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1   **Comparative Seismic Performance Analysis of Tall Buildings with Diagrid Systems**

2   **Chintan B. Naik[1*], Dr. Pratima Patel[2], Dr. Kamlesh Dalal[3]**

3   **[1*]Research Scholar, Civil Engineering Department, Sarvajanik University, Surat,**

4   **Gujarat, India**

5   **[2]Professor, Civil Engineering Department, Sarvajanik University, Surat,**

6   **Gujarat, India**

7   **[3]Assistant Professor, Civil Engineering Department, Sarvajanik University, Surat,**

8   **Gujarat, India**

9   ***Abstract:*** *The diagrid structural system has emerged as a preferred solution for high-rise*

10   *buildings because of its high lateral stiffness, reduced material usage, and aesthetic flexibility.*

11   *This study compares the seismic performance of a thirty-storey steel building using two lateral*

12   *load-resisting systems—(i) a conventional moment-resisting frame and (ii) a perimeter*

13   *diagrid frame—both modelled in ETABS following IS 875 and IS 1893 (Part 1): 2016. The*

14   *models' dimensions are the same (30 m × 30 m plan, 3.2 m storey height). Comparative*

15   *parameters include fundamental period, storey displacement, inter-storey drift, and base*

16   *shear. Results indicate that diagrid systems exhibit superior lateral stiffness and drift control:*

17   *fundamental period reduced by ≈ 41 %, top-storey deflection by > 50 %, and inter-storey drift*

18   *by > 60 %. The 4-module diagrid had the best stiffness and deformation control of all the*

19   *configurations that were examined. The findings show that the diagrid system can be used in*

20   *seismically active regions and has the potential to be an affordable alternative to conventional*

21   *frames.*

22   ***Keywords:*** *Diagrid system; high-rise building; lateral load-resisting system; seismic*

23   *performance; ETABS analysis.*

24   **1. Introduction**

25   In recent years, the design and construction of high-rise structures have increasingly relied on

26   innovative building technologies to satisfy the needs of urban expansion and development.

There are two primary categories of high-rise structures: interior and exterior. The interior systems consist of shear walls, wall frames, core outriggers, and stiff and braced frames. The exterior structural systems can be classified based on their internal and external load transfer mechanisms, such as tubes, grids, or tube-in-tube systems (1,2). By the time (3) had updated the interior system charts, the exterior system charts had also been updated.

Additionally, tall buildings are more affected by lateral loads than gravitational loads. Therefore, when tall structures are designed, lateral loads must be assessed since lateral loads are directly proportional to height. Many studies have been conducted to propose novel structural systems to improve the lateral force performance of high-rise structures. Among structural engineers and researchers researching tall buildings, the diagrid has undoubtedly gained considerable attention. According to related research, diagrids have become the most preferred structural system for skyscrapers because of their superior appearance and lateral rigidity (4,5). To sustain horizontal and vertical loads, the structure uses axial deformation of diagonals in triangular configurations on its exterior facade. (6,7) Structural efficiency can be achieved by utilising diagonals as bracing and vertical resisting elements, making buildings with 100-130 stories competitive (1,3).

To make efficient use of structural parts, the structural system chosen must meet the design specifications. Tall structures with rigid frame systems should not exceed 20 stories high, as this causes excessive storey drift due to shear racking from the bending of columns and beams. In tall buildings, an extra diagonal or bracing is included in the frame to prevent column and beam bending and lessen storey drift. (8)

A diagrid is a kind of space truss that is composed of triangulated truss systems arranged in a perimeter grid. (9) It is composed of horizontal and diagonal elements that intersect. Figure 1 shows the Swiss Re in London, the Hearst Tower in New York, and the Capital Gate Tower in Abu Dhabi as well-known examples of diagrid buildings. (9)

52   **Figure 1. Diagrid buildings: (a) Swiss Re in London, (b) Hearst Tower in New York, and**

53   **(c) Capital Gate Tower in Abu Dhabi.** (9)(10)

54   Ali et al. (1) presented a methodology for the initial design of diagrids with uniform angles,

55   focusing on their stiffness characteristics and featuring rectangular shapes. The initial findings

56   indicate that a diagonal angle has been determined, achieving the necessary strength and

57   stiffness standards while also reducing the overall weight of the structure. Diagonals with an

58   approximate inclination of 35 degrees effectively resist shear forces, whereas those inclined

59   at 90 degrees are the most efficient at transferring overturning moments (11,12). Therefore, it

60   can be inferred that the ideal angle falls within these defined parameters, typically ranging

61   from 65° to 75° (13,14). The best value is dependent on the interaction between the bending

62   and shear forces. In tall structures, the bending moment is the more dominant factor, thus

63   supporting higher optimal angle values.

64   The seismic performance of high-rise buildings is a primary concern in structural engineering,

65   especially in areas classified as Seismic Zones IV and V as per IS 1893 (Part 1): 2016 (15).

66   Conventional steel moment-resisting frame systems, the most common structural systems,

67   suffer from high lateral flexibility and increased fundamental time periods, leading to more

68   storey displacements and interstorey drifts due to seismic loading (8).

69   To maintain compliance with code-specified drift limits, these systems often require large

70   member sizes and complex ductile detailing, which can increase material usage and

71   construction costs. Diagrid structural systems, composed of a network of diagonally inclined

72   steel members forming a triangulated perimeter, have emerged as promising alternatives for

73   high-rise buildings due to their improved lateral stiffness, reduced structural weight, and

74   efficient seismic force resistance through axial action (16,17).

75   Granted, diagrid systems have come to be recognised as structural and architectural boons;

76   however, rigorous comparisons of these building systems with conventional steel frames

77   under seismic excitation, particularly in the Indian design context, have thus far been limited.

78   Hence, there is currently a knowledge gap regarding the applicability of these materials as

79   earthquake-resistant materials in high seismic zones.

80   The objective of this study is to present a comparative analysis of a 30-storey high-rise steel

81   building modelled in ETABS with two unique lateral load-resisting systems: (i) a

82   conventional steel moment-resisting frame and (ii) a perimeter diagrid system. Gravity and

83   wind loads are per IS 875 (Parts 1–3) (18–20), and seismic zones IV and V are per IS 1893

84   (Part 1):2016 (15). A standard plan of 30 m by 30 m is considered. With ETABS software,

85   structural member modelling and analysis were carried out.

86   **2. Methodology**

87   **2.1. Model Development**

88   To construct the diagrid structural model, a grounded vertical cantilever beam that offers a

89   longitudinal division that complies with the diagrid configuration must be used (21). A

90   module is identified by a single diagrid level that spans a specific number of stories, indicated

91   by the letter 'n.' A six-storey diagrid structural module is shown in the model in Figure 2. All

92   the required lateral stiffnesses are assigned to the perimeter diagrids to improve the accuracy

93   of the lateral rigidity estimation provided by the diagrids. (22) The diagonal members are

94   presumed to be pinned. As a result, they can sustain moment-by-axial action and transverse

95   shear. This idealisation helps to ease the design difficulty by identifying the usual cross-

96   sectional areas of the web and flange members for each module. Equations (1) and (2), tailored

97   for each design instance using the design technique suggested by (23), can be used to

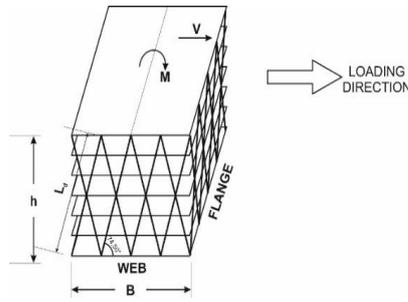98   determine module member sizes.

99

Figure 2: Typical 6-storey diagrid module

$$A_{d,w} = \frac{VL_d}{2N_{d,w}E_d h\gamma \cos^2 \theta} \tag{1}$$

$$A_{d,f} = \frac{2ML_d}{(N_{d,f} + \delta)E_d h\chi \sin^2 \theta} \tag{2}$$

The areas of each diagonal on the web and the flange are denoted by $A_{d,w}$ and $A_{d,f}$, respectively. V represents the shear force. M represents the moment, L_d represents the diagonal length, E_d represents the modulus of elasticity of steel, $N_{d,w}$ represents the number of diagonals on every web plane, $N_{d,f}$ Represents the number of diagonals on each flange plane, d represents the contribution of the web diagonals to the bending rigidity, B represents the width of the structure along the path of the applied force, q represents the angle of the diagonal members, γ represents the transverse shear strain, and χ represents the curvature. (16,23)

2.2. Building Configuration

A 30-storey structure was modelled and analysed for a diagrid structure (24) and a conventional steel structure. (25) The building's plan area is 30 m × 30 m, with a 12 m × 12 m central core. The building's overall height is 96 m, with each storey standing 3.2 m tall. Modelling and analysis of the diagrid structures are carried out via ETABS software. The earthquake load is calculated via the following parameters: medium soil, zone factor of 0.2, importance factor of 1, and response reduction factor of 5(15). The floor slab is subjected to a live design load of 4 kN/m²(20). The typical configuration and layout of the building are

122   shown in Figures 3 and 4. Table 1 presents the properties of the Diagrid structure and the

123   conventional structure used for the study. This includes the plan dimensions, the location of

124   the building, the construction material, and the type of soil.
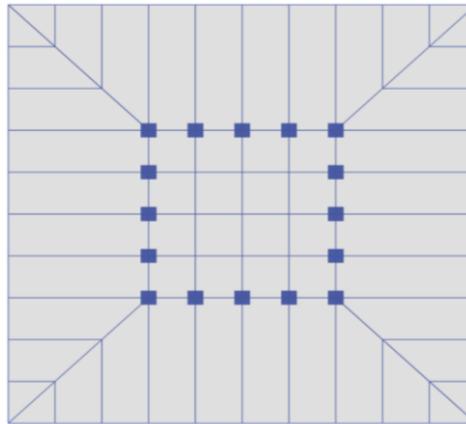
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126   **Figure 3: Building plan**
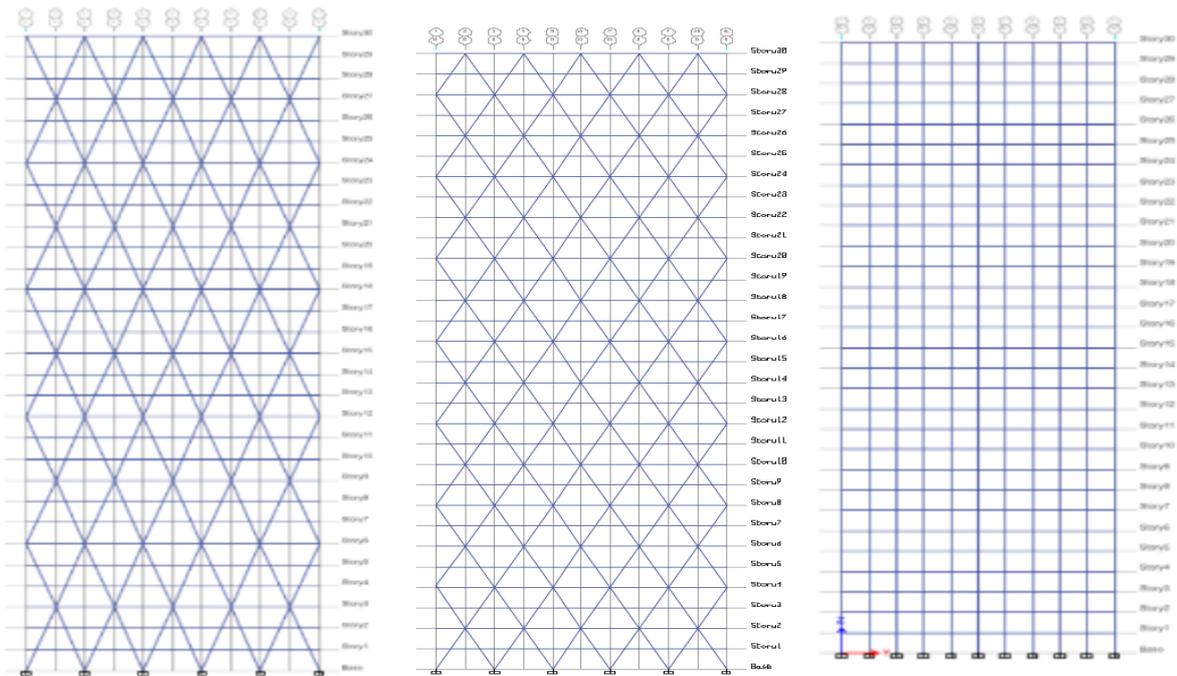
127   **Figure 4 (a) Elevation of the diagrid structure (b) Elevation of the conventional structure**

128   **Table 1: Properties of the Diagrid structure and conventional structure**

Description	Diagrid Structure	Conventional Structure
Plan Dimension	30 m x 30 m	30 m x 30 m
Interior Column	1000 mm x 1000 mm	-
Exterior Column	-	ISWB 550
Beam	ISMB 500, ISWB 550	ISMB 500

| Diagrid | Steel Pipe with 500 mm x 25 mm | - |

129 **2.3. Analysis of the building**

130 The linear static analysis is also called the equivalent lateral force method. A linear static

131 analysis is a standard method for effective structural design and modelling of a diagrid, a

132 triangulated structural system. A linear static analysis determines structural displacements and

133 stresses, assuming a linear relationship between the applied loads and the structural response.

134 For the linear static analysis stage of the diagrid, the designer assumes the design loads (i.e.,

135 dead loads, live loads, and wind or seismic loads) are applied to the modelling software to

136 establish internal forces and deflections. The most important aspect of linear static analysis is

137 its speed and ease of computational analysis, which allows for quick preliminary design and

138 optimisation of sections. For diagrids specifically, this process is used to verify that the

139 diagonal members and nodes are appropriately sized to transfer axial forces and to justify

140 deflections considered acceptable for use. Although values from linear static analysis provide

141 a reasonable first estimate of the structural response by considering physical phenomena, they

142 do not account for complex behaviour, including material or geometric nonlinearities, which

143 can become more significant under extreme loading conditions. Thus, assessing the

144 displacements of a diagrid system through a linear static analysis is often a first step prior to

145 conducting a nonlinear analysis.

146 **3. Results and Discussion**

147 **3.1. Time Period**

148 Figure 5 shows the fundamental time periods of three structural systems: a conventional

149 structure, a 6-module diagrid structure, and a 4-module diagrid structure. Compared with

150 those of the other systems, the conventional structure has the longest time period of 3.046 s,

151 demonstrating that the structure is less stiff and more flexible. The 6-module diagrid structure

152 has the shortest time period at 2.031 s, and the 4-module diagrid structure has the shortest

153 time period at 1.799 s. The reduction in period from the conventional to the four-module

154 diagrid, which exhibits an increase in global stiffness of about 41%, validates the diagrid's

155   superior rigidity. These findings are consistent with those of Moon (2008) and Asadi and

156   Adeli (2017), who found that the period decreased as diagonal inclination increased.
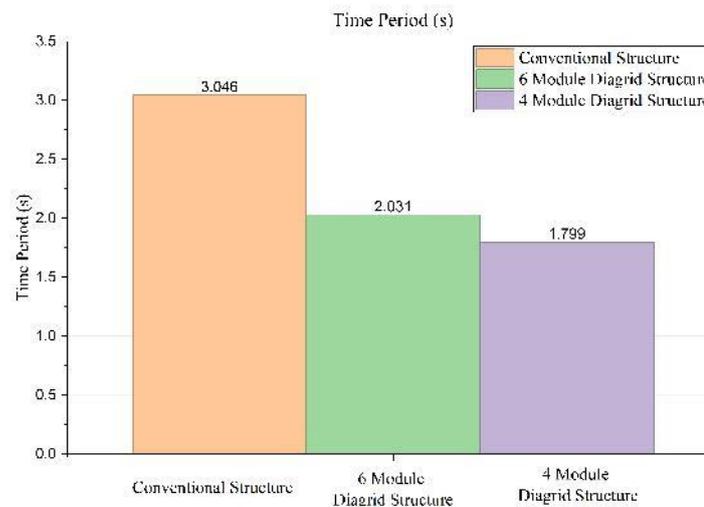
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158   **Figure 5: Time periods for the conventional structure and diagrid structure**

159   **3.2. Standard Displacement**

160   Figure 6 shows the storey-wise displacement profiles for three structural systems: the

161   conventional structure, the 6-module diagrid structure, and the 4-module diagrid structure.

162   The displacement increases with height for all the structures; however, the displacement

163   magnitude varies due to differences in the lateral flexibility and stiffness of the structure. The

164   conventional structure reaches its maximum displacement at the top storey, nearly 110 mm,

165   indicating greater lateral flexibility and less lateral stiffness. The 6-module diagrid structure

166   exhibits lower displacement, with a maximum of approximately 60 mm, indicating that the

167   diagrid system allows greater lateral stiffness than the conventional system. The 4-module

168   diagrid structure has minimal displacement at the top storey, consistently less than 50 mm,

169   indicating that increasing the diagrid angle (fewer modules) results in even greater stiffness

170   and reduced lateral deflection. The diagrid systems reduce top-storey deflection by 55–60 %

171   compared with the conventional frame. The steeper four-module configuration (72°

172   inclination) provides the highest stiffness. Similar performance improvement was observed

173   by Jani and Patel (2013) for steel diagrids exceeding 25 storeys.
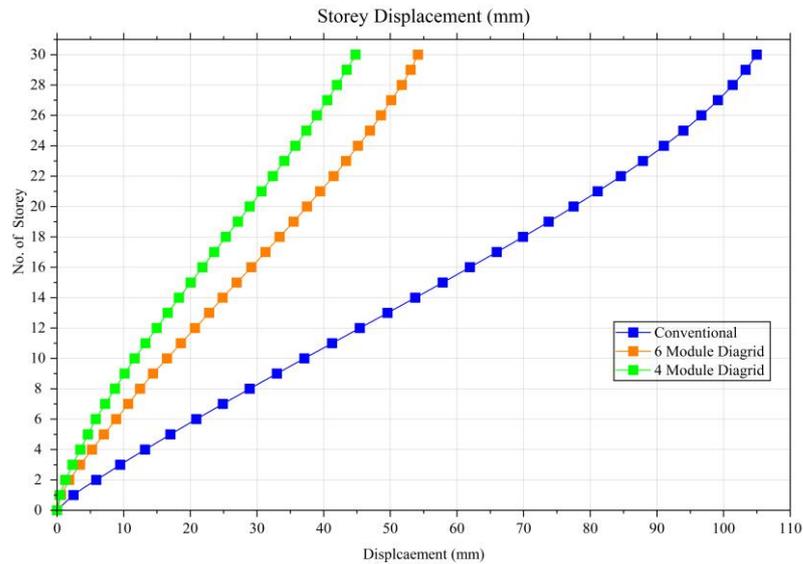
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175 **Figure 6: Storey displacement for diagrid and conventional structures**

176 **3.3. Storey Drift**

177 Figure 7 and Figure 8 show the profiles for storey drift in the X- and Y-directions for three

178 types of structures: the conventional structure, the diagrid structure with six modules, and the

179 diagrid structure with four modules. The conventional structure has the most drift in the X

180 direction, with a peak occurring around the middle of the structure at approximately 0.0025.

181 The Diagrid Structure 6-Modules had less drift, with a peak of roughly 0.0012. The Diagrid

182 Structure 4 module had the least negligible drift, remaining below 0.001. It clearly shows that

183 diagrid systems limit lateral deformation and that the 4-module system has the most

184 extraordinary capacity for stiffness, control, or limiting the relative movement of the floor

185 plates.

186 In the Y direction, the trend remains the same. The conventional structure had the most

187 considerable prepack drift, particularly in the X-direction, with a value near 0.0026 at mid-

188 height. The Diagrid Structure 6-Modules had better performance with a moderate maximum

189 drift near 0.0013, whereas the Diagrid Structure 4-Modules had the lowest maximum drift,

190 near 0.0008.

191   Both graphs illustrate that diagrid systems decrease storey drift more than traditional frames

192   do, whereas fewer diagrid modules (greater diagrid angles) maximise the reduction in

193   interstorey drift. In regions of seismic risk, the return to obtain diagrids is substantial, as

194   diagrid systems impact not only structural safety but also the comfort of occupants by

195   controlling interstorey drift.
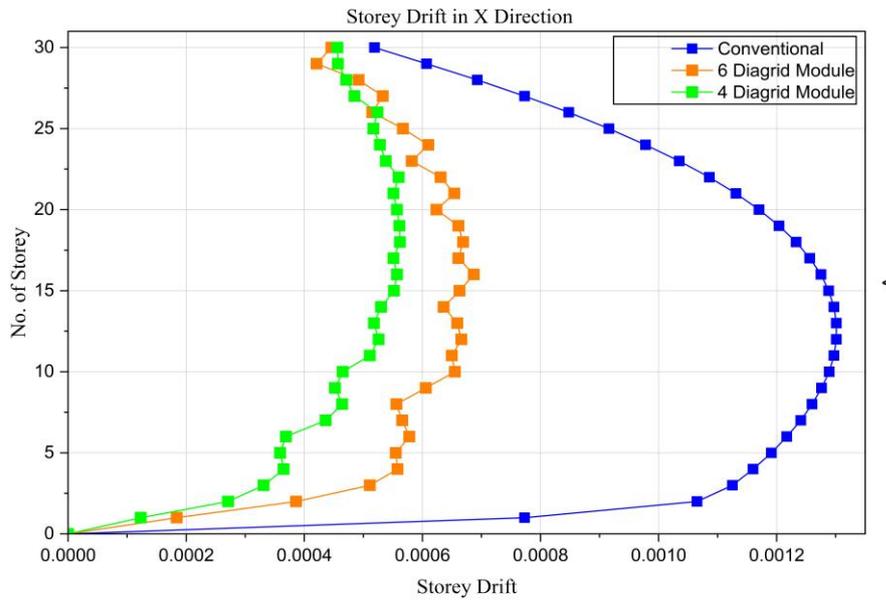
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197   **Figure 7: Storey drift in the X direction for diagrid and conventional structures**
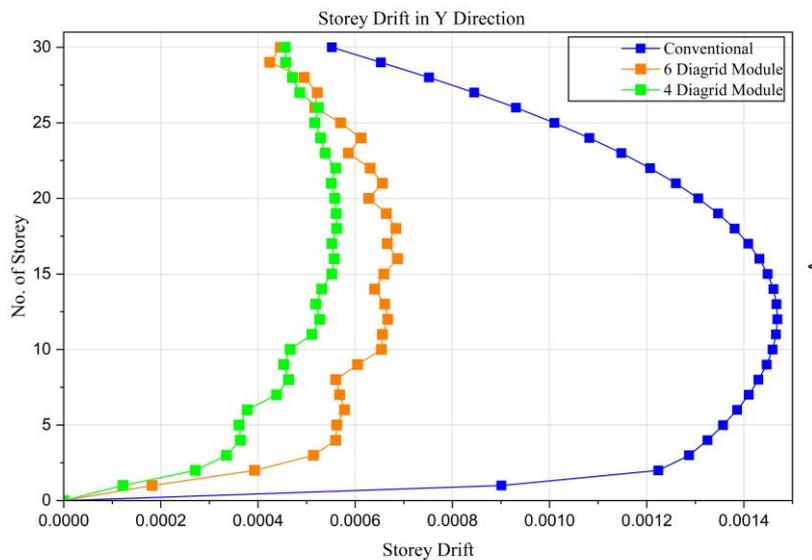
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199   **Figure 8: Storey drift in the Y direction for diagrid and conventional structures**

200   **4.   Conclusion**

201 This study focused on the effects of seismic action on diagrid and conventional frame 30-

202 symmetrical live steel structures. After being modelled in ETABS and analysed according to

203 the procedures of IS 1893:2016, the results essentially confirmed the advantages of the diagrid

204 system. When the lateral stiffness increased, the fundamental time period of the building

205 decreased, and the storey displacement, interstorey drift, and acceleration were strongly

206 controlled. These advantages arise principally because of the triangular avenue of diagrids,

207 which permits adequate seismic force redistribution and any additional bracing or heavy beam

208 constructions. Furthermore, the angles of the diagrids affect the displacement response of a

209 building and thus emphasise the importance of geometric optimisation during the design

210 process. In addition to the structural advantages, the diagrid system also provides architectural

211 freedom and reduces material usage by eliminating the need for (perimeter) columns. In

212 general, this means that diagrids are serious competitors to typical frames, especially for high-

213 elevation buildings in high-seismic-risk regions. Further research could focus on nonlinear

214 analysis, long-term behaviour, and cost-effectiveness to fully exploit these factors in practical

215 construction.

216 **5. Funding statement**

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