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Deflection Behavior at the Top of Circular Steel Medium Silo in Wind Environment

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Abstract

Wind forces are responsible for huge destruction in the world. This damage can be largely controlled, by the application of rigorous analysis of wind loads to ensure maximum safety at the lowest cost of the clients. The present study was made on circular steel silo subjected to rigorous wind loading and its effects on the amchorage requirements of medium silos. For the analysis of such a situation, there were few techniques available namely, finite element method, structural matrix analysis. This paper reports the comparison of results by various analysis of medium silos for deflection behavior in wind environment. For intermediate silos, there was increase in maximum tip deflection with the increase in height to diameter ratio from 1.25 to 3.0. The present analysis is on the basis of wind speed data around Delhi, but the model can be used for any wind speed and location.
Key words : Circular steel silo, Wind excitation, Deflection, Probability density function, Aspect ratio.

Strong winds in the form of hurricanes, cyclones, tornadoes and thunderstorms cause a great damage in the form of loss of lives, property and livestock. So while designing structures, it is to be ensured that the performance of structures subjected to action of wind will be adequate during their anticipated life from viewpoint of both structural safety and serviceability. To achieve these objectives, it is desirable to improve the understanding of the behavior of the wind environment on structures with an emphasis on more precise definition of wind forces for structural design. The behavior of deflection on circular steel silos of shallow height in wind environment was earlier reported (1). Due to rapid advancement in the materials and construction techniques, nowadays tall and light weight structures are being constructed. Such structures generally exhibit an increased susceptibility to the action of winds. The conventional procedure of design and analysis includes the assumption of wind load as static or quasi-static. In peak wind approach; depending upon parameters such as risk level, local topography, terrain roughness, height and size of the silo, design wind pressure is determined. From value of design wind pressure, wind load is determined using pressure coefficients and frontal area of the silo. For using mean wind approach, besides the parameters required for peak wind approach (2) value of gust factor is required for which fundamental natural frequency of the structure is required to be estimated. This was not applicable for highly flexible thin walled structures subjected to no internal pressure, e.g. silos during empty condition. Normally wind loads effects on even tall structures were omitted in the design. Even in the case of this inclusion, it was considered to be on a simplistic assumption. The wind load was taken as uniformly distributed or considered as triangular linear variation or even trapezoidal. This concept was not a valid one for thin walled structures such as surface type silo especially made of thin steel walls. To arriv at the thickness of steel wall, economic considerations required the estimation of it by thin cylinder theory and dynamic grain pressure theory. But then how effectively the wind load was incorporated remained a mute point. This called for the spatial behavior of the slender structures by a random wind loading. This enabled the automatic treatment of vibrations effects on the outer face of the structure.

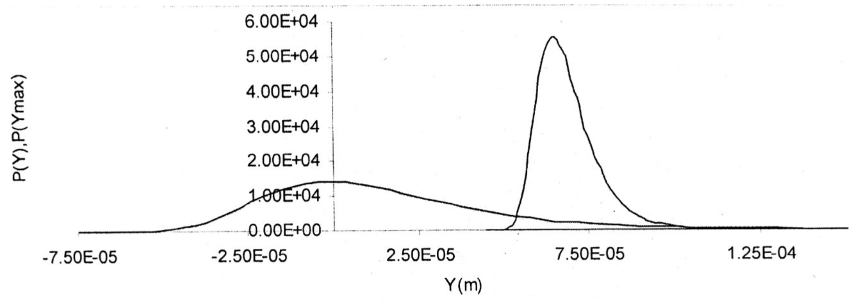

Figure 1. PDF of maximum tip deflection for medium silo 15m height.

The anchorage requirement for the empty silos considering wind load effects was analyzed (3). They adopted the quasi-static wind load approach. Even in this case the authors approach was quasi-static analysis. However the aerodynamic characteristics of structure were not considered. The wind load effect through a mathematical model was analyzed to include the equivalent wind spectrum technique considering the schematization of the wind as a stochastic stationary Gaussian process (4). However the mathematical technique adopted in the research was a closed form approach. The paper considered in an elaborate manner the probability density function for the wind response of the structures. This approach gave a more weight to the anchorage requirement.

Methods

The approaches used for the analysis of such structures are : static, quasi-static were even dynamic needed the thorough modification to include the random. The designed thickness of the shell wall was governed by the counteracting internal grain pressure to the fullest capacity of that shell and the extreme wind load.

The wall thickness was not only going to be parameters to counter the wind load effects but the proper anchorage at the base against overturning of the top about the base. This work was based particularly on the above background. For the purpose of computations, the steel of the cylindrical shell has a modulus of elasticity E=200 Gpa, poison's ratio of 0.30, and mass density of 7,900 kg/m^3. The high-frequency base technique is applicable to the large majority of tall structures and has the advantage of allowing the structural engineer to easily update the results in the case of a change in the structure's stiffness, mass or natural frequency. Several computer programs were prepared by the author for using this technique.

In the present case five circular steel silos having height to diameter ratio. The intermediate silos investigated had height to diameter (H/D) ratio of 1.25, 1.43, 1.67, 2.0, 2.5 and 3.0, with a single height of 15m silo subjected to the condition of height to diameter ratio is less than 3.0 but more than 1.0. This choice was based on the study reported Briassoulis and Packnold (3). The concept of dynamic grain pressure during the filling and emptying process was also based on well established Janssen theory for calculating the wall thickness in preliminary design (5). In view of this the spectral analysis technique, which considered the response of random nature of wind, was of value in this study. The study of wind effect was paramount important especially for the proper anchorage requirements of designed to stabilize the entire structure against overturning. Further the entire structure was assumed to be mathematically lumped at three places namely lower, middle, and top. After inverting the stiffness matrix the flexibility matrix was formed for conjugate beam method. Such analysis was quite common in the stress analysis of

Table 1. First three natural frequencies (Hz) for medium silos.

Diameter (m)	12.0	10.5	9.0	7.5	6.0	5.0
Height (m)	15.0	15.0	15.0	15.0	15.0	15.0
First frequency	11.80	11.69	11.64	11.57	11.45	11.32
Second frequency	55.69	40.55	29.40	22.39	17.13	15.55
Third frequency	88.7	73.5	65.2	58.5	44.7	34.2

Table 2. Mode shapes for Intermediate silos.

	Height (m)	Diameter (m)	Bottom	Middle	Top
1	1.50E+01	1.20E+01	1.68E-03	5.41E-03	8.00E-03
			1.25E-02	2.69E-03	-3.14E-03
			5.69E-03	-7.60E-03	4.55E-03
2	1.50E+01	1.05E+01	1.94E-03	6.24E-03	9.20E-03
			1.44E-02	3.08E-03	-3.61E-03
			6.54E-03	-8.75E-03	5.25E-03
3	1.50E+01	9.00E+00	2.10E-03	6.98E-03	1.06E-02
			1.63E-02	3.79E-03	-4.12E-03
			7.75E-03	-9.99E-03	5.81E-03
4	1.50E+01	7.50E+00	2.81E-03	8.91E-03	1.30E-02
			2.04E-02	4.25E-03	-5.13E-03
			9.14E-03	-1.24E-02	7.52E-03
5	1.50E+01	6.00E+00	3.24E-03	1.07E-02	1.61E-02
			2.48E-02	5.66E-03	-6.27E-03
			1.17E-02	-1.52E-02	8.91E-03
6	1.50E+01	5.00E+00	3.81E-03	1.25E-02	1.88E-02
			2.90E-02	6.59E-03	-7.34E-03
			1.36E-02	-1.78E-02	1.05E-02

structures. With the use of the above matrix, first three natural frequencies (6) were obtained (Table 1). The representative mode shapes are shown in Table 2. For random analysis, the wind velocity was divided into two parts namely, static part and fluctuating part. For the fluctuating part the basic mathematical wind model developed by Sharma (7), was followed for spectral analysis in this study. The mean square value of the fluctuating component of the response was calculated following the standard procedure given in AS : 1170 (Part-2) 1989 (8). The static part of the response due to the mean component of wind loading was calculated as per IS : 875 (Part-3) 1987 (9). In regard to the consideration of a time series effect, one-hour interval time was adopted as proposed by Davenport (10). For probability analysis extreme value type-1 distribution was used and the computer program was developed accordingly.

Results and Discussion

The results of the study as shown in Figure 1 were on the probability density function (PDF) based curves comprising the deflection at the top. As stated earlier the present physical nature of study was primarily aimed to ensure maximum safety at the lowest cost of the clients. The random analysis gave an acceptable range of tip deflection for various H/D ratios, which was considered to be a reasonable one as opposed to the deflection by various other methods. So for all practical purposes the wind load effect based on random analysis was relatively better proposition as compared to all other methods in respect of structural stability, safety and reasonable economy in designing the silo junction with the base.

Comparison of Tip Deflection for Intermediate Silos. Table 3 shows that corresponding to the maximum tip deflections by static analysis, the maximum tip deflection by quasi-static analysis using Indian code, quasi-static analysis using Australian code, dynamic analysis and random analysis are 26.77, 172.31, 149.43 and 49.20 percent higher for silo 15 m height and 12 m diameter, 27.04, 173.41, 149.24 and 47.88% higher for silo with 15 m height and 10.5 m diameter, 27.14, 171.44, 151.26 and 50.35% higher for silo with 15 m height and 9 m diameter, 26.60, 170.21, 148.94 and 47.87% higher for silo with 15 m height and 7.5 m diameter, 26.96, 169.56, 151.01 and 42.61% higher for silo with 15 m height and 6 m diameter and 26.93, 167.60, 150.00 and 40.49% higher than for silo with 15 m height and 5 m diameter.

In static analysis the maximum tip deflection observed for silo having 15 m height and 10.5 m diameter was 51.49% higher than the maximum tip deflection observed for silo having 15 m height 12 m diameter. It was 49.70% higher for silo having 15 m height and 9 m diameter than silo having 15 m height and 10.5 m diameter, 89.70% higher for silo having 15 m

Table 3. Values of tip deflections (m) by various analysis for intermediate silos.

Height	Diameter	H/D ratio	Static	Q-Static-1	Q-Static-A	Dynamic	Random
15.00	12.00	1.25	4.37E-05	5.54E-05	1.19E-04	1.09E-04	6.52E-05
15.00	10.50	1.43	6.62E-05	8.41E-05	1.81E-04	1.65E-04	9.79E-05
15.00	9.00	1.67	9.91E-05	1.26E-04	2.69E-04	2.49E-04	1.49E-04
15.00	7.50	2.00	1.88E-04	2.38E-04	5.08E-04	4.68E-04	2.78E-04
15.00	6.00	2.50	3.45E-04	4.38E-04	9.30E-04	8.66E-04	4.92E-04
15.00	5.00	3.00	5.68E-04	7.21E-04	1.52E-03	1.42E-03	7.98E-04

height and 7.5 m diameter than for silo having 15 m height and 9 m diameter, 83.51% higher for silo having 15 m height and 6 m diameter than for silo having 15 m height and 7.5 m diameter, 64.64% higher for silo having 15 m height and 5 m diameter than for silo having 15 m height and 6 m diameter.

In quasi-static analysis using Indian code the maximum tip deflection observed for silo having 15 m height and 10.5 m diameter was 51.80% higher than the maximum tip deflection observed for silo having 15 m height and 12 m diameter. It was 49.82% higher for silo having 15 m height and 9 m diameter than for silo having 15 m height and 10.5 m diameter, 88.89% higher for silo having 15 m height than for silo having 15 m height and 9 m diameter, 84.03% higher for silo having 15 m height and 6 m diameter than for silo having 15 m height and 7.5 m diameter and was 64.61% higher observed for silo having 15 m height and 5 m diameter than for silo having 15 m height and 6 m diameter.

In quasi-static analysis using Australian code the maximum tip deflection observed for silo having 15 m height and 10.5 m diameter was 52.10% higher than the maximum tip deflection observed for silo having 15 m height and 12 m diameter. It was 48.62% higher for silo having 15 m height and 9 m diameter that for silo having 15 m height and 10.5 m diameter, 88.85% higher for silo having 15 m height and 7.5 m diameter than for silo having 15 m height and 9 m diameter, 83.07% higher for silo having 15 m height and 6 m diameter than for silo having 15 m height and 7.5 m diameter, 63.44% higher for silo having 15 m height and 5 m diameter than for silo having 15 m height and 6 m diameter.

In dynamic analysis the maximum tip deflection observed for silo having 15 m height and 10.5 m diameter was 51.37% higher than the maximum tip deflection observed for silo having 15 m height and 12 m diameter. It was 50.90% higher for silo having 15 m height and 9 m diameter than for silo having 15 m height and 10.5 m diameter, 87.95% higher for silo having 15 m height and 7.5 m diameter than for silo having 15 m height and 9 m diameter, 85.04% higher for silo having 15 m height and 6 m diameter than for silo having 15 m height and 7.5 m diameter. 63.97% higher for silo having 15 m height and 5 m diameter than for silo having 15 m height and 6 m diameter.

In random analysis the maximum tip deflection observed for silo having 15 m height and 10.5 m diameter was 50.15% higher than the maximum tip deflection observed for silo having 15 m height and 12 m diameter. It was 52.20% higher for silo having 15 m height and 9 m diameter than for silo having 15 m height and 10.5 m diameter, 86.58% higher for silo having 15 m height and 7.5 m diameter than for silo having 15 m height and 9 m diameter, 76.98% higher for silo having 15 m height and 6 m diameter than for silo having 15 m height and 7.5 m diameter, 62.20% higher for silo having 15 m height and 5 m diameter than for silo having 15 m height and 6 m diameter.

Conclusions

The intermediate silos investigated had H/D ratio of 1.25, 1.43, 1.67, 2.0, 2.5 and 3.0. The maximum tip deflections (m) for silos having H/D ratio 1.25 were 4.37E-05, 5.54E-05, 1.19E-04, 1.09E-04 and 6.52E-05 from static analysis, quasi-static (IS code), quasi-static (AS code), dynamic and random analysis respectively. Similar trends were obtained for other H/D ratios. The increase in maximum tip deflection for all H/D ratios for quasi-static (IS code), random, quasi-static (AS code) and dynamic analysis were approximately 27, 50, 170 and 150% respectively than the values obtained from static analysis. For intermediate silos, there was increase in maximum tip deflection with the increase in height to diameter ratio from 1.25 to 3.0. This technique is better option for those who are not well conversant with finite element method.

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