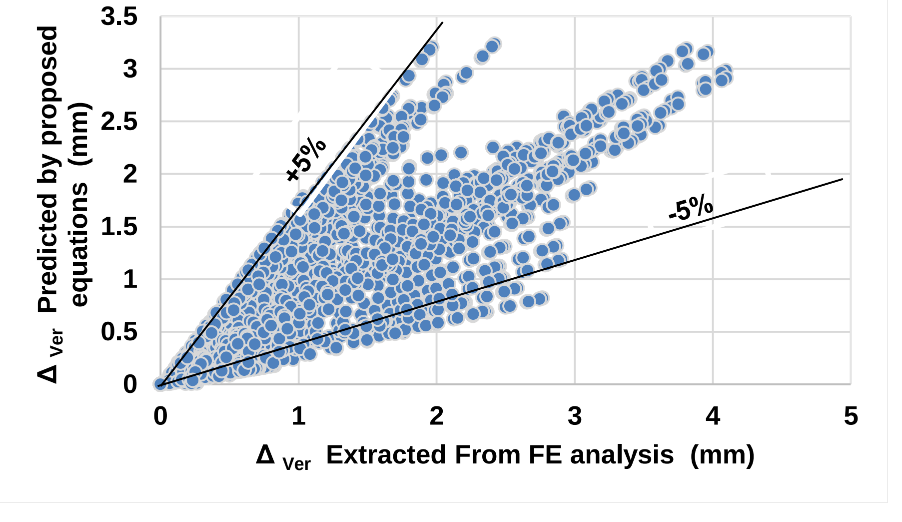

Figure 3. Δ ver. Predicted by the proposed equation compared to the ones extracted from FE analysis.

The dots in this graph represent a comparison between the analytical results and the ones calculated from the function for the vertical displacement, while the lines drawn show the degree of confidence of 95%. The dots under the bottom line are to be excluded as they are out of range.

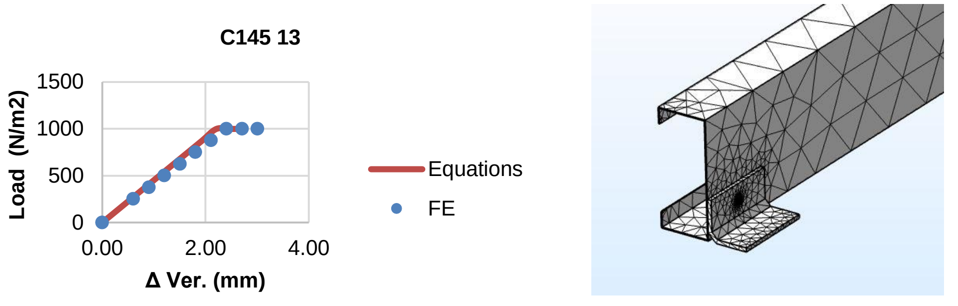

Figure 4. Load – vertical displacement of cold formed with equal Height (H= 145 mm and thickness = 1.3mm, Support connections in third height).

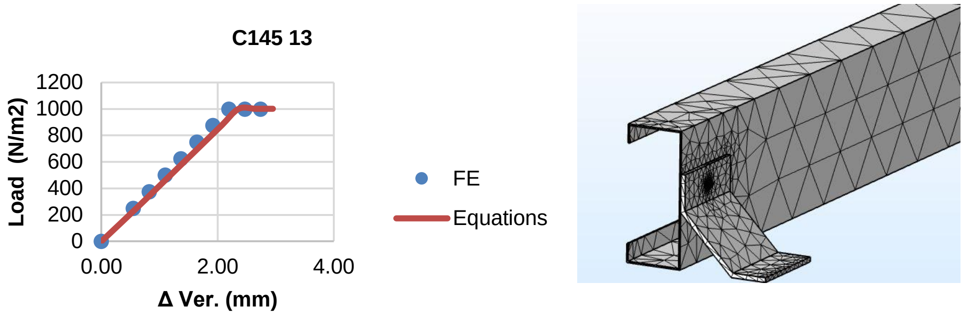

Figure 5. Load – vertical displacement of cold formed with equal Height (H= 145 mm and thickness = 1.3mm, Support connections in mid height).

2.5. VALIDATE OF THE PROPOSED EQUATION (ΔHOR.)

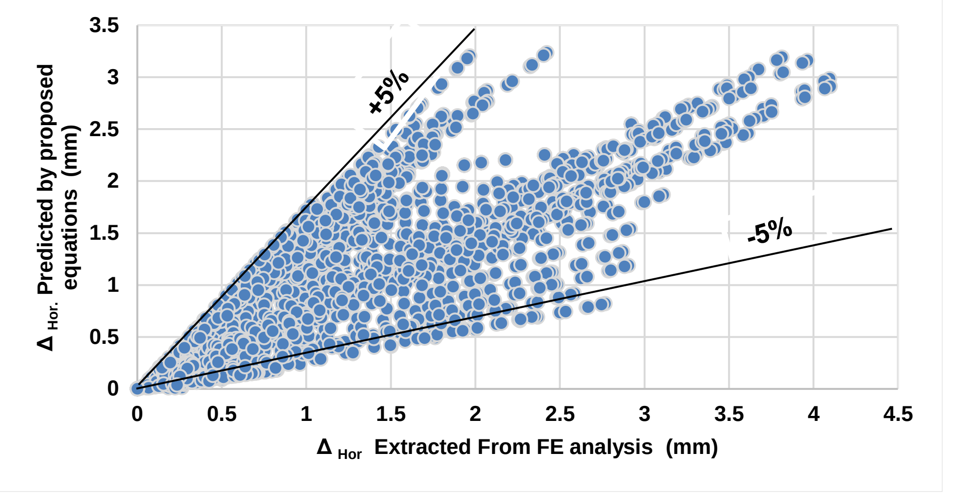

Figure 6. Δ Hor. Predicted by the proposed equation compared to the ones extracted from FE analysis.

The dots in this graph represent a comparison between the analytical results and the ones calculated from the function for the horizontal displacement, while the lines drawn show the degree of confidence of 95%. The dots under the bottom line are to be excluded as they are out of range.

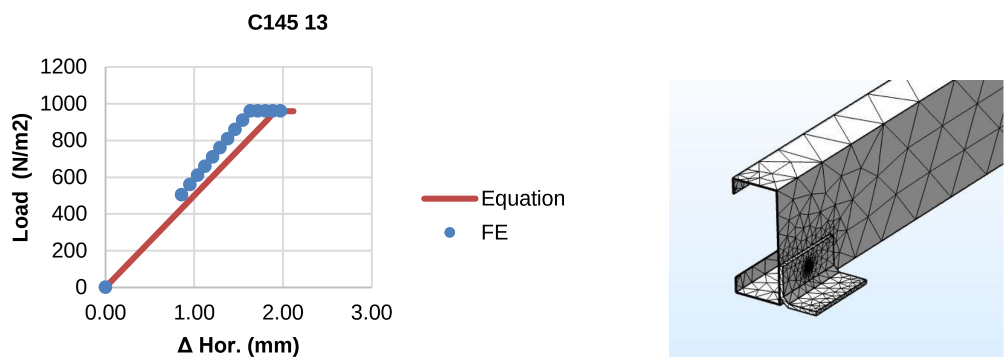

Figure 7. Load – horizontal displacement of cold formed with equal Height (H= 145 mm and thickness = 1.3mm, Support connections in third height).

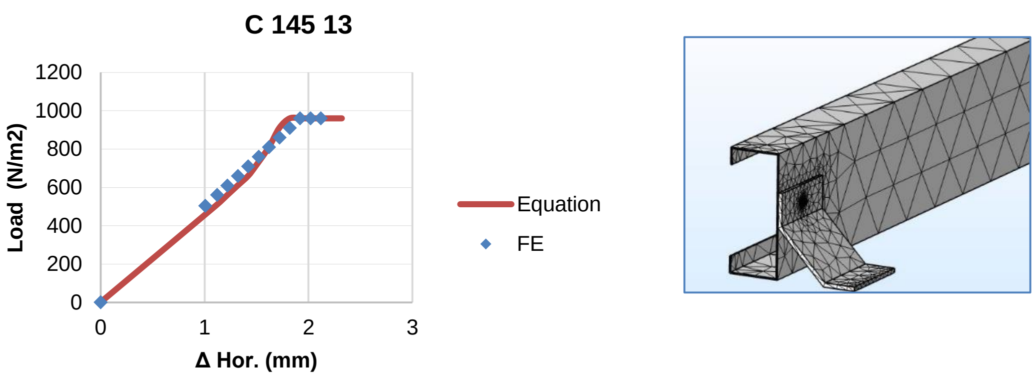

Figure 8. Load – horizontal displacement of cold formed with equal Height (H= 145 mm and thickness = 1.3 mm, Support connections in mid height).

2.6. VALIDATE OF THE PROPOSED EQUATION (∲)

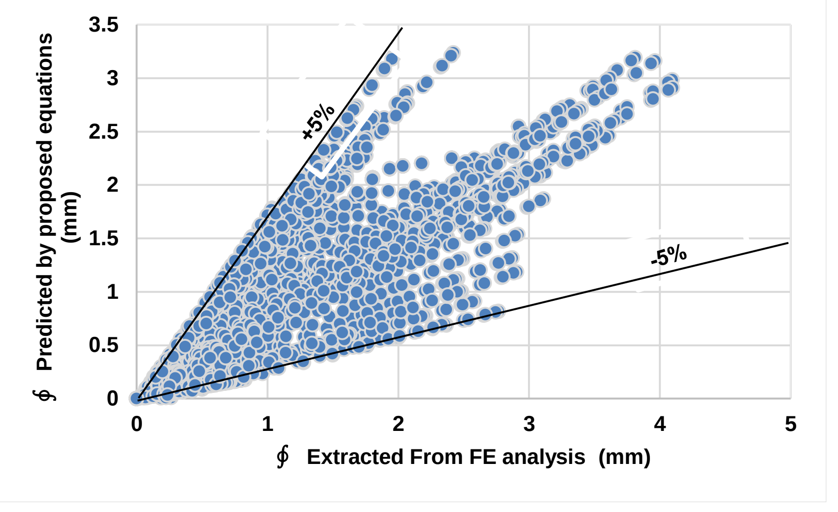

Figure 9. (∲) rotation predicted by the proposed equation compared to the ones extracted from FE analysis.

The dots in this graph represent a comparison between the analytical results and the ones calculated from the function for the horizontal displacement, while the lines drawn show the degree of confidence of 95%.

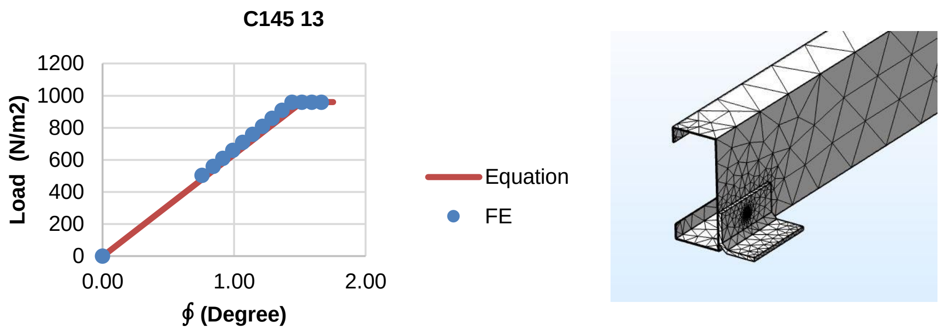

Figure 10. Load – rotation displacement of cold formed with equal Height (H= 145 mm and thickness = 1.3mm, Support connections in third height)

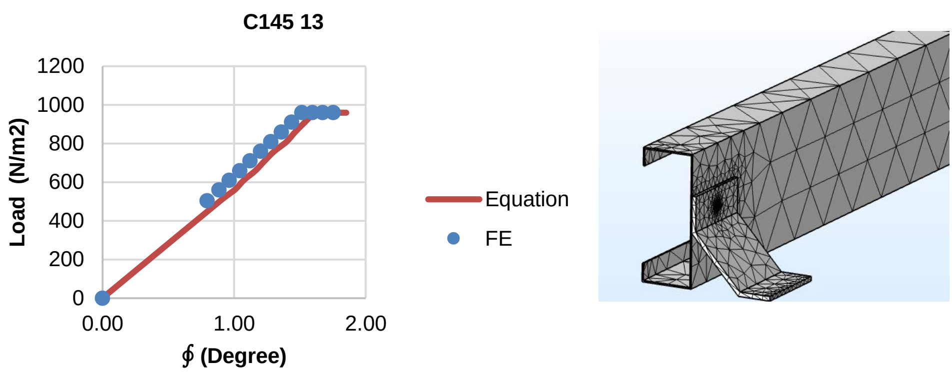

Figure 11. Load – rotation displacement of cold formed with equal Height (H= 145 mm and thickness = 1.3mm, Support connections in mid height)

3. CONCLUSION

-The equations developed through the finite elements provide results very close to those results of the finite element method, consequently the designer can use them with a confidence level of 95%.

-Based on the curves drawn the results from the equations provide values greater than finite elements, which provides a higher safety factor for the designer.

-Increasing the number of tests and assigning an equation for each displacement individually resulted into increasing the degree of confidence and the results became closer to those in reality.

-The concluded equations are easy to use and are based on clear scientific basis that are results of the calculations of the finite element alongside statistical calculations for a number of 2016 of different specimens.

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