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Effect of Aspect Ratio on Performance of Diagrid Structure Circular in Plan

KIRAN KAMATH AND NAWAZ AHAMED
Department of Civil Engineering, Manipal Institute of Technology, Manipal, Karnataka, India
Email: *kiran.kamath@manipal.edu, nawazap@gmail.com*

Abstract: In present study an attempt is made to understand the behavior of diagrid structure circular in plan. A circular plan is developed. ETABS 2013 software is used for analyzing the models subjected to gravity, wind and seismic forces. Various models are developed for aspect ratios of 3.6, 5, 6, 7 and 8 and for varying angle of diagonal column. The angles of the diagrid provided are 64.00°, 72.00°, 76.30° and 90.00°. Graphs indicating top story displacement, time period for various mode shapes, inter-story drift and lateral load distribution on diagrid and internal columns are plotted. Optimum brace angle for diagrid structures circular in plan is determined for various parameters.

Keywords: *Diagrid, Circular plan, Aspect ratio*

1. Introduction

As height of building increases, lateral load resisting system dominates over gravity system. With the concept of tubular structure, buildings are taken to a remarkable height. They possess greater flexural rigidity than shear rigidity. Diagrid structures contain inclined columns in the periphery as a result of which a diagrid structure possess greater flexural rigidity as well as shear rigidity. Lateral forces are transferred to ground by axial forces though diagonal columns whereas by bending in structure containing vertical columns. A diagrid structure may not require shear core as it possesses greater shear rigidity. Plan of the structure so far considered is square. No much research is made on diagrid structure circular in plan. Moon et al., (2007) studied the behaviour of diagrid structure square in plan. Size of the plan is 36m x 36m. Braced core is also provided. Shear lag effect is compared between diagrid and tubular structure. They concluded that for a diagrid structure square in plan, the optimal angle lies between 65° to 75°. They also suggested member sizing methodology for preliminary design of diagrid structure so that structural and architectural decisions can be made at an early stage [1]. Kyoung (2011) studied the behaviour of diagrid structure with floor twisting at different rates. He found that twisted tower perform better than straight tower under across wind loading. Optimal angle of twist is though not established [2]. Jani and Patel (2012) analysed and designed diagrid structure square in plan for an angle of 74.5° [3]. Montuori et al., (2014) varied the diagrid density and angle of diagonal columns along the height for square plan. The models are compared in terms of structural weight and performances. The efficiency potentials of different models are discussed [4]. Here plan of the diagrid structure considered is circular. Models are developed for aspect ratios of 3.6, 5, 6, 7 and 8. The diagonal columns are aligned at angles of 64.00°, 72.00°, 76.30° and 90.00°. The performance of the various models is studied for various aspect ratios and varying angle of diagrid.

2. Building Plan and Analysis

Circular plan with radial and circular beams is considered. Plan is shown in Figure 1. Elevations of 36 storied diagrid structure with diagonal columns inclined at 64.0°, 72.0°, 76.0° and 90° are shown in Figure 2 through 5 respectively. Diameter of the structure is 36m. Floor height is 3.6m and slab thickness is 150mm. Live loads applied are $2.5kN/m^2$. Diagonal columns are provided along the perimeter at angles of 22.5°. Wind loads as provided assuming wind speed of 30m/s and terrain category III. Seismic forces are provided for zone factor 0.16, importance factor 1 and response reduction factor 5. The structure is analysed in ETABS 13 software. Along dynamic wind loads are computed by gust factor method as per IS 875-III (1987). Beams are divided in four groups viz., B1, B2, B3 and B4. Vertical and diagonal columns are designed for all the load cases. Beams are designed only for gravity loads. Supports provided are hinge type. Diagonal columns are modelled as truss elements. All the structural elements are designed to satisfy their strength needs as per IS:800 (2007). Sections of beam are shown in Table 2. Details of vertical columns are shown in Table 3. Section of vertical column provided is shown in Figure 10.

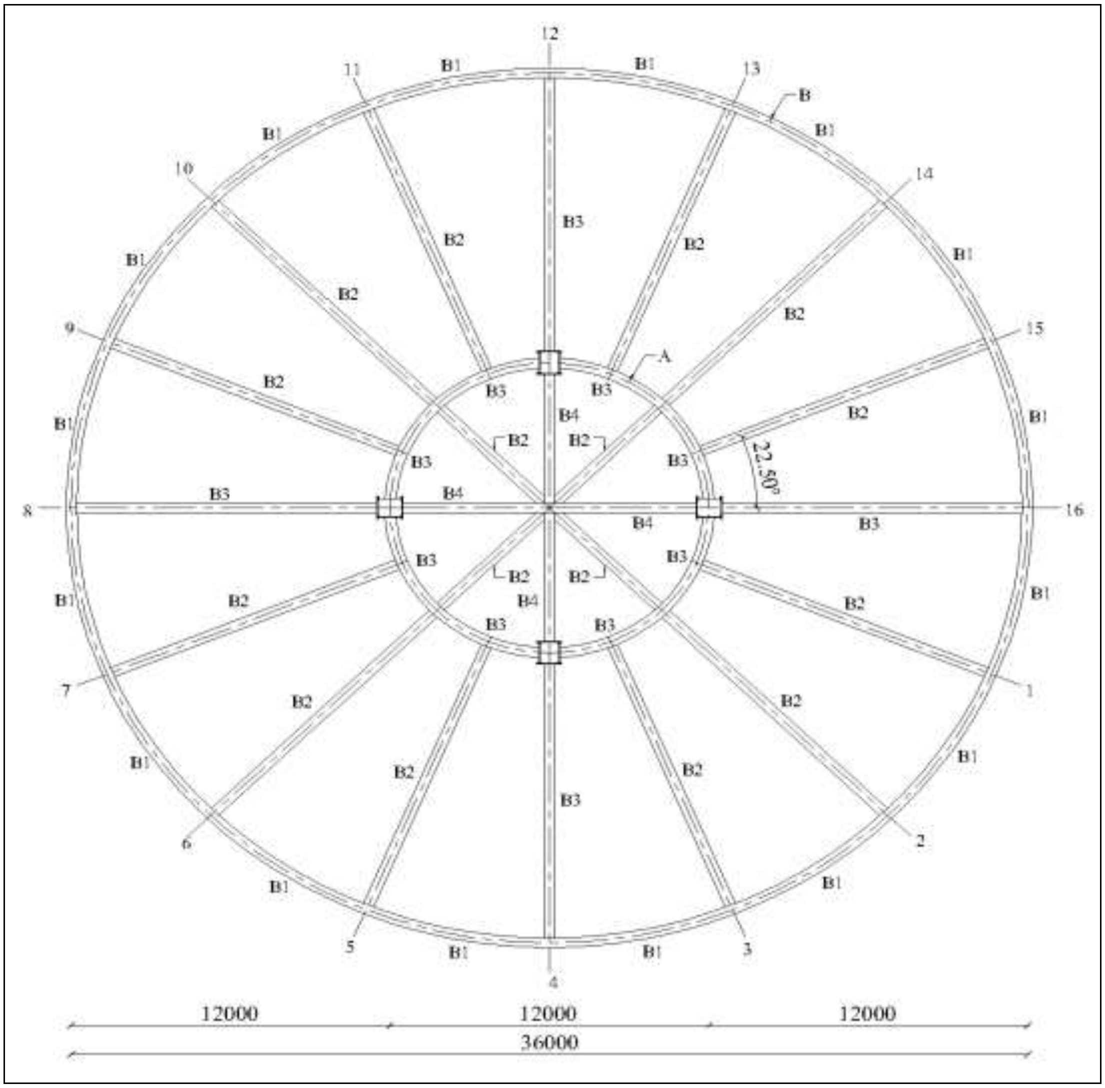

Figure 1: *Typical floor plan*

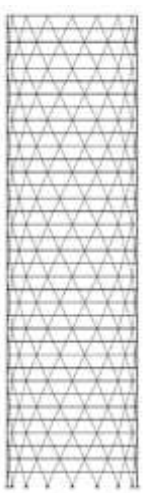

Figure 2: *Diagonal columns inclined at 64.0°*

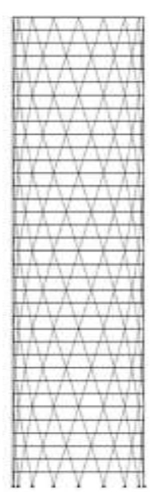

Figure 3: *Diagonal columns inclined at 72.0°*

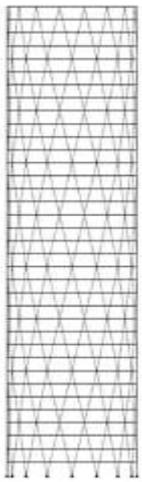

Figure 4: *Diagonal columns inclined at 76.3°*

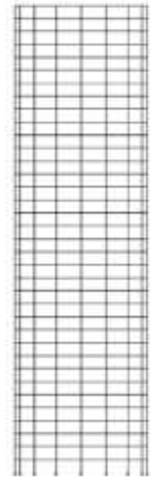

Figure 5: *Structure with all columns vertical*

Table 1: *Top storey displacement, maximum inter-story drift, and time period for first mode shape and percentage lateral load resisted by diagrid*

Aspect ratio	Angle of diagrid	Top story displacement in mm	Maximum inter-story drift	Time period for first mode shape in sec	Percentage lateral load resisted by diagrid
3.6	64°	**32.2**	0.000308	**2.468**	**91.49**
	72°	34.4	**0.000305**	2.619	91.32
	76°	41.9	0.000393	2.939	89.99
	90°	225.8	0.002963	7.601	88.07*
5	64°	104.2	0.000699	**4.221**	88.29
	72°	**103.7**	**0.000664**	4.255	**88.76**
	76°	116.4	0.000743	4.568	87.85
	90°	498.6	0.004596	11.032	88.25*
6	64°	180.4	0.001028	5.447	87.94
	72°	**172.4**	**0.000936**	**5.354**	**88.71**
	76°	186	0.000987	5.621	88.13
	90°	748.1	0.005753	13.453	88.48*
7	64°	271.6	0.001346	6.632	87.43
	72°	**253.5**	**0.001203**	**6.439**	**88.43**
	76°	265.9	0.001219	6.663	88.08
	90°	1064.7	0.006586	16.425	88.48*
8	64°	377.2	0.001655	7.773	88.05
	72°	**345.2**	**0.001456**	**7.457**	**89.14**
	76°	358.1	0.001457	7.643	88.98
	90°	1437.9	0.007954	19.044	88.67*

**lateral load resisted by vertical columns in the periphery*

3. Results and Discussions

Top storey displacements, maximum interstory drifts, time periods for first mode shape and lateral load resisted by diagrid are tabulated as shown in Table 1 and graphs are plotted for various aspect ratios and varying angle of diagonal columns. From Figure- 6, it is seen that for 3.6 aspect ratio, top storey displacement is minimum for angle of 64.0°. For rest of the structures, the optimal angle is 72.0°. For all the diagrid structures, the top story displacements are within permissible limits. As shown in Figure 7, for all the aspect ratios, angle of 72.0° is found to be optimum for inter-story drift. As the angle of diagonal columns increase beyond 72.0°, inter-story drift is seen to increase considerably. It can be due to lesser shear rigidity as the diagonal columns tend to be vertical. Top storey displacement and interstory drift is maximum when all the columns are vertical. Lateral load resisted by diagrid is around 90% upto an angle of 76° beyond which it decreases. Lateral forces are transferred as axial forces in diagonal columns. As the angle of diagrid increases, axial rigidity of the diagonal columns decreases. Hence lateral load resisted by diagrid decreases. As shown in figure 8, for aspect ratio of 3.6, resistance to lateral load is maximum for an angle of 64.0°. For other structures the same angle is 72.0°. As the building height increases, flexural mode of sway dominates; hence maximum resistance to lateral load is obtained at relatively higher angle. From Figure 9, it is seen that for aspect ratio of 3.6, resistance to lateral load is maximum for an angle of 64.0°. For other structures the same angle is 72.0°. Time period increases considerably when angle of diagrid is greater than 76°. For aspect ratio of 3.6 and 5.0, time period for first mode shape is minimum when the diagrid angle is 64°. For the rest of the structures, time period is minimum for an angle of 72.0°.

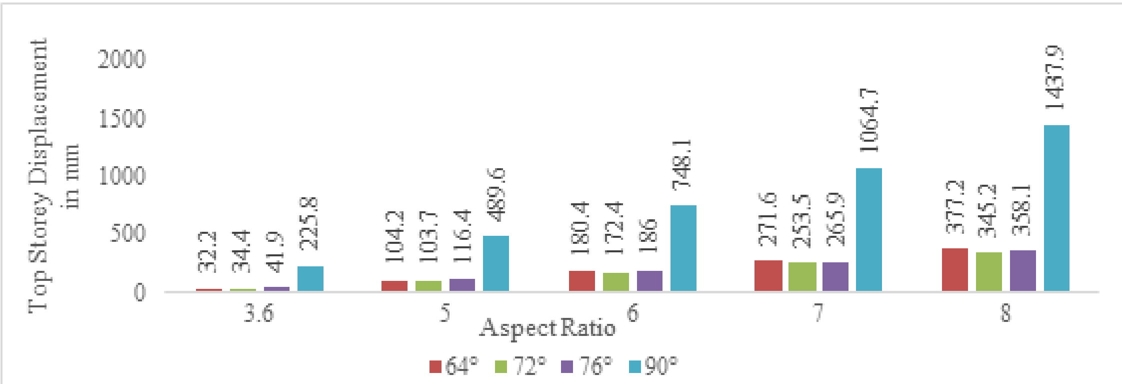

Figure 6: *Top storey displacement for models of varying aspect ratio and varying angle of diagrid*

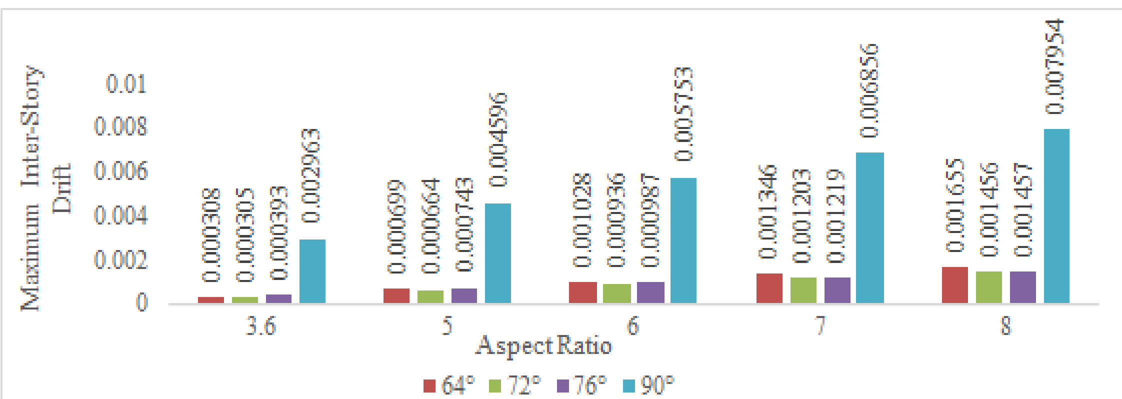

Figure 7: *Maximum inter-storey drift for models of varying aspect ratio and varying angle of diagrid*

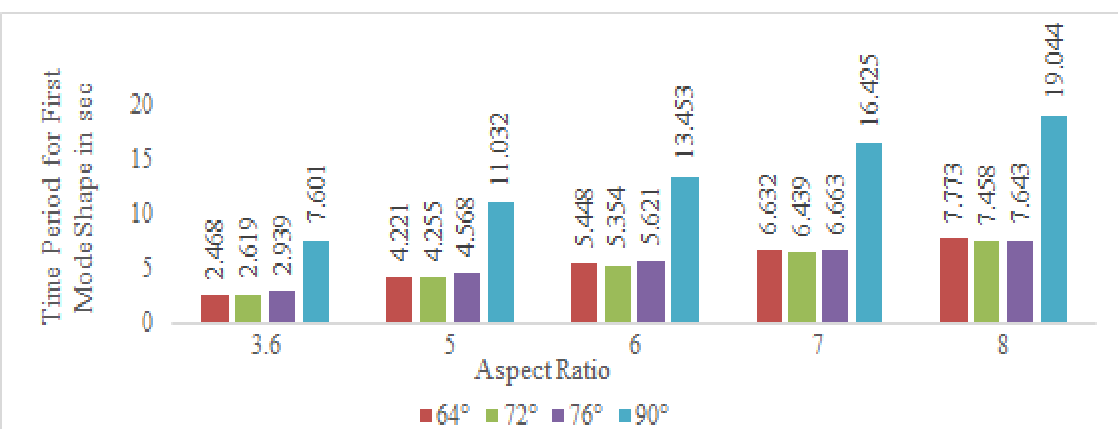

Figure 8: *Time period for first mode shape for models of varying aspect ratio and varying angle of diagrid*

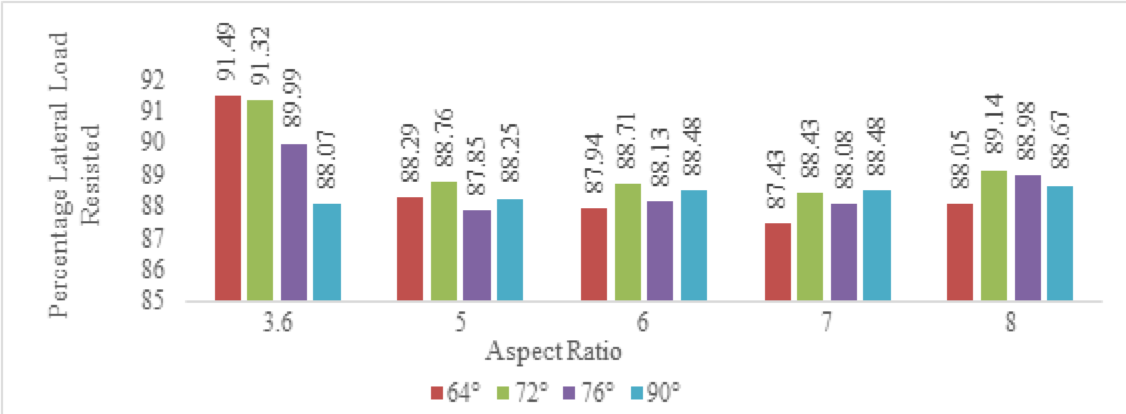

Figure 9: *Lateral load resisted by diagrid by models of varying aspect ratio and varying angle of diagrid*

Table 2: *Details of beams*

Beams	
B1	ISMB 350
B2	ISMB 600
B3	ISMB 600 with cover plates of 150mm x 20mm
B4	ISLB 200

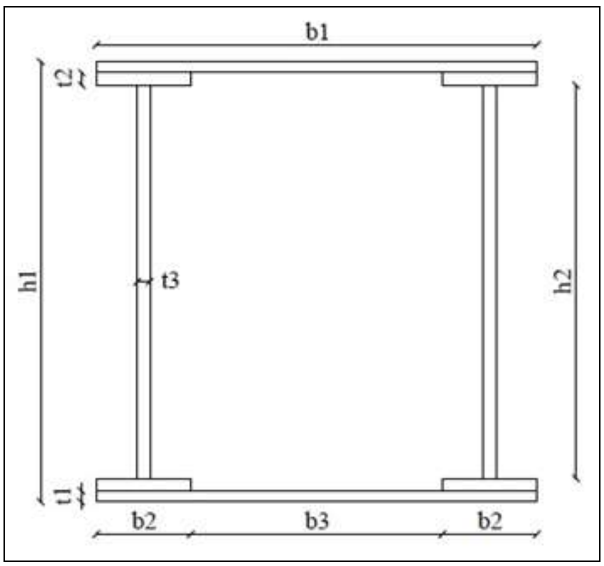

Figure 10: *Typical Section of vertical column*

Table 3: *Details of section provided for diagonal columns and vertical columns*

ASPECT RATIO	**DIAGONAL COLUMN**		**COLUMN**						
	EXTERNAL DIAMETER	**THICKNESS**	**b1 and h1**	**b2**	**t1**	**t2**	**t3**	**b3**	**h2**
3.6	475	25	1400	300	35	40	40	800	1250
5	350	50	1600	350	50	50	50	900	1400
6	425	50	1700	350	60	50	40	1000	1480
7	425	50	1900	350	75	50	50	1200	1650
8	525	50	2150	350	75	50	50	1450	1900

All dimensions are in millimetres

4. Conclusions

The results can be concluded as follows:

1) With diagrid structures, sway and inter-story drift are reduced considerably. Diagrid structure containing diagonal columns at an angle of 72° show lesser roof displacement and interstory drift. For angle above 80°, maximum interstory drift is observed at first story, due to shear mode of displacement.
2) For increase in aspect ratio, the optimal angle for sway and inter-story drift tends to increase as the structure sways in flexure mode.
3) It is seen that considerable amount of steel can be saved in a diagrid structure compared to structure with only vertical columns. Further framed structure requires lateral load resisting systems which add up to the overall cost.
4) For all the aspect ratios, as angle of diagonal column increases, shear rigidity decreases due to which time period increases.
5) No other lateral load resisting systems are required upto an angle of 76° as most of the lateral load is resisted by diagonal columns.

5. Acknowledgments

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