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(Research Article)

Parametric Study on Structural System Supporting Multiple Silos

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Abstract

This study presents a parametric Study of structural systems supporting multiple silos to optimize design for stability and cost-efficiency. Using STAAD. Pro Software, key parameters such as silo spacing, beam dimensions, and material properties were varied under standardized loading Department conditions. The analysis focused on minimizing stress and enhancing structural performance for industrial applications. Results indicate that optimal configurations, including a 6-meter silo spacing and steel beams. These findings offer practical design solutions for economical silo support systems, addressing challenges in Cement material load management and structural stability. The study provides valuable insights for engineers and industry professionals seeking to improve the efficiency of multi-silo structures.

Keywords: silo structures, bracing system, parametric analysis, structural stability, silo supporting systems, industrial structures, load analysis.

1. Introduction

Silos are important structures for storing materials in industries such as agriculture, cement, and mining, but their Supporting systems face significant challenges due to complex loading conditions, including granular pressure and dynamic forces. Existing structural designs for multiple silo configurations often rely on conservative assumptions, leading to overdesigned systems that increase construction costs without guaranteeing optimal performance. Recent studies highlight the need for parametric analysis to explore design variables like silo spacing, beam dimensions, and material properties to enhance stability and efficiency. However, limited research addresses the optimization of support systems for multiple silos under standardized loading conditions, such as those specified in IS 875:1987 (Part 1 to 4). This study aims to conduct a parametric analysis of structural systems supporting multiple silos using STAAD. Pro Software to identify optimal design parameters that minimize stress and cost. The scope includes evaluating key variables under Indian Code-specified loads to provide practical design solutions for industrial applications. By addressing these gaps, this research contributes to cost-effective and robust silo support designs.

- Classification of Silos based on Stored Material: Silos can be classified based on stored materials like Grain, Coal, Cement, Carbon black, Pallets, Iron ore etc.
- Classification of Silos based on Construction Material: Silos can be classified based on Construction materials like RCC, Steel Plates, Wood etc.
- Classification of Different Bracing Patterns in Industrial Buildings:
    - Horizontal Types:
        - Triangulated Bracing
        - Diaphragms
    - Vertical Types:
        - V- Bracing
        - Inverted V-Bracing
        - Single Diagonal Bracing
        - Cross Bracing or X- Bracing
        - K-Bracing

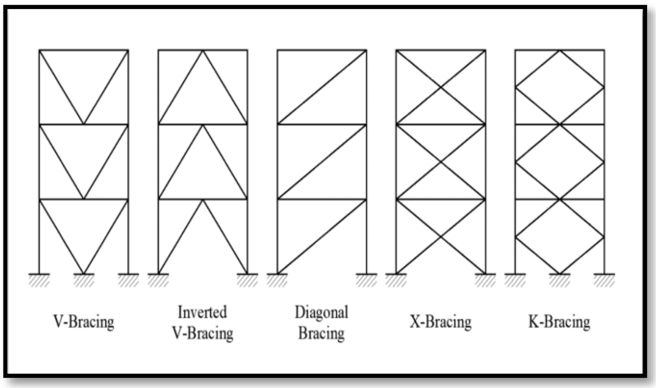

Figure 1. Types of vertical bracing

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2. Parametric Study of Structure

This Parametric Study examines a structural system supporting three cylindrical silos, each with 8-meter diameter and 14-meter height, arranged in a square grid for a cement storage facility. The objective was to optimize the support structure's design using parametric analysis to minimize stress and construction costs while ensuring stability under granular and dynamic loads. Analysis was conducted using Software, with parameters including silo spacing (6 meters) and material properties (steel). Loading conditions followed IS 875:1987 (Part 1 to 4) accounting for Wind Loads and IS 1893 Part-1 & Part-4 for Seismic loading.

The Silos rest in a steel Structure composed of steel structure with different types of bracing patterns (Like, X-Bracing, A-Bracing and Single Diagonal Bracing).

2.1 Details of silo supporting structure: Silo supporting structure considered here are rectangle shape in plan having total height of 12 m. The buildings are assumed to be in Bhuj in Seismic Zone-V. Column to Colum distances are 6m in X & Z direction (Figure 2). Dimensions in the modelling are given Table 1.

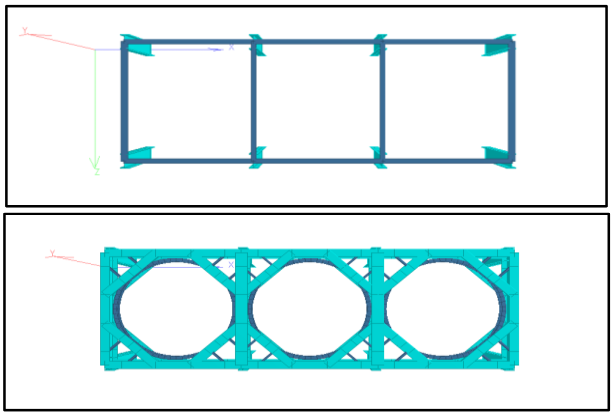

Figure 2. Plan of the modelled building and columns which are considered for analysis

Table 1. Description of the building and frame elements

Sr. no.	Particulars	Details
1.	Storey height	0.3m (ground Level) and 6.0 m (other floors)
2.	Number of floors	2
3.	Height of building	12 m
4.	Centre to center distance between columns	6.0 m in both directions
5.	Column cross section	WH1100 x 600 x 50 x 32
6.	6.0 m level Beam cross section	UC305 x 305 x 198.1
7.	12 m Level Beam cross section	WH1500 x 600 x 50 x 40
8.	Silo plate thickness	12mm
9.	Bracing cross section	UC356 x 406 x 287

These dimensions are finalized after visiting industrial sites and taking some real-life examples for dead load and live load. Dead load of silo is taken over Diagonal beams (Figure 2) in STAAD. Pro software.

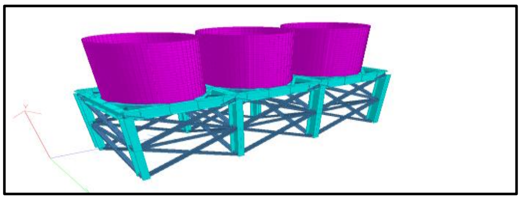

Figure 3. 3D modelled building

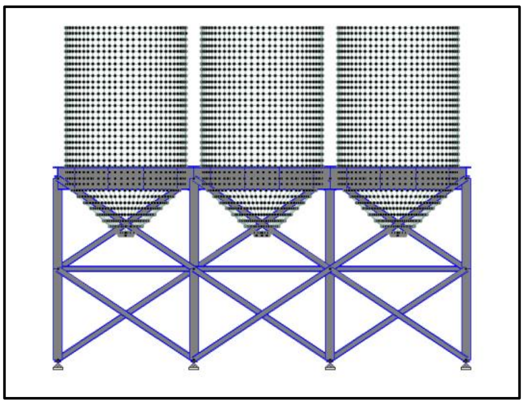

Figure 4. Elevation view

2.2 Software model development: In this research, STAAD. Pro Software Connect Edition version 23.00.01.25 was used to develop 3D Models for further analysis.

The Beams and columns are connected at EL.+12.00m with shear connection approach and at El.+6.00m, Beams and columns are connected only for force transfer mechanism purpose. Loading of silos which are applied on EL+12.00m are calculated based on Codal provisions (IS 1978:1979 Part-1 to 3). As per Figure 2 & 3, Model was created for 6.00m spanning on both X and Z direction to support Three Nos. of silos with 1000 T Capacity per silo.
Silos are modelled by using Plate model Method, Plate loading on silos plates are applied as per calculation mention in code (IS 1978:1979 Part-1 to 3). For more detail understanding for model refer Figure 2 & 3.

2.3 Loads and load combinations: Dead and live loads are fundamental for designing stable silo support systems, calculated as IS 875:1987 (Part 1 for Dead Loads, Part 2 for Live Loads). Dead loads include the self-weight of structural components (e.g., steel beams, columns) and silo contents (e.g., cement at 14.4 kN/m³). For a three-silo support system, each silo (8 m diameter, 14 m height) was assigned a dead load based on material densities (steel: 78.5 kN/m³, concrete: 25 kN/m³). These loads were input in software using the

SELFWEIGHT and MEMBER LOAD commands, ensuring accurate weight distribution.

Live loads, as per IS 875:1987 Part 2, account for variable loads like maintenance activities and equipment on the support structure, typically 5 kN/m² for industrial platforms. In Software, live loads were applied as FLOOR LOAD across the support framework.

Load combinations were defined from IS 1893:2016, Clause 6.3.2.2, for ultimate limit state (ULS) design with IS 800:2007, chapter 12, clause 12.2.3 for key combinations.
Loading Condition "0-0-0", "50-50-50", "100-100-100" indicates that all three Silos are in empty condition, Half full and Full condition, which shows silo empty/Half-Full/Full conditions.

2.4 Structure analysis: Seismic load analysis is vital for silo support systems in Zone V, India's highest seismic risk zone, where dynamic forces challenge structural stability. This study employs the response spectrum method per IS 1893:2016 (Part 1) to calculate seismic loads, implemented using STAAD. Pro software. Key parameters include the zone factor ($Z = 0.36$ for Zone V), importance factor ($I = 1.5$ for industrial structures), response reduction factor ($R = 4.0$) and soft soil type (Type III). The fundamental period (T) was calculated as $T = 0.09h/\sqrt{d}$, where h is the silo support height and d is the base dimension.

3D model of a Three-silo (Figure 2) support system was created, with parametric variables like silo spacing (6meters). Seismic loads were defined using the DEFINE 1893 LOAD command, specifying $Z = 0.36$, $I = 1.5$, $R = 4.0$, and soil type III. The response spectrum was applied per IS 1893:2016, Which is automatically calculating Sa/g based on T. The base shear (Vb) was computed as $Vb = (Ah \cdot W)$, where $Ah = (Z/2) \cdot (I/R) \cdot (Sa/g)$ and W is the seismic weight (including silo contents).

3. Results and Discussion

The parametric analysis of the silo support system, modeled in STAAD .Pro, evaluated the effects of silo supporting structure under dead, live, and seismic loads, as per IS 875:1987 and IS 1893:2016 (Zone V). The response spectrum method was used for seismic analysis, with load combinations applied per IS 1893:2016 Clause 6.3.2.2 and IS 800:2007, chapter-12, clause 12.2.3. Key findings indicate that X-Type bracing is more economical compared to other two types (A- Brace, Single Diagonal Bracing) on structural performance. This configuration reduced maximum Deflection and base shear under the critical load combinations.

3.1 Base shear: Base shear values for different Model types and brace configurations (X-Brace, A-Brace, Diagonal Brace), ranging from 1568.639 kN to 7417.97 kN. For instance, the 100-100-100 Model type exhibited the highest base shear (7417.97 kN for X-Brace), indicating increased dynamic response with higher Modal participation. In contrast, the 0-0-0 configuration showed the lowest base shear (1568.639 kN), suggesting stability with minimal dynamic effects.

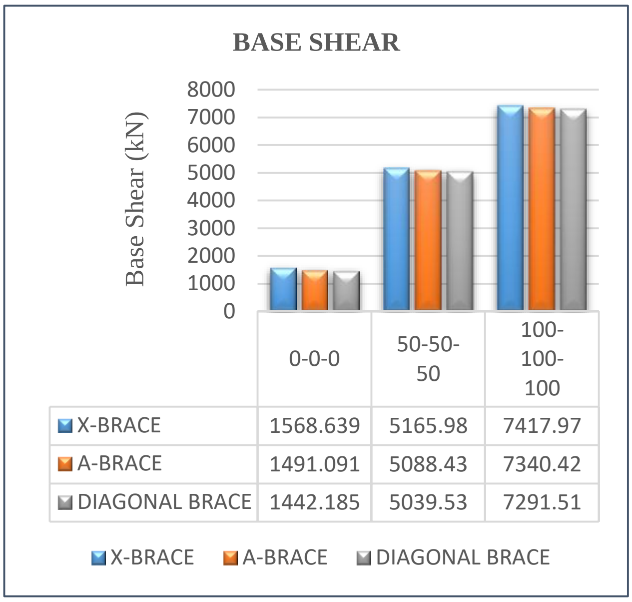

Figure 5. Base shear comparison for various loading conditions

3.2 Mass participation: Mass participation percentages for various Model types and brace configurations (X-Brace, A-Brace, Diagonal Brace), ranging from 73.218% to 93.61% for X-Brace. The 100-100-100 Model type achieved the highest participation (93.61% for X-Brace), indicating effective capture of dynamic mass, while 0-0-0 showed the lowest (73.218%). A-Brace and Diagonal Brace followed similar trends, with maximums at 93.40% and 92.52%, respectively.

Mass participation is calculated for multiple modes, not just the fundamental mode.

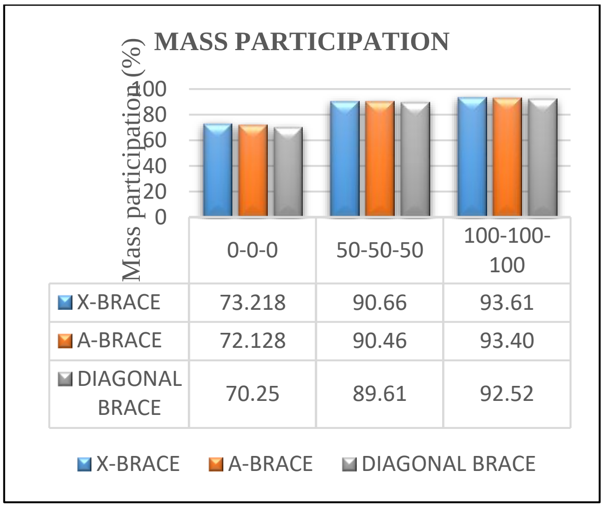

Figure 6. Mass participation for various loading conditions

3.3 Displacement in X direction: Displacement values for various Model types and brace configurations (X-Brace, A-Brace, Diagonal Brace), ranging from 1.692 mm to 26.726 mm for X-Brace and Diagonal Brace respectively. The 100-100-100 Model type exhibited the highest displacement

(13.591 mm for X-Brace), indicating increased flexibility with higher Model participation, while 0-0-0 showed the lowest (1.692 mm). A-Brace and Diagonal Brace followed, with maximums at 18.58 mm and 26.08 mm, respectively.

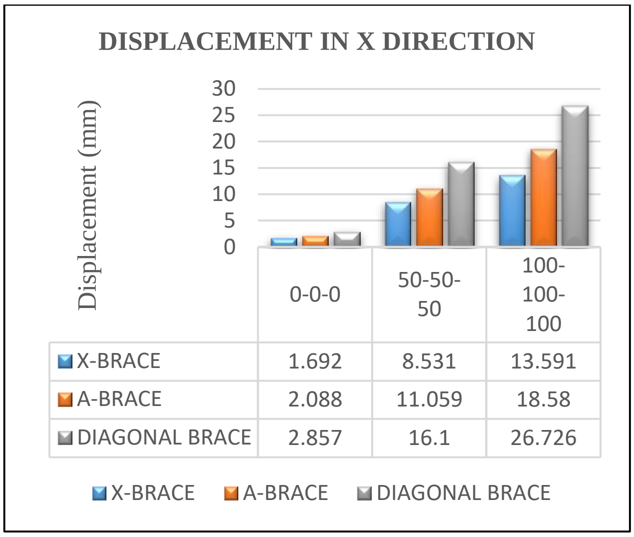

Figure 7. Displacement in X-direction for various loading conditions

3.4 Displacement in Z direction: Displacement values for various Model types and brace configurations (X-Brace, A-Brace, Diagonal Brace), ranging from 1.1.867 mm to 28.178 mm for X-Brace and Diagonal Brace respectively. The 100-100-100 Model type exhibited the highest displacement (14.774 mm for X-Brace), indicating increased flexibility with higher Model participation, while 0-0-0 showed the lowest (1.867 mm). A-Brace and Diagonal Brace followed, with maximums at 19.988 mm and 28.178 mm, respectively.

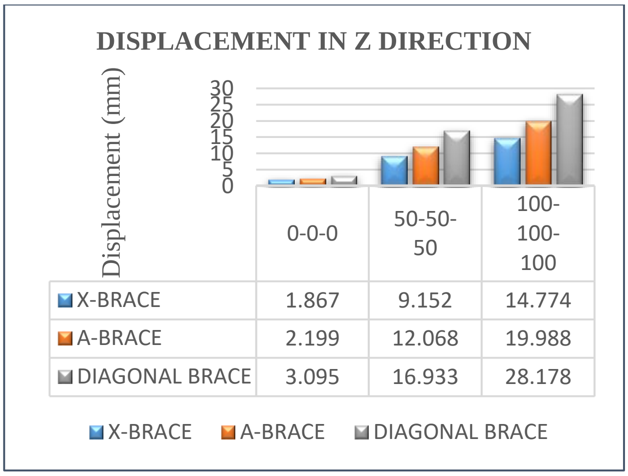

Figure 8. Displacement in Z-direction for various loading conditions

3.5 Frequency: Frequency values for various Model types and brace configurations (X-Brace, A-Brace, Diagonal Brace), ranging from 8.01 to 2.26 for X-Brace. The 0-0-0 Model type exhibited the Highest frequency (8.01), indicating lower flexibility, while 100-100-100 showed the lowest (2.26), reflecting increased stiffness with higher Model participation. A-Brace and Diagonal Brace followed similar trends, with maximums at 2.10 and 1.75, respectively.

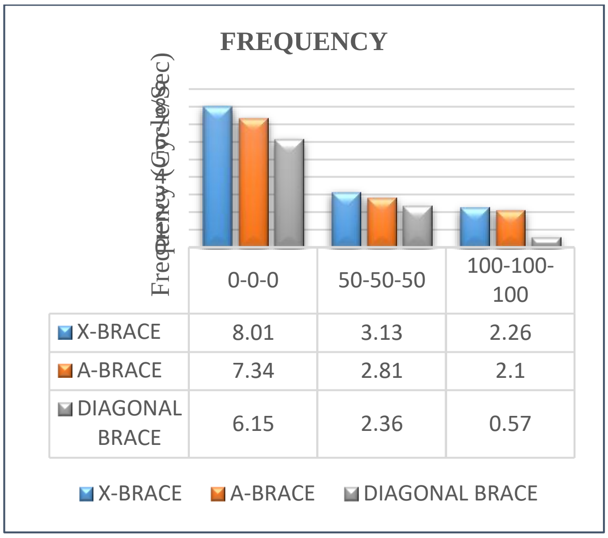

Figure 9. Frequency for “0-0-0”, “50-50-50”, “100-100-100”

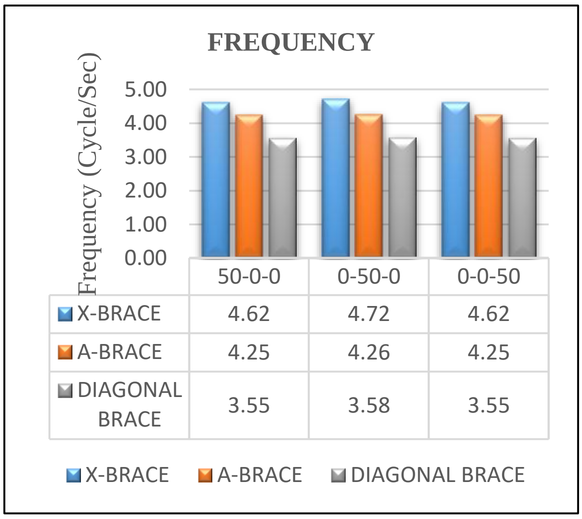

Figure 10. Frequency for “50-0-0”, “0-50-0”, “0-0-50”

4. Conclusions

We can give conclusion using STAAD.Pro, offers an in-depth evaluation of design optimization for stability and cost-efficiency, particularly in India’s Zone V (Z = 0.36) seismic region. The analysis, based on a Parametric Study of three 8-meter diameter, 14-meter height silos with 6-meter spacing, integrated key parameter silo spacing, beam dimensions, and bracing types (X-Brace, A-Brace, Diagonal Brace)—under dead, live, and seismic loads per IS 875:1987, IS 1893:2016 and IS 800:2007. Results reveal significant variations: base shear ranged from 1568.639 kN (0-0-0) to 7417.97 kN (100-100-100) with X-Brace showing the highest dynamic response; mass participation peaked at 95.61% for 100-100-100 (X-Brace), indicating effective dynamic mass capture; displacements reached 26.726 mm (X) and 28.178 mm (Z) for 100-100-100, reflecting flexibility; and frequency varied from 0.81 Hz (0-0-0) to 2.66 Hz (100-100-100), highlighting X-Brace’s stiffness.

4.1 X-brace's structural superiority:

- X-Brace reduced maximum displacement by 49% in X-Direction (13.591 mm vs. 26.726 mm for Diagonal Brace in 100-100-100 Model type), and by 48% in Z-Direction (14.774 mm vs. 28.178 mm for Diagonal Brace in 100-100-100 Model type) enhancing rigidity under critical load combinations.

4.2 Mass participation efficiency:

- X-Brace achieved 93.61% mass participation in the 100-100-100 Model type, compared to 93.40% (A-Brace) and 92.52% (Diagonal Brace), ensuring effective dynamic load distribution.
- Even in the 0-0-0 configuration, X-Brace maintained 73.218% mass participation, indicating consistent performance across varying dynamic conditions.

4.3 Seismic stability in zone V:

- Base shear ranged from 1568.639 kN (0-0-0) to 7417.97 kN (100-100-100) for X-Brace, aligning with IS 1893:2016 seismic requirements for Zone V.
- X-Brace's natural frequency (8.01 Hz in 0-0-0 to 2.26 Hz in 100-100-100) stayed above critical seismic ranges, reducing resonance risks in high-seismic zones.

4.4 Displacement control:

- X-Brace exhibited the lowest displacement (1.692 mm in 0-0-0), compared to 18.58 mm (A-Brace) and 26.08 mm (Diagonal Brace) in higher Model types, ensuring structural integrity under lateral loads.
- In the 100-100-100 Model type, X-Brace's 13.591 mm displacement was within acceptable IS code limits, unlike less rigid alternatives.

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