Analysis of multi-storey building frames for lateral loads using Portal Method –A Critical Review

V.Venkat Ramayya[1*], K. Krishna Bhavani Siram[1], K.V.Ramana Reddy[2], K.V.Krishna Reddy[2], R.Abhishek[1]

***Abstract:** Structural analysis comprises the set of physical laws and mathematics required to study and predict the behaviour of structures. Structural analysis incorporates the fields of mechanics and dynamics as well as failure theories. From a theoretical perspective, the primary goal of structural analysis is computation of deformations, internal forces and stresses. Analysis involves assessment of various types of loads coming on to the structure and computation of member forces.Various methods of analysis were proposed to determine the internal forces in elements of structures. Approximate methods are quite handy when compared to methods of exact analysis but however the member forces may not be accurate. It is a customary to carry out the lateral load analysis separately and results are superimposed with the results of analysis for gravity loads to arrive at final moments.*

This work aims to study the performance of Portal Method, which is used to determine member forces for lateral load analysis. The wind loads are estimated using stipulated codes from India. A computer program in C Language was developed to calculate the member forces adhering to Portal method and results of Staad.Pro were used to compare through statistical parameters. It was concluded from the study that the results of Portal method are in close agreement with the Staad. Pro results when the height to width ratio is greater than five.

Key Words: Exact & Approximate Methods, Portal Method, Lateral Loads, C Programming.

1. Introduction

Structural analysis comprises the set of physical laws and mathematics required to study and predicts the behaviour of structures. Structural analysis incorporates the fields of mechanics and dynamics as well as many failure theories. From a theoretical perspective, the primary goal of structural analysis is to compute stresses and deformations. Analysis involves assessment of various types of loads coming on to the structure and computation of performance of members under these loads. Design is a process of arriving at the dimensions of the elements of the structure based on their strength and deformation limits. Various methods of analysis are available in literature including approximate methods.

Approximate methods are quite often used to analyse structures for lateral loads alone or for the combination of gravity and lateral loads. Attention is still being given to these methods notwithstanding the availability of exact methods and computational software [7] Leet and Uang (2005) [6] have illustrated that in order to understand the behaviour of a structure, the approximate methods can offer clues regarding member relative stiffness and approximate dimensions of the various elements of the structure. The two classical approximate methods mentioned in the literature for lateral loads are Portal and Cantilever methods [4, 5, 9-10]. Arum and Aderinlewo (2005, 2006) [1-2] have used quantitative parameters to show that in building frames of moderate height, the analysis results obtained using the Portal method are closer to the exact results than Cantilever method.

There is a great potential for research in this area to establish the performance of these methods when compared to exact methods. It is with this background, the current research is taken up to investigate the performance of Portal method by comparing with that of exact methods. Researchers have come out with few practical recommendations on Portal method by modifying the set of fundamental assumptions made in the literature for computing moments near to exact methods (Arum, 2008) [3]. In this research, the performance of Portal method with its proposed theoretical assumptions has been studied at macro level through selected statistical parameters.

2. Objective

In the light of discussion made in the previous section, it was intended to study the performance of Portal Method for single bay multi-storeyed portal frames up to 25 storeys. Staad.Pro software was used to assess the exact moments. A computer program in C language was used to calculate end moments using Portal Method.

3. Loads Assessment

In this section, the method of assessment of wind loads (IITK GSDMA-Prem Krishna et al. [8]) was detailed and assessed joint loads were presented. The loads were assessed by assuming the structure is located in Hyderabad, Telangana State of India.

3.1 Wind Load Analysis

In general, wind speed in the atmospheric boundary layer increases with height from zero at ground level to a maximum at a height called the gradient height. The design wind speed, V_z at any height, Z for the chosen structure include the following effects:

(a) Risk level

(b) Terrain roughness and height of structure

(c) Local topography

(d) Importance factor for the cyclonic region.

It can be mathematically expressed as $V_z = V_b k_1 k_2 k_3 k_4$

Where

[1]Asst. Professor, Department of Civil Engineering, Mahatma Gandhi Institute of Technology, Gandipet, Hyderabad.

[2] Professor, Department of Civil Engineering, Mahatma Gandhi Institute of Technology, Gandipet, Hyderabad.

V_z- design wind speed at any height z in m/s,
k_1- probability factor (risk coefficient)
k_2- terrain roughness and height factor
k_3- topography factor, and
k_4- importance factor for the cyclonic region.

1.K_1 Probability factor or Risk Coefficient:
Basic Wind Speed of 44 m/s is to be considered for the Hyderabad location.All general buildings and structures, whose mean probable design life of Structure is considered as 50 years, the risk coefficient K_1 is taken as 1
2. K_2 Terrain Roughness and Height factor:
Selection of terrain categories shall be made with due regard to the effect of obstructions which constitute the ground surface roughness. The terrain category used in the design of a structure may vary depending on the direction of wind under consideration. In the present study ***Category 1*** – Exposed open terrain with a few or no obstructions and in which the average height of any object surrounding the structure is less than 1.5 m is considered.
3. K_3 Terrain Roughness and Height factor:
The effect of topography is to accelerate wind near the summits of hills or crests of cliffs, escarpments or ridges and decelerate the wind in valleys or near the foot of cliffs, steep escarpments, or ridges. The effect of topography considered in the study is the upwind slope (θ) below 3^o, hence value of k_3 is taken equal to 1.0.
4. K_4 Importance factor for Cyclonic Region:
In order to ensure greater safety of structures, the value of k_4 are stipulated according to the importance of the structure and for all other structures (excluding Industrial structures and Structures of post – cyclone importance), the value of k_4 is taken as 1.0
3.2 Joint loads assessment
The wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind speed:

$$P_z = 0.6\, V_z^2 \quad (1)$$

where
p_z - wind pressure in N/m^2 at height z, and
V_z - design wind speed in m/s at height z.

The joint loads due to wind forces have been estimated as detailed in section 3.1 and were presented through Table 1.

Table 1 Assessed Joint Loads for different stories with K_1, K_3 and K_4 values equal to 1

Height	V_b (m/s)	K_2	V_z (m/s)	Pressure (P_z) (kN/m^2)	Load on the joint	Final (kN)
3	44	1.00	44.00	1.162	10.46	10.5
6	44	1.00	44.00	1.162	10.46	10.5
9	44	1.00	44.00	1.162	10.46	10.5
12	44	1.07	47.08	1.380	12.42	12.5
15	44	1.09	47.96	1.380	12.42	12.5
18	44	1.11	48.84	1.431	12.88	12.5
21	44	1.12	49.28	1.457	13.11	13.0
24	44	1.13	49.72	1.483	13.35	13.5
27	44	1.14	50.16	1.510	13.59	13.5
30	44	1.15	50.60	1.536	13.82	13.5
33	44	1.16	51.04	1.563	14.07	14.0
36	44	1.17	51.48	1.590	14.31	14.5
39	44	1.17	51.48	1.598	14.38	14.5
42	44	1.18	51.92	1.617	14.55	14.5
45	44	1.19	52.36	1.645	14.81	15.0
48	44	1.20	52.80	1.673	15.06	15.0
51	44	1.20	52.80	1.676	15.08	15.0

54	44	1.20	52.80	1.686	15.17	15.0
57	44	1.21	53.24	1.696	15.26	15.0
60	44	1.21	53.24	1.706	15.35	15.0
63	44	1.22	53.68	1.716	15.44	15.0
66	44	1.22	53.68	1.727	15.54	15.5
69	44	1.22	53.68	1.737	15.63	15.5
72	44	1.23	54.12	1.747	15.72	16.0
75	44	1.23	54.12	1.757	15.81	16.0

In order to overcome the complexity of calculations for the taller frames, a computer program using C language was developed for obtaining moments by Portal method.

4. Comparison of Results

4.1 Parameters for comparison of results

The following statistical parameters have been chosen to compare the results by both the methods.

1. Root Mean Square Error (RMSE)

Let MS - joint moments obtained by Staad. Pro

MP - joint moments obtained by Portal Method

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(MS_i - MP_i)^2}{n}} \qquad (2)$$

2. Correlation coefficient

$$\text{Correlation Coefficient } (\rho) = \frac{\sum_{i=1}^{n}(MS_i - \overline{MS_i}) * (MP_i - \overline{MP_i})}{(n-1)S_{MS}S_{MP}} \qquad (3)$$

3. Percentage of Deviation

$$\text{PD} = \frac{|MS_i - MP_i|}{|MS_i|} X100 \qquad (4)$$

In this work, frames were considered up to twenty five storeys starting from storey two to twenty four and height of each storey is taken as 3m. The lateral loads were calculated in accordance with [IITK GSDMA - Prem Krishna et al.] for the Hyderabad region. The calculations were presented in 3.2

Using Staad.pro all the frames were analysed and the results were presented for both the methods in Graphical form from Fig 1 to 6 for selected stories. The magenta colour indicates the 45^0 line and the data points indicate the end moments of both columns and beams.

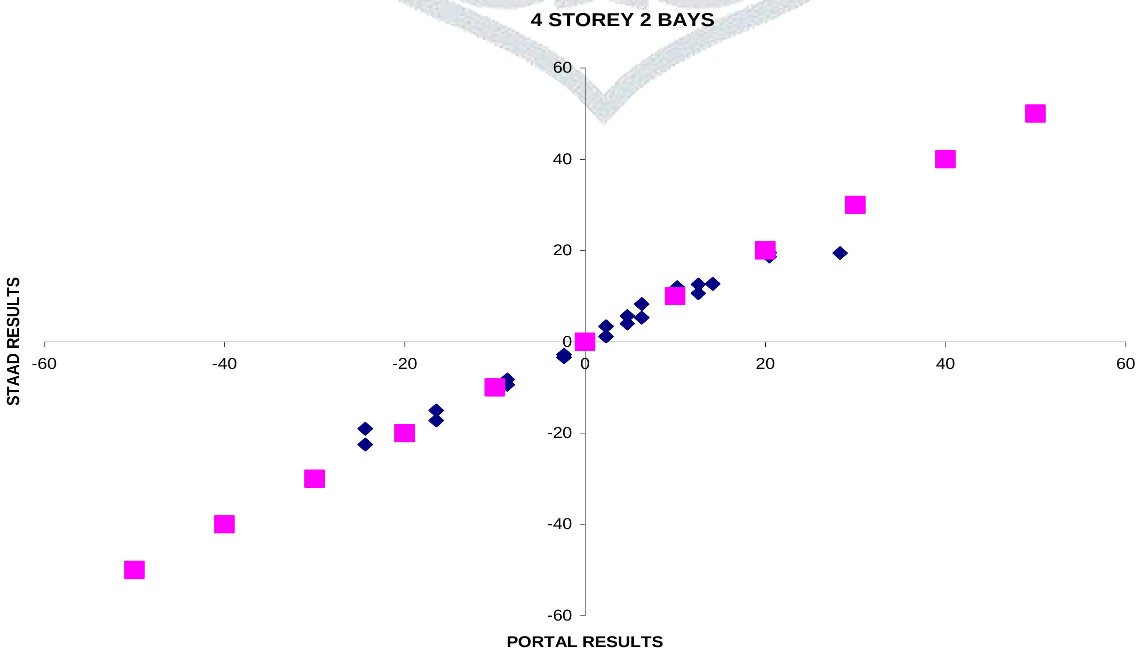

Fig 1 Four storey and Two bays

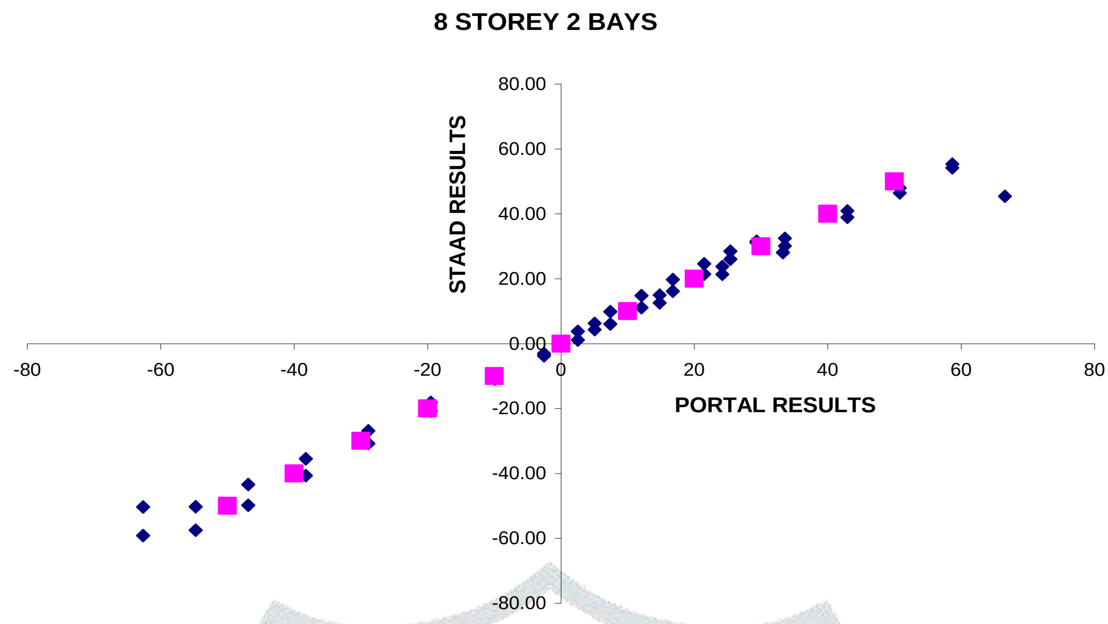

Fig 2 Eight storey and Two bays

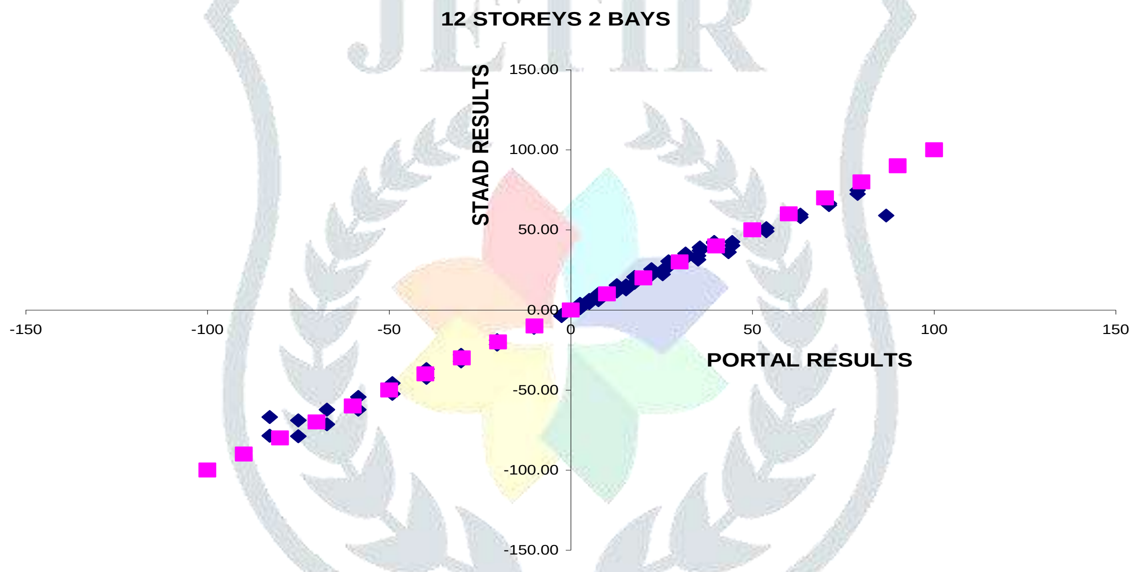

Fig 3 Twelve storey and Two bays

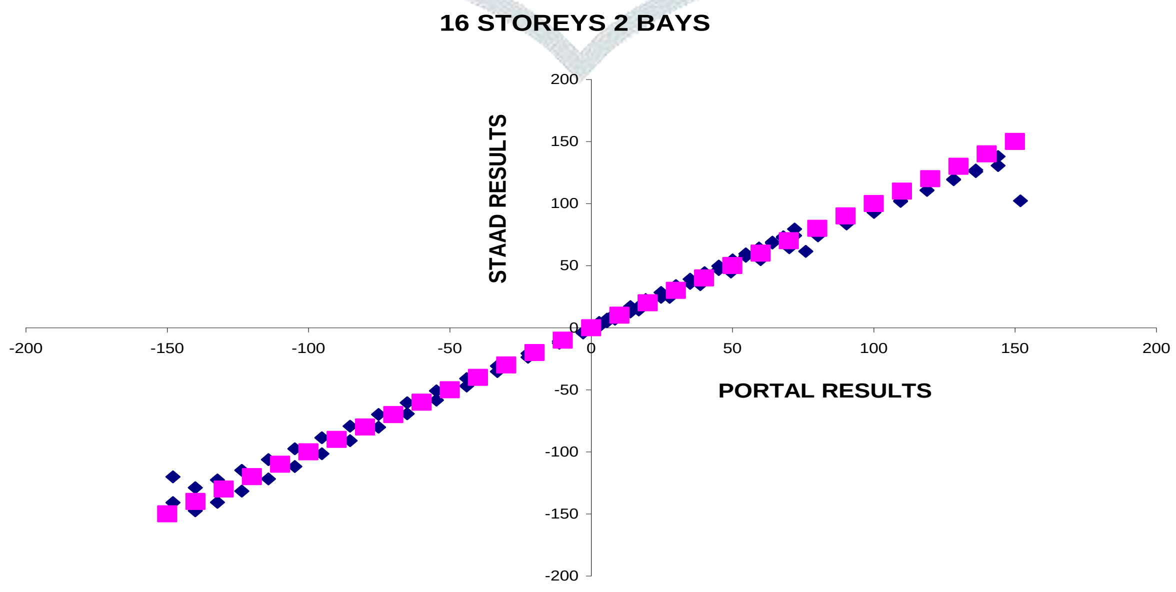

Fig 4 Sixteen storey and Two bays

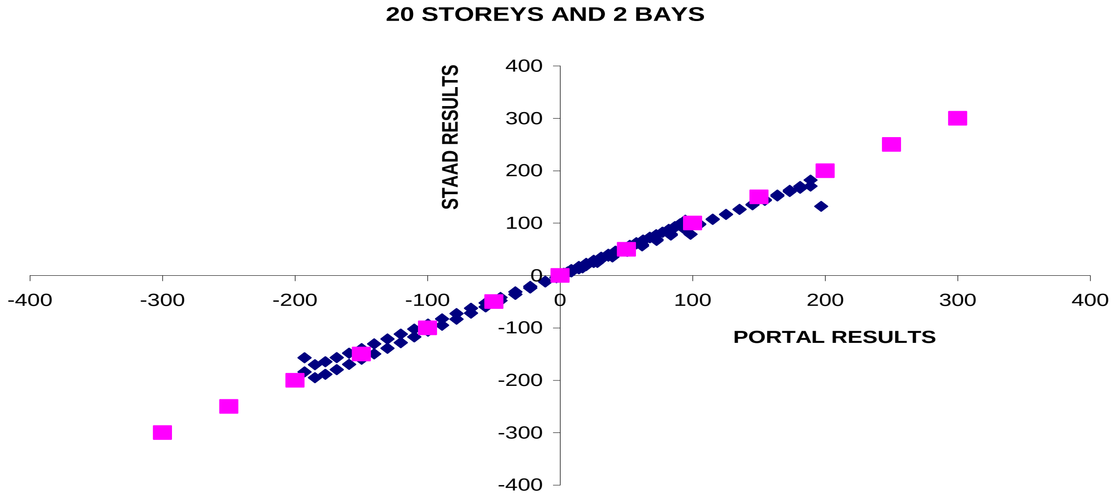

Fig 5 Twenty Storey and Two bays

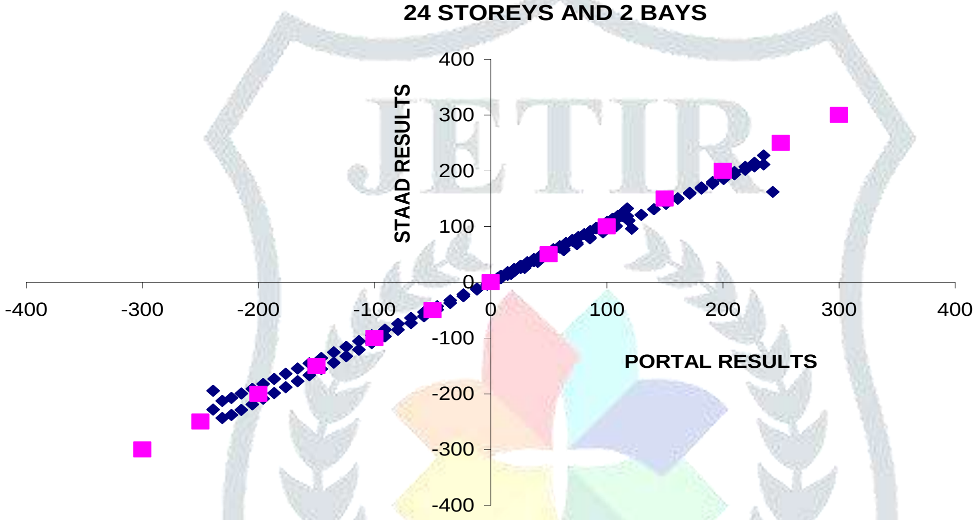

Fig 6 Twenty-Four storey and Two bays

From the above graphs it was observed that the results by the approximation method are close to exact methods. In order to quantify the closeness following statistical parameters were chosen.

4.2 RMS Absolute between Staad. Pro and Portal Results

The results by both the methods have been compared based on the above parameter. The formula used to calculate the RMS absolute is given in the previous sections. The values obtained are presented in the Table 2 and RMS absolute is found to increase with the increase in h/b ratio.

Table 2 RMS absolute of joint moments for Portal and Staad.Pro Method

Height to Width Ratio	1	2	3	4	5	6	7	8	9	10	11	12
RMS Absolute	1.17	2.16	3.04	3.88	4.70	5.54	7.16	8.09	8.15	9.00	9.88	10.78

The RMS absolute between the results obtained by both the methods is found to increase with the increase in height to width ratio. This might be due to the increase in the volume of the data.

4.3 Correlation between Staad.Pro and Portal Method Results

The statistical parameter Correlation coefficient has been chosen to assess the degree of dependency between the Portal and Staad.Pro results. From Fig 7 it can be observed that the results are highly correlated and correlation is found to achieve stability for h/b ratio more than 5.

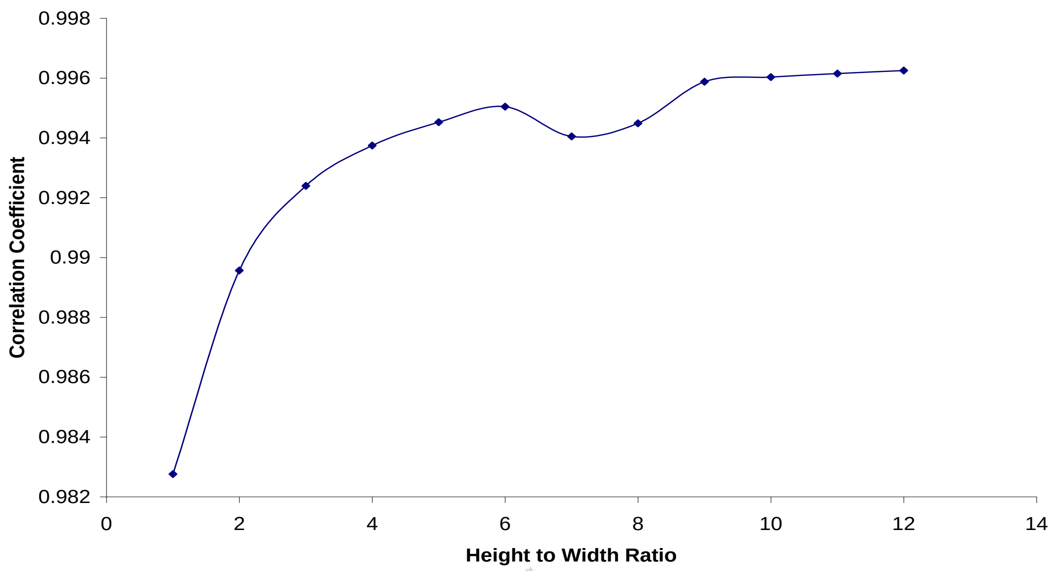

Fig 7 h/b ratio Vs Correlation Coefficient

4.4 Deviation between the results obtained by both the methods

The parameter percentage of mean deviation was used to calculate the degree of closeness of the results obtained by Portal Method to that of Staad.Pro results. The formula for the percentage of deviation is presented in the Section 4.1. For every frame and for every end moment of a member, the percentage deviation is computed and tabulated as shown in the Table 3. Five categories have been chosen and are sample percentage less than 10 %, 20 %, 30%, 40% and 50% deviation.

Table 3 Percentage of sample

Percentage deviation	Height/Width Ratio					
	2	4	6	8	10	12
	Sample Percentage					
<10	10.81	59.74	71.79	78.34	81.73	84.81
<20	18.92	81.82	87.18	89.81	91.88	93.67
<30	29.73	88.31	92.31	94.90	95.43	96.20
<40	32.43	92.21	94.87	96.82	96.95	97.47
<50	32.43	92.21	94.87	96.82	96.95	97.05

The results presented in the above Table were dipicted graphically in Fig 8 for better visualization.

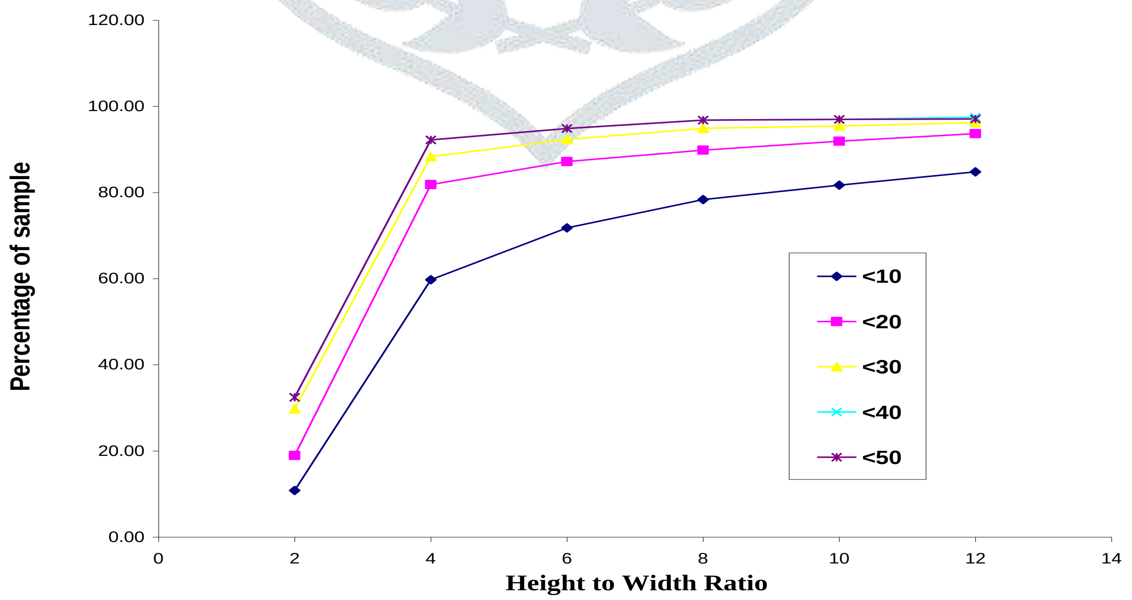

Fig 8 Height to Width Ratio Vs Percentage of sample for a specified percentage of deviation

From the graph it can be observed that the percentage of sample for specified criteria (less than 10% or less than 20% etc) is found to stabilize after a ratio of 5. Hence it concluded that the Portal method will give satisfactory results for building frames whose height to width ratio is greater than 5. Similar conclusion can also be drawn from the statistical parameter, correlation coefficient as observed from Fig 7.

5. Conclusion

Based on the analysis carried out by using three chosen statistical parameters, the following conclusions were made in respect of the performance of Portal method used for the analysis of building frames for lateral loads.

The parameter RMS absolute is found to increase with the increase in h/b ratio and no conclusion can be made as the increase is obvious as a result of increase in the volume of data as the ratio h/b increases. The graph between the correlation coefficient and h/b ratio gave an insight into the performance of the method. The correlation is found to increase initially and later became stable for h/b ratio more than 5.

Finally the **'Percent deviation'** parameter could show the way to strongly conclude about the performance of the method. For every frame and for the end moments of every member percentage deviation was computed. From the data for a particular frame the sample percentage for five categories was computed and the graph shown in Fig 8, it is evident that the percentage of sample for a particular percentage deviation is found to become stable for h/b ratio more than five. It can be observed from the Table 3 that the percentage of sample for <10 category shoot up from 10.81 for h/b ratio 2 to 59.64 for h/b ratio 4. And later increase in the sample percentage for higher order frames is found to become marginal indicating the results will be close to exact methods when the height to width ratio of the frame is more than 5.

6. Acknowledgement

The principal author would like to thank Mr. D. Karthik for his support in analysing frames using Staad.Pro analysis.

References

[1] Arum C. and Aderinlewo O.O. (2006). Inflection Points of Windswayed Reinforced Concrete Frames. Journal of Engineering and Engineering Technology (FUTAJEET), Federal University of Technology, Akure, Vol.5, No.1, pp. 46-51.

[2] Arum C. and Aderinlewo O.O. (2005). Comparison of Cantilever and Portal Methods with Elastic Analysis for Building Frames. International Research Journal in Engineering, Science and Technology, Vol. 2, No.2, pp. 176-186.

[3] Arum. C (2008), Practical Recommendations for the Preliminary Design Analysis of Multi-Storey Moment-Resisting Frames, African Research Review, Volume 2(4), September, pp. 17-30.

[4] Englekirk R. (2003). Steel Structures. Controlling Behaviour through Design. John Wiley & Sons, Singapore.

[5] Kassimali A. (1993). Structural Analysis, PWS-Kent Publishing Co., London.

[6] Leet K.M. and Uang C. (2005), Fundamentals of Structural Analysis. McGraw-Hill, New York.

[7] Nilson A.H., Darwin D. and Dolan C.W. (2004). Design of Concrete Structures. McGraw-Hill, New York.

[8] Dr.Prem Krishna,Dr.Krishen Kumar and Dr.N.M. Bhandari, *IS: 875 (Part3): Wind Loads on Buildings and Structures - Proposed Draft &Commentary*, Department of Civil Engineering, Indian Institute of Technology Roorkee.

[9] Raju N.K. (2005). Advanced Reinforced Concrete Design. CBS Publishers, Delhi.

[10] Wang C.K. (1983). Intermediate Structural Analysis. McGraw-Hill, New York.