Static and Dynamic Behavior of Circular Silo with Different Lateral Load Resisting Systems

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Abstract— Circular silos are constructed for many industries to store the material such as food grains, cement, clinker etc. in large quantities. The lateral loads such as earthquake and wind have a vital effect on the structure causing a lot of damage, failure of structure and huge loss to the industry. Hence it is necessary to study the response of such structures under earthquake forces. The behavior depends upon the ground motion characteristics as well as the mass ensiled in the silo. In order to reduce the effect of such forces, various lateral load resisting systems are provided in supporting sections i.e. in between columns. The present study is about the static and dynamic behaviour of silo subjected to earthquake forces situated in all zones of India. Shear plate elements as well as bracing elements are used as lateral load resisting units between adjacent columns. The 3D modelling and analysis is carried out using structural analytical tool SAP-2000. The combinations of loads are defined as per guidelines provided in Indian standard codes. Response spectrum method of analysis is used for the dynamic analysis of silo structure. In this study, results are obtained and compared in the form of base shear, maximum displacement, natural time period and stresses. From the comparison of results the best suitable element is obtained and suggested to enhance the performance of the silo structure under earthquake loads.

Key words: Circular Steel Silo, Steel Plate Shear Walls, Bracings, Base Shear, Displacement, Natural Time Period, Stresses, Response Spectrum Method, SAP 2000

I. INTRODUCTION

Silos are the type of structures used for storing bulk materials like agricultural grains, cement, coal, factory made pozzolanic materials such as fly ash, silica fume etc. There are three types of silos used for the commercial construction. They are bunker silos, tower silos and bag silos. Cement concrete and steel are the type of material used for the construction of such silos. The depth of the silo is greater than twice the breadth or the diameter and the plane of rupture drawn from the bottom edge does not intersect the free surface.

Steel silos are used widely over concrete silos because they are easy to erect and install accessories like doors and ladders etc. they provide greater storage capacity per unit cost. Also steel has physical properties like the high ductility, high strength per unit weight, the high yield strength and ultimate strength which are important and result in slender sections. Ductile nature of the steel structures helps in forming excessive deformations within permissible limits before final fracture and hence an advance warning helps in maintenance of the structure. In case of the seismic resistant design these properties of steel play a vital role. The major force that affects the stability is dynamic force such as seismic force or earthquake force.

A. *Shear Wall*

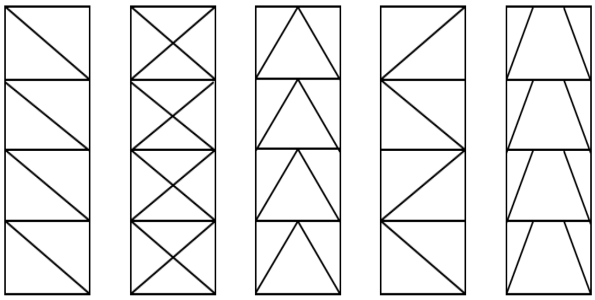
Shear walls are an important part of mid-rise structures and high rise structures. These walls are provided in structural plans to reduce earthquake forces and considered as an important part of the seismic design of structures. The in plane lateral loads acting along the height are resisted by shear walls and hence increasing the seismic resistance of the structure. Shear walls provide the required lateral strength to resist earthquake forces acting in horizontal direction.

The shear walls have advantages in lateral load resisting structures like,

- Enhanced strength
- Higher ductility
- Higher stiffness
- High plastic energy absorption capacity.

B. *Bracings*

Braced frames provide resistance to lateral forces acting on silo structure. The members of a braced frame act as a stress system and are subjected primarily to axial stress. Depending on the diagonal force, required length, clear distance between members and stiffness, the diagonal members can be built up of double angles, channels, Tees tubes or even wide flange shapes. Besides performance the shape of the diagonal is often based on connection considerations. The braces are often placed around service core and elevators, where framed diagonals may be enclosed within permanent walls. This is invariably the best way of providing lateral resistance and stiffness to the silo structure.



(a) (b) (c) (d) (e)

Fig. 1: Types of bracings (a) Single diagonal bracing (b) X or cross bracings (c) V bracing (d) k bracing (e) knee bracing

An axially loaded member loses strength and does not return to its original straight configuration. To reduce the possibility of this occurring during moderate earthquakes, more straighten design requirements are imposed on bracing member. Thus, ordinary concentrically braced frames are not allowed in Seismic zones IV and V and for buildings with an importance factor greater than unity (I > 1.0) in zones III, single diagonal, V, K bracing is not permitted in earthquakes zones by the codes because the inelastic deformation and buckling of these bracing members may produce lateral deflection of the connected columns, causing collapse and hence cross or X bracings are provided.

C. Objectives

Following are the objectives

1) To evaluate and compare the variation of base shear for different zones of earthquake in India i.e. zone II to zone V.
2) To compare the response of circular silo structure in the form of natural time period for various elements.
3) To determine the maximum displacement resulting in silo when dynamic loads are applied for different zones of earthquake in India i.e. zone II to zone V.
4) To evaluate and compare the variation of stresses for different zones of earthquake in India i.e. zone II to zone V.

II. METHODOLOGY

The present study is to find the effect of shear wall on different silo models by performing lateral load analysis i.e. dynamic analysis using method of response spectrum. In the analysis, three different silo models are considered

1) Silo without any lateral load resisting systems.
2) Silo with plate elements.
3) Silo with bracing elements between supporting columns.

III. MODELING AND ANALYSIS

The project includes seven type of models studied by considering each seismic zone separately for the parameters such as base shear, displacement, natural time period and stresses. The types of models are listed below,

1) Basic silo model without any element (BM)
2) Silo with shear wall plate elements in long direction (SWX)
3) Silo with shear wall plate elements in short direction (SWY)
4) Silo with shear wall plate elements in all directions (SWA)
5) Silo with bracing elements in long directions (BRX)
6) Silo with bracings elements in short directions (BRY)
7) Silo with bracings elements in all directions (BRA)

A. Structural Models

In the present study silos are modelled with structural analysis software SAP 2000

Type of structure	Industrial structure(silo)
Column Height	4.6m
Vertical wall height	26m
Diameter of silo	6m
Material Property	
Grade of Concrete	M25
Concrete density	24 KN/m³
Young's Modulus of concrete	500√fck
Modulus of elasticity of steel	200 KN/mm^2
Live Load on Roof	1.5 kN/m^2
Floor Finish	2 kN/m^2

Table 1: Structural Details

B. Input Details of Models

Below tabular column lists the details of Ring Beam, Column size, type of bracing and shear wall thickness.

Ring beam size	ISHB300@576.8 N/m
Column size	ISHB400@759.3 N/m
Box type bracing	150mm X 150mm
Shear wall thickness	10mm

Table 2: Member Dimensions

Seismic Zone	Zone-II to Zone V
Type of Structure	Ordinary shear wall with OMRF
Damping ratio	2% for steel frame structure
Seismic zone factor - Z	Z1-0.10, Z2-0.16, Z3-0.24, Z4-0.36
Importance factor - I	1.5
Response reduction factor - R	3.0

Table 3: SeismicDetails

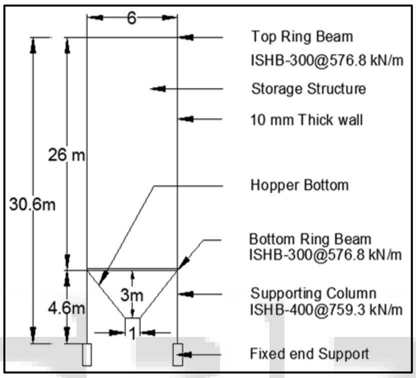


Fig. 2: Elevation of silos

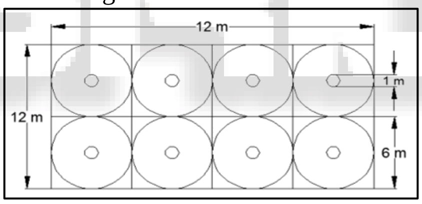


Fig. 3: Plan of silos

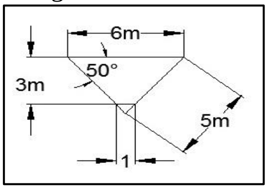


Fig. 4: Hopper Bottom Dimensions

C. SAP 2000 Model

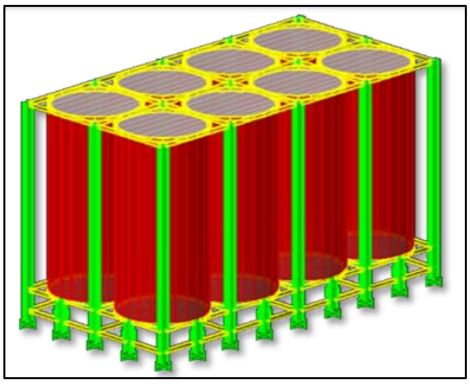


Fig. 5: Basic 8 silos model without any lateral load resisting unit

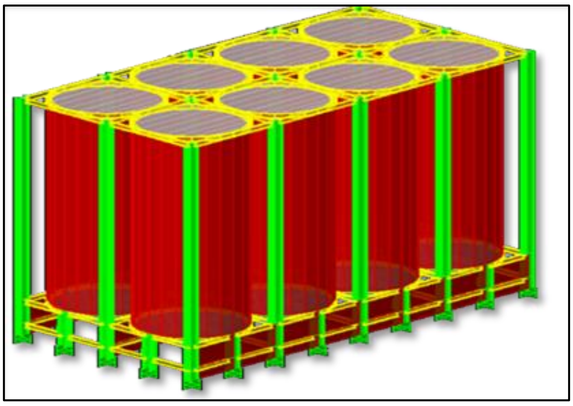


Fig. 6: Silos model with steel plates as lateral load resisting unit along long direction

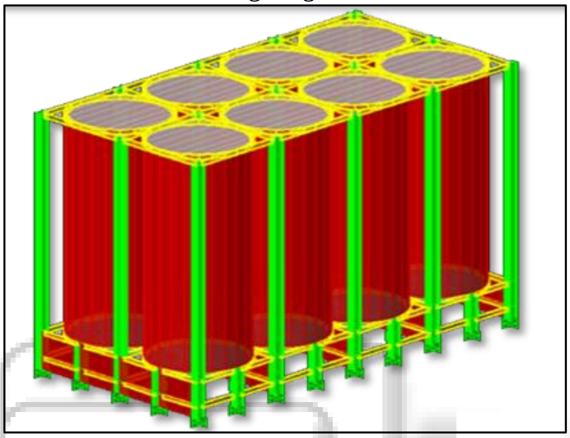


Fig. 7: Silos model with steel plates as lateral load resisting unit along short direction.

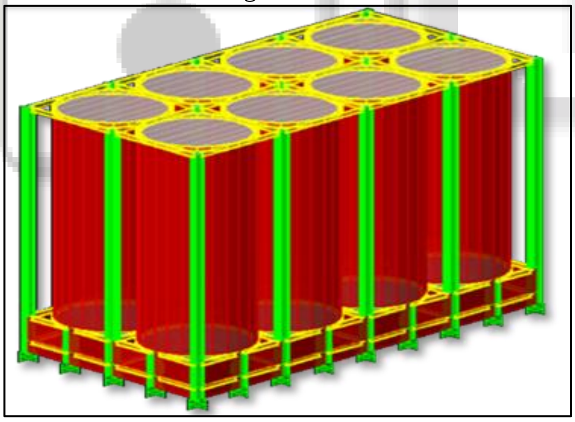


Fig. 8: Silos model with steel plates as lateral load resisting units in all directions

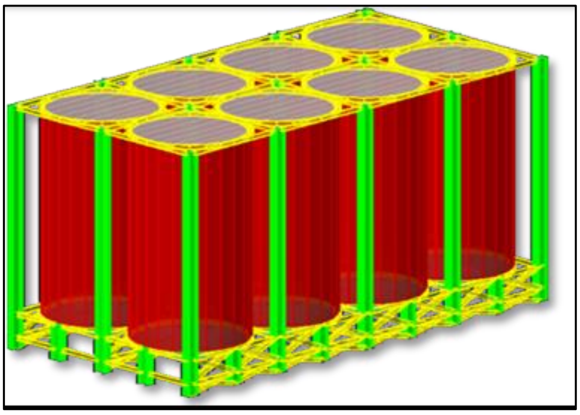


Fig. 9: Silos model with bracings as lateral load resisting unit along long direction

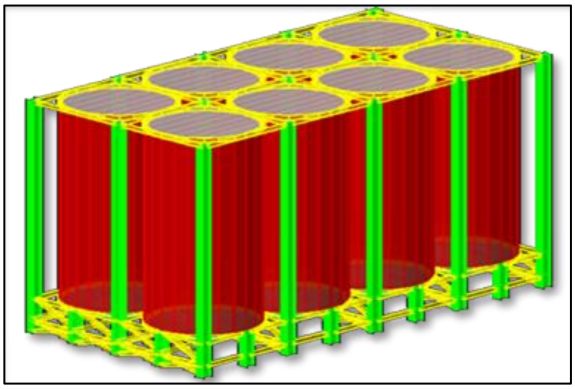


Fig. 10: Silos model with bracings as lateral load resisting unit along short direction

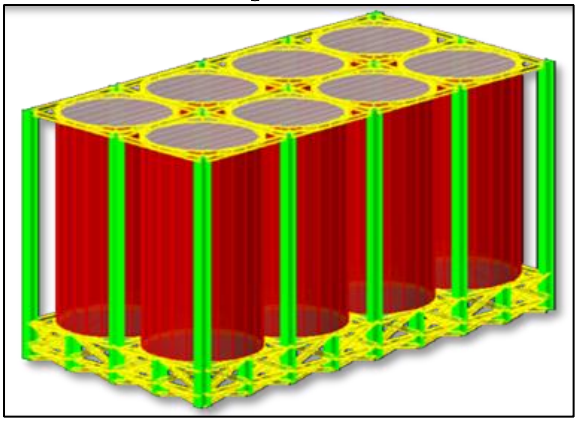


Fig. 11: Silos model with bracings as lateral load resisting units in all directions

IV. Results

A. Base Shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of the structure. It depends on various factors such as probability of significant seismic ground motion, the fundamental period of vibration etc.

The base shears are shown for Response Spectrum Analysis (RSA) for the different silo models. The further section shows the results of Base shear (in kN) for Silo with Plate element for Zone II to V.

1) *Zone II*

Seismic Force - X - Direction			
Type of Model	Base shear for 8 Silos		Static Base Shear
	X	Y	
BM	516.48	2251.2	565.103
SWX	438.56	2250.7	486.993
SWY	522.65	2251.02	909.562
SWA	440.14	2254.67	833.595
BRX	444.5	2250.7	753.098
BRY	521.88	2251.23	1239.354
BRA	446.36	2259.15	1150.424

Table 5.1 Base shear for zone II seismic force in long direction

Seismic Force -Y - Direction			
Type of Model	Base shear for 8 Silos		Static Base Shear
	X	Y	
BM	296.94	2444.35	2447.584
SWX	296.44	2453.24	2508.57

SWY	296.77	2384.34	2388.251
SWA	300.41	2385.12	3477.418
BRX	296.44	2451.09	3008.787
BRY	296.98	2381.53	2384.875
BRA	304.89	2389.64	2938.578

Table 5.2: Base shear for zone 2 seismic force in short direction

The table represents the values of base shear obtained by the application of earthquake forces in X and Y directions respectively for the different models for zone II. It is observed that the there is increase in the base shear values when the lateral load resisting systems are provided to the silo structure. When the earthquake forces are applied in X direction the base shear increases in the same direction. This increase obtained is about 76.8 KN for 8 silo model. In the same way when the earthquake forces are applied in Y direction the base shear values increase in Y and this increase is about 63 KN for 8 silo model.

2) *Zone III*

Seismic Force in X – Direction			
Type of Model	Base shear for 8 Silos		Static Base Shear
	X	Y	
BM	507.67	2251.17	585.467
SWX	432.87	2250.69	510.363
SWY	393.63	2251.01	1779.145
SWA	438.48	2254.50	1622.434
BRX	438.57	2250.69	932.326
BRY	512.86	2251.21	1660.818
BRA	440.35	2258.80	1566.852

Table 5.3: Base shear for zone III seismic force in long direction

Seismic Force in Y – Direction			
Type of Model	Base shear for 8 Silos		Static Base Shear
	X	Y	
BM	296.92	2437.56	2442.735
SWX	296.43	2445.14	2533.668
SWY	296.75	2378.98	2385.238
SWA	300.23	2379.73	4127.406
BRX	296.43	2443.07	3335.387
BRY	296.95	2382.05	2387.402
BRA	304.54	2384.08	3262.38

Table 5.4: Base shear for zone III seismic force in short direction

The table represents the values of base shear obtained by the application of earthquake forces in X and Y directions respectively for the different models for zone III.. When the earthquake forces are applied in X direction the base shear increases in the same direction. This increase obtained is about 119 KN. In the same way when the earthquake forces are applied in Y direction the base shear values increase in Y and this increase is about 65 KN.

3) *Zone IV*

Seismic Force in X – Direction			
Type of Model	Base shear for 8 Silos		Static Base Shear
	X	Y	
BM	613.36	2251.49	730.055
SWX	501.16	2250.76	617.4
SWY	622.25	2251.23	1678.223
SWA	503.43	2256.48	1435.445
BRX	509.71	2250.76	1250.344
BRY	621.14	2251.54	2343.078
BRA	512.38	2262.93	2202.133

Table 5.5: Base shear for zone IV seismic force in long direction

Seismic Force in Y - Direction			
Type of Model	Base shear for 8 Silos		Static Base Shear
	X	Y	
BM	297.23	2531.07	2538.832
SWX	296.51	2542.43	2675.223
SWY	296.98	2443.2	2452.586
SWA	302.23	2444.34	5065.856
BRX	296.5	2539.32	3877.79
BRY	297.28	2447.8	4169.738
BRA	308.68	2450.84	4140.593

Table 5.6: Base shear for zone IV seismic force in short direction

The table represents the values of base shear obtained by the application of earthquake forces in X and Y directions respectively for the different models for zone IV. When the earthquake forces are applied in X direction the base shear increases in the same direction. This increase obtained is about 121 KN. In the same way when the earthquake forces are applied in Y direction the base shear values increase in Y and this increase is about 100 KN.

4) *Zone V*

Seismic Force in X - Direction			
Type of Model	Base shear for 8 Silos		Static Base Shear
	X	Y	
BM	771.90	2251.96	946.94
SWX	603.60	2250.87	777.96
SWY	785.23	2251.58	1694.58
SWA	607.01	2259.45	1460.22
BRX	616.42	2250.87	1727.37
BRY	783.57	2252.03	3366.48
BRA	620.43	2269.12	3155.06

Table 5.7: Base shear for zone V seismic force in long direction

Seismic Force in Y - Direction			
Type of Model	Base shear for 8 Silos		Static Base Shear
	X	Y	
BM	297.70	2671.33	2682.973
SWX	296.61	2688.37	2887.559
SWY	297.32	2539.53	2540.683
SWA	305.20	2541.22	4242.01
BRX	296.61	2683.71	4691.421
BRY	297.78	2546.43	2558.472
BRA	314.87	2550.99	4527.166

Table 5.8: Base shear for zone V seismic force in short direction

The table represents the values of base shear obtained by the application of earthquake forces in X and Y directions respectively for the different models for zone IV. When the earthquake forces are applied in X direction the base shear increases in the same direction. This increase obtained is about 170 KN. In the same way when the earthquake forces are applied in Y direction the base shear values increase in Y and this increase is about 120 KN.

B. *Displacement*

Displacement in a structure is caused due to the action of external force such as lateral force which are earthquake forces. It is the shortest distance from the initial position of a point in a structure to it's deform final position. The further section shows the results of maximum displacements (mm) for Silo with Plate element for Zone II to V.

1) *Zone II*

Seismic Force in X – Direction		
Type of Model	Maximum displacements for 8 Silos	
	X	Y
BM	0.153	6.5
SWX	0.023	5.965
SWY	0.148	3.936
SWA	0.019	3.521
BRX	0.027	6.276
BRY	0.146	4.209
BRA	0.028	4.043

Table 5.9: Displacement due to lateral loads on silo in zone II

Earth Quake Force in Y – Direction		
Type of Model	Maximum displacements for 8 Silos	
	X	Y
BM	0.634	5.789
SWX	0.209	5.305
SWY	0.618	3.524
SWA	0.197	3.152
BRX	0.234	5.582
BRY	0.6255	3.766
BRA	0.231	3.614

Table 5.10: Displacement due to lateral loads on silo in zone 2

The table represents the values of maximum displacements obtained by the application of earthquake forces in X and Y directions respectively for the different models for zone II. It is observed that the there is decrease in the maximum displacement values when the lateral load resisting systems are provided to the silo structure. This reduction in the percentage varies from 45 % to 88 %. The maximum reduction in the displacement is obtained in case of silo model with shear plate elements provided in all directions.

2) *Zone III*

Seismic Force in X - Direction		
Type of Model	Maximum displacements for 8 Silos	
	X	Y
BM	0.172	6.501
SWX	0.0279	5.965
SWY	0.167	3.936
SWA	0.027	3.521
BRX	0.0361	6.277
BRY	0.1657	4.2099
BRA	0.0363	4.0433

Table 5.11: Displacement due to lateral loads on silo in zone III

Seismic Force in Y - Direction		
Type of Model	Maximum displacements for 8 Silos	
	X	Y
BM	0.6348	5.818
SWX	0.2092	5.331
SWY	0.618	3.54
SWA	0.197	3.168
BRX	0.2348	5.612
BRY	0.6256	3.784
BRA	0.2311	3.632

Table 5.12: Displacement due to lateral loads on silo in zone III

The table represents the values of maximum displacements obtained by the application of earthquake forces in X and Y directions respectively for the different models for zone III. It is observed that the there is decrease in the maximum displacement values when the lateral load resisting systems are provided to the silo structure. This reduction in the percentage varies from 46 % to 85 %. The maximum reduction in the displacement is obtained in case of silo model with shear plate elements provided in all directions.

3) *Zone IV*

Seismic Force in X - Direction		
Type of Model	Maximum displacements for 8 Silos	
	X	Y
BM	0.659	6.499
SWX	0.263	5.965
SWY	0.619	3.935
SWA	0.158	3.521
BRX	0.283	6.276
BRY	0.649	4.208
BRA	0.274	4.043

Table 5.13: Displacement due to lateral loads on silo in zone IV

Earth Quake Force in Y – Direction		
Type of Model	Maximum displacements for 8 Silos	
	X	Y
BM	0.633	5.476
SWX	0.209	5.014
SWY	0.618	3.342
SWA	0.197	2.989
BRX	0.234	5.276
BRY	0.624	3.571
BRA	0.23	3.426

Table 5.14: Displacement due to lateral loads in Y direction on silo in zone IV

The table represents the values of maximum displacements obtained by the application of earthquake forces in X and Y directions respectively for the different models for zone IV. It is observed that the there is decrease in the maximum displacement values when the lateral load resisting systems are provided to the silo structure. This reduction in the percentage varies from 46 % to 76 %. The maximum reduction in the displacement is obtained in case of silo model with shear plate elements provided in all directions.

4) *Zone V*

Seismic Force in X – Direction		
Type of Model	Maximum displacements for 8 Silos	
	X	Y
BM	0.400	6.490
SWX	0.199	5.960
SWY	0.398	3.930
SWA	0.186	3.520
BRX	0.212	6.270
BRY	0.411	4.200
BRA	0.207	4.040

Table 5.15: Displacement due to lateral loads in X direction on silo in zone V

Seismic Force in Y – Direction	
Type of	Maximum displacements for 8 Silos

Model	X	Y
BM	0.632	4.962
SWX	0.208	4.538
SWY	0.617	3.044
SWA	0.197	2.723
BRX	0.234	4.776
BRY	0.623	3.249
BRA	0.230	3.117

Table 5.16: Displacement due to lateral loads in Y direction on silo in zone V

The table represents the values of maximum displacements obtained by the application of earthquake forces in X and Y directions respectively for the different models for zone V. It is observed that the there is decrease in the maximum displacement values when the lateral load resisting systems are provided to the silo structure. This reduction in the percentage varies from 45 % to 69 %. The maximum reduction in the displacement is obtained in case of silo model with shear plate elements provided in all directions.

C. Natural Time Period

Natural period of any structure is defined as the time period of undamped free vibration and it is expressed in terms of seconds. It is inversely proportional to the frequency. The mass and the stiffness are the two governing factors of natural time period. The natural period values obtained from Response spectrum method are as follows,

Type of Model	Time Period in seconds 8 Silos Model
BM	0.632
SWX	0.208
SWY	0.617
SWA	0.197
BRX	0.234
BRY	0.623
BRA	0.230

Table 5.17: Natural time period for all type of silos

It is observed that the natural time period is minimum in the case of silo model provided with the shear plate elements compared to basic model. The reduction in the time period is observed to be about 68.8 %.

D. Stresses

Stresses are induced due to application of lateral or earthquake forces. These stresses are distributed over the members. The maximum stress values of basic model are noted down in the form of tables and compared with other models. The resulting graphical variation pattern of stresses is shown in following Fig.

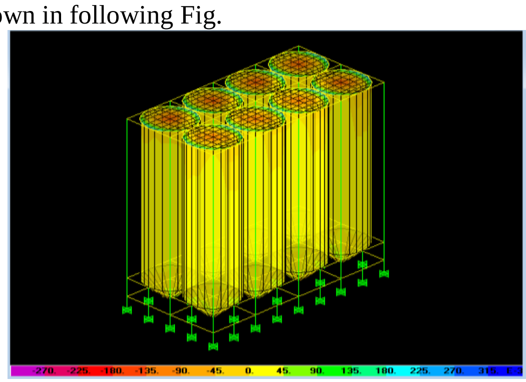


Fig. 5.4.1: Global distribution of stresses

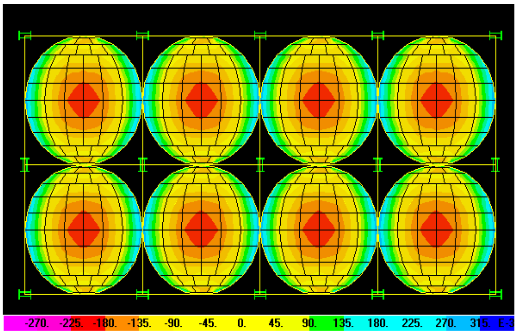


Fig. 5.4.2: Distribution of stresses over silo top

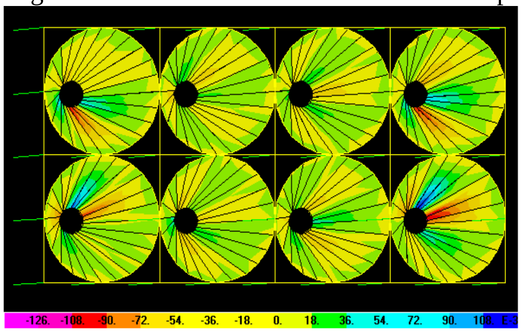


Fig. 5.4.3: Distribution of stresses in hopper bottom

The different colours indicate the magnitude of stresses at different parts of the silos as shown in Fig. 5.4.1 and Fig. 5.4.2. The negative stresses are shown in darker shades of red color variation. The positive stresses are shown in green and blue color variation indicating maximum and minimum range of stresses. However, to find the maximum stress in the whole structure, individual sections are to be considered. Hence top surface and hopper bottom surfaces are considered for the identification of maximum stress.

Maximum stresses (8 Silos)				
Type of model	Zones			
	II	III	IV	V
BM	268.23	342.52	425.11	512.62
SWX	172.14	212.43	276.44	368.63
SWY	196.75	250.67	314.35	396.73
SWA	135.18	186.33	257.19	348.07
BRX	176.38	196.34	298.02	374.18
BRY	202.22	234.12	335.41	421.35
BRA	146.36	198.47	280.21	360.06

Table 5.18: Maximum stress values for 8 silo models in zone II to V.

Table 5.18 shows the maximum stress values for the different models on the application of earthquake forces in different zones i.e. from zone II to zone V. It is observed that as the zone increases the stress values decreases from 32 % to 50 %.

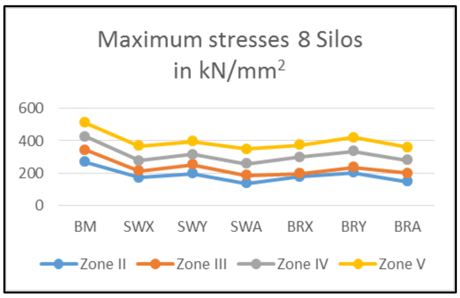


Fig. 5.4.4: Variation of maximum stresses for different models

V. CONCLUSION

1) Base shear increases in members provided in the direction of applied lateral load. It is observed that base shear increases by an amount of 60 – 170 kN along X-direction and 40 – 120 kN in Y direction when earthquake forces are applied in X and Y direction respectively.
2) The average percentage reduction in displacement is obtained as 60% on addition of shear plate elements and 40 % on providing bracings respectively.
3) Maximum reduction of 70 % is obtained in maximum displacement of silos on addition of shear plate elements in both X and Y direction to the silo structure.
4) Natural time period decreases from 45.5 % to 68.8 % for the silos with shear plate elements provided in both X and Y direction.
5) Natural time period remains same for the silo structure in each zone due to same mass distribution and stiffness i.e. structural configuration.
6) Frequency increases by 45.5 % for the silo structure on addition of shear plate elements in both the directions.
7) Maximum stress reduction is obtained to be 32 to 50 % in 8 silo model and 45 to 61 % in 4 silo model respectively.
8) From all the study carried out it is recommended to provide shear plate elements in the supporting structure as it is more effective in resisting the lateral loads or earthquake forces.

A. *Future Scope*

– The behaviour of silos can be studied for other lateral load resisting systems such as steel wall plates with openings.
– The silos models can be provided with intermediate stiffeners in vertical and horizontal directions and effect of them under the action of lateral loads can be studied.

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REFERENCES

[1] Hamdy H. A. and Abdel-Rahim, "Response of the cylindrical elevated wheat storage silos to seismic loading",IOSR Journal of engineering, Vol. 04, Issue 01, January 2014, pp. 42-55.
[2] Sivbala. P, Elangovan. G, Kameshwari. B, "Effect of shear wall panels on the dynamic response of silo", International Journal of Civil and Structural Engineering, Volume 1, N0 4, 2011, pp 958-967
[3] Manish S. Takey, S.S. Vidhale, "Seismic response of steel building with linear bracing system", IJECSCSE, ISSN 2277-9477, Vol II, pp 17-25
[4] R.S. Londhe, A.P. Chavan, "Behaviour of Building Frames with Steel Plate Shear Walls", Asian Journal Of Civil Engineering, Vol. 11, 2010, pp 95-102.
[5] Jaspal Singh V.R.Sharma N.K. Khullar "Analysis of Hopper Bottom Cylindrical Silos Subjected to Earthquakes", The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG) October 2008, Goa, India, pp. 2595-2603
[6] F. Nateghi and M. Yakhchalian, "Seismic Behavior of Silos with Different Height to Diameter Ratios Considering Granular Material structure Interaction", Structural Engineering Research Center, International Institute of Earthquake Engineering and Seismology, Tehran, Iran Vol -25, February 2012, pp 27-36.
[7] S. Silvestri, T. Trombetti and G. Gasparini, "Flat-Bottom Grain Silos Under Earthquake Ground Motion", The 14th World Conference On Earthquake Engineering, October 2008, Beijing, China.
[8] Earnesto F. Cruze, and Anil K. Chopra. M.ASCE, "Simplified procedures for earthquake analysis of buildings", Journal of Structural Engineering, Vol. 112, No 3, March, 1986. Paper No. 2044, pp. 461-466.
[9] Abolhassan Astaneh-Asl, "Seismic Behavior and Design of Steel Shear Walls", Paper Distributed and presented at the 2001 SEOANC Seminar, Structural Engineers Assoc. of Northern California, November 7, 2001.
[10] Agarwal. P and Shrikhande. M, "Earthquake Resistant Design of Structures", Prentice Hall of India Private Limited New Delhi India, 2008.
[11] Dr.Ramchandra and Virendra Gehlot, "Design of Steel Structures - 1" Standard Publishers, New Delhi India, 2009.
[12] Dr.Ramchandra and Virendra Gehlot, "Design of Steel Structures - 2" Standard Publishers, New Delhi India, 2010.
[13] IS: 1893(Part-4): 2004 Criteria for Earthquake Resistant Design of Structures, Part-4 General Industrial structures including Stack like structures First Revision, Bureau of Indian Standard, New Delhi, India.
[14] IS: 9178(Part I) :1978 Criteria for Design of Steel Bins for storage of Bulk Materials, Part I General requirements and Assessment of Loads, Bureau of Indian Standard, New Delhi India.
[15] IS: 9178(Part II) :1979 Criteria for Design of Steel Bins for storage of Bulk Materials, Part II Design Criteria, Bureau of Indian Standard, New Delhi India.
[16] IS: 9178(Part III) :1980 Criteria for Design of Steel Bins for storage of Bulk Materials, Part III, Bins

Designed for Mass Flow and Funnel Flow, New Delhi India.
[17] Steel tables, Birla Publications Pvt. Ltd, New Delhi India.