Stability of a Six Storey Steel Frame Structure

Shamshinar Salehuddin [1], Nur Liza Rahim [2], and Norlia Mohamad Ibrahim [3]
[1,2] Pusat Pengajian Kejuruteraan Alam Sekitar, Universiti Malaysia Perlis,
Kompleks Pusat Pengajian Jejawi 3,
02600 Arau, Perlis, Malaysia.
Email: shamshinar@unimap.edu.my; nurliza@unimap.edu.my; norlia@unimap.edu.my

***Abstract*-- The world nowadays requires more tall buildings to overcome limited land space and creating high esthetic value. However, these high rise buildings require high frame structure stability for safety and design purposes. This research focused on non linear geometric analysis to be compared to previous studies on linear analysis. The linear analysis did not consider deformed configuration which can be considered as least accurate. On top of this, several designers did not incorporate the wind load which could lead to sway effect to tall buildings. In this study, a six storey 2-D steel frame structure with twenty four meter height has been selected to be idealized as tall building model. The model was analyzed by using SAP2000 structural analysis software with the consideration of geometric non linear effect. At the same time, several factors including the use of bracing and varying distributed loads on beam's element were also applied to study the sway and stability of the building. In addition, several cases including placing a fully bracing, bracing at half height of the building and alternate bracing were also studied. This study showed that a steel frame with the consideration of wind load produce greater sway value as compared to the steel frame without wind load. The sway prediction by using linear analysis was found to be less compared to the sway prediction from non linear analysis. This indicates that the non linear analysis is vital and significant element to be adopted for the analysis of tall building. The study also found that the use of bracing system results in small sway values compared to the frame without bracing system. As for consideration to costing aspect, the use of alternate bracing provide better option compared to half bracing in terms of stability of the building. The analysis results also showed that the adjustment of distributed load at upper part of steel frame structure able to provide different sway values which increases the stability of the building.**

***Index Term*-- Geometric non linear, stability, bracing system, steel frame structure**

I. Introduction

Tall building is the most structure that requires stability because it consist a lot of frame structure with different width and height. Building will be unstable if inadequate of lateral support and may resulted to collapse. Buildings and structures are considered stable with lateral supports by using either bracing system or shear system or both such as wall to ensure the stability of the building. Moreover, the important thing to consider are the software to be used to analysis the tall building structure and a wind speed at construction area to avoid any problem in future.

A fundamental consideration in designing a structure is that of assuring its stability under any type of loading condition. All structures undergo some changes in shape under load. In a stable structure, the deformations induced by the load are typically small, and internal forces are generated by the action of the load that tends to restore the structure to original shape after the load has been removed. In an unstable structure, the deformations induced by a load are typically massive and often tend to continue increase as long as the load is applied. By contrast, an unstable structure does not generate internal forces that tend to restore the structure to its original configuration. Unstable structures quite often collapse completely and instantaneously as a load is applied to them. It is a fundamental responsibility of the structural designer to assure that a proposed structure does indeed form a stable configuration. As example in Figure 1 is instability of frame structure under horizontal loads. Any horizontal load can cause deformations and clearly shows that the structure has no capacity to resist horizontal loads, nor does it have any mechanism that tend to restore it to its initial shape after the horizontal load is removed [1].

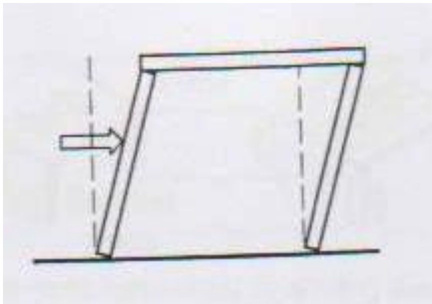

Fig. 1. Instability of frame structure under horizontal loads

In linear analysis, the material is assumed to be unyielding and no movement of load because base on undeformed configuration and do not have any iteration process. The calculation to obtain the result is also not complicated as second order analysis. Linear analysis is also known as first order analysis.

In non linear analysis the effects of finite deformations and displacements of the system are accounted for formulating the equations of equilibrium. Figure 2 show the straight elastic bar with horizontal and vertical load at edge of the bar. The axial force, P that acts on top of the bar has move follow the displacement in deformed configuration that use for next iteration process because of the presentation of horizontal load, αP. Point b to b' is representing the displacement, Δ. This is only happen in non linear analysis that also known as second order analysis analysis [2].

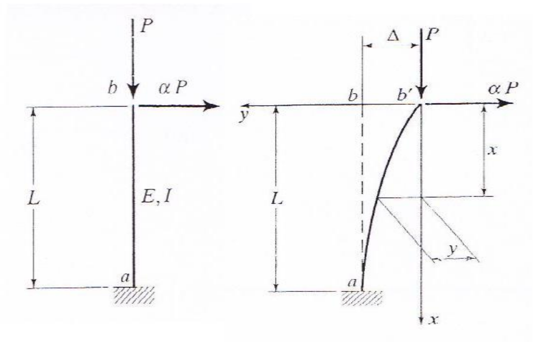

Fig. 2. Pictorial representation of bar with second order effect

Braces are important parts in steel frames to resist lateral loads. But very few research have been carried out due to its complication in calculation. A brace is dominantly subjected to axial force and can be represented with a truss element. The force in braces is simple, but they are possibly buckled in compression, and elastic or elasto plastic bending deformations take place, which makes the relationship between the axial force and the axial deformation of braces becomes complex as shown in Figure 3 [3]. N represents the load acted at edge of the bracing and it can be in tension or compression, and at the same time it can becomes shorter or longer indicated as δ.

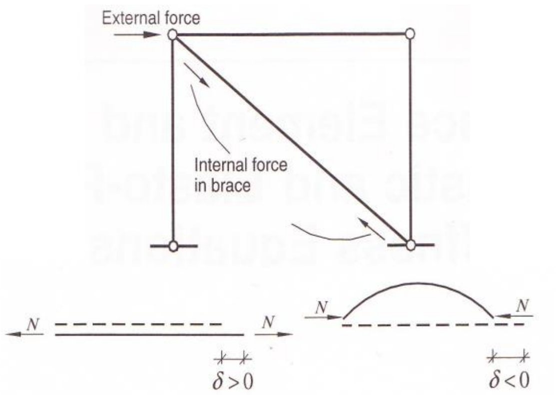

Fig. 3. Deformation of brace

There have been so many cases in which the structures failed due to instability which require P-Delta analysis. One of the problems is affected from wind load. Wind creates inward and outward pressures acting on building surfaces, depending on the orientation of the surface such as flat. This pressure increases uplift on parts of the building, forcing the building apart if it is too weak to resist the wind loads. Therefore, the most important thing to overcome this problem is the connection between beam and column in a frame such as rigid or pin ended should be considered for a realistic design. It will become instability structural which means loss of some situation and come close to a failure such as buckling and sway if the structure cannot sustain for a certain load whether from dead load, imposed load, wind load and also natural phenomena like earthquake [4].

II. The Distributed Load on Beam and Wind Calculation

The distributed load acted on the beam element of the frame structure was calculated base on selfweight of slab and beam refers to plan view as shown in Figure 4. While the horizontal load is a wind load calculated using CP3, Chapter V (Part 2) [5]. The distributed load is 0.05 kN/mm for steel frame.

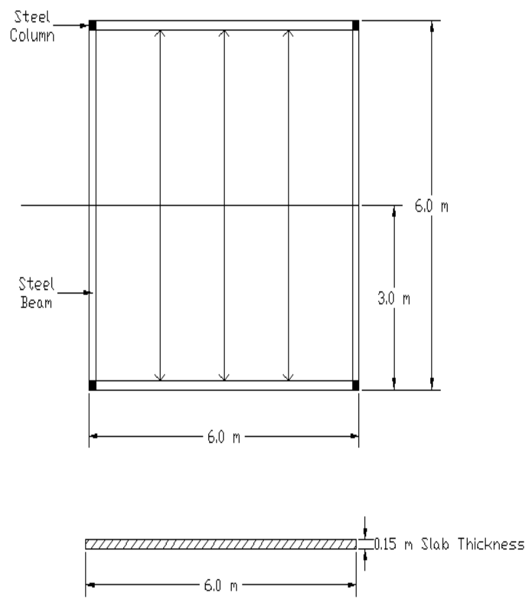

Fig. 4. The plan view of building which was used for the calculation for distributed load

The formulas for wind calculation based on CP3 are as follows :

i. Design wind speed :

$$V_s = VS_1S_2S_3 \qquad (1)$$

ii. Dynamic pressure :

$$q = kV_s^{\,2} \qquad (2)$$

iii. Wind force :

$$W_k = C_f q \qquad (3)$$

Figure 5 is the plan shape of the steel frame structure that was hit by wind and all parameter which was used in this calculation to obtain the C_f value. While in Table 1, the result of wind calculation using all formula explains previously.

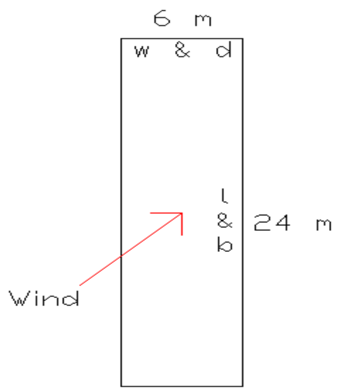

Fig. 5. The plan shape of the steel frame structure that hit by the wind

TABLE I.
WIND CALCULATION RESULT USING CP3, CHAPTER V (PART 2)

Z (m)	V (m/sec)	S_1	S_2	S_3	V_s	q	C_f	Wind Force (kN)
0	0	1.0	0.550	1.0	0.00	0.00	1.5	0.00
4	32.5	1.0	0.575	1.0	18.69	214.07	1.5	0.32
8	32.5	1.0	0.654	1.0	21.26	276.94	1.5	0.42
12	32.5	1.0	0.726	1.0	23.60	341.27	1.5	0.51
16	32.5	1.0	0.794	1.0	25.81	408.20	1.5	0.61
20	32.5	1.0	0.850	1.0	27.63	467.81	1.5	0.70
24	32.5	1.0	0.878	1.0	28.54	499.13	1.5	0.75

III. CASES TO BE ANALYZED USING SAP2000

A. Case 1

Six storeys of steel frame without wind load and only distributed load is applied which is 0.05 kN/mm for all beams. The model is shown in Figure 6.

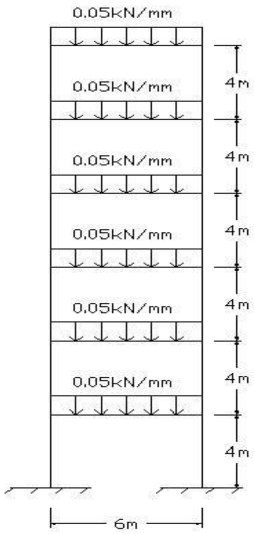

Fig. 6. Analytical model for Case 1

B. Case 2

In order to study the wind effect on the steel frame and to compare to Case 1, a six storeys of steel frame structure with wind load acted at left hand side of the frame was considered. All beams are also subjected to distributed load of 0.05 kN/mm. The model is shown in Figure 7. The values of horizontal load comes from winds, which also applied for next cases, are 0.32 kN, 0.42 kN, 0.51 kN, 0.61 kN, 0.70 kN and 0.75 kN respectively. These was based on CP3, Chapter V (Part 2).

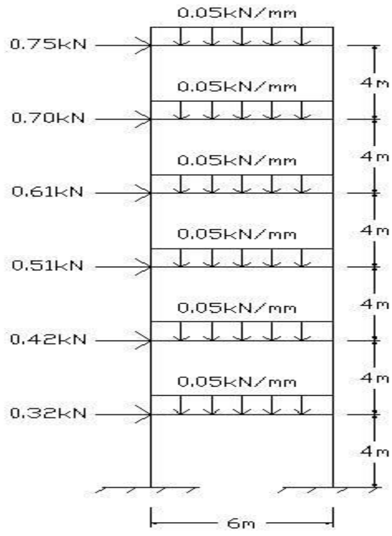

Fig. 7. Analytical model for Case 2

C. Case 3

The same six storeys steel frame structure is fully braced. The uniform distributed load and wind load are considered as shown in Figure 8. The type of brace used for this case is double channel with size of 260 x 90 x 35, mass per meter is 34.8 kg/m which is similar to case 5 and 6 respectively. Case 4 to 6 were based on the effect of brace to the stability of frame structure and the best brace system is identified to be proposed in real world.

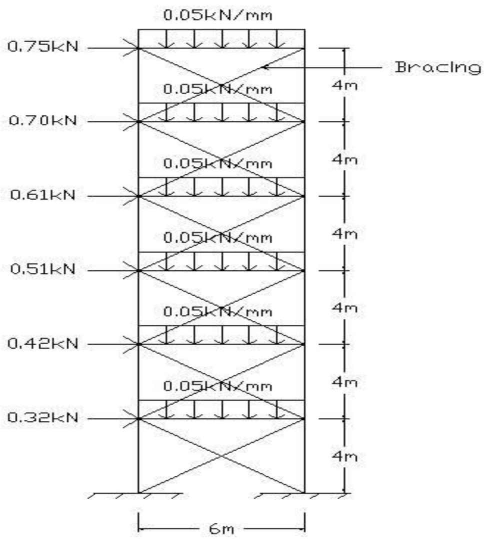

Fig. 8. Analytical model for Case 3 : Steel frame structure with fully braced

D. Case 4

The same six storeys steel frame structure with wind load and uniform distributed load partially braced consideration is from mid height of the building to top of the building. The model is shown in Figure 9.

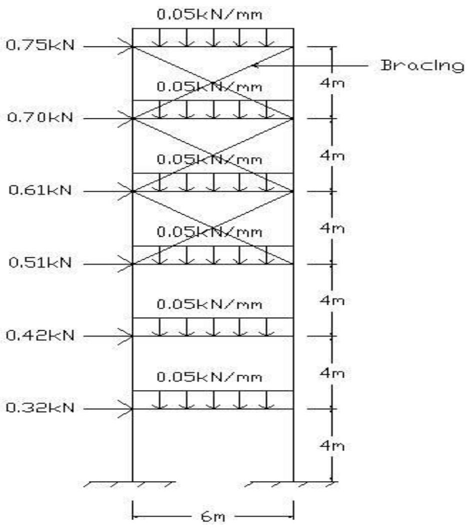

Fig. 9. Analytical model for Case 4 : Partially braced steel frame structure

E. Case 5

The six storeys steel frame structure with wind load and uniform distribution load consideration was applied with alternate bracing. Figure 10 shows the model for case 5.

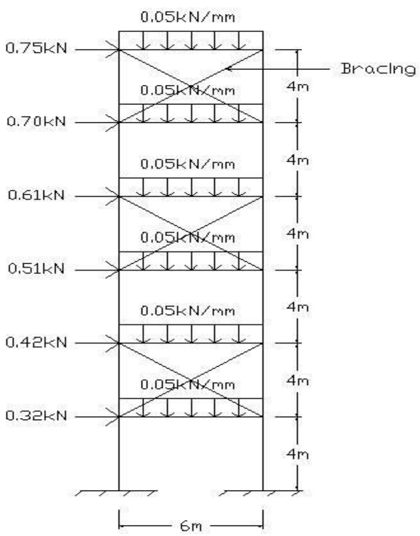

Fig. 10. Analytical model for Case 5 : Steel frame structure with alternate bracing system

F. Case 6

The six storeys steel frame structure with wind load and distributed load consideration, the value of distributed load at third level to top level was increased from 0.05 kN/mm to 0.07 kN/mm. The value of distributed load was increased to study the effect of distributed load on the stability of the frame structure. A clear picture of this model is shown in Figure 11.

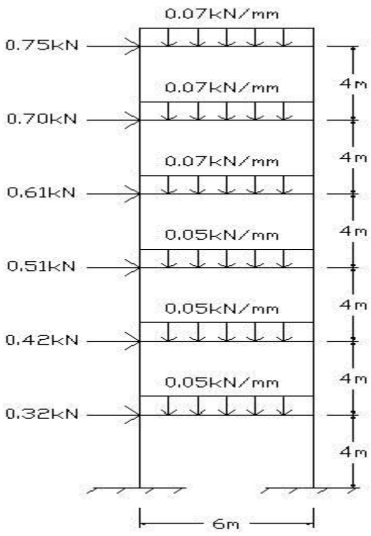

Fig. 11. Analytical model for Case 6 : Higher value of distributed load

G. Case 7

The six storeys steel frame structure with wind load and distributed load consideration, the value of distributed load from third to top level of the frame was decreased from 0.05 kN/mm to 0.03 kN/mm. The results from this model was combined together with Case 6 to study the effect of distributed load to the stability of the structure. A clear picture of this model is shown in Figure 12. Case 6 and 7 are also important especially to designers in designing the building structure.

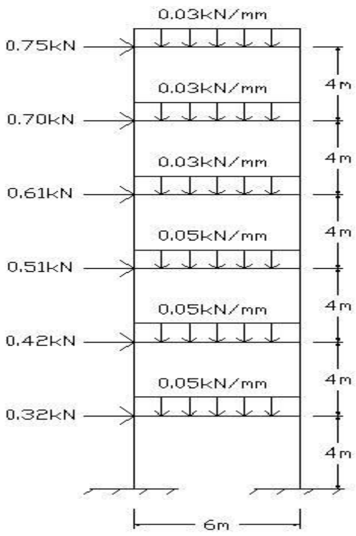

Fig. 12. Analytical model for Case 7 : Lower value of distributed load

IV. RESULTS AND DISCUSSIONS

Case 1 represents the linear and non linear analysis of steel frame without wind load. The result of sway was obtained from SAP2000 for floor's level 0, 1, 2, 3, 4, 5 and 6 as shown in Table 2.

TABLE II
SWAY FOR LINEAR AND NON LINEAR ANALYSIS OF STEEL FRAME WITHOUT WIND LOAD – CASE 1

Level	Linear (mm)	Non Linear (mm)
0	0.0000	0.0000
1	0.0183	0.0183
2	-0.0029	-0.0029
3	0.0008	0.0008
4	0.0025	0.0025
5	0.0157	0.0157
6	-0.0521	-0.0521

The displacement at level 0 for all cases was 0 mm because of fix restraint at joint. From Table 2 it shows that a frame with the absence of wind load or horizontal force was stable because the column can be considered stable in tension and unstable in compression. The displacement value only consider x direction or sway, U1 in SAP2000.

Case 2 is a linear and non linear analysis of steel frame structure with the consideration of wind load. The result of sway was obtained from the analysis using SAP2000 for floor's level 0, 1, 2, 3, 4, 5 and 6 as shown in Table 3.

TABLE III
SWAY FOR LINEAR AND NON LINEAR ANALYSIS OF STEEL FRAME WITH THE CONSIDERATION OF WIND LOAD - CASE 2

Level	Linear (mm)	Non Linear (mm)
0	0.0000	0.0000
1	0.3123	0.3261
2	0.6853	0.7192
3	1.0503	1.1005
4	1.3475	1.4086
5	1.5892	1.6566
6	1.6582	1.7287

Sway for steel frame structure by considering no wind effect was found smaller than the sway of steel frame caused by wind. The difference was found more than 90%, as shown in Table 4 for both linear and geometric non linear analysis, respectively. This shows that it is more practical to consider wind factor and areas to construct tall building to avoid sway problem. Engineers are suggested not to underestimate the load comes from wind because at certain wind speeds it can cause major crack resulted from the sway effect.

For tall building structures, height/1000 is a limit required for acceptable movement of sway at the top side of the buildings. For example, sway at top side for case 2 was 24.2466 mm and was found greater than height/1000 which was 24 mm. Thus this structure is considered unsecure. Another factor require attention is the height of the steel frame structure is keep 24 m because the limit to analysis as static is $h/b \leq 4$. Furthermore, analysis as dynamic is more complicated and SAP2000 only can analysis a static analysis for horizontal load. This is the reason why the wind speed is a huge factor to reach the limit of failure for this steel frame structure.

TABLE IV
SWAY VALUE DUE TO WIND AND NO WIND EFFECT PREDICTED FROM LINEAR AND NON LINEAR ANALYSIS

Type of Analysis	Sway (mm)					
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Linear Analysis (wind effect)	0.3123	0.6853	1.0503	1.3475	1.5892	1.6582
Linear Analysis (no wind effect)	0.0183	-0.0029	0.0008	-0.0025	0.0157	-0.0521
Percentage Different (%)	94.14	100.42	99.92	100.19	99.01	103.14
Non Linear Analysis (wind effect)	0.3261	0.7192	1.1005	1.4086	1.6566	1.7287
Non Linear Analysis (no wind effect)	0.0183	-0.0030	0.0008	-0.0025	0.0158	-0.0521
Percentage Different (%)	94.39	100.42	99.93	100.18	99.05	103.01

Linear analysis and geometric non linear analysis require different formula and approach to overcome any structural problem. Of these differences, the geometric non linear was conducted based on deformed configuration [6]. At the same time, the stiffness matrix, will be updated and become reduced. This is to ensure that the sway results predicted from geometric non linear analysis is greater than linear analysis approximately more than 4%. The graph shown in Figure 13 was used to illustrate more clearly about the sway results obtained from linear and geometric non linear analysis. This finding shows that geometric non linear analysis seems to be important and cannot be underestimated. But with this small percentage difference, it can be neglected if the structure is not categorized as tall building.

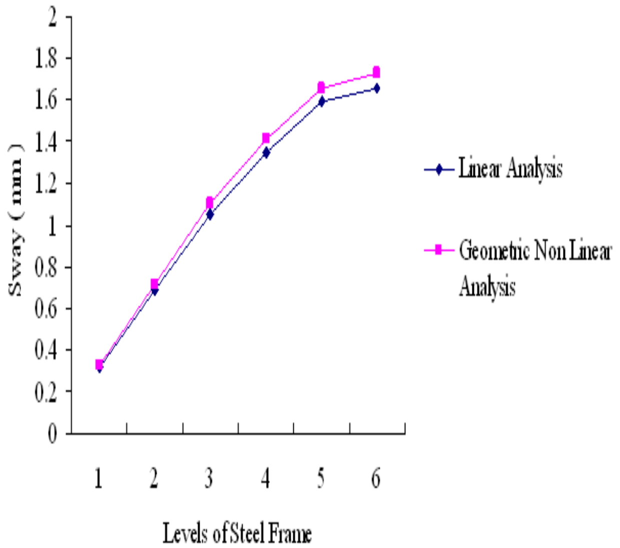

Fig. 13. Comparison between the results from linear and geometric non linear analysis

Case 3,4 and 5 is referring to linear and non linear analysis of steel frame structure with full bracing, placed at half of the building at top side and alternate bracing. The distributed load and wind load at different level of the steel frame structure is similar to Case 2. The result of sway is summarized in Table V.

TABLE V
COMPARISON OF SWAY FOR SEVERAL METHODS OF BRACING SYSTEM

Level	Fully		Placed at half of building (top side)		Alternate	
	Linear (mm)	Non Linear (mm)	Linear (mm)	Non Linear (mm)	Linear (mm)	Non Linear (mm)
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.1897	0.1899	0.3116	0.3255	0.3173	0.3254
2	0.1584	0.1586	0.6793	0.7127	0.3316	0.3401
3	0.1769	0.1773	1.0350	1.0813	0.5382	0.5534
4	0.1851	0.1857	1.0957	1.1428	0.5776	0.5933
5	0.2308	0.2315	1.1360	1.1839	0.7291	0.7473
6	0.1778	0.1787	1.0835	1.1321	0.6986	0.7173

There are several approaches that can be applied to decrease the sway such as using bracing system, applying different distributed load on beams and increasing the column sizes. From the analysis results shows that full bracing on steel frame gives smaller sway values as compared to the sway induced by placing the bracing at upper part of the building and an alternate bracing. If cost aspect is considered, alternate bracing system provide better solution and less sway values as compared to the steel frame build up with bracing system at upper part of the building as shown in Figure 14. The result also shows that the shape of sway is similar to S shape that also known as double curvature and can be considered as stiff. This is the best shape of sway compared to the other types of shape of sway [7].

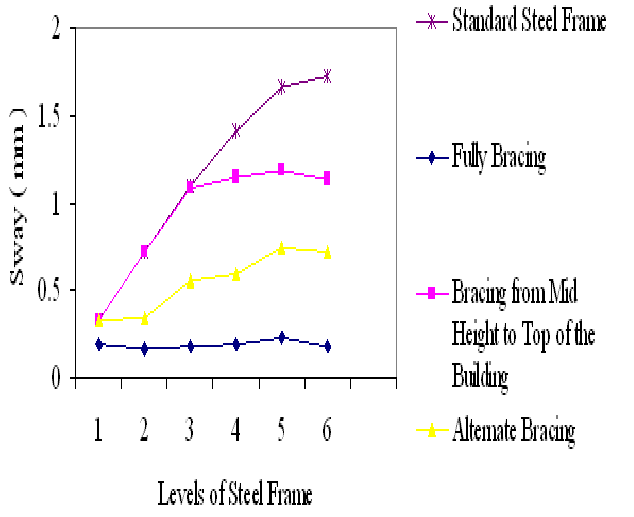

Fig. 14. Comparison of sway prediction (Geometric non linear analysis) due to different type of bracing system

From the analysis result for case 6 and 7, it shows that the average decreasing of distributed load on beam's element gave a smaller value of sway and increased in the stability of the building (see Table 6). Accordingly, for a tall building structure, it is suggested to have small load at the upper part of the building or can be decided to decrease the load gradually from bottom to top floor. Figure 15 shows the sway for steel frame structure due to normal, higher and lower values of distributed load acted on beam's element.

TABLE VI
COMPARISON OF SWAY FOR SEVERAL METHODS OF BRACING SYSTEM

Sway (mm)	Linear	Non Linear	Linear	Non Linear	Linear	Non Linear
Level	Standard Steel Frame		Higher Distributed Load		Lower Distributed Load	
1	0.3123	0.3261	0.3125	0.3291	0.3120	0.3231
2	0.6853	0.7192	0.6839	0.7252	0.6867	0.7131
3	1.0503	1.1005	1.0592	1.1215	1.0414	1.0796
4	1.3475	1.4086	1.3553	1.4323	1.3396	1.3849
5	1.5892	1.6566	1.5940	1.6796	1.5844	1.6337
6	1.6582	1.7287	1.6379	1.7276	1.6785	1.7279

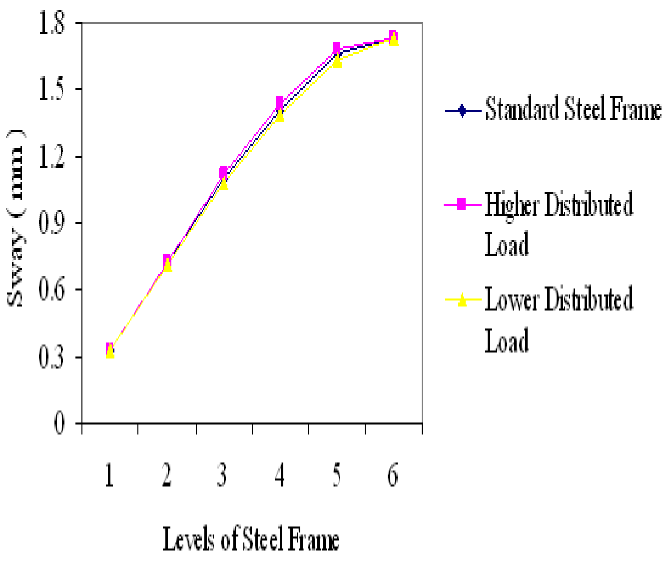

Fig. 15. Comparison of sway due to different distributed load from geometric non linear analysis

V. CONCLUSIONS

Based on the results obtained from the analysis of steel frame structure, the following conclusions can be made.

1. It is recommended to consider the wind load and the area to construct tall building which able to eliminate or reduce the wind effect that may hit the building and increases the sway values. A threshold limit of wind speed is necessary to ensure the building is secure prior use.

2. This study clearly shows that the sway prediction from geometric non linear analysis is greater than linear analysis approximately 4 to 5 % different. Therefore, this study suggested that geometric non linear analysis is not significant to be applied in the analysis of structure because of the small percentage difference. This is because the model of steel frame structure is only 24 m and maybe more applicable for real tall building. Therefore, it is more practicable to use geometric non linear analysis because the

slenderness of the structure will be counted in the geometric non linear analysis.

3. It is more practicable to put bracing system, to decrease the distributed load on upper part of the building and at the same time having higher stiffness at lower part of the building which decreases the sway value and improve the stability of the building.

ACKNOWLEDGMENT

In the process of preparing and completing this report, I was in contact either directly or indirectly with many people, academicians and wholesaler. They have contributed towards my understanding and thought.

In particular, I wish to express my greatest appreciation to my supervisor, Assoc. Prof. Dr. Suhaimi Abu Bakar for his encouragement, guidance, critics, and motivations. Without his continued support and interest, this study would have been the same as presented here.

At the same moment, I am grateful to all my family members for their support and encouragement. My sincere appreciations also to my beloved husband, Mohd Faisal bin Mohd Azlan and my father in law, Dr. Mohd Azlan bin Yahya who have provided assistance and useful tips indeed. Finally, special thank dedicated to Universiti Malaysia Perlis and Ministry of Higher Education for giving opportunity to sponsor my master and those who directly or indirectly involve in the process of producing this study.

I hope my findings in this study will expand the knowledge in this field and contribute to all of us in future.

REFERENCES

[1] Daniel L. Schodek, "*Structures, Fifth Edition*", Pearson Prentice Hall, page 15 -21, 2004.

[2] Mc Guire, W., Gallagher, R.H. and Ziemian, R.D., "*Matrix Structural Analysis Second Edition*", John Wiley & Sons Publication, page 217-218, 2000.

[3] Hingginbotham , A.B. and Hanson, *Axial Behaviour of Steel Members*, Journal of the Structural Engineering Division, ASCE, Volume 106, 1976.

[4] Emil Simiu and Robert H. Scanlan, *Wind Effects on Structures*, 1996, John Wiley & Sons Publication, 1996.

[5] British Standard, CP3 Chapter V (Part 2). *Wind Loads*, London, 1972.

[6] El Zanaty, M. H and Murray, D.W, "*Nonlinear Finite Element Analysis of Steel Frames*", Journal of Structural Engineering, Volume 109, No. 1 – 4, 1983.

[7] M. Farshad, "*Stability of Structures*", Elsevier Science B.V, page 2, 1994.

Mrs. Shamshinar binti Salehuddin is a junior lecturer of civil engineering at Universiti Malaysia Perlis, Malaysia for almost 3 years. She received her degree of civil engineering from Universiti Teknologi Malaysia, Malaysia on 2008 and master of civil engineering (structure) on 2011.

She has working experience as engineer civil and structure for 1 year more in design and building construction. While her research more focuses in material and structure. Example papers already published are 'Properties of Modified Sand Brick Using Coconut Shell' and 'Performance of Nonwoven Geotextile as a Filter at Road Shoulder'.

She was a member of Board of Engineers Malaysia (BEM), Institute of Engineers Malaysia (IEM), International Association of Computer Science and Information Technology (IACSIT) and Science and Engineering Institute (SCIEI).