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Comparative Study of Pentagrid and Hexagrid Structural System for Tall Building

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Abstract: **Due to heavy urbanisation and population growth, vertical growth has become challenging thing in the building industry. This challenge is handled by using material of high strength and light weight. In addition to imposition of advanced efficient structural forms for gravity and lateral loads, there is continuous development to control structural distortions, in this regard bracing systems have the responsibility of controlling lateral responses. The present investigation involves the study of efficiency of peripheral pentagrid and hexagrid bracing systems compared with the basic model (without bracings) at standard loading conditions. Three tall buildings of 40, 50 and 60 stories with structural forms of rigid frame-slab, shear walls with flat slabs, flat slabs with columns are considered for comparison. Lateral bracings of pentagrid & hexagrid shape with rigid connections are made to these models by using RC members of 200 x 200 mm. The lateral response of these models are compared for least displacements.**

1. INTRODUCTION

Due to the heavy urbanisation and population growth, the cost of land is increasing rapidly and the land availability has become a constraint for developers & builders. And this creates a picture of vertical growth as natural process. Control of lateral responses keeping an eye on constructability & cost become order of the day for structural engineers. The increased wind pressure due to the large exposed area of the building, high intensity of the wind at higher elevations and the earthquake loads add to the bulk of structural forces. The present study is based on such bulk lateral forces & minimising their effects on life of tall structure. Here it is attempted to derive at a stability optimised structural system – i.e pentagrid structural system, which is configured to transfer the lateral loads to the foundation mostly through the axial forces in the members of it.

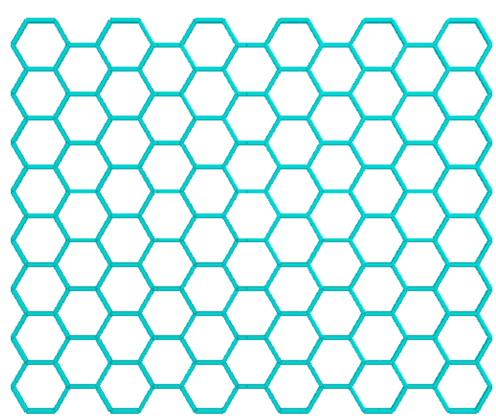
2. EFFICIENCY OF LATERAL LOAD RESISTING SYSTEM

Most common structural forms & their efficiencies are given a first thought which bear their own advantages, disadvantages and efficiency. The moment resisting frame is the structural system developed by forming the rigid joints between beams and columns of a structure.

Framed tubular structure developed by forming rigid joints between several closely spaced columns and deep spandrel beams on perimeter can be of steel or concrete has the disadvantage of shear lag which hinders the true behaviour of tubular structure. ***Braced tubular structure*** is a tubular structure with diagonal bracings spanning multiple stories can be made up of steel & concrete and can efficiently resists shear by axial forces in the diagonal members with wider column spacing are observed to have reduced shear lag but with the obstructions to architectural view. ***Bundled tube*** is a type of moment resisting frame formed by bundling several tubular structure side by side by using both steel and concrete materials. It has an advantage of reduced shear lag but internal planning can be obstructed because of bundling of several tubes. ***Diagrid*** structural systems are of quite new origin inspired by diagonal bracings. Here the lateral load resisting mechanism has an ideal advantage of transforming the lateral shear into axial force in the diagonal members but has complicated joints for steel material and expensive formwork for concrete material.

3. THE HEXAGRID STRUCTURAL SYSTEM

The Hexagrid structural system recently evolved, rarely executed is inspired by the 'Beehive' (one of the stable structure of nature). This structural system is made by arranging several hexagons of height equal to story height in a unique way as in Beehive.



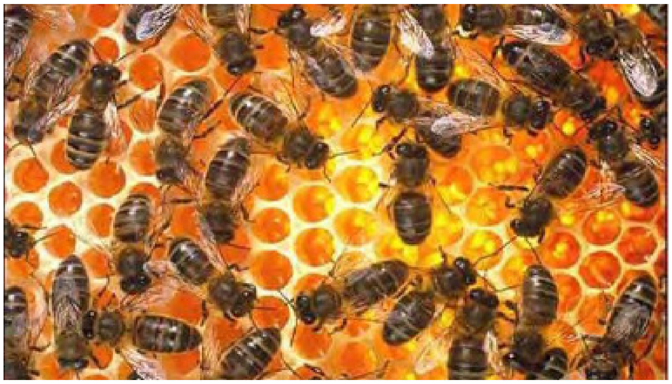


Fig. 3.1. (a) Hexagrid structural system (b) Beehive

Hexagrid system rests on a regular polygon with six elements system. This system has an advantage of uniform distribution of stresses in itself due to uniform angle of 120^0 between any two elements but has disadvantage of very less lateral stiffness.

4. THE PENTAGRID STRUCTURAL SYSTEM

The pentagrid structural system is derived by smartly arranging several technically developed irregular pentagons - alternatively inverted both in horizontal as well as vertical directions. This structural system is developed by using ***multi angle concept*** by which all the elements share both gravity as well as lateral loads partially. Actual pentagrid structural system used is shown in the figure 4.1.

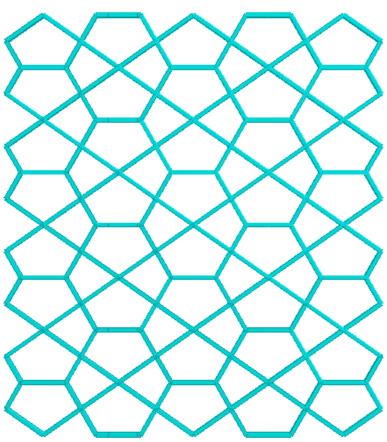


Fig.4.1. Pentagrid structural system

Unlike most of other structural systems this structural system is non nature inspired but it is technically devised by applying mathematics so that it can resists both shear force as well as bending moment developed in the structure due to gravity as well as lateral loads. The figure 4.2 shows a technically devised irregular pentagon with notations, angles and its dimensions.

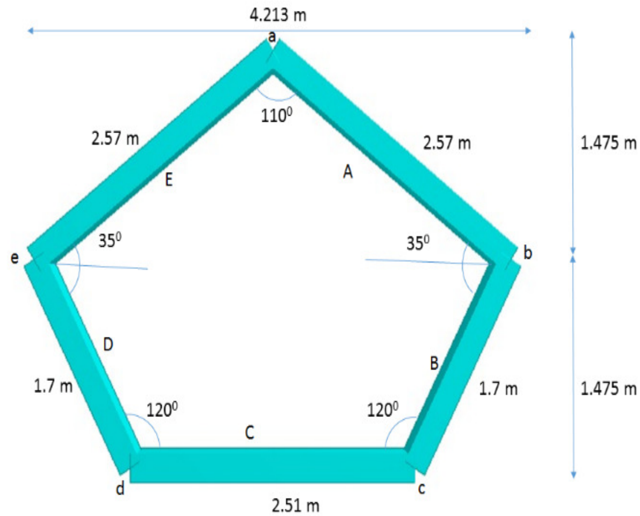


Fig. 4.2. Pentagon of a pentagrid structural system

There are 5 elements in the pentagrid structural system. ***The length of each element is depend on the story height***. Referring to figure 4.3 the elements A and E are inclined to the horizontal at an angle 35^0 and ***their vertical height is fixed to half the story height***. Other half of story height is provided with elements B and D whose internal angle is made sure to have an internal angle of 120^0 with the horizontal element C.

The angle 35^0 of the elements A and E in the figure 4.2 is decided on the optimisation technique to reduce lateral displacement (*K. Moon – 2007).* The following procedure has been adopted.

Referring to figure 4.3 the total vertical shear in the diagonal elements is given by,

$$V = 2F_d cos\theta \qquad (1)$$

Assuming linear elastic behaviour, the member forces can also be expressed in terms of strain ε_d by,

$$F_d = A_d\sigma_d = A_d E_d \epsilon_d \qquad (2)$$

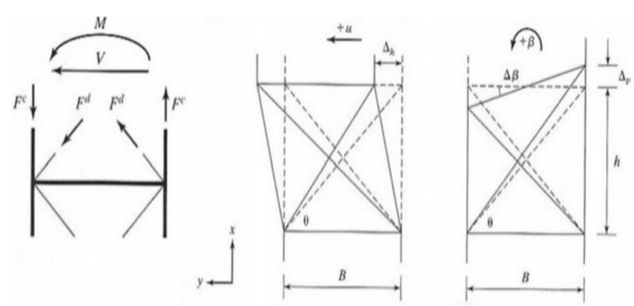


Fig.4.3. Brace frame model

The extensional strain due to the relative lateral motion between adjacent nodes is a function of Δ_f and θ,

$$\varepsilon_d = \frac{E_d}{L_d} = \frac{\Delta_h cos\theta}{\frac{h}{\sin\theta}} = \frac{\Delta_h cos\theta sin\theta}{h} \quad (3)$$

We obtain the following approximation for the total extensional strain

$$\varepsilon_d = \frac{\Delta_h}{h} cos\theta sin\theta = \frac{\Delta_h sin2\theta}{2h} \quad (4)$$

Combining the above equations results in the following expression for this shear force:

$$V = (A_d E_d sin2\theta cos\theta)\frac{\Delta_h}{h} \quad (5)$$

It follows that,

$$\Delta h = \frac{Vh}{A_d E_d \sin 2\theta \cos\theta} \quad (6)$$

The equation 6 can be used to calculate the optimal angles of members A and E with the horizontal. The plot of θ against displacement is shown in Figure 4.4, indicating that the optimal angle for maximum shear rigidity of the system is about ***35***°.

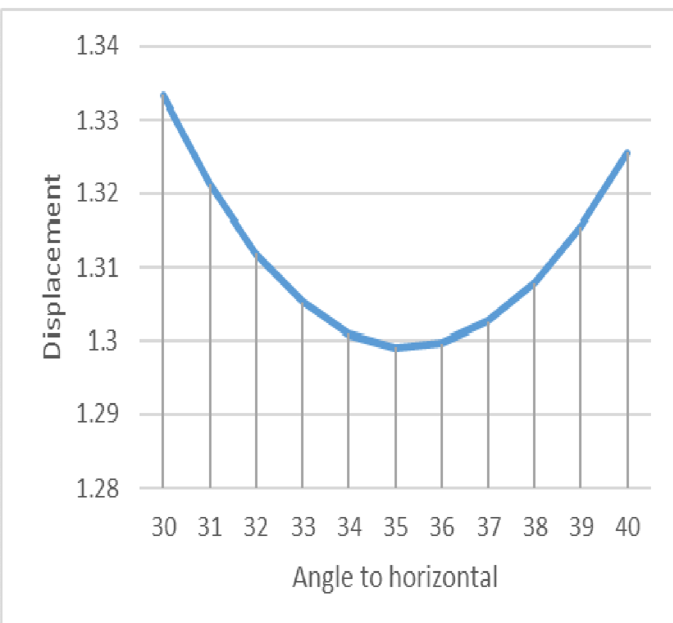


Fig. 4.4. Displacement v/s θ curve

The angles of elements B and D are selected straight forwardly 120^0 as in Hexagrid structural system assuming there will be equal distribution of the stresses between elements B, D and C as discussed in section 3.

These pentagons are arranged alternatively inverted to derive at the pentagrid structural system as shown in the figure 4.1. There are continuous diagonal load paths formed which can effectively resists the shear due to lateral load by axial stresses in it. This structural system shares the loads quite differently unlike the other structural systems. The diagonal patterns of the pentagrid structural system shares the maximum percentage of lateral loads but minimum percentage of gravity loads whereas pattern formed similar to hexagrid system shares minimum percentage of the lateral loads but maximum percentage of the gravity loads.

To understand the behaviour of pentagrid and hexagrid system following 9 basic structural models are analysed.

M1) Rigid frame beam column slab system

M2) Column – flat slab system

M3) Column – shear walls system

M4) Rigid frame beam column slab with Pentagrid

M5) Column – flat slab Pentagrid system

M6) Column – shear walls Pentagrid system

M7) Rigid frame beam column slab with Hexagrid

M8) Column – flat slab Hexagrid system

M9) Column – shear walls Hexagrid system

Above 9 models are considered for 40, 50 & 60 stories resulting in 9 x 3 = 27 Models .The lateral response of these 27 models for standard load conditions are synthesised and studied for their efficiency.

5. RESULTS & DISCUSSIONS

These 27 Models are analysed for static load combinations and lateral responses are tabulated as under.

Table 4.1) 40 Storied Rigid frame beam column slab

Load combination	M1-MODELNo bracing	Hexagrid M7-MODEL	Pentagrid M4-MODEL
1.5(DL+WLX)	100	66	27
1.2(DL+LL+WLX)	100	67	27
1.5(DL+ELX)	100	73	28
1.2(DL+LL+ELX)	100	73	28
1.5(DL+ELZ)	100	91	53
1.2(DL+LL+ELZ)	100	91	53
1.5(DL+WLZ)	100	92	71
1.2(DL+LL+WLZ)	100	93	71

Table 4.2) 50 Storied Rigid frame beam column slab

Load combination	M1-MODEL No bracing	Hexagrid M7-MODEL	Pentagrid M4-MODEL
1.5(DL+WLX)	100	65	29
1.2(DL+LL+WLX	100	66	33
1.5(DL+ELX)	100	73	30
1.2(DL+LL+ELX)	100	73	30
1.5(DL+ELZ)	100	92	57
1.2(DL+LL+ELZ)	100	92	57
1.5(DL+WLZ)	100	91	72
1.2(DL+LL+WLZ)	100	92	72

Table 4.3) 60 Storied Rigid frame beam column slab

Load combination	M1-MODEL No bracing	Hexagrid M7-MODEL	Pentagrid M4-MODEL
1.5(DL+WLX)	100	65	31
1.2(DL+LL+WLX	100	66	32
1.5(DL+ELX)	100	73	33
1.2(DL+LL+ELX)	100	74	33
1.5(DL+ELZ)	100	92	61
1.2(DL+LL+ELZ)	100	93	61
1.5(DL+WLZ)	100	90	74
1.2(DL+LL+WLZ)	100	91	74

Table 4.4) 40 Storied Column – Flat Slab Model

Load combination	M2-MODEL No bracing	Hexagrid M8-MODEL	Pentagrid M5-MODEL
1.5(DL+WLX)	100	68	28
1.2(DL+LL+WLX)	100	69	28
1.5(DL+ELX)	100	74	28
1.2(DL+LL+ELX)	100	75	28
1.5(DL+ELZ)	100	91	55
1.2(DL+LL+ELZ)	100	91	55
1.5(DL+WLZ)	100	92	71
1.2(DL+LL+WLZ)	100	93	73

Table 4.5) 50 Storied Column – Flat Slab Model

Load combination	M2-MODEL No bracing	Hexagrid M8-MODEL	Pentagrid M5-MODEL
1.5(DL+WLX)	100	66	30
1.2(DL+LL+WLX)	100	67	30
1.5(DL+ELX)	100	74	30
1.2(DL+LL+ELX)	100	74	30
1.5(DL+ELZ)	100	92	59
1.2(DL+LL+ELZ)	100	92	59
1.5(DL+WLZ)	100	92	74
1.2(DL+LL+WLZ)	100	93	74

Table 4.6) 60 Storied Column – Flat Slab Model

Load combination	M2-MODEL No bracing	Hexagrid M8-MODEL	Pentagrid M5-MODEL
1.5(DL+WLX)	100	66	31
1.2(DL+LL+WLX)	100	66	32
1.5(DL+ELX)	100	74	32
1.2(DL+LL+ELX)	100	74	32
1.5(DL+ELZ)	100	93	63
1.2(DL+LL+ELZ)	100	93	63
1.5(DL+WLZ)	100	92	76
1.2(DL+LL+WLZ)	100	93	76

Table 4.7) 40 Storied Column – Shear Wall Model

Load combination	M3-MODEL No bracing	Hexagrid M9-MODEL	Pentagrid M6-MODEL
1.5(DL+WLX)	100	76	32
1.2(DL+LL+WLX)	100	76	32
1.5(DL+ELX)	100	84	39
1.2(DL+LL+ELX)	100	84	39
1.5(DL+ELZ)	100	93	83
1.2(DL+LL+ELZ)	100	94	85
1.5(DL+WLZ)	100	95	92
1.2(DL+LL+WLZ)	100	96	96

Table 4.8) 50 Storied Column – Shear Walls Model

Load combination	M3-MODEL No bracing	Hexagrid M9-MODEL	Pentagrid M6-MODEL
1.5(DL+WLX)	100	66	27
1.2(DL+LL+WLX)	100	75	34
1.5(DL+ELX)	100	83	39
1.2(DL+LL+ELX)	100	83	39
1.5(DL+ELZ)	100	93	85
1.2(DL+LL+ELZ)	100	94	87
1.5(DL+WLZ)	100	94	88
1.2(DL+LL+WLZ)	100	94	91

Table 4.9) 60 Storied Column – Shear Walls Model

Load combination	M3-MODEL No bracing	Hexagrid M9-MODEL	Pentagrid M6-MODEL
1.5(DL+WLX)	100	75	36
1.2(DL+LL+WLX)	100	75	36
1.5(DL+ELX)	100	83	40
1.2(DL+LL+ELX)	100	83	40
1.5(DL+ELZ)	100	94	86
1.2(DL+LL+ELZ)	100	94	88
1.5(DL+WLZ)	100	93	87
1.2(DL+LL+WLZ)	100	93	88

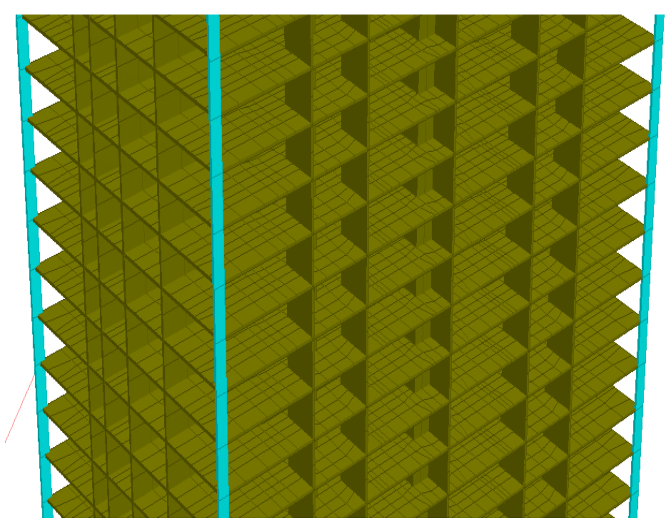


Fig.4.1 Shear walls – Flat slabs model without bracing

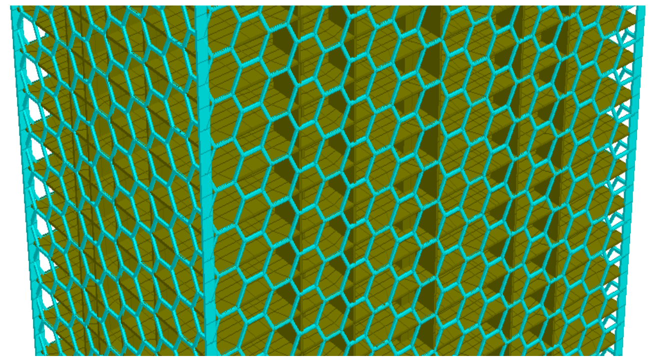


Fig.4.2. Shear walls – Flat slabs model with Hexagrid bracing

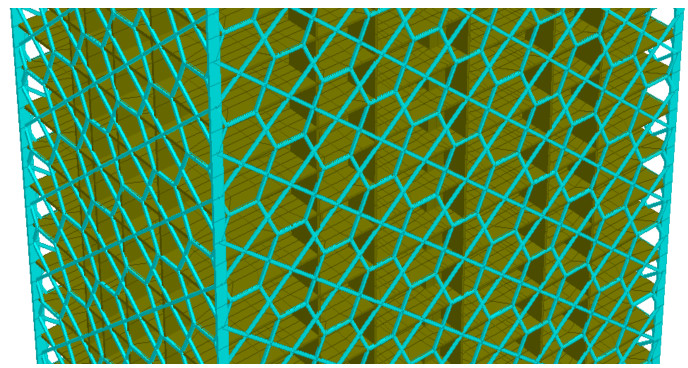


Fig. 4.3. Shear walls – Flat slabs model with pentagrid bracing

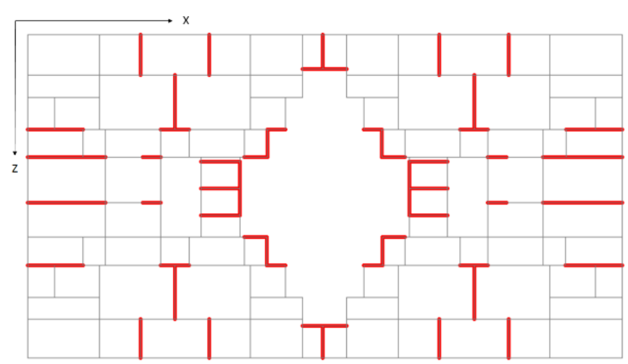


Fig. 4.4 Plan showing shear walls locations in the Shear walls – Flat slab model

From the simple static analysis, for standard gravity and lateral load system including wind and seismic, analysis results indicate the efficiency of the proposed system of Pentagrids. It is observed that Hexagrid and Pentagrid bracings performs better in the lateral load direction and both system increase their efficiency with increase in the number of unit cells in the horizontal direction. The proposed pentagrid system performs better than the Hexagrid system, it reduces displacement by about 27 to 34% for 40 stories height and 26 to 35% for 60 stories height. From this it is observed that the pentagrid structural system is efficient by more than 200% compared to regular Hexagrid system.

However it is quite interesting to observe that the efficiency of Hexagrid bracing system increases with increase in height whereas the efficiency of pentagrid system decreases with increase in height. Further comparison of structural forces for these 27 models indicate pentagrid members experience more axial forces & less moments than Hexagrid system.

6. CONCLUSIONS

The present investigation of pentagrid system for lateral load resisting of tall building forces is more efficient than Hexagrid system. The number of cells per unit are being more the cost would be little separated and construction details need additional care.

REFERENCES

[1] Mir M. Ali and Kyoung Sun Moon, Structural Developments in Tall Buildings: Current Trends and Future Prospects, Architectural Science Review, Volume 50.3, 2007, pp 205-223

[2] K. Moon, Design and Construction of Steel Diagrid Structures, NSCC2009

[3] Howard Hershberg, Diagrid: Not a Recent Idea, Louisiana Department of Natural Resources/Technology Assessment Division, November 2011

[4] Kyoung-Sun Moon, Jerome J. Connor and John E. Fernandez, Diagrid Structural Systems for Tall Buildings: Characteristics and Methodology for Priliminary Design, The Structural Design of Tall and Special Buildings, Vol 16, 2007, 205-230

[5] T. M. Boake, Diagrid Structures: Innovation and detailing, School of Architecture, University of Water bro, Canada

[6] Wang, A. J., & McDowell, D. L. (2004). In-plane stiffness and yield strength of periodic metal honeycombs. Journal of Engineering Materials and Technology, 126, 137-156.

[7] Roelofs, R. (2008). Trussed Façade Constructions: A Study of the Opportunities of a Structural System. Eindhoven: Eindhoven University of Technology.

[8] Dr. Peyman Askarinejad, Beehive (Hexagrid), Council on Tall Building and Urban Habitat, September 2012

[9] Bungale S. Taranath, Reinforced Concrete Design of Tall Buildings, CRC press

[10] Bryan Stafford Smith and Alex Coull, Tall Building Structures: Analysis and Design, Wiley publishers, 1991

[11] Skyscraper, www.wikipedia.org

[12] CTBUH height criteria, www.ctbuh.org

[13] Hexagrid, Pentagrid, www.google.co.in

[14] Bryan Stafford Smith and Alex Coull, Tall Building Structures: Analysis and Design, Wiley publishers, 1991

[15] Skyscraper, www.wikipedia.org

[16] CTBUH height criteria, www.ctbuh.org

[17] Hexagrid, Pentagrid, www.google.co.in

[18] Mir M. Ali and Kyoung Sun Moon, Structural Developments in Tall Buildings: Current Trends and Future Prospects, Architectural Science Review, Volume 50.3, 2007, pp 205-223

[19] K. Moon, Design and Construction of Steel Diagrid Structures, NSCC2009

[20] Howard Hershberg, Diagrid: Not a Recent Idea, Louisiana Department of Natural Resources/Technology Assessment Division, November 2011

[21] Kyoung-Sun Moon, Jerome J. Connor and John E. Fernandez, Diagrid Structural Systems for Tall Buildings: Characteristics and Methodology for Priliminary Design, The Structural Design of Tall and Special Buildings, Vol 16, 2007, 205-230

[22] T. M. Boake, Diagrid Structures: Innovation and detailing, School of Architecture, University of Water bro, Canada

[23] Bungale S. Taranath, Reinforced Concrete Design of Tall Buildings, CRC press

[24] Bungale S. Taranath, Reinforced Concrete Design of Tall Buildings, CRC press