Development of a Framework for Preliminary Sizing of Multi-Storey Structural Elements Using Cantilever and Portal Methods.

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Abstract

The use of computers in the engineering industry has dramatically reduced the complexities of different aspects of solutions to civil engineering problems. Computer innovations have led to good time, cost, resources, analysis, and design management. This research outlines the development of a framework for preliminary sizing of multistory structural elements using cantilever and portal methods of analysis. The framed structure selected for a case study was a five-storey building in Lagos Island, Nigeria, and its analysis was carried out using the cantilever method and portal method, considering the wind loadings on the structure based on the geographical location of the structure. Algorithms were developed for the frame structure analysis, which was done by cantilever and portal method, and the solution was coded into a computer program and tested using VB.NET medium. The approximate methods of structural analysis, cantilever method, and portal method gave varying results, with different results in the shear forces in the members and slightly different results in the moment computations. Finally, the results of the manual calculation and the computer were compared and found to be approximately the same, about 95%, and the remaining 5% was because of the decimal approximations done by the computer in calculations. Hence, using the computed framework for preliminary sizing, cost-effective, time-saving, and less complex building designs can be achieved with minimal error.

Introduction

In the past years, structural analysis has changed with the enormous expansion of computer power. Various computer-aided programs for structural analysis and design have been developed. The emergence of the electronic computer has brought solutions to difficulties in solving structural analysis formulations (Plevris & Tsiatas, 2018). Moreover, long-hand calculations are not fashionable since the computer can perform such analysis. Hence, building design and construction have dramatically improved from just simple analysis and design of bungalows to multi-storey structures and mega structures. The need for quick analysis and design of these structures calls for the use of computer-assisted programs.

Generally, analysis and design of multi-storey structures by manual methods is a rigorous process (Varia & Patel, 2016). The analysis processes which lead to the selection of the size of members and checking for adequacy are large and significantly cumbersome. The need to eliminate the complexities and difficulty of sizing multi-storey frame structures towards a cost-effective design of structures and management of materials and time is inevitable. The application of a computer in structural engineering differs from its common use in the business and social world. There are practical difficulties associated with the help of computers, which, if not catered adequately for can cause considerable errors in structural analysis and results. Some of these are the introduction of errors through misuse of or inadequate control of data and the use of unqualified personnel for the structural analysis with the assumption that the in-built computer knowledge will compensate for the lack of human incompetency (Littlewood & Strigini, 2000). Therefore, this paper proposes a framework for preliminary sizing of elements of multi-storey plane frames by cantilever and portal methods, which are approximate methods of structural analysis.

Over time, statically indeterminate structures can be analysed by using exact methods of analysis, such as the flexibility matrix method and stiffness method (Gere & Timoshenko, 1991). However, this work includes the analysis of five storey plane frame with the cantilever method and portal method, manual development of algorithms for the member forces, coding of the algorithms developed into a computer program for quick solution, adaptability of the results obtained with the cantilever and portal method to general arrangement of the structure.

The sizing of multi-storey plane frame members is a complex process. Structural analysis includes analysing the loading conditions and the structural response to those conditions. It can also involve systematically examining cost, member sizes and ease of construction. A framed structure is composed of an interconnected assemblage of beams and columns. If the members of a frame are rigidly connected, it is called a rigid frame.

In most cases, the axial stresses in rigid frames are small compared to the bending stresses (Negussie, 1983). For engineers to analyse a structure properly, certain idealisations must be made regarding how the members are supported and connected. Also, the forces in the members and their displacement must be checked (Negussie, 1983). Before the introduction of the electronic digital computer, the traditional methods of analysis (theorem of three moments, moment area method, strain energy method, moment distribution method, etc.) were initiated by engineers who endeavored to obtain solutions based on strict scientific reasoning with no regard to the resulting calculations (Ogu,1992). However, some of these methods still need computers for handling large structures.

The search for a single method that can be used on all types of frames, no matter how complicated the frames may be, led to the adoption of modern techniques, which are: approximate methods, stiffness metrix method, flexibility metrix method, energy method, and finite element method of structural analysis. The approximate method of structural analysis is an inexact method often used in preliminary design processes because of its simplicity (Wu, 1995). The analysis is less complex, with a trade-off of reduced accuracy. It involves obtaining numerical solutions to an indeterminate system through analysis using the physical properties of the structural members. The results obtained from approximate methods could then be used for final analysis using any exact method, such as the stiffness method, finite element method or any other method (Methods, 1965).

Methods of Analysis.

Sizing is primarily based on the loads allocated to a particular element. Loading was based on the following codes: (CP 3 Part 2, 1971/1972; BS 6399 Part 1 & 2). The building frame function is assumed to be an office area. For a material to be structurally sustained, its weight is called its load. Therefore, all loads, whether permanent (dead) or transient (live), are the weight of the materials in question and, at times, their impact on the structure, e.g., wind load.

Approximate Methods.

For an initial design, the member sizes will be unknown. Preliminary sizing of members was made by performing an approximate analysis on an initially modelled structure. This method can roughly calculate the member forces and moments affecting initial designs (Kuckartz et al., 2008). The approach of the method of structural analysis is to have the frame reduced into determinate structures by suitable assumptions. A plane frame building can be easily optimised using these methods because only the stiffness of two elements is required: beams and columns. An approximate analysis provides insight into a structure's behaviour under load. In other words, an approximate method of analysis is used to develop a simple model of a statically determinate structure to solve a statically indeterminate problem. In multistoried frames, two loading cases are observed, namely lateral and vertical loading.

The approximate methods considered in this research work are *portal* and *cantilever methods*. The portal method is used for bridges and industrial buildings. It was developed by A. Smith in 1915 (Aslam, 2011). Unlike the portal method, the cantilever method begins by determining vertical forces rather than horizontal forces. If the frame is high and thin or comprises columns with varying cross-sectional areas, the cantilever approach will only be considered approximate.

Portal Method.

Some types of portal support are partial fixity, fixed support, and pin support. It was assumed that at the half height of every column of a portal frame, there is an occurrence of an inflexion point and at the point of each girder. Likewise, the overall horizontal shear per storey is assumed to be divided between the columns of the storey, thereby making the internal column of the storey to carry twice the shear of the external column (Bill et al., 2007); Negussie, 1983).

The reduction of the frame structure to a single statically determinate under loading is sufficiently achieved by the assumptions. The formulated procedures of analysis of a portal frame based on the above assumptions go thus:

1. Do a top-down analysis of the frame.
2. At the height of the points of inflection, draw an imagined horizontal segment that spans two floors; the column's sectional areas only encounter axial and shear stresses.
3. The sum of the lateral shear Force above the imagined section is transferred twice as much on innate columns onto the outside columns based on relative stiffness.
4. Determine the bending moments at the ends of the columns.
5. Calculate the bending moments at the beam ends using the joints' equilibrium, beginning at a joint on the outside. Since the terminal moments of each beam are assumed to be equal, the inflection points lie at mid-span.
6. Determine the shear forces in the beams by dividing the total of the beam end moments by the span lengths.
7. The total shear forces in all beams above a column are equal to the axial Force in that column.

Cantilever Method.

This approach is utilised for high-rise frames under lateral loading and is primarily based on a broad cantilevered beam subjected to a longitudinal load. When a frame is subjected to lateral stress, it often topples over or spins about an equilibrium axis in the horizontal plane that runs through the columns at each floor level. For the cantilever method, the point of inflexion is said to occur at the mid-point of each girder and the mid-height of each column. A column's axial stress is directly correlated with its distance from the cross-sectional area of the column's core at any given floor level. Since stress is equal to Force per area, the Force within a column is also proportional to its distance from the column areas' centroid in the exceptional situation of columns with equal cross-sectional areas (Bill et al., 2007; Negussie, 1983).

The following procedure is assumed in the cantilever method:

1. Draw a free-body diagram; insert a hinge at the centre of each member, which makes all the moments at the centre of the members zero.
2. Examine the frame using a top-down approach.
3. At the height of the inflection points, draw an imaginary horizontal section between any two levels.
4. Determine the overall toppling moment (M) based on the lateral loads; observe positive tension on the right side.

5. Derive the axial Force in each column as;

$$N_i = \boldsymbol{\sigma} iAi. \qquad \text{Eq. (1)}$$

$$\boldsymbol{\sigma} i = \frac{M}{I} Zi. \qquad \text{Eq. (2)}$$

$$I = \sum_{i=1}^{K} Zi^2 \mathrm{A}\, i. \qquad \text{Eq. (3)}$$

   where zi is the distance from the neutral point of the global cross-section to the column, K is the number of columns in each storey, i is the column number, I is the moment of inertia, and Ai is the column number's cross-sectional area.

6. The shear Force in each beam equals the difference in axial torque between columns.
7. Use the shear forces to calculate the end moments in the beams as follows:

$$V=2M/L,\ M=VL/2. \qquad \text{Eq. (4)}$$

8. The column bending moment can be obtained from the joint's equilibrium.

Programming and Data Preparation.

VB.NET (Visual Basic.NET), a scientific language, was used to develop the framework. Visual Basic (VB) is an object-oriented computer programming language implemented on the .NET Framework. The choice of VB as the development tool for this research work was because the structure of the programming language is straightforward to understand. The graphical user interface (GUI) can be easily constructed, as it provides intuitively appealing views for managing the program structure in large and various entities such as classes, modules, etc. (Daene, 2014).

The solution to the example structural problem was achieved by the approach illustrated in Fig 1.

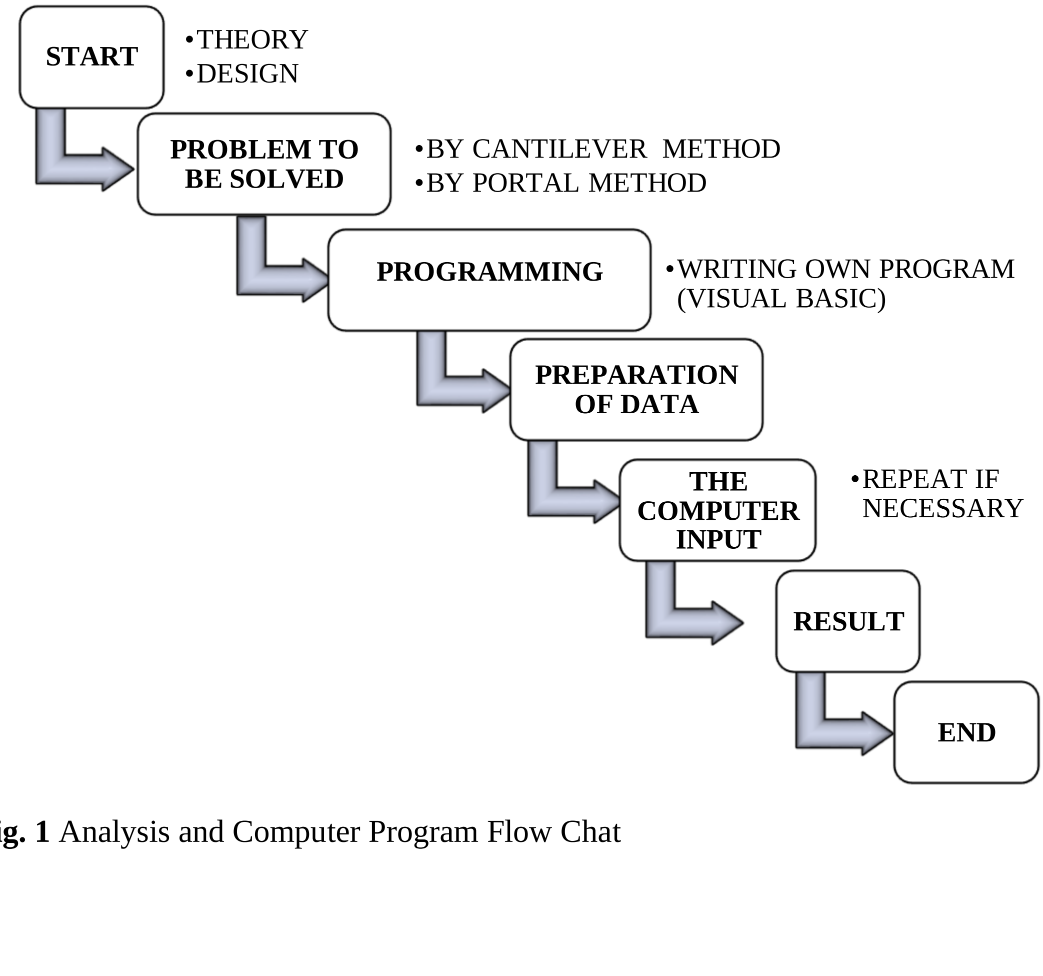

Fig. 1 Analysis and Computer Program Flow Chat

Cantilever Method of Analysis Algorithms.

The following are the general calculation inputs:

Let P be the axial load in the columns

Let VSF be the vertical shearing Force in the beams

Let HSF be the horizontal shearing Force in the columns

Let XFloorload be the lateral load per floor in Kilo-newton [kN]

Let i be the no of floors

Let axial Force be N

Let Axialdirection be +1 and -1

Let Nlegs be the no of columns

Where Nlegs = 4

Xleg(i) = the column spacing in metres [m]

Xleg1 = 0

Xleg2 = 0 + 6 = 6 [m]

Xleg3 = 0 + 6 + 4 = 10 [m]

Xleg4 = 0 + 6 + 4 + 6 = 16 [m]

Let SumP = SumP * Xleg (i) * AxialRatio * AxialDirection

Where SumP remains the same for each floor and

AxialRatio is 1:4 (i.e. the ratio of the number of columns to building span = 4:16)

For 5th Floor Computation:

Axial load (P) = Absolute [(XFloor5load * (Floor5Height/ 2)] / SumP

Axial Forces in the columns:

N(i) = P * AxialRatio

Vertical shear Force (VSF):

$VSF_1 = N_1$

$VSF_2 = N_1 + N_2$

$VSF_3 = VSF_1$

Horizontal shear Force (HSF):

$HSF_1 = [N_1 * (Xleg_4 / 2)] / (Floor5Height /2)$

$HSF_2 = [N_1 * (Xleg_4 / 2)) + ((N_3 – N_2) / 2) + (N_2 * ((N_3 – N_2) / 2)) – (HSF_1 * (Floor5Height/2))]/ (Floor5Height/2))$

$HSF_3 = HSF_2 * AxialDirection$

$HSF_4 = HSF_1 * AxialDirection$

Beam bending moment:

$MB_1 = (Xleg_2 / 2) * VSF_1$

$MB_2 = [VSF_2 * ((Xleg_3 – Xleg_2)/2)]$

$MB_3 = MB_1$

Column Bending Moment:

$MC_1 = HSF_1 * (Floor5Height / 2)$

$MC_2 = HSF_2 * (Floor5Height / 2)$

$MC_3 = MC_1$

$MC_4 = MC_2$

For 4th Floor Computation:

Axial load (P) = Absolute [(XFloorload5 * (Floor5Height + Floor4Height / 2)] + [(XFloorload4 * (Floor4Height / 2)] / SumP

Axial Forces in the columns:

N(i) = P * AxialRatio

Vertical shear Force (VSF):

$VSF_1 = N_1(Floor4) – N_1(Floor5)$

$VSF_2 = [N_1(Floor4) + N_2(Floor4)] – [N_1(Floor5) + N_2(Floor5)]$

$VSF_3 = VSF_1$

Horizontal shear Force (HSF):

$HSF_1 = [[(N_1(Floor4) – N_1(Floor5)) * (Xleg_2 / 2)] – [HSF_1(Floor5) * (Floor5Height/2)]] / (Floor5Height /2)$

$HSF_2 = [((XFloorLoad5 + XFloorLoad4) / 2) – (HSF_1(Floor4))$

$HSF_3 = HSF_2 * AxialDirection$

$HSF_4 = HSF_1 * AxialDirection$

Beam bending moment:

$MB_1 = (Xleg_2 / 2) * VSF_1$

$MB_2 = [VSF_2 * ((Xleg_3 – Xleg_2)/2)]$

$MB_3 = MB_1$

Column Bending Moment:

$MC_1 = HSF_1 * (Floor4Height / 2)$

$MC_2 = HSF_2 * (Floor4Height / 2)$

$MC_3 = MC_1$

$MC_4 = MC_2$

Algorithms for Portal Method of Analysis.

For 5th Floor Computation:

Let SumF be the sum of the horizontal shear forces in the column

Therefore, SumF = $HSF_1 + 2(HSF_2) + 2(HSF_3) + HSF_4$

Horizontal shear Force (HSF_C) in column:

HSF_{C1} = (XFloor5Load) / SumF

$HSF_{C2} = 2 * HSF_{C1}$

$HSF_{C3} = HSF_{C2}$ * AxialDirection

$HSF_{C4} = HSF_{C1}$ * AxialDirection

Horizontal shear Force (HSF_B) in beam:

HSF_{B1} = XFloor5Load - HSF_{C1}

$HSF_{B2} = HSF_{B1} - HSF_{C2}$

$HSF_{B3} = HSF_{B2} - HSF_{C3}$

Vertical shear Force (VSF):

VSF1 = [(XFloor5load * Floor5Height/2) + (HSF_{B1} * Floor5Height/2)]/ ($Xleg_2$/2)

VSF2 = [(HSF_{B1} * Floor5Height/2) + (HSF_{B2} * Floor5Height/2)] / [($Xleg_3 – Xleg_2$)/2]

VSF3 = [(HSF_{B2} * Floor5Height/2) + (HSF_{B3} * Floor5Height/2)] / [$Xleg_2$/2]

Axial Forces in the columns:

$N_1 = -VSF_1$

$N_1 = -VSF_2$

$N_3 = VSF_3$

$N_4 = -VSF_3$

Column Bending Moment:

$MC_1 = HSF_1$ * (Floor5Height / 2)

$MC_2 = HSF_2$ * (Floor5Height / 2)

$MC_3 = MC_1$

$MC_4 = MC_2$

Beam bending moment:

MB_1 = Floor5 (MC_1)

MB_2 = Floor5 (MC_2) – Floor5 (MC_1)

MB_3 = Floor5 (MC_3) - Floor5 (MB_2)

For 4th Floor Computation:

Horizontal shear Force (HSF_C) in column:

HSF_{C1} = (XFloor5Load + XFloor4Load) / SumF

HSF_{C2} = 2 * HSF_{C1}

HSF_{C3} = HSF_{C2} * AxialDirection

HSF_{C4} = HSF_{C1} * AxialDirection

HSF_{B1} = XFloor5Load - HSF_{C1}

HSF_{B2} = HSF_{B1} - HSF_{C2}

HSF_{B3} = HSF_{B2} - HSF_{C3}

Vertical shear Force (VSF):

VSF1 = [(XFloor4load * Floor4Height/2) + (HSF_{B1} * Floor4Height/2)]/ ($Xleg_2$/2)

VSF2 = [(HSF_{B1} * Floor4Height/2) + (HSF_{B2} * Floor4Height/2)] / [($Xleg_3$ – $Xleg_2$)/2]

VSF3 = [(HSF_{B2} * Floor4Height/2) + (HSF_{B3} * Floor4Height/2)] / [$Xleg_2$/2]

Axial Forces in the columns:

N_1 = -VSF_1

N_2 = -VSF_2

N_3 = VSF_3

N_4 = -VSF_3

Column Bending Moment:

MC_1 = HSF_{C1} * (Floor4Height / 2)

MC_2 = HSF_{C1} * (Floor4Height / 2)

MC_3 = MC_1

MC_4 = MC_2

Beam bending moment:

MB_1 = Floor5 (MC_1) + Floor4 (MC_1)

MB_2 = Floor5 (MC_2) + Floor4 (MC_1) – Floor4 (MB_1)

MB_3 = Floor4 (MB_1).

Cantilever Method and Portal Method Analysis.

Wind Load Computation.

This is a lateral load, and it is mandatory for a structure with more than five storeys. A building with the ratio of height/width must also be considered for wind. Wind pressure is uniform and depends mainly on locality and the isopleths of basic wind speed. (CP 3 Part 2 ;1971/1972; BS 6399 Part 1 & 2).

The basic wind speed is converted to wind force as follows.

Let V be the local basic wind speed, which is 40 [m/s] for Lagos Island, Nigeria.

$$V_s = V\ S_1\ S_2\ S_3\ [m/s]. \quad \text{Eq. (5) and}$$

$$q = kV_s^2\ [N/m^2]. \qquad \text{Eq. (6)}$$

Where: q = dynamic pressure and k = 0.613.

V_s = Maximum design wind speed in m/s, S_1 = topological factor, which can be taken as 1.0. But if it is very exposed where the acceleration of speed tends to occur, it is taken as 1.1. The speed will be reduced for areas sheltered from the wind, and 0.9 will be used.

S_2 = Ground roughness, building size and height above ground factor, obtainable from literature and ranges between 0.55 and 1.27. Also from (CP 3 Part 2, 1971/1972).

S_3 = Statistical factor, i.e. multiplying factor related to the structure's life, which can be taken as 1.0, corresponding to an excessive speed occurring once in fifty years.

To find the overall wind load (F), use the formula:

$$F = C_f\ q\ A_e\ [N/m^2]. \qquad \text{Eq. (7)}$$

$$F = (C_{pe} - C_{pi})\ qA. \qquad \text{Eq. (8)}$$

Where C_f = force coefficient, A_e = effective frontal area of the structure. C_{pe} = external pressure coefficient, C_{pi} = internal pressure coefficient (CP 3 Part 2, 1971/1972), A = area of the building surface.

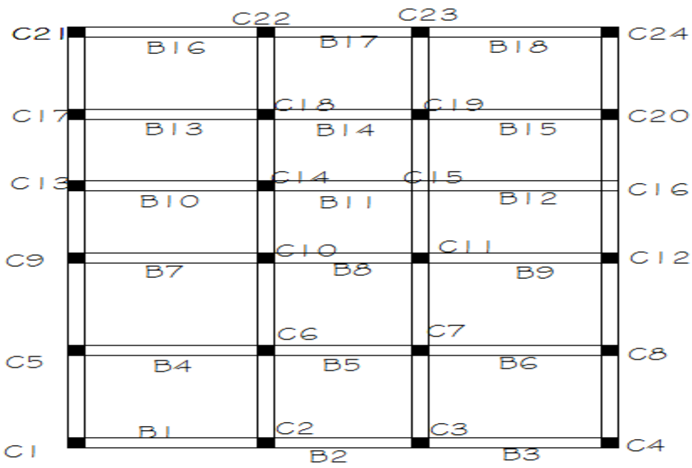

Fig. 2 Proposed Framed Structure Plan

Note: C1 - C24 = Column Labels.

B1 – B18 = Beam Labels.

Bending Moments due to wind load:

The bending moments in the beams and columns at those parts of the connection can be calculated from the equivalent forces by using the following:

Beams = M_B = F x ½ beam span. Eq. (9)

Columns = M_C = H x ½ storey height. Eq. (10)

where the column bending moment is denoted by MC, and the beam bending moment is denoted by MB (Oyenuga, 2008).

Table 1 Example Wind Loading for the Proposed Frame Structure

Ref.	**Office Building** **Wind Loading Calculations**	Output
	Assumed structural Location: Lagos Island	
From Nigerian wind Isoplethe	Basic wind speed v: 40[m/s]	
	From Eq. 5: $Vs = v.S_1.S_2.S_3$	
	Where Vs = maximum design wind speed in [m/s].	
	S_1 = topographical factor = 1.0	
	S_2 = ground roughness	
	S_3 = statistical factor = 1.0	
Table 3, (CP 3 Part 2, 1971/1972)	**For 1st Floor:**	
	Proposed Storey height = 4[m]	
	$S_2 = 0.54$	21.6[m/s]
	Vs = 40 x 1 x 1 x 0.54 = 21.6 [m/s]	
	From Eq. 6: $q = K (Vs)^2$	286[N/m^2]
	$= 0.613 \times (21.6)^2 = 286$ [N/m^2]	
	From Eq. 8: $F = (C_{pe} – C_{pi})qA$	
	$C_{pe} = 0.7$, $C_{pi} = 0.2$	
	Building Area = 4 x 16 = 64[m$^{2.}$]	
	Therefore,	
	F = (0.7-0.2) x 286 x 64	9.15[kN]
	= 9152[N] = 9.15[kN]	
	For 2nd Floor:	
	Storey height = 8[m]	
	$S_2 = 0.59$	
	Vs = 40 x 1 x 1 x 0.59 = 23.6 [m/s]	23.6 [m/s]
	$q = K (Vs)^2$	
	$= 0.613 \times (23.6)^2 = 341.42$ [N/m^2]	341.42[N/m^2]
	$F = (C_{pe} – C_{pi})qA$	
	$C_{pe} = 0.7$, $C_{pi} = 0.2$	
	Building Area = 4 x 16 = 64[m^2]	
	Therefore,	
	F = (0.7-0.2) x 341.42 x 64	

Table 3, (CP 3 Part 2, 1971/1972)	$= 9152[N] = 10.93[kN]$ **For 3rd Floor:** Storey height = 11.5[m] $S_2 = 0.64$ $Vs = 40 \times 1 \times 1 \times 0.64 = 25.6$ [m/s] $q = K (Vs)^2$ $= 0.613 \times (25.6)^2 = 401.74$ [N/m^2] $F = (C_{pe} – C_{pi})qA$ $C_{pe} = 0.7$, $C_{pi} = 0.2$ Building Area = 4 x 16 = [64m^2] Therefore, $F = (0.7-0.2) \times 401.74 \times 64$ $= 12855.68[N] = 12.86[kN]$ **For 4th Floor:** Storey height = 15[m] $S_2 = 0.69$ $Vs = 40 \times 1 \times 1 \times 0.69 = 27.6$ [m/s] $q = K (Vs)^2$ $= 0.613 \times (27.6)^2 = 466.96$ [N/m^2] $F = (C_{pe} – C_{pi})qA$ $C_{pe} = 0.7$, $C_{pi} = 0.2$ Therefore, $F = (0.7-0.2) \times 466.96 \times 64$ $= 14942.72[N] = 14.94[kN]$	10.93[kN] 25.6 [m/s] 401.74[N/m^2] 12.86[kN] 27.6 [m/s] 466.96[N/m^2] 14.94[kN]

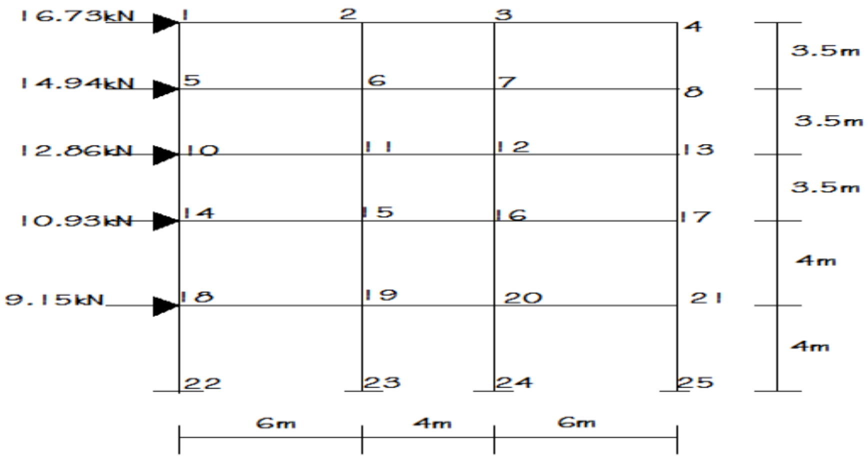

Fig. 3 Sectional Elevation Along C1 – C4 of the Framed Structure

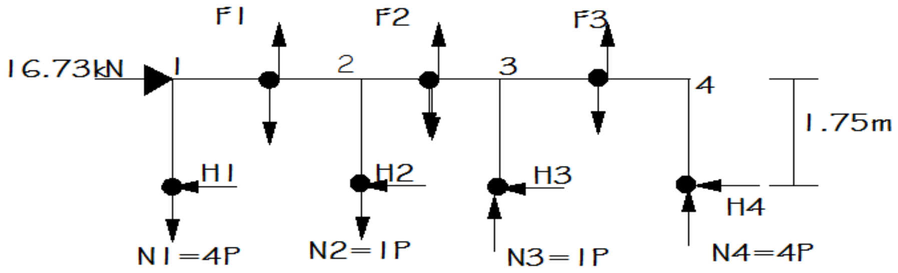

Fig. 4 Frame of the Roof with Hinges

The ratio of the axial Force in the exterior column to the axial Force in the interior column is 4:1.

where N_1 - N_4 = Axial Force.

H_1 - H_4 = Column's horizontal Shear force.

F = Beam's vertical shear Force.

P = Axial load.

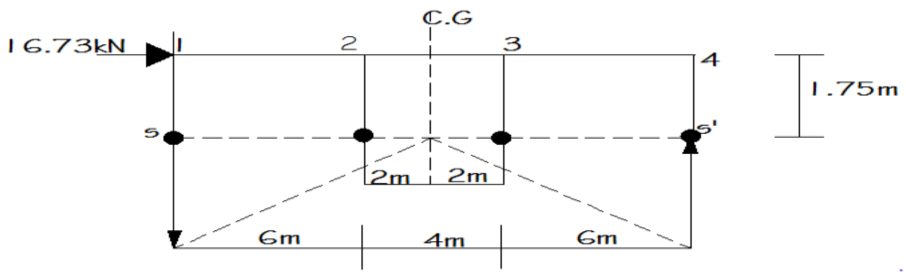

Fig. 5 The Frame Structure's Centroid

The total span of the structure is 16[m], and the centroid of the span will be at $16 \div 2 = 8$[m] from the exterior column.

Cantilever Method Analysis.

Using the Cantilever method to analyse the frame by breaking or cutting the frame into sections starting from the top-story (Roof) columns downward and introducing a hinge at the centroid (Kharagpur, 2008). By subjecting the frame to lateral loading, the approximated frame is shown below:

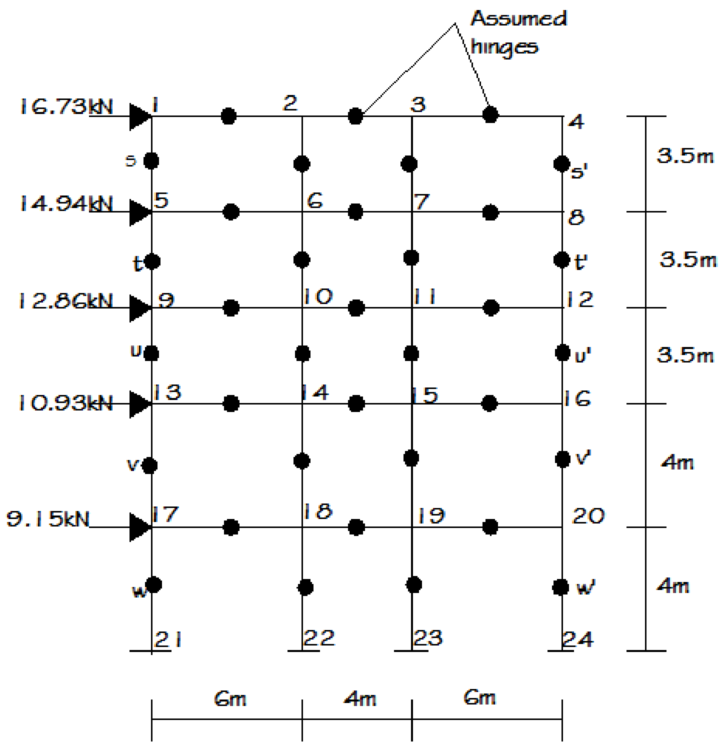

Fig. 6 Framed Structure with Hinges at Centroid of Beams and Columns

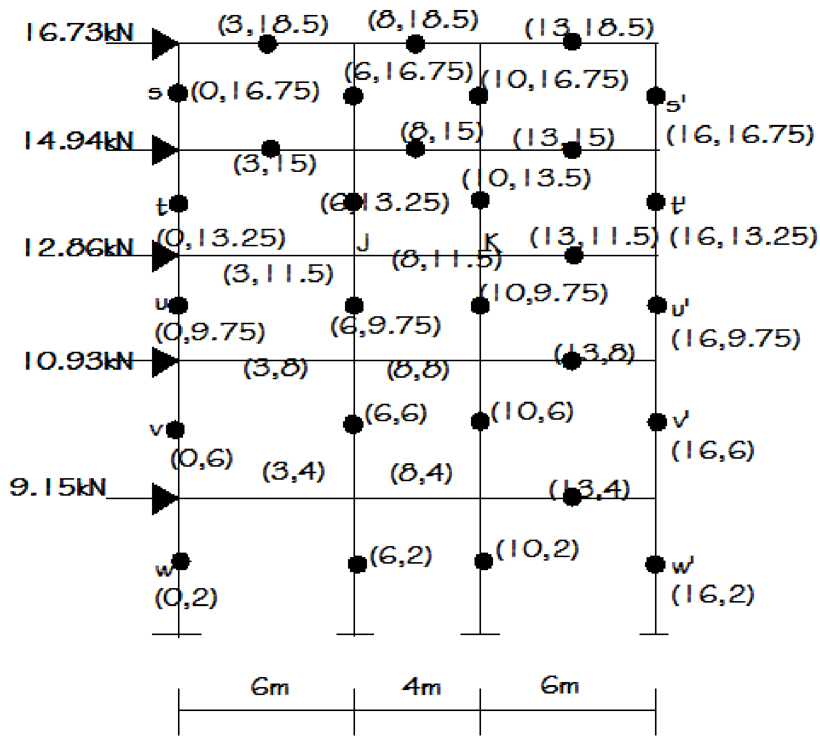

Fig. 7 Coordinates of the Frame Hinge Points

Calculating the axial forces in the column:

By taking moments about point **s**;

$$\sum M \; @ \; \mathbf{s} = 0;$$

16.73 x 1.75 + 1P x 6 – 1P x 10 – 4P x 16 = 0

P=29.28/68 = 0.431[kN]

$N_1 = -N_4$

$4P = N_1$

$N_1 = 1.724[kN]$

$\therefore N_4 = - 1.724[kN]$

$N_2 = -N_3 = 1P$

$N_2 = 1 \times 0.431 = 0.431[kN]$

$N_3 = -0.4315[kN]$

Vertical Shearing Force F in the beams:

$\sum F = 0$, for each part of the sub-frame.

$\therefore F_1 = N_1 = 1.724[kN]$

$F_2 = N_1 + N_2 = 2.16[kN]$

$F_3 = F_1 = 1.724[kN]$

Horizontal sharing force H in columns:

Take a moment about the points of contra flexure of each beam, i.e.,

$\sum M$ @ $F_1 = 0$

$(H_1 \times 1.75) – (1.724 \times 3[m]) = 0$
$H_1 = 5.172/1.75 = 2.96[kN]$

Taking moment @ $F_2 = 0$

$H_1 \times 1.75 + H_2 \times 1.75 – N_1 (6+2) – N_2 (2) = 0$

$H_2 = 5.4[kN]$

$H_4 = H_1$ and

$H_3 = H_2$

Taking moment @ $F_3 = 0$
$2.96 \times 1.75 + 5.4 \times 1.75 + H_3 \times 1.75 – 1.724 \times 13 – 0.431 \times 7+0.431 \times 3 = 0$
then, $1.75H_3 = 9.506$

$H_3 = 9.506/1.75 = 5.43[kN]$
$H_4 = 2.96[kN]$

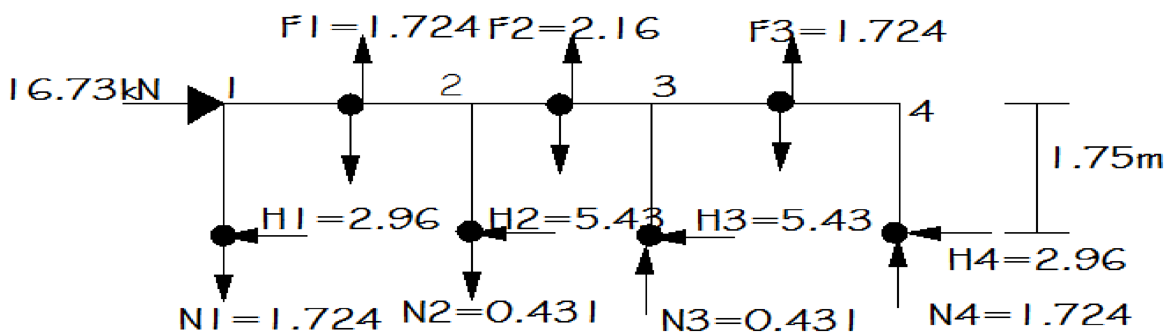

Fig. 8 Computed forces in the roof frame

By transferring the forces to the 4th,3rd, 2ndand 1st floor frames, respectively, to get the equivalent forces.

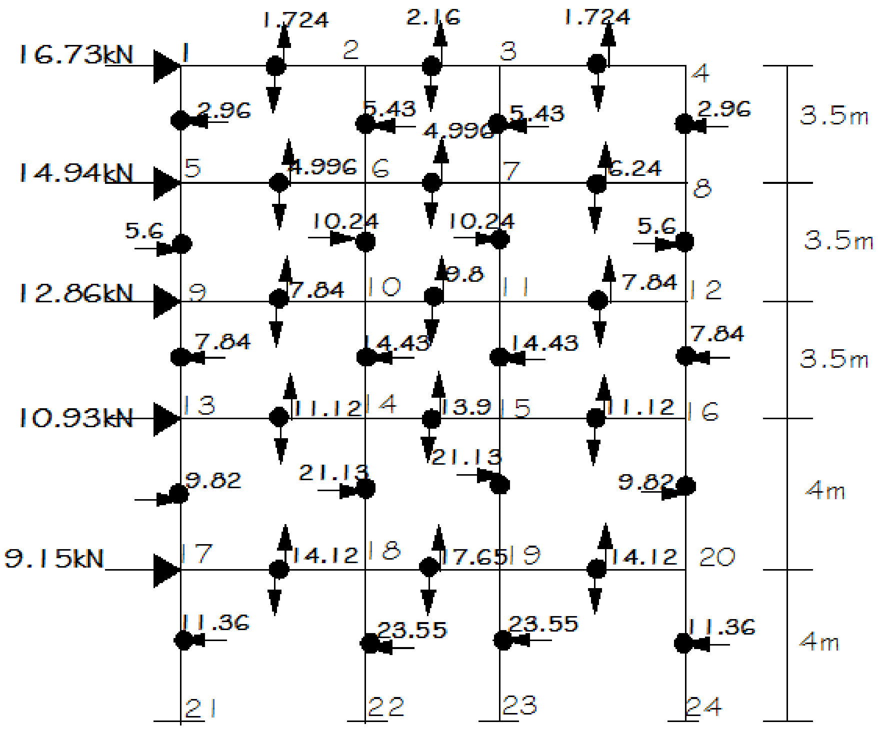

Fig. 9 Assembled axial forces, vertical and horizontal shearing forces in the frame structure

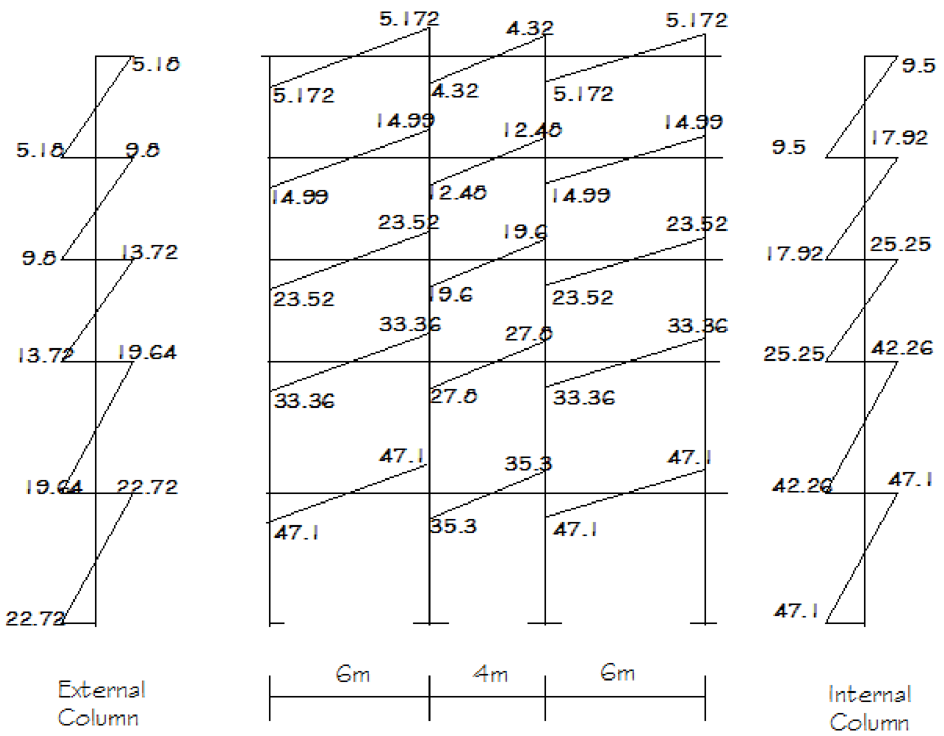

Fig. 10 Bending moment diagram due to characteristic wind loads in all the storey columns and beams

Note: As a check, at each joint, the summation of beam moment must be equal to the summation of column moment, i.e. $\sum M_B = \sum M_C$. (Umer & Muzamil, 2008).

Portal Method Analysis.

By introducing hinges to the frame to find the shear and moment in the frame.

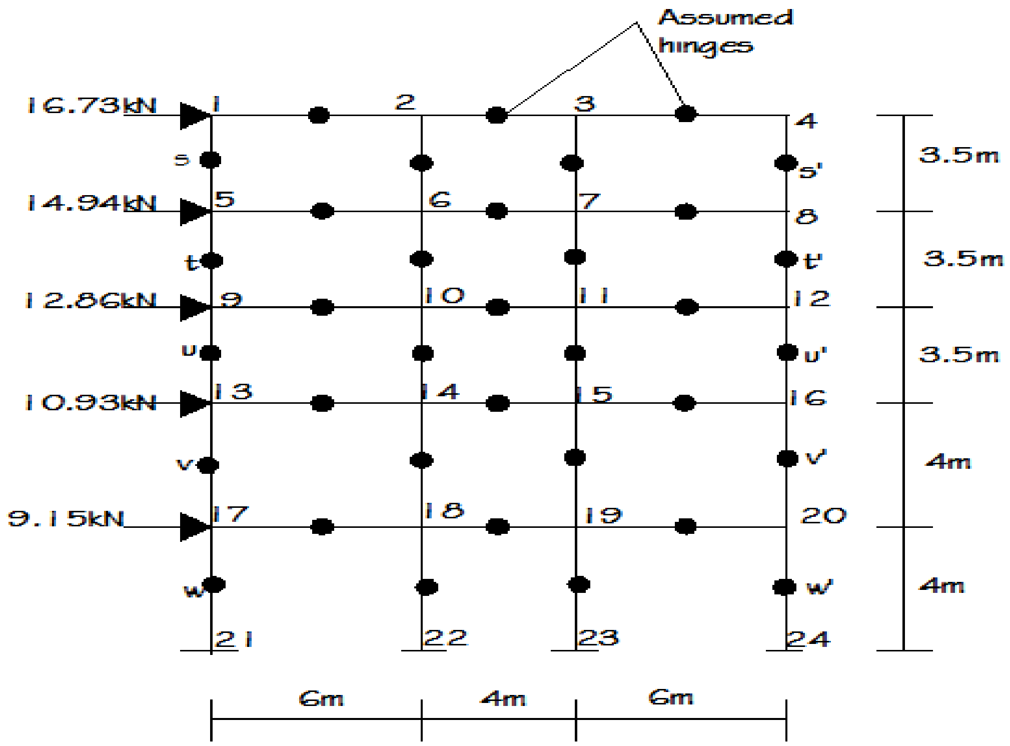

Fig. 11 Portal Frame with Hinges

Note: for the portal method, the cut can be made at any point along the height of the storey when finding column shear.

By cutting the roof frame at point s,

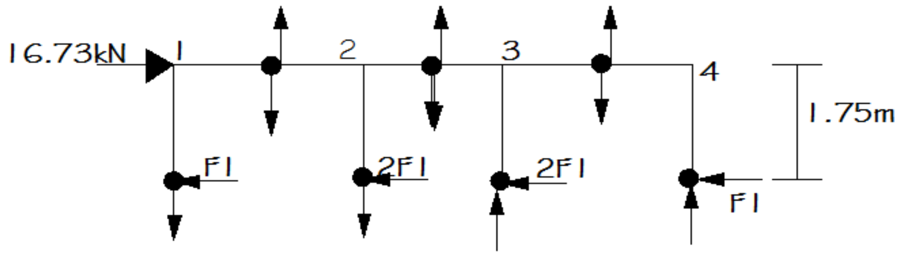

Fig. 12 Roof frame for portal analysis

Assuming that the total of all horizontal forces is equal to zero. i.e. $\sum Fx = 0$

$F_1 + 2F_1 + 2F_1 + F_1 - 16.73 = 0$

$F_1 = 2.79[kN]$

Therefore $2F_1 = 2 \times 2.79 = 5.58[kN]$

Taking the sum of horizontal forces to be zero for 4th floor frame

$\sum Fx = 0$

$F_1 + 2F_1 + 2F_1 + F_1 - (16.73 + 14.94) = 0$

$6F_1 - 31.67 = 0$

$F_1 = 31.67/6 = 5.28[\text{kN}]$

$\therefore 2F_1 = 2 \times 2.63 = 10.56[\text{kN}]$

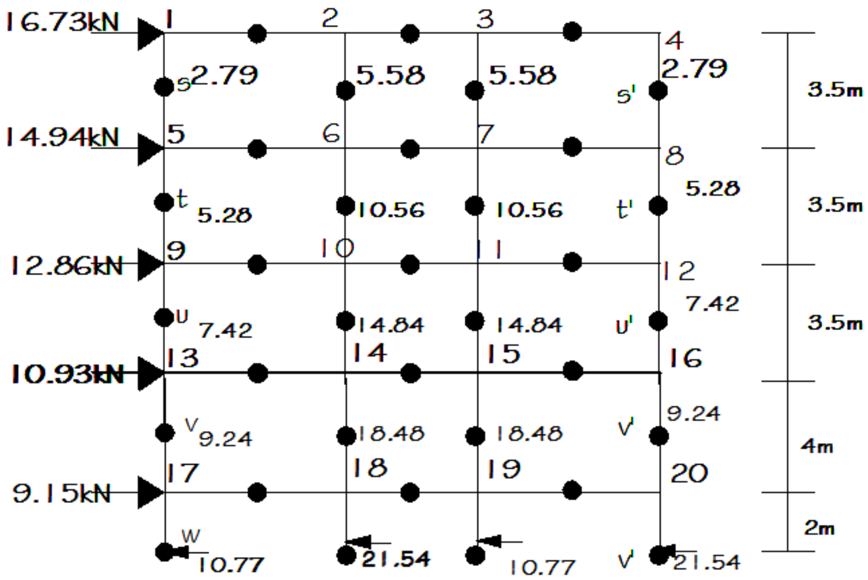

Fig. 13 Completed Floor Frame for Portal Analysis

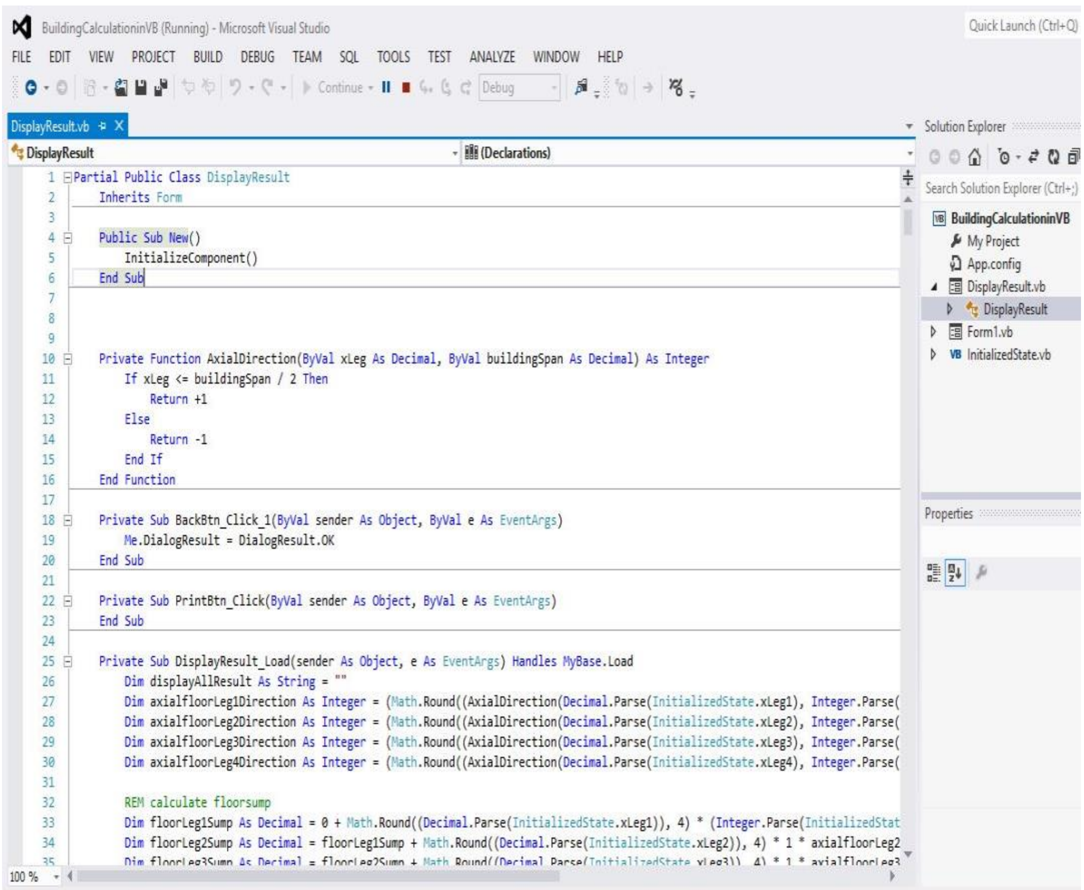

Fig. 14 Coding phase of the computer program using Visual Basic

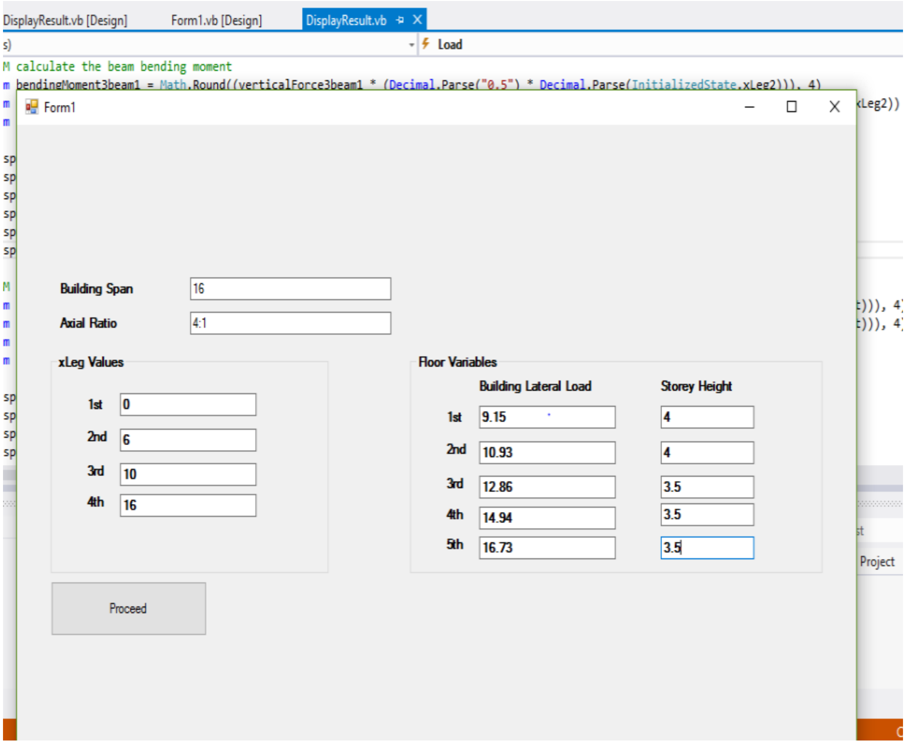

Fig. 15 Data input of sampled frame member forces and dimensions

Results and Discussion

All calculations were performed manually, and a computer program was written to analyse the frame structure using visual basic programming language (Daene, 2014). While the portal approach measured vertical loading, the cantilever method estimated the lateral loading on the frame structure. The manual calculation results are well compared to the computer-assisted analysis results, as shown in Table 2 to Table 4.

The two methods adopted for the structural analysis, the cantilever method and portal method, gave different results in the shear forces in the members and slightly different results in the bending moment values, as shown in the tables. Analysis of multi-storey frames is cumbersome manually (Negussie Tebedge, 1983; Kassimali A, 2011), hence the need for an assisted program. A five-storey frame building was analysed manually and with the assistance of a computer program developed for that purpose. Adopting the resulting outputs will aid fast design delivery as well as ease of alteration in design at any stage.

Table 2 Summary of Column Shear Forces on the Sample Frame Using Cantilever Method

Example by Cantilever Method				
Storey	**Computer Result**		**Manual Calculation Results**	
	External Column Shear Force [kN]	**Internal Column Shear Force [kN]**	**External Column Shear Force [kN]**	**Internal Column Shear Force [kN]**
5th	2.953	5.413	2.96	5.43
4th	5.588	10.247	5.6	10.24
3rd	7.859	14.405	7.84	14.43
2nd	9.785	17.945	9.82	21.13
1st	11.404	20.901	11.36	23.55

Table 3 Summary of Column Shear Forces on the Sample Frame Using Portal Method

Example by Portal Method.				
Storey	Computer Results		Manual Calculation Results	
	External Column Shear Force [kN]	Internal Column Shear Force [kN]	External Column Shear Force [kN]	Internal Column Shear Force [kN]
5th	2.788	5.577	2.79	5.58
4th	5.274	10.557	5.28	10.56
3rd	7.421	14.843	7.42	14.84
2nd	9.243	18.487	9.24	18.48
1st	10.768	21.537	10.77	21.54

Table 4 Summary of Beam Shear Forces for Sample Frame by Cantilever Method

Worked Example by Cantilever Method				
Storey	Computer Results		Manual Calculation Results	
	External Beam Shear Force [kN]	Internal Beam Shear Force [kN]	External Beam Shear Force [kN]	Internal Beam Shear Force [kN]
5th	1.724	2.16	1.72	2.2
4th	4.996	6.236	4.996	6.24
3rd	7.838	9.77	7.84	9.8
2nd	11.148	13.88	11.12	13.9
1st	14.115	17.648	14.12	17.65

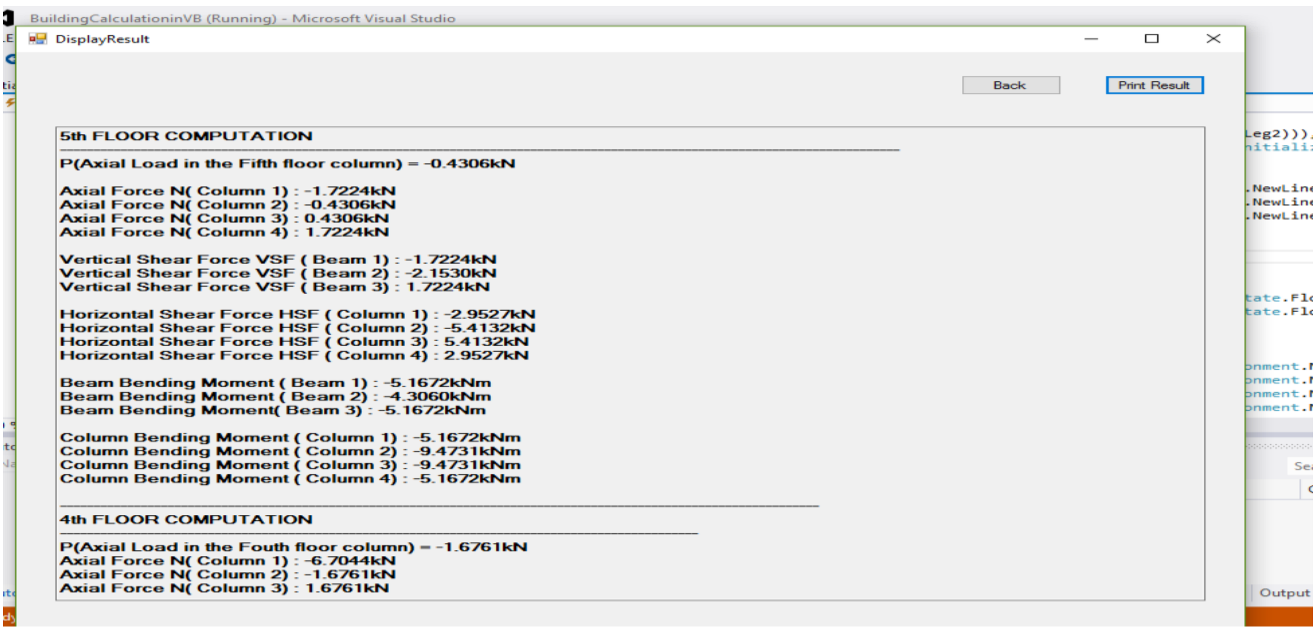

Fig. 16 Data Output of the Structural Frame; Computer Result Display

Conclusion

A five-storey frame building was analysed manually and with the assistance of a computer program developed for that purpose. By adopting the cantilever and portal method of analysis, the following conclusions have been drawn:

1. The two methods adopted for the structural analysis gave different results in the shear forces in the members and slightly different results in the bending moment values. By comparing the generated results from these methods, about 0.1 – 0.2 difference in value was noticed, which is relatively insignificant.
2. The manual computations were compared with the results from the computer-assisted analysis. The results of the manual calculation and the computer are the same at about 95%; the remaining 5% was because of the decimal approximations done by the computer in calculations which validates the correctness of the algorithm.
3. The structural analysis of multi-storey buildings by approximate method requires the application of suitable lateral loadings in determining the member forces and moment for the preliminary sizing of the frame elements. To validate the efficiency of the algorithm and the computer-aided framework for the sample frame structure, an example frame analysis data from a textbook (Bill Mosley et al., 2007) was adopted and tested. The output was about 1% different compared to the textbook results, hence the computer-aided framework validation. This framework can be extended to handle higher multi-storey structures to estimate the sizes of the constituent elements of any frame structure.

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Author Contributions.

All authors contributed to the study's conception and design. Ruth Oluwadamilola Akingbade and Noah Kayode Ojoko performed material preparation, data collection and analysis. Ruth Oluwdamilola Akingbade wrote the first draft of the manuscript, and the second author commented on previous versions. All authors read and approved the final manuscript.