Development of Csharp-Based Computer Program for the Design of Single Storey Fixed-Feet Pitched-Roof Portal Frame

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Abstract

This paper presents the design results of a simple task-specific Csharp-based computer program developed for the design of single storey fixed-feet pitched-roof portal frame. The program accommodates varying stanchion/rafter lengths and loadings. The overall process in the development of the program includes: formulation of the portal frame design outline, coding the outline into computer algorithm using Csharp programming language, implementing the developed program, development of the graphical user interface, testing the developed program and validation of results. Several sets of steel pitched-roof portal frame models were designed using the developed program and the design results were validated using established software - MasterSeries. Those frames were varied in span, slope angle and frame spacing. The design results obtained using the developed Csharp program were similar to the results obtained using standard software – MasterSeries, with greatest variation in the values standing at a mere 0.8%. Furthermore, the developed program was used to establish the relationships between span, slope angle, frame spacing and mass of framework steel of a single storey, fixed-feet pitched-roof portal sample frame building.

Keywords; fixed-feet pitched-roof portal frame, code, Csharp

1. Introduction

1.1 General Overview

The use of steel framed structures for large industrial buildings permits the creation of buildings with large and uninterrupted span areas, with the advantage of low cost, light weight and easy installation (Vasanthakumar, 2013). Steel portal frame is the dominant form of structure for single-storey industrial and commercial buildings. It has become the most common structural form in pitched-roof buildings, because of its economy and versatility for a wide range of spans (Morris and Plum, 1988). The connections between the columns and the rafters are designed to be moment-resistant. Due to these very strong and rigid joints some of the bending moment in the rafters is transferred to the columns (Ming, 1972). This means that the size of the rafters can be reduced or the span can be increased for the same size of rafters (Dennis *et al*., 2004).

Due to the large number of similar framed structures, the desire to automate the design and manufacturing process has been popular from the very early stage (Dowling *et al*., 1982). Owing to the continued increase in the price of materials, civil engineers and manufacturers are forced to reduce the costs of construction and shorten the implementation period to maintain their competitiveness. As a result, a new design trend was born: the use of the analysis and design software to evaluate feasible design options, replacing the conventional design methods (Vasanthakumar *et al*., 2013). According to Fady (2008), the introduction of software usage in the structural engineering industry has greatly reduced the complexities of different aspects in the analysis and design of projects, as well as the amount of time necessary to complete the designs. Concurrently, this leads to greater savings in material and reductions in costs.

Member sizes can be optimized automatically (Arora and Govil, 1977). The ability of engineers to produce better designs relies on the techniques available for design optimization (Faluyi and Arum, 2012). Portal frames for industrial buildings have been extensively studied because of their widespread use. The improvement of the design methods for portal frames is one of the recurring topics in the field of steel structures (Petr *et al*., 2010). Vu and Werner (2009) developed a computer code at the Bauhaus University Weimar, Germany, which aimed to produce optimum design of portal frames. Ghassan (2012) developed a Matlab-algorithm to find the optimum design of steel portal frames according to the recommendations of Eurocode 3.

Low (2011) developed a computer algorithm for plane frame analysis by using Matlab with numerical meshfree method. Abubakar and Abdulkadir (2011) developed a reliability based design program for portal frames.The program considered analysis of the steel pitched portal frames using elastic analysis, and the design using the requirements of BS5950. The programming language that was adopted was FORTRAN. In yet another work, Goh (2011) designed portal frames, based on BS 5950 and Euro code 3 and made comparison between the designs.

The main goal of this research is to develop a simple task-specific Csharp-based computer program for the design of fixed-feet pitched-roof portal frames, and establish the relationship between span, slope angle, frame spacing and mass of framework steel of a sample single storey, fixed-feet pitched-roof portal frame building.

1.2 Csharp-Based Algorithm

Sedgewick and Wayne (2011) defined an algorithm as a special series of instructions that define how a given computer problem can be solved in a finite number of steps. C# (pronounced "See Sharp") is a simple, modern, object-oriented, and type-safe programming language. C# has its roots in the C family of languages and C, C++, and Java programmers are acquainted with it (Michealis, 2010).

2. Methodology

The research work was carried out in two stages, which include:

i. Development of a computer program (or code), using Csharp programming language, for the design of single span, fixed support, pitched-roof portal frame. The program accommodates varying stanchion/rafter lengths and loadings.

ii. Validation of the design results obtained using the developed code in (i) above by means of established design software (MasterSeries).

2.1 Program Development Steps

The overall process in the development of the program (or code) is shown in a schematic diagram in Figure 1.

2.1.1 Portal Frame Design Outline

Elastic design method was adopted for the design of the portal frame. The design process used to develop the code for the pitched roof portal frame from BS 5950-1(2000) is summarised as follow:

a) Analysis

Analysis was performed using factored loads (Clause 5.2.2 of BS 5950-1-2000). The program was developed based on the formulae for rigid frames developed in 1931 by Kleinlogel (as cited by Righiniotis, 2003), for the analysis of fixed-feet gable frame with vertical legs.

b) Classification of Sections

The section was checked with reference to Clause 3.5.2 and table 11 of BC 5950: Part 1 (2000).

c) Slenderness Check

The slenderness was checked with reference to Annex E.2 and Clause 5.1.3 of BS 5950-1 (2000).

The beam and the column stiffnesses were respectively computed according to Eqns. (1) and (2). Thus:

$$k_{beam} = 1.5\frac{I_{xx}}{L_{beam}} \qquad (1)$$

$$k_c = \frac{I_{yy}}{L_{beam}} \qquad (2)$$

The stiffness of the foundation was assumed equal to the column stiffness.

The distribution factors for the ends of the column-length were obtained by Eqns. (3) and (4) as follows:

$$k_1 = \frac{k_c}{k_c + k_{base}} \qquad (3)$$

$$k_2 = \frac{k_c}{k_c + k_{beam}} \qquad (4)$$

The effective length ratios about the Y and the X axes were obtained respectively by Eqns (5) and (6).

$$\frac{L_{EY}}{L} = 0.5 + 0.14(k_1 + k_2) + 0.055(k_1 + k_2)^2 \qquad (5)$$

$$\frac{L_{EX}}{L} = \left[\frac{1 - 0.2(k_1 + k_2) - 0.12k_1k_2}{1 - 0.8(k_1 + k_2) + 0.6k_1k_2}\right]^{0.5} \qquad (6)$$

The slenderness ratios about the X and the Y axes were computed using Eqns. (7) and (8) respectively.

$$\lambda_x = \frac{L_{EX}}{r_x} \qquad (7)$$

$$\lambda_y = \frac{L_{EY}}{r_y} \qquad (8)$$

where;

k_c is column stiffness

k_{beam} is beam stiffness

L is length of span

L_{EX} and L_{EY} are the effective lengths about the two orthogonal axes X and Y.

r_x and r_y are the radii of gyration about the two orthogonal axes X and Y.

λ_x and λ_y are the slenderness values about the two orthogonal axes X and Y.

d) Compression Resistance

The compression resistance was checked according to Clause 4.7.4 of BS 5950-1 (2000).

For plastic, compact and semi-compact sections the compression resistance P_c is given by Eqn. (9):

$$P_c = A_g\, p_y \qquad (9)$$

where;

P_c is compression resistance;

A_g is gross cross-sectional area; and

p_y is the compressive strength.

e) Shear Capacity Check

The shear capacity was checked using Clause 4.2.3 of BS 5950-1 (2000).

$$P_V = 0.6 p_y A_V \qquad (10)$$

$$A_V = tD \text{ (for rolled sections)} \qquad (11)$$

where:

P_V is the Shear capacity of a member;

p_y is the design strength of steel;

A_V is the effective shear area;

D is the depth of section; and

t is the thickness of web.

e) Moment Capacity Check

The moment capacity was checked using Clause 4.2.5 of BS 5950-1 (2000). If the shear force F_v is not greater than 60% of the shear capacity ($F_v \leq 0.6P_v$) we have the case of low shear. The moment capacity in that case was determined according to Eqn. (12) for class 1 plastic and class 2 compact sections.

$$M_C = p_y S \qquad (12)$$

If the Shear forces F_v is greater than 60% of the shear capacity ($F_v > 0.6P_v$) we have the case of high shear. The moment capacity in that case was determined according to Eqn. (13) for class 1 plastic and class 2 compact sections.

$$M_C = p_y (S - \rho S_V) \qquad (13)$$

where:

M_C is the plastic moment capacity of the section;

p_y is the design strength of steel;

S is the plastic modulus;

ρ is reduction factor; and

S_V is the plastic modulus of the shear area.

f) Local capacity check

The capacity and buckling resistance of members was checked using Clause 4.8.3.2 of BS 5950-1 (2000). The cross-sectional capacity of compression members was checked using relationship (14):

$$\frac{F_c}{A_g P_y} + \frac{M_x}{M_{cx}} + \frac{M_y}{M_{cy}} \leq 1 \qquad (14)$$

where:

F_c is the ultimate axial compression at the critical location;

M_x is the ultimate bending moment about the major axis;

M_y is the ultimate bending moment about minor axis;

A_g is the gross cross-sectional area of the section of the member;

P_y is the design strength;

M_{cx} is the moment capacity about the major axis (X-X axis); and

M_{cy} is the moment capacity about the minor axis (Y-Y axis).

g) Overall buckling check

The member buckling resistance was checked according to relationship (15) (Ray, 1998) by ensuring that relationship (15) was satisfied.

$$\frac{F_c}{A_g P_c} + \frac{m M_x}{M_b} + \frac{m M_y}{P_y Z_y} \leq 1 \qquad (15)$$

where:

P_c is the compressive strength;

F_c is the ultimate axial compression at the critical location;

M_x is the ultimate bending moment about the major axis;

M_y is the ultimate bending moment about the minor axis;
A_g is the gross cross-sectional area of member section;
P_y is the design strength;
M_b is the buckling resistance moment;
m is the equivalent uniform moment factor; and
Z_y is the elastic section modulus about the Y-Y axis (minor axis).

(i) *Stability Check*

The stability of the frame was checked using the sway-check method (Salter *et al*., 2004).

- **Sway-check method**

The sway-check method was used to verify the in-plane stability of the portal frames if each bay satisfies the following conditions:
(a) Span, L does not exceed five times the mean height h of the columns;
(b) Height, h_r of the apex above the tops of the columns does not exceed
0.25 times the span, L.

The ratio of the effective span of a bay to the cross-sectional depth of the rafter must satisfy the inequality (16) (Salter *et al*., 2004).

$$\frac{L_b}{D} \le \frac{44L}{\Omega h}\left(\frac{\rho}{4+{pL_r}/{L}}\right)\left(\frac{275}{p_{yr}}\right) \tag{16}$$

In which

$$\rho = \left(\frac{2I_c}{I_r}\right)\left(\frac{L}{h}\right) \text{ for a single frame} \tag{17}$$

where;
D is the cross-section depth of the rafter;
h the mean column height;
I_c the in-plane second moment of area of the column;
I_r the in-plane second moment of area of the rafter;
L the span of the bay;
L_b is the effective span of the bay;
Ω is the arching ratio;
L_r the total developed length of the rafters; and
P_{yr} the design strength of the rafters in N/mm^2.

2.1.2 Coding the outline

CSharp programming language was used as the language to code the design outline into an algorithm.

2.1.3 Implementation of the Developed Program

The graphical interface was created using a windows application called Windows Presentation Foundation (WPF) in visual studio.Net. Extensible Application Markup Language (XAML) was used to implement the appearance of the interface.

2.1.4 Testing the Program

Several sets of steel pitched roof portal frame models were designed using the developed program. Those frames were varied in span, slope angle and frame spacing, as tabulated and shown in Tables 1, 2 and 3.

The dead and imposed loads on the frame were obtained with reference to BS 6399-1 (1997) and information provided by relevant manufacturers in the case of proprietary products. The loadings are shown in Table 4.

Other relevant information includes the following:
Young Modulus E = 210GPa
Steel Grade p_y = 275 N/mm^2

2.1.5 Validation of results

Currently, there are quite a number of structural design software applications present in the market. Their use has become prevalent amongst a majority of structural engineers and engineering firms. An example of these established software application is MasterSeries.

MasterSeries was used to design the same sets of frames earlier designed using the developed program, in order to validate the design results obtained using the developed program.

2.1.6 Application Flow Chart

The flow diagram illustrating the step by step process of a rigid pitched roof portal frame design as developed in this research is shown in Fig. 2.

3. Results and Discussions

Several sets of portal frame configurations were set to validate the design results of the developed program.

3.1.1 Design Case 1: Varying Span Length

As shown in Table 1, for this design case, four different spans (30m, 40m, 50m and 60m) were considered for fixed column height of 6m and slope angle of 6 °.

a) Analysis

The analysis results from the developed algorithm and MasterSeries were compared. The Maximum bending moments in each frame are shown in Table 5. The percentage difference between the developed algorithm and MasterSeries was calculated by Eqn. (18) and the results are shown in Table 5.

$$\% \text{ difference} = \frac{|\text{Result from MasterSeries} - \text{Result from Developed Program}|}{\text{Result from MasterSeries}} \times 100 \quad (18)$$

Similar distributions of bending moments were obtained using the developed program and MasterSeries for the various portal frame configurations and the values of maximum forces were obtained at the same locations. Table 5 shows that the developed algorithm gave a maximum difference of 0.78% for the analysis of bending moment compared with the result from MasterSeries. The cross-sectional area of column and rafter sections in each frame at varying span length is shown in Table 6 for comparison. As Table 6 shows, the areas of sections of the frame members increase as the span of the portal frame increases; consequently, the mass of the portal frame increases. This shows that the longer the span, the greater the mass of the frame.

b) Design check

The design procedure includes the checking of the axial compression, bending moment, as well as the interaction between the bending and the axial compression to ensure the capacity of the member is sufficient.

3.1.2 Design Case 2: Varying Slope angle

Four different Slope angles (6 °, 8 °, 10 °and 12 °) were considered for fixed column height of 6m and frame span of 30m.

a) Analysis

The results from the developed algorithm and MasterSeries tabulated and compared. The maximum bending moment values in each frame are shown in Table 7. The table shows that an increase in slope angle translates to reduction in the maximum moment developed in each frame, which is similar using the developed program and the MasterSeries. This is logical since moment distribution is dependent on the geometrical properties of the frame.

b) Design

The cross-sectional areas of column and rafter sections in each frame at varying slope angles are shown in Table 8. The table shows that increase in slope angle translates to reduction in the area of section of the members and by inference reduction in the mass of the portal frame. This shows that frames with higher pitch are more economical. Furthermore, Table 8 shows that the cross-sectional areas obtained using Masterseries and the results obtained by using the developed code, are similar.

3.1.3 Design Case 3: Varying Frame Spacing

Table 9 shows the frame and building details necessary to carry out this design case. Four different frame spacings (2m, 4m, 6m and 8m) were considered for fixed column height of 6m, frame span of 30m and slope angle of 6 °. The optimum sections obtained for the purlins at varying frame spacing were tabulated for comparison and shown in Tables 10 and 11. Table 10 shows the comparison of the purlin design section sizes obtained by using parallel flange channels for frame spacings of 2m and 4m, and universal beam sections for frame spacings of 6m and 8m. Universal beams were used for 6m and 8m spacings because the depths of the available standard parallel flange channel sections were inadequate for such spans. Table 11 shows the comparison of the purlin design section sizes obtained by using universal beam sections only for all frame spacings considered (2m, 4m, 6m, 8m).

The mass of structural steel of the pitched roof portal frame building as determined for varying spacing using universal beam sections only, is shown in Tables 12 and 13 for the developed program and for Masterseries respectively. As both tables show, the mass of purlin increases as the frame spacing increases. Smaller frame spacing resulted in the initial very low mass of purlin. Finally, the overall mass of the structure increases as the frame spacing increases.

4. Conclusions

The design results obtained using the developed Csharp algorithms were similar to the results obtained using standard software MasterSeries with greatest variation in the values standing at 0.78%. Besides, this research work has established the relationship between span, slope angle, frame spacing and mass of framework steel of single storey, fixed-feet pitched-roof portal frame building. The results show that increase in frame spacing of the building, results in increase in the mass of framework steel. For instance, for a 24m long fixed-feet frame building at 2m spacing with slope angle of 6 °and span length of 30m, the overall mass of frame was 52,565 kg whereas a mass of 118,141 kg was obtained for the same building for a frame spacing of 8m.

References

Abubakar, I. and Abdulkadir, O. (2011). Reliability - Based Design of a Rigid Pitched Steel Portal Frame. *International Journal of Civil & Environmental Engineering*, IJCEE IJENS Vol. 11, No. 6, pp. 92 – 99.

Arora, J. and Govil, A. (1977). An efficient method for optimal structural design by substructures. *Computers and Structures*, Vol. 7, pp. 507-515.

Faluyi, F. and Arum, C. (2012). Design Optimization of Plate Girder Using Generalized Reduced Gradient and Constrained Artificial Bee Colony Algorithms. *International Journal of Emerging Technology and Advanced Engineering,* IJETAE Volume 2, Issue 7, pp. 304 – 312.

British Standards Institution (2000). *Structural use of steelwork in building. Part 1: Code of practice for design in simple and continuous construction: hot rolled sections*. BS 5950, BSI, London.

British Standards Institution (1997). Loading for buildings. Part 1: Code of practice for dead and imposed loads. BS 6399, BSI, London.

Dennis, L., Thien, C. and Sing-Ping, C. (2004). Structural Steelwork, Design to Limit State Theory, Elsevier Butterworth-Heinemann.

Dowling P.J., Mears T., Owens G. and Raven K. (1982). A development in the automated design and fabrication of portal framed industrial buildings, The Structural Engineer, vol. 60A, pp. 311-319.

Fady, R. S. R. (2008). Computer Analysis and Reinforced Concrete Design of Beams. *Fadzter Engineering*. Available from: www.fadzter.com/engineering. (Accessed: 30 January 2014)

Ghassan, N. (2012). *Design and optimization of steel portal frames according to Eurocode using genetic algorithm*. A Thesis Submitted in partial fulfilment of the Requirements of Lund Institute of Technology for the Degree of Master of Science. Sweden: Lund Institute of Technology.

Goh, K. (2011). *Analysis and design of pinned base portal frame to euro code 3*. A Thesis Submitted in partial fulfilment of the Requirements of University of Technology Malaysia for the Degree of Master of Science. Malaysia: University of Technology Malaysia.

Righiniotis, J. (2003). Plane Frame Analysis. *In*: Davison, B. and Owens, G. W. (Eds). Steel Designers' Manual; The Steel Construction Institute; Blackwell Publishing.

Low, G. (2011). *Software Development for Plane Frame Analysis by using Matlab with Numerical Meshfree Method*. A Thesis Submitted in Partial Fulfilment of the Requirements of University of Technology Malaysia for the Degree of Master of Science. Malaysia: University of Technology Malaysia.

Michealis, M. (2010). Essentials of C# 4.0. Pearson Education, Inc., United State.

Ming, C. (1972). *Development of Computer Program for the Analysis of Gable Frame using Column Analogy*. A Thesis Submitted in Partial Fulfilment of the Requirements of Brigham Young University for the Degree of Master of Science. Utah, United State: Brigham Young University

Morris, L. J. and Plum, D. R. (1988). Structural Steelwork Design to BS 5950, Part 1, *Longman Scientific & Technical.*

Petr, H., Matti, M. and Ludovic, F. (2010). Advanced design and optimization of steel portal frames. *Journal of Structural Mechanics*. Vol. 43, No 1, pp. 44-60.

Ray, S. S. (1998). Structural Steelwork: Analysis and Design, Wiley-Blackwell.

Salter, P., Malik, A., and King, C. (2004). Design of Single Span Steel Portal Frame to BS 5950-1:2000. *The Steel Construction Institute*, Berkshire.

Sedgewick, R. and Wayne, K. (2011). Algorithms, Pearson Education, Inc., Boston, 4th Edition.

Vasanthakumar, C., Ganesh, G. M. and Santhi, A. S. (2013). Structural Optimization of an Industrial Building Frame by Genetic Algorithm, *International Journal of Engineering, Science and Technology*, IJEST Vol. 5 No. 06S, pp. 7 – 12.

Vu, A.-T. and Werner, F. (2009). Optimization of Steel Frame Structures Based on Differential Evolution Algorithm, *International Conference on the Application of Computer Science and Mathematics in Architecture and Civil Engineering*; Weimar, Germany.

Table 1. Portal Frame with Varied Span (Column Height h_c = 6m; Slope Angle θ =6 º; Frame Spacing = 5m)

Frame	1	2	3	4
Span (m)	30	40	50	60

Table 2. Portal Frame with Varied Slope Angle (Column Height h_c = 6m; Span = 30m; Frame Spacing = 5m)

Frame	1	2	3	4
Slope Angle (º)	6	8	10	12

Table 3. Portal Frame with Varied Frame Spacing (Column Height h_c = 6m; Span = 30m; Slope Angle θ = 6 º)

Building (Length =	1	2	3	4
Frame Spacing (m)	2	4	6	8

Table 4. Portal Frame Loadings

Load Contributor	Sheetings	Purlins	Frame	Services	Total Dead Load	Total Live Load
Load (kN/m^2)	0.04	0.07	0.11	0.28	0.5	0.6

Table 5. Comparison of Maximum Bending Moments in Each Frame at Varying Span Length

	Maximum Bending Moment (kNm)		
Span Length (m)	Developed Algorithm	MasterSeries	% Difference
30	508.2	510.8	0.509
40	811.2	817.6	0.783
50	1276.1	1280.9	0.383
60	1864.7	1860.5	0.226

Table 6. Comparison of Area of section at Varying Span Length

	Area of section, cm^2			
	Developed Code		MasterSeries	
Span Length (m)	Column	Rafter	Column	Rafter
30	117	105	117	105
40	159	159	159	159
50	220	220	220	220
60	286	256	256	256

Table 7. Comparison of Maximum Bending Moments in Each Frame at Varying Slope Angle

	Maximum Bending Moment (kNm)		
Slope Angle (º)	Developed Code	MasterSeries	% Difference
6	508.2	510.8	0.509
8	498.8	499	0.040
10	461.8	461.4	0.087
12	446.2	446.52	0.072

Table 8. Comparison of Area of Section at Varying Slope Angle

	Area of section, cm^2			
	Developed Code		MasterSeries	
Slope Angle (º)	Column	Rafter	Column	Rafter
6	117	105	117	105
8	117	105	117	105
10	105	104	104	104
12	105	104	104	104

Table 9. Additional Details of the Pitched-roof Portal Frame Building

Length of Building (L)	24m
Slope Angle	6º
Height of Roof	1.58m
Rafter Length (L_r)	15.1m
Number of Purlins (along Slope)	25 @ 1.2m interval

Table 10. Comparison of Purlin Design Section Sizes at Varying Frame Spacing using Parallel Flange and Universal Beam Sections

	Section Designation		
Frame Spacing (m)	Developed Program	MasterSeries	Section Name
2	150x75x18	150x75x18	Parallel Flange Channel
4	380x100x54	380x100x54	Parallel Flange Channel
6	457x191x98	533x210x92	Universal Beam
8	686x254x170	610x305x179	Universal Beam

Table 11. Comparison of Purlin Design Section Sizes at Varying Frame Spacing using Universal Beam Sections only

	Section Designation		
Frame Spacing (m)	Developed Algorithm	MasterSeries	Section Name
2	152x89x16	152x89x16	Universal Beam
4	356x171x57	356x171x57	Universal Beam
6	457x191x98	533x210x92	Universal Beam
8	686x254x170	610x305x179	Universal Beam

Table 12. Variation of Mass of Structural Steel of a Fixed-feet Pitched-Roof Building using the Developed Program

Frame Spacing s (m)	Number of frame $n_f = (L/s)$	Mass of Rafters M_R (kg)	Mass of Columns M_C (kg)	Mass of Frame $M_F = (M_R + M_C)$ (kg)	Mass of Purlin (M_P) (kg)	Mass of Structure $(M_S) = (M_F + M_P)$ (kg)
2	12	29,717	13,248	42,965	9,600	52,565
4	6	14,858	6,624	21,482	34,200	55,682
6	4	9,906	4,416	14,322	58,800	73,122
8	3	7,429	3,312	10,741	102,000	112,741

Table 13. Variation of Mass of Structural Steel of a Fixed-feet Pitched-roof Building using MasterSeries

Frame Spacing s (m)	Number of frame $n_f = (L/s)$	Mass of Rafter M_R (kg)	Mass of Column M_C (kg)	Mass of Frame $M_F = (M_R + M_C)$ (kg)	Mass of Purlin (M_P) (kg)	Mass of Structure $(M_S) = (M_F + M_P)$ (kg)
2	12	29,717	13,248	42,965	9,600	52,565
4	6	14,858	6,624	21,482	34,200	55,682
6	4	9,906	4,416	14,322	55,200	69,522
8	3	7,429	3,312	10,741	107,400	118,141

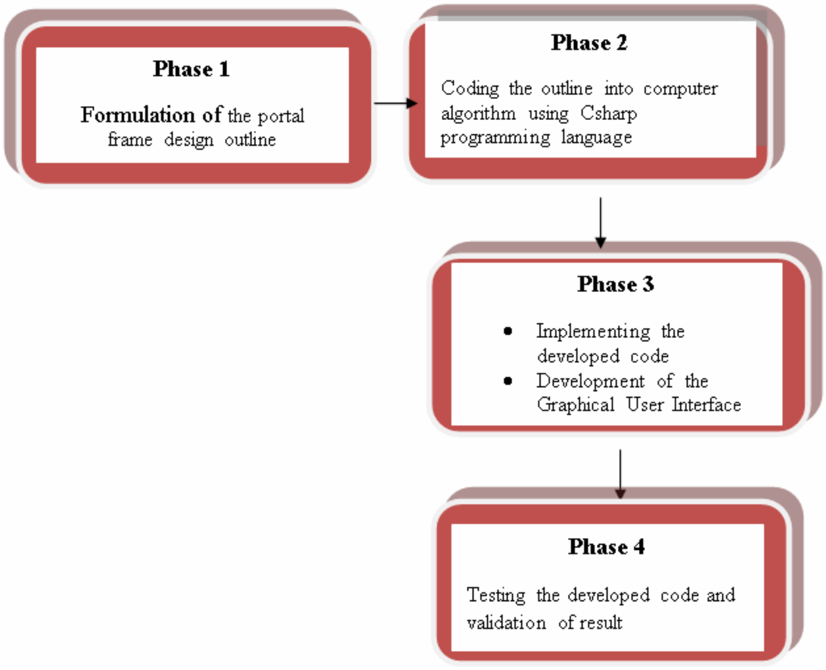

Figure 1. Schematic diagram showing the overall process of the code development

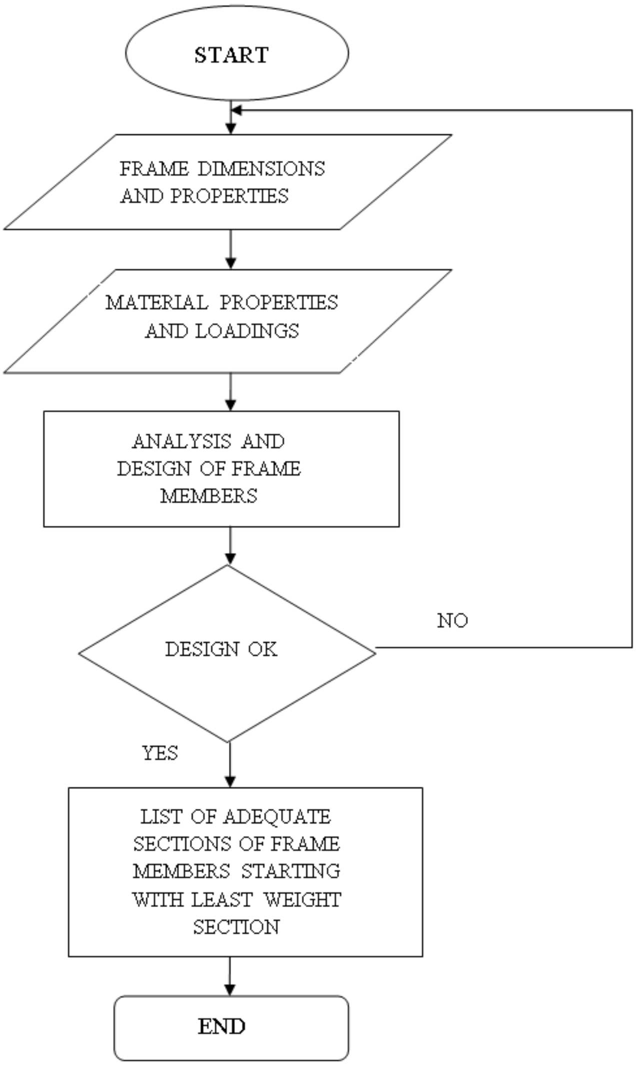

Figure 2. Developed Flowchart for the Design of Rigid Pitched-roof Portal Frame using Csharp Programming Language.

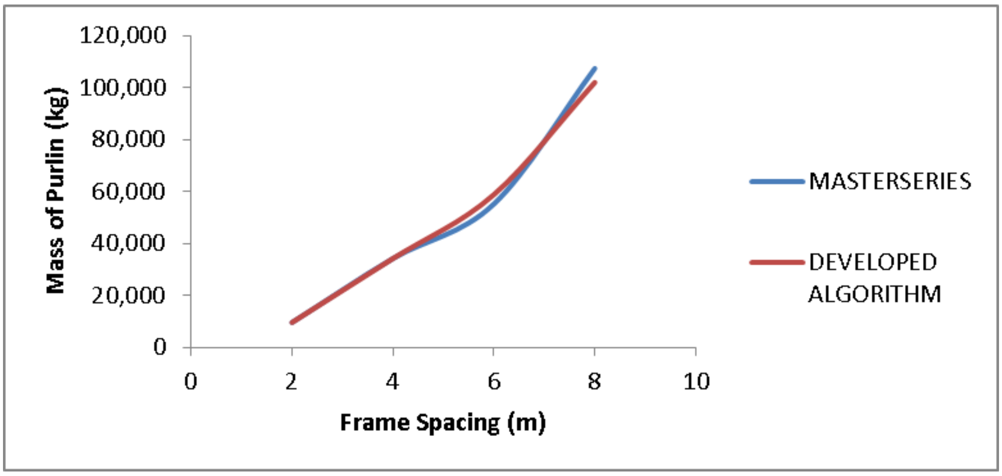

Figure 3. Relationship between Frame spacing and Mass of Purlin

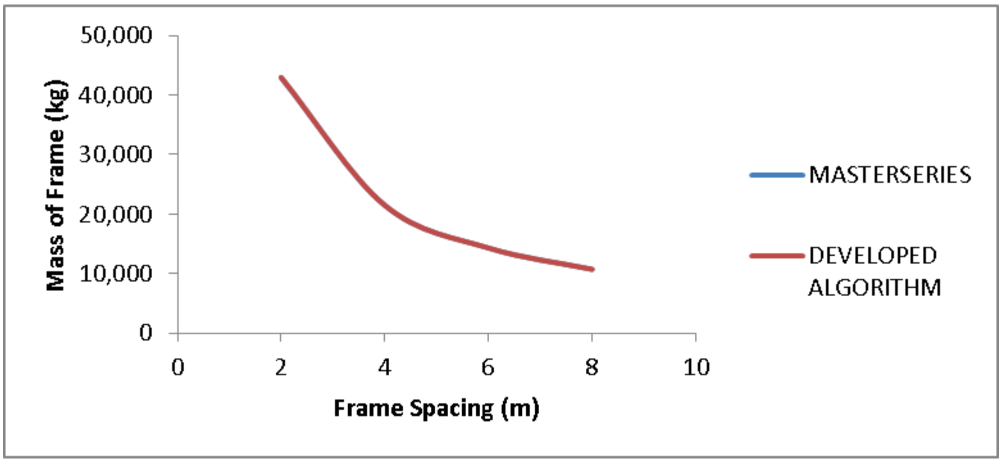

Figure 4. Relationship between Frame Spacing and Mass of Frame

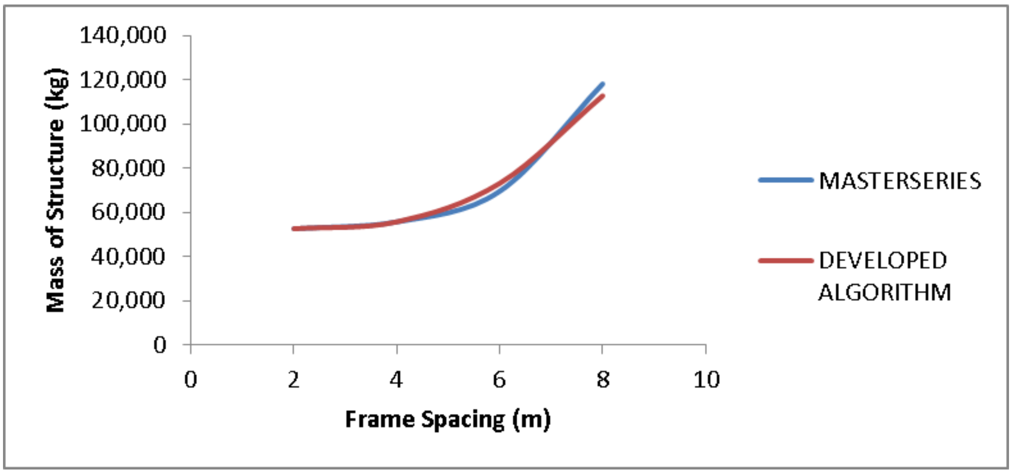

Figure 5. Relationship between Frame Spacing and Mass of Structure