International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:4, No:12, 2010

Deflection Control in Composite Building by Using Belt Truss and Outriggers Systems

S. Fawzia and T. Fatima

Abstract**—**The design of high-rise building is more often dictated by its serviceability rather than strength. Structural Engineers are always striving to overcome challenge of controlling lateral deflection and storey drifts as well as self weight of structure imposed on foundation.

One of the most effective techniques is the use of outrigger and belt truss system in Composite structures that can astutely solve the above two issues in High-rise constructions.

This paper investigates deflection control by effective utilisation of belt truss and outrigger system on a 60-storey composite building subjected to wind loads. A three dimensional Finite Element Analysis is performed with one, two and three outrigger levels. The reductions in lateral deflection are 34%, 42% and 51% respectively as compared to a model without any outrigger system. There is an appreciable decline in the storey drifts with the introduction of these stiffer arrangements.

Keywords**—**Composite building, belt truss, deflection, FE model, outrigger truss, 3D analysis.

I. Introduction

DURING the last few decades several buildings have been built utilizing belt truss and outrigger system for the lateral loads transfer (throughout the world). This system is very effective when used in conjunction with the composite structures especially in tall buildings (Fig 1).

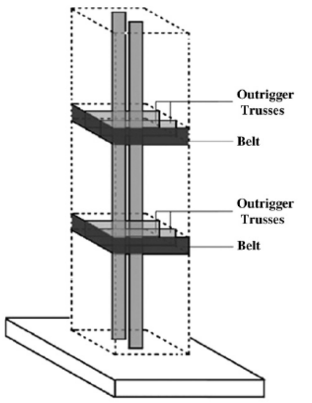

Fig. 1 Multi-level belt truss and outrigger

S. Fawzia is with Department of Urban Development, Faculty of Built Environment and Engineering, Queensland University of Technology, Brisbane 4000, Australia. (Phone: 617-31381012; fax: 617-3138 1170; e-mail: sabrina.fawzia@qut.edu.au).

Tabassum Fatima is with Department of Urban Development, Faculty of Built Environment and Engineering, Queensland University of Technology, Brisbane 4000, Australia. (e-mail: tabassum.fatima@qut.edu.au).

Taranath, [1], states that apart from economy of material and speed of construction, composite structures due to being light weight inflict less severe foundation conditions hence results in greater cost savings. Moreover; stiffness of concrete is more effective in controlling the drifts caused by lateral loads.

An example is 53 storeys Chifley tower, constructed in 1992 Sydney, Australia. This building exploits the composite construction along with the use of belt truss and outrigger system for deflection control. It has central steel braced frame core and outriggers placed at two levels along the building height.

Gunel and Ilgin [2], documented that belt truss and outrigger is basically an evolution of braced frame or shear wall framed system.

The belt truss tied the peripheral column of building while the outriggers engage them with main or central shear wall. Therefore; exterior columns restrained the core wall from free rotation through outrigger arms. This system is also effective in the control of differential settlement of columns.

Iyengar [3], demonstrated the deflection control on a two dimensional model with the use of outriggers trusses. A 25% reduction is achieved by the use of this system as well as 32% reduction is attained with steel exterior column.

Kian and Siahaan [4], has studied effectiveness of belt truss and outrigger in concrete high rise building. They have shown that deflections can be controlled effectively by the efficient use of this arrangement.

The effectiveness of belt truss and outrigger arrangement is an established fact, though; there is always argument on the reduction of operational space at the outrigger level. This however; can be minimized by the use of diagonal cross bracing mostly in line with columns as well as use of horizontal truss that can be embedded in the false ceiling.

Nair, [5], proposed the concept of "virtual" outrigger system where floor diaphragms, which are typically very stiff and strong in their own plane, transfer moment in the form of a horizontal couple from the core to trusses or walls that are not connected directly to the core.

Composite structure has long been established itself as a distinctive construction system which is a blend of structural steel and reinforced concrete. However; there is a lacking of detailed investigation on various aspects of this system and one being the effective utilisation of Belt truss and Outrigger system in Composite buildings for lateral deflections control.

As contrast to concrete structure composite construction utilises the use of structural steel section in columns that results in higher strength but less section size and thereby reducing the stiffness of vertical building elements. In the same way profiled sheeting serve as sagging reinforcement increasing the strength and reducing the cross-section areas of slab. These results in lower self weight, but; their behaviour to the lateral loads and provision of cross bracings need to be examined. Therefore; this paper presented the impact of steel diagonal outriggers and belt truss system when used with a composite high-rise building.

II. Modelling description:

The equivalent transformed properties of the structural elements i.e. composite slab and composite columns have been used in a three dimensional model to get the maximum realistic behaviour of the building under dynamic wind loads. These loads are calculated for 25 years return period based on the guidelines provided in Australian Standard, Appendix C [6]. The full advantage of the various structural components is achieved through three dimensional (3D) analysis of building in Strand7 [7] software.

Provision of two and more outriggers is desirable in most of slender and tall structures. This is to provide sufficient stiffness and avoid undesirable vibrations and discomfort to the tenants as well as to supply additional stability against the higher lateral loads. Therefore the option of three outrigger arrangement is also investigated in this paper.

CTBUH (Council on Tall buildings and Urban Habitat) provides no specific definition of a tall building and argued that the defining factors are its location whether it is situated in Hong Kong or in a provisional European suburb. Therefore in this case, the criterion of height selection is solely based on the urban norm of Australia. The floor to floor height chosen is also being used as a general practice in offices to facilitate concealment of the service ducts, wiring etc.

A typical layout has been selected with 5 equal bays (7400 mm) in long direction (X-Axis) and 3 bays of different size in short direction (Y-direction) as shown in (Fig. 2). Structural modelling configuration used for modelling is given in Table 1.

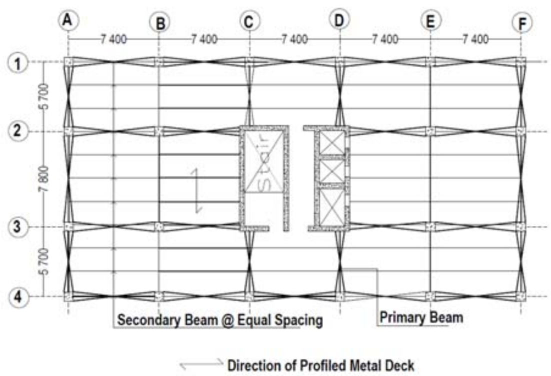

Fig. 2 Floor Layout

TABLE I
Model Structural configuration

Element	Description
Slab	Concrete deck with profiled sheeting
Main and Secondary Beams	Structural Steel Universal Beam sections.
Column	Steel WC and UC section encased in reinforced concrete
Core wall	Reinforced concrete
Belt Truss and outriggers	Structural Steel Universal column sections

A. *Model assumptions*:

1) The model is 60 storeys with floor to floor height of 3.5 m making total height of the building as 210m (Fig. 3).

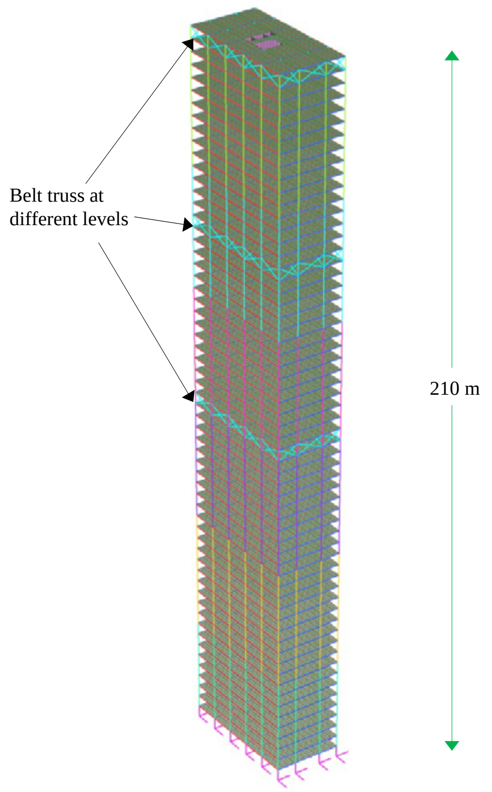

Fig.3 Strand7 3D building elevation

2) Braced core frame i.e. reinforced concrete core acting in conjunction with the belt truss and outrigger provides the resistance to the wind loads (Fig. 4, 5, 6, 7).

International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:4, No:12, 2010

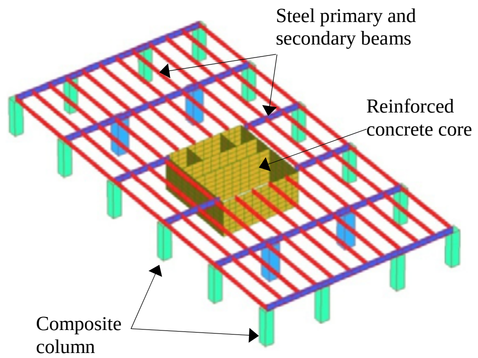

Fig. 4 Strand7 3D view of floor layout

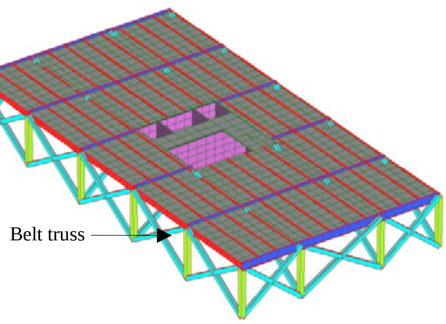

Fig.5 Strand7 3D view of floor slab and belt truss

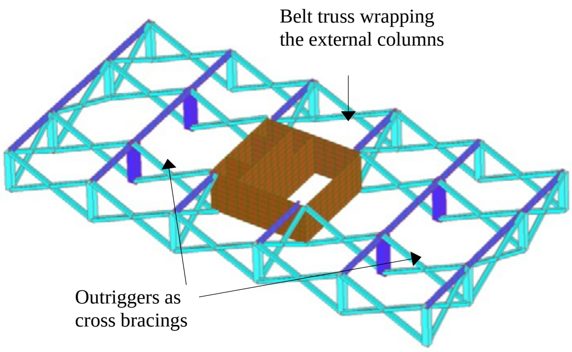

Fig.6 Strand7 3D view of Outrigger and belt truss

3) Simple construction is adopted for this building based on definition provided in Australian Standards [8]. Rotation end releases are provided to all beams to get the pinned action. Therefore columns only provide the gravity load path to the base.

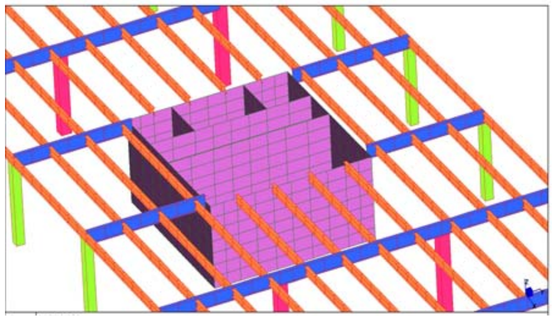

Fig.7 Strand7 3D enlarged view of floor layout

4) The axial stiffness of the central core and column decreases linearly with the structural height.
5) Fixed support is provided to the core at the base while column are pinned (Fig. 8).

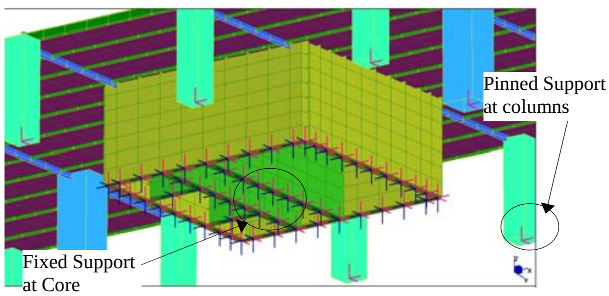

Fig. 8 Strand7 3D view showing support conditions

6) One level outrigger is provided in all options.
7) Steel sections are chosen from ASI design capacity tables for the calculation of column equivalent transformed properties [9].
8) Lysaght bondek manual is used for the properties of profiled metal sheeting [10].

To get the maximum effects of composite system equivalent transformed properties of slabs and columns are calculated for the model. Slab consists of metal sheeting with concrete topping while WC and UC sections are used in columns.

Transformed Elastic Modulus of composite Section is:

$$A_c E_c + A_{ST} E_s = A_g E_T$$

Transformed Density of Composite Section is:

$$A_c \gamma_c + A_{ST} \gamma_s = A_g \gamma_T$$

Here:
A_g = Gross area of section
A_c = Area of concrete
A_{ST} = Area of steel
E_c = Elastic modulus of concrete
Es = Elastic Modulus of steel
E_T= Elastic modulus of transformed section
γ_c =Density of concrete
γ_s = Density of steel

γ_T = density of transformed section

The building is analysed for the Dynamic along wind response applied to the weak axis of the building. The wind loads are calculated based on Australian standards [11] for Non-cyclonic region B and terrain category 4. The regional wind speed of 39 m/s is considered for an annual probability of exceedance of 1/25. The loads are varied along the height of the structure (Fig.9).

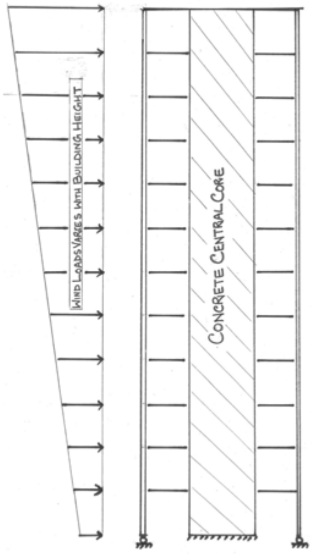

Fig. 9 Diagrammatic representation of variable wind loads

B. Basic model arrangements:

1) Model without belt truss and outrigger (MT0).
2) Model with one belt truss and outrigger (MT1). Various models are run in order to get the optimum location of the belt truss.
3) Model with double belt truss and out rigger (MT2). This model has one belt truss and outrigger fixed at top level, whereas many models has been run to find the optimum placement of second outrigger.
4) Model with three belt truss and outrigger (MT3). One location for the belt truss and outrigger is fixed at the top level whereas the many models have been run to get the best location of rest of the two cross bracings.

III. Results

The use of outrigger and the belt truss has improved the serviceability of the structure. Four options are compared in Fig.10, including the structure without any outriggers. The results show appreciable decline in the deflection with the use of outrigger system. There is 34% reduction by the use of one outrigger at the effective level. Whereas 41% and 51% drop is achieved by the use of two and three outrigger levels with respect to MT0 (Table 2).

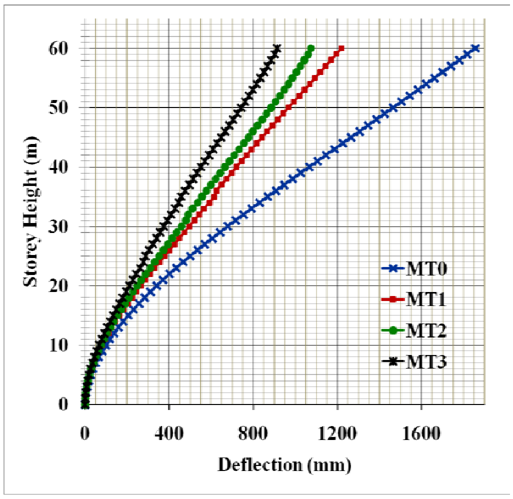

Fig. 10 Comparison of various outrigger options

TABLE II
Maximum Displacement and Percentage Reduction in Deflection for Each Option

Outrigger Options	MT0	MT1	MT2	MT3
Δ @ Top (mm)	1855.21	1219.4	1073.80	913.63
% Reduction in Δ	-	34%	42%	51%

There is a sudden fluctuation and change in the gradient of slope with the addition of outrigger levels as can be seen in Fig.11. The outrigger levels for MT1and MT2 are level 36, level 32 respectively whereas outriggers are provided at level 25 and Level 35 for MT3.This variation indicates the higher stiffness at these levels. This stiffness is helping the structure to control the inter-storey drift and consequently minimising the displacements of the building. a similar trend in the percentage reduction of storey drift is also obtained (Table 3) as is present in deflection reduction of different outrigger arrangements.

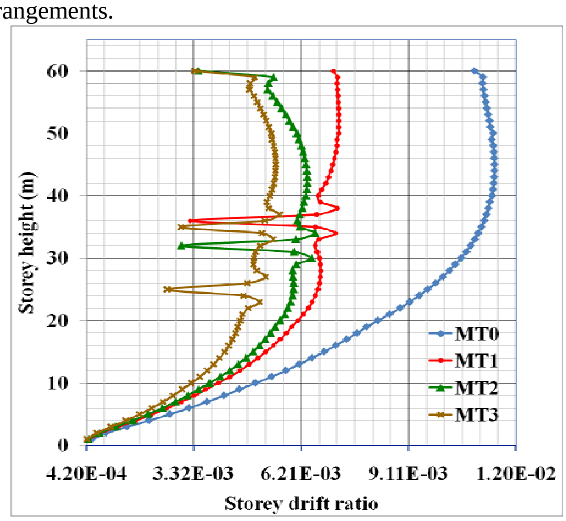

Fig. 11 Storey drifts comparison of various outrigger options

TABLE III
MAXIMUM STOREY DRIFT AND PERCENTAGE REDUCTION IN STOREY DRIFT (δ) FOR EACH OPTION

Outrigger Options	MT0	MT1	MT2	MT3
Max. drift δ (mm)	1.14E-02	7.23E-03	6.59E-03	5.61E-03
% Reduction in δ	-	37%	42%	51%

Fig. 12 shows that the best location for one outrigger option (MT1) is at level 36, i.e. 0.6 times the height of the structure. The best location for second outrigger of two outrigger system (MT2) is 0.5 times the structure height while one is fixed at the top level Fig. 13.

Three outrigger options is run for various arrangements of levels (see Table 4). The optimum location obtained as can be seen in Fig.14, is MT3_1 which has outriggers at level 25 and level 35 while one is provided at the top level. It is noted that an additional 17% reduction in deflection is obtained by the introduction of the two outrigger levels at the optimal position along the structure height.

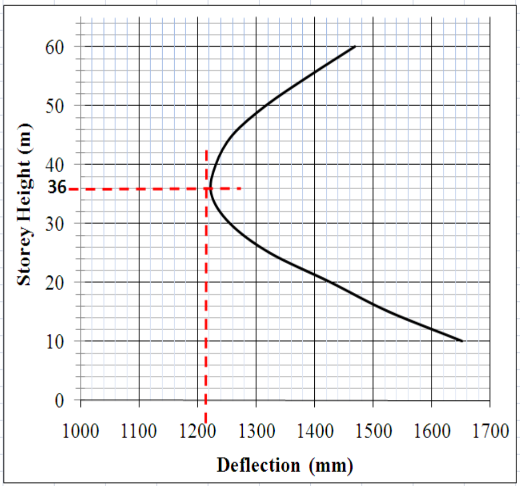

Fig. 12 Optimum Location of Outrigger for MT1

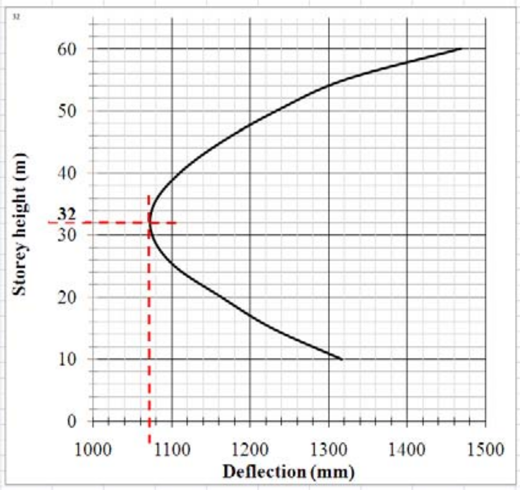

Fig. 13 Optimum Location of Outrigger for MT2

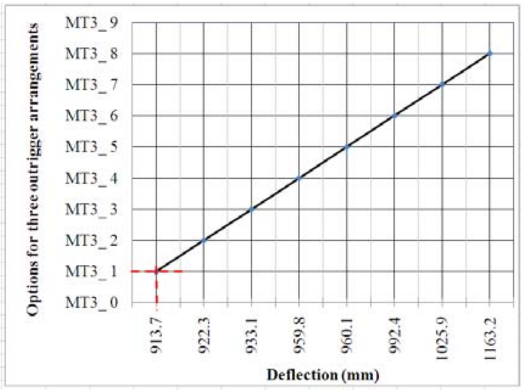

Fig. 14 Optimum Location of Outrigger for MT3

TABLE IV
VARIOUS ARRANGEMENTS FOR THREE OUTRIGGER OPTIONS

Type	Outrigger Levels		
MT3_1	L60	L25	L35
MT3_2	L60	L30	L40
MT3_3	L60	L30	L45
MT3_4	L60	L30	L50
MT3_5	L60	L35	L45
MT3_6	L60	L15	L45
MT3_7	L60	L40	L50
MT3_8	L60	L20	L40

IV. CONCLUSION

The rigorous three dimensional analyses provided very approving results in the form of effective deflection control in somewhat slender and tall structure. The Belt truss and outrigger system is not only proficient in controlling the overall lateral displacement but also very capable of reducing the inter-storey drifts in composite building.

The introduction of two and three outrigger levels results in a further 8% and 9% deflection reduction respectively. A comparable fashion can be seen in the reduction of inter-storey drifts as in displacements.

REFERENCES

[1] B.S. Taranath, *Structural Analysis & Design of Tall Buildings*. New York, Mc Graw Hill, 1998.

[2] M. H. Gunel, and H.E. Ilgin, *A proposal for the classification of structural systems of tall buildings*. Faculty of Architecture, Middle East Technical University, Ankara 06531, Turkey, 4 July 2006.

[3] I. Hal, *Composite and Steel High Rise Systems*. Habitat and The High-Rise, Tradition & Innovation. In Proceedings of the Fifth World Congress. 14-19 May 1995.Amsterdam, The Netherlands, Bethlehem, Pa : Council on Tall Building and Urban Habitat, Lehigh University

[4] P.S. Kian and F.T.Siahaan, *The use of outrigger and belt truss system for high-rise concrete buildings*. Dimensi Teknit Sipil, Volume 3, No1, Maret 2001, Page 36-41,ISSN1410-9530.

[5] R. S. Nair, *Belt Trusses and Basements as "Virtual" Outriggers for Tall Buildings*. Engineering Journal / Fourth Quarter/ 1998.

[6] Standards Australia/Standards New Zealand, *Structural design actions*, Part 0: General principles, Appendix C, Guidelines for Serviceability Limit State (Informative), AS/NZS 1170.0:2002.

[7] Strand7 Pty Ltd. Strand7, *Finite Element Analysis System*, User's Manual 2005, Sydney, Australia.

[8] Standards Australia, *Steel Structure*, , AS 4100:1998.
[9] Australian Steel Institute (ASI), *Design Capacity Tables*, Volume 1, Fourth edition 2009.
[10] BlueScope Lysaght Manual, *Using Bondek- design and construction guide 2003 edition*, BlueScope Steel limited, Australia.
[11] Standard Australia/Standard New Zealand ,*Structural design actions* Part 2: Wind actions, ASNZS 1170.2:2002