Analysis and Design of Diagrid Building and Comparing with Conventional Frame Building

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Abstract- *In this study, concrete diagrid structure is analyzed and compared with conventional concrete building. To this study a regular five storey RCC building with plan size 15 m × 15 m located in seismic zone V is considered for analysis. STAAD.Pro software is used for modelling and analysis of structural members. All structural members are designed as per IS 456:2000 and load combinations of seismic forces are considered as per IS 1893(Part 1): 2002. According to the analysis results the structural design of diagrid building is governed by lateral loads due to wind or earthquake. Lateral load resistance of the structure is provided by interior structural system or exterior structural system.In diagrid structure, due to inclined columns the major portion of lateral load is taken by external diagonal members which in turn release the lateral load in inner columns. This causes economical design of diagrid structure compared to conventional structure. Drift in diagrid building is approx. half to that obtained in conventional building. In this study, steel reinforcement used in diagrid structure is found to be 33.21% less compared to conventional building.*

Keywords:- Diagrid building, conventional building, storey drift, economy, seismic forces.

I. INTRODUCTION

Tall building development involves various complex factors such as economics, aesthetics look, technology, municipal regulations, and politics. Among these, economics has been the primary governing factor. For a very tall building, its structural design is generally governed by its lateral stiffness. Comparing with conventional orthogonal structures for tall buildings such as framed tubes, diagrid structures carry lateral wind loads much more efficiently by their diagonal member's axial action. A Diagrid structure provides great structural efficiency without vertical columns have also opened new aesthetic potential for tall building architecture. Diagrid has a good appearance and it is easily recognized. The configuration and efficiency of a diagrid system reduces the number of structural element required on the façade of the buildings, therefore less obstruction to the outside view. The structural efficiency of diagrid system also helps in avoiding interior and corner columns, and therefore allowing significant flexibility with the floor plan. "Diagrid" system around perimeter saves approximately 20 percent of the structural steel weight when compared to a conventional moment-frame structure. The diagonal members in diagrid structural systems carry gravity loads as well as lateral forces due to their triangulated configuration. Diagrid can save upto 20% to 30% the amount of structural steel in a high-rise building.

The term "diagrid" is a combination of the words "diagonal" and "grid" and refers to a structural system that is single-thickness in nature and gains its structural integrity through the use of triangulation. Diagrid systems can be planar, crystalline or take on multiple curvatures, they often use crystalline forms or curvature to increase their stiffness. Perimeter diagrids normally carry the lateral and gravity loads of the building and are used to support the floor edges.

II. OBJECTIVE OF THE STUDY

Safety and minimum damage level of a structure could be the prime requirement of high rise buildings .To meet these requirements, the structure should have adequate lateral strength & sufficient ductility. In this thesis, two G+5 storey buildings are considered for analysis, one for diagrid and other for conventional frame, in which every storey is of 3m height is taken in both building and analysis values are compared in terms of Bending moment, Shear force, Axial force, Displacement, Drift and also the economical aspect is compared for the seismic zone V.

The main objective of this thesis is to investigate the behaviour of buildings, i.e., diagrid and conventional frame under the seismic zone V. For comparison of two buildings under the same seismic zone, the parameter in both the buildings is taken same. The work is to be carried out by conducting-

(a) Modelling of both the building frames.
(b) Analysis of building frames considering seismic parameters.
(c) Study of results in terms of moments, forces, drift, deflection, and also the economy.

III. METHODOLOGY

In this study comparison of diagrid and conventional building under seismic forces is done. Here G+ 4 storey is taken and same live load is applied in both the buildings for its behaviour and comparison.

The framed buildings are subjected to vibrations because of earthquake and therefore seismic analysis is essential for these building frames. The fixed base system is analyzed by employing in both building frames in seismic zone V by means of Staad.Pro software. The response of both the building frames is studied for useful interpretation of results.

Steps For Comparison

A comparison of results in terms of moments, displacements, shear force, axial force, drift and economy has been made. Following steps are adopted in this study:-

1. Step-1 Selection of building geometry and Seismic zone: The behaviour of both the models is studied for Zone V of Seismic zones of India as per IS code 1893 (Part 1):2002 for which zone factor (Z) is 0.36. Five storey building is taken. Each storey is of 3m height. Depth of foundation is taken as 1.5 m.
2. Step-2 Formation of load combination: Six primary load case and thirteen load combination is considered for analysis and design.
3. Step-3 Modelling of building frames using STADD.Pro software
4. Step-4 Analysis of both the building frames is done under seismic zone v and each load combination.
5. Step-5 Comparative study of results in terms of maximum moments in columns and beams, storey displacement, shear force, axial force, drift and economy.

Structural Models

Structural models are shown in Fig 1

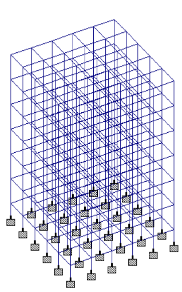

Fig. 1- Structure model of conventional building

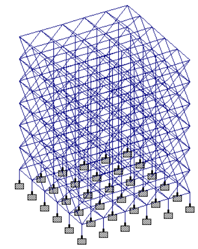

Fig.2- Structure model of diagrid building

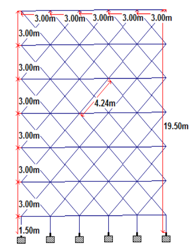

Fig.3- Elevation of diagrid building

A regular floor plan of 15m x 15m is considered in both buildings. Storey height is 3m. The angle of inclined column(45o) is kept constant throughout the height. The design dead load and live load are 4.5 kN/m2 and 4 kN/m2 respectively. Exterior wall load is taken negligible in both the buildings. Both the building frames are analyzed for seismic zone V. Seismic parameters are taken as per Indian code IS 1893(Part 1) : 2002.

Table No 1 Size of beam and column

Member	Conventional building	Diagrid building
Beam	200 x 400 mm	200 x 400 mm
Column (inner)	450 x 450 mm (for bottom two storey) 400 x 400 mm (for top Four storey)	600x600(Footing Column) 300 x 300 mm (throughout the building)
Diagonal member	No diagonal member	300 x 300 mm

Table No 2 Material properties considered in the modelling –

Material properties	Values
Density of RCC	25 kN/ m^3
Density of Masonry	20 kN/m^3
Young's modulus of concrete, E_c	21718 N/mm^2
Poisson ratio, μ	0.17
Compressive strength, F_{ck}	25 N/mm^2
Steel Grade	F_e 415

Interior Column Analysis:

The analysis of the interior column is carried out at each floor in terms of axial force, bending moment in y and z direction. The plan of the selected location for analysis is shown below. The behaviour of the rest of interior column is shown by symmetry.

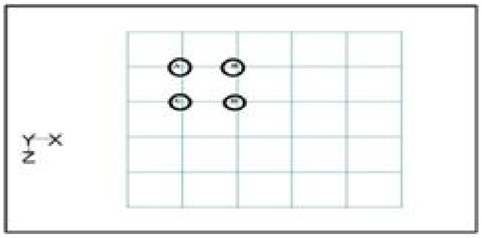

Fig. 4 Selected location of the column for result discussion.

Table No 3 Comparison of column forces at location A between conventional and Diagrid building.

Location A	Conventional Building			Diagrid Building			Ratio		
	Axial force Fx (kN) (1)	Bending moment My (kN-m) (2)	Bending moment Mz (kN-m) (3)	Axial force Fx (kN) (4)	Bending moment My (kN-m) (5)	Bending moment Mz (kN-m) (6)	(4/1)	(5/2)	(6/3)
Ground Floor	1062	123.02	123.02	1142	23.48	23.48	1.08	0.19	0.19
First Floor	851.14	102.04	102.04	933.22	21.75	21.75	1.10	0.21	0.21
Second Floor	644.49	82.37	82.37	720.09	21.32	21.32	1.12	0.26	0.26
Third Floor	444.55	62.83	62.83	504.95	17.58	17.58	1.14	0.28	0.28
Fourth Floor	246.42	30.52	30.52	286.48	6.89	6.89	1.16	0.23	0.23
Fifth Floor	112.03	4.27	4.27	130.11	8.62	8.62	1.16	2.02	2.02

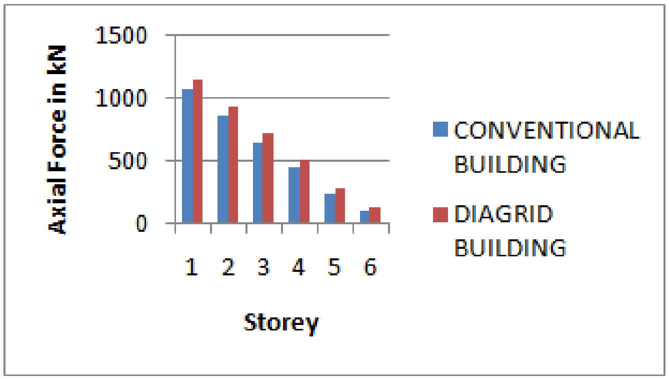

Fig. 5 Comparison of axial force in column at location x a A

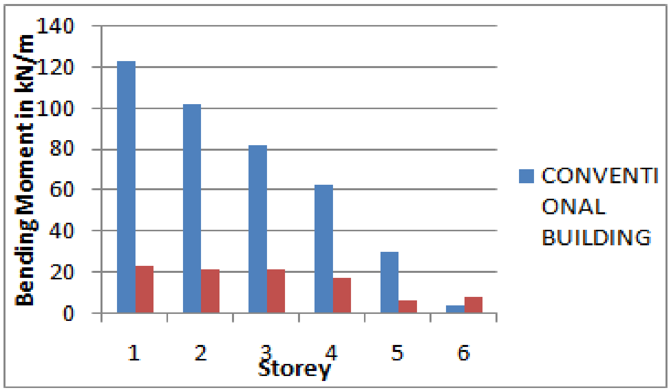

Fig.6 Comparison of bending moment My in column at location A, (same graph for Mz).

From graph it is cleared that bending moment in interior column is relaxed in diagrid structure, although axial force is nearly same. Similar behavior is seen in location at B, C & D. This is due to internal column in diagrid structure carry only gravity load and seismic force is resist by external diagonal column while in conventional both internal and external column resist gravity and seismic load.

BEAM ANALYSIS

Due to symmetry of building, only a part of building is selected for presentation and interpretation of analysis results. The plan of selected beam is shown below.

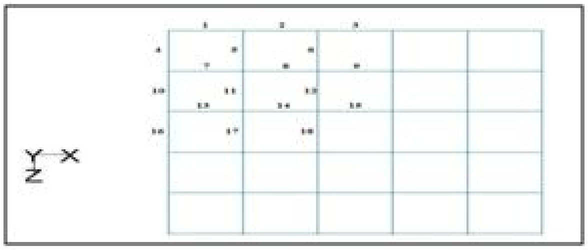

Fig.7 Plan of building showing the selected beam numbering

The shear force and bending moment in beam for different floors are compared between conventional and diagrid structure. Size of beam is taken as 200 x 400 mm for both buildings. Detailed beam analysis at each floor is carried out.

Lateral Displacement and Max. Drift: Lateral displacement means the total displacement of the floor w.r.t ground. It is caused due to lateral forces (wind or seismic) acting on building

Table No 4 Lateral displacement (in mm)

Floor	Conventional building	Diagrid building
Ground Floor	0.67	0.42
First Floor	6.8	3.4
Second Floor	15.05	7.3
Third Floor	24	11.12
Fourth Floor	31.2	14.23
Fifth Floor	35.62	15.847
Sixth Floor	37.52	16.217

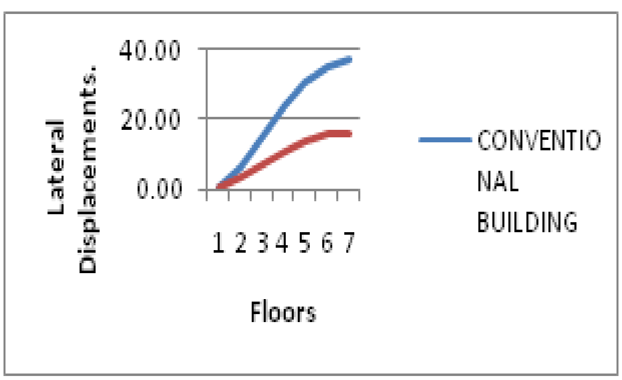

Fig.8 Lateral Displacement at each floor w.r.t Ground.

Drift is the relative displacement of floor w.r.t lower one.

Table No 5 Maximum Drift due to load (in mm)

Floor	Conventional building	Diagrid building
Ground Floor	0.7	0.3
First Floor	6.2	3.6
Second Floor	8.3	4.4
Third Floor	8.8	4.4
Fourth Floor	6.8	3.8
Fifth Floor	3.9	2.3

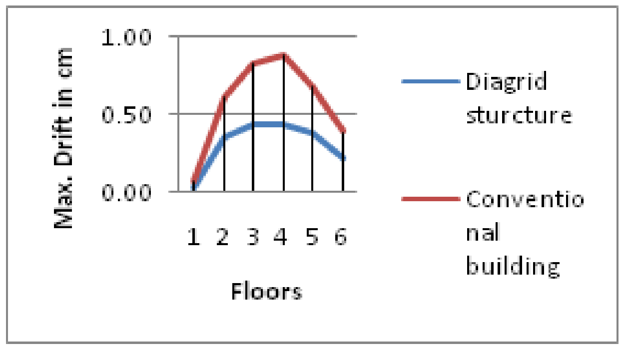

Fig.9 Maximum Drift of floor w.r.t adjacent floor.

Discussion:

Displacement in diagrid structure is approx. half to that in conventional building. This shows the behaviour of diagrid in lateral force resistance is more as compared to conventional building.

Materials Comparison

Table 6 Material comparison in both the building.

Quantity of Material	Conventional building	Diagrid building
1) Volume of Concrete, in m^3	233.1	237.8
2)Weight of Steel, in kN	303.16	202.47

IV. CONCLUSIONS

In this study, it is observed that due to diagonal columns in periphery of the structures, the diagrid structure is more effective in lateral load resistance. Due to this property of diagrid structure, interior column is used of smaller size for gravity load resistance and only small quantity of lateral load is considered for it. While in case of conventional frame building, both gravity and lateral load is resisted by exterior as well as interior column.

The following points are concluded from above study about diagrid structure:

- Structural performance: Diagrid building shows less lateral displacement and drift in comparison to conventional building.
- Material saving property: Although volume of concrete used in both building is approx. same, but diagrid shows more economical in terms of steel used. Diagrid building saves about 36% steel without affecting the structural efficiency.
- Better resistance to lateral loads: Due to diagonal columns on its periphery, diagrid shows better resistance to lateral loads and due to this, inner columns get relaxed and carry only gravity loads. While in conventional building both inner and outer column are designed for both gravity and lateral loads.
- Aesthetic look: In comparison to conventional building, diagrid buildings are more aesthetic in look and it becomes important for high rise buildings.

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