

Deflection Response at the Top of Circular Steel Tall 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, if not totally eliminated, by the application of rigorous analysis of wind loads to ensure maximum safety at the lowest cost of the clients. The present research was on the study of circular steel silo subjected to rigorous wind loading and its effects on the anchorage requirements of tall 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 tall silos for deflection response in wind environment. The maximum tip deflections (m) for silos having H/D ratio 7.5 were 2.34E-02, 3.15E-02, 4.64E-02, 3.27E-02 and 3.78E-02 from static analysis, quasi-static (IS code), quasi-static (AS code), dynamic and random analysis respectively. 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. The paper suggests that conventional methods of analysis gives more conservative results and hence penalty to the clients.

Key words : Wind excitation, Response spectrum, 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 (Bansal et al. 2008).

Design of structures against wind forces requires knowledge of wind characteristics as well as form and stiffness of structures. Major dynamic effects of wind on structures are forced vibrations and self excited vibrations. Wind forces act as an external forces and their magnitude depends upon area of the exposure and the shape of the structure unlike earthquake forces which act as inertia forces on account of earthquake motion of the ground, their magnitude depending upon the mass of the structure. Due to rapid ad-

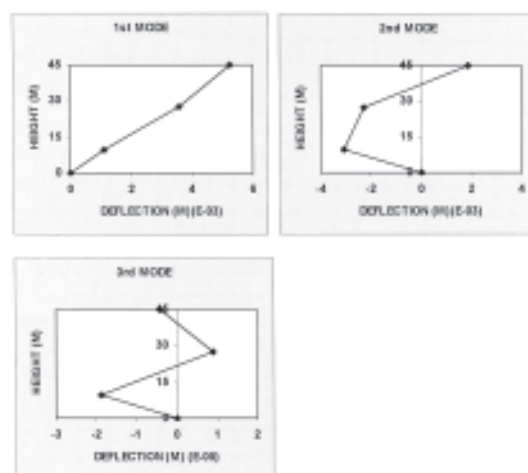
vancement in the materials and construction techniques, nowadays tall and light weight structures are being constructed. Such structures generally exhibit an increased susceptibility to the action of winds. In recent past civil engineering structures considered to come under the category of conventional analysis were designed and analyzed in a more rigorous manner. This has become possible due to the emergence of sophisticated computing techniques and advancement in materials. Further the conventional analysis and design over simplifies the requirements of special treatment for non-conventional structures. The conventional procedure of design and analysis includes the assumption of wind load as static or quasistatic. 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 (Singh et al. 2008), value of Gust factor is required for which fundamental natural frequency of the structure is required to be

Table 1. Required sheet thickness (mm) at various depth from top.

Diameter- Depth (m)	12.0	10.5	9.0	7.5	6.0
0—5	5.2	4.5	3.8	3.2	2.5
6—10	6.8	5.8	4.9	4.0	3.3
11—15	7.9	6.8	5.6	4.7	4.0
16—20	8.7	7.5	6.2	5.5	4.7
21—25	9.5	8.0	7.0	6.2	5.3
26—30	10.2	8.7	7.8	6.9	5.9
31—35	10.8	9.5	8.5	7.5	6.4
36—40	11.4	10.4	9.3	8.2	6.9
41—45	12.3	11.2	10.1	8.8	7.4
46—50	13.3	12.0	10.7	9.3	7.8

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 liner 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 arrive 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.

The anchorage requirement for the empty silos considering wind load effects was analyzed (Briassoulisa and Packnold 1986). They adopted the quasi-static wind load approach. This had limitations when the wind load had a random nature. However this analysis assumed significance in the sense, a finite element discretization had been adopted which included a large number of degree of freedom. They further analyzed the empty steel silos under wind load conditions and suggested the methodology for stiffening cylindrical shells. 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

**Figure 1.** First three mode shape for silo height 45 m.

model was analyzed to include the equivalent wind spectrum technique considering the schematization of the wind as a stochastic stationary Gaussian process (Solari 1988). However the mathematical technique adopted in the research was a closed form approach. The paper considered advantageously the estimation of the dynamic response of wind-excited structures. The paper considered in an elaborate manner the probability density function for the wind response of the structures. The significance of this study was the advantage of simultaneous treatment of both vertical and horizontal portions of the structures. This approach gives a more weight to the anchorage requirement.

Methods

The approaches for the analysis of such structures under static, quasi-static were even dynamic response needed the thorough modification to include the random wind loading. The random wind loading could be accounted by a spectral loading with probability analysis to find the exact response. The designed thickness of the shell wall (Table 1) was governed by the counteracting internal grain pressure to the fullest capacity of that shell and the extreme wind load. But then when the shell was empty and the wind load was extensive what was going to happen to the wall and at the base.

Wind loads not only exert a constant oscillating

Table 2. Values of tip deflection (m) by various analysis for tall silos.

Height	Diameter	H/D Ratio	Static	Q-Static-I	Q-Static-A	Dynamic	Random
45.00	12.00	3.75	3.46E-03	4.66E-03	6.65E-03	4.83E-03	5.91E-03
45.00	10.50	4.28	5.07E-03	6.84E-03	1.00E-02	7.12E-03	8.59E-03
45.00	9.00	5.00	7.71E-03	1.04E-02	1.53E-02	1.08E-02	1.29E-02
45.00	7.50	6.00	1.26E-02	1.71E-02	2.52E-02	1.77E-02	2.09E-02
45.00	6.00	7.50	2.34E-02	3.15E-02	4.64E-02	3.27E-02	3.78E-02

force, but also increases as the height of the structure increases. An evenly distributed load can roughly approximate the loading of a tall, thin tower, it being a vertical cantilever.

For a massive concrete/masonry structures such as a gravity dam, the entire self weight will take care of to counter the effect of horizontal water pressure, wind force and similar other forces acting on it. Even though one can had an apparent similarity between the dam and silo, the silo needs a special attention in the thickness of shell wall. The wall thickness was not only going to be parameter 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 this background. For the purpose of computations, the steel of the cylindrical shell has a modulus of elasticity $E=200$ Gpa, poisson's ratio of 0.30, and mass density of $7,900$ kg/m³. 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. The traditional techniques are approximate and do not accurately represent the correct distribution of loads, but are cheaper and less complex. 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 3.75, 4.28, 5.0, 6.0 and 7.5 with a single height of 45 m silo subjected to the condition of height to diameter ratio more than 3.0 was selected as this ratio represented a workable H/D ratio (aspect ratio) in this region. This choice was based on the study reported Briassoulisa and Packnold (1986). The concept of dynamic grain pressure during the filling and emptying process was also based on the well established Janssen theory for calculating the wall thickness in preliminary design (Janssen

1895). Wind loading will be effective and severe when it will be empty, so the wind load under the circumstances was considered to be critical. In view of this the spectral analysis technique, which considered the response of random nature, 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 structures. With the use of the above matrix, first three natural frequencies (Singh and Sharma 2007) were obtained. The representative mode shapes for one case is shown in Figure 1. 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 (1993) 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). The static part of the response due to the mean component of wind loading was calculated following IS : 875 (Part-3) (1987). In regard to the consideration of a time series effect, one-hour interval time was adopted as proposed by Davenport (1964). 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 2 were on the probability density function (PDF) based curves comprising the deflection at the top. The physical nature of study was primarily aimed to ensure

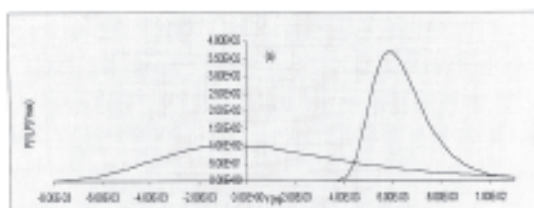


Figure 2. PDF of maximum tip deflection for silo height 45 m.

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 a 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 Results for Tall Silos Calculated from Various Approach

Table 2 shows that corresponding to the maximum tip deflection by static analysis, the maximum tip deflections by quasi-static analysis using Indian code, quasi-static analysis using Australian code, dynamic analysis and random analysis were 34.68, 92.19, 39.6 and 70.81% higher respectively for silo having 45 m height and 12 m diameter. The corresponding values were 34.91, 97.23, 40.43 and 69.43% higher for 45 m high and 10.5 m diameter, 34.88, 98.44, 40.08 and 67.31% higher for 45 m high and 9 m diameter, 35.71, 100.0, 40.47 and 65.87% higher for 45 m high and 7.5 m diameter, 34.61, 98.29, 39.74 and 61.54% higher for 45 m high and 6 m diameter.

In static analysis the maximum tip deflection observed for silo having 45 m height and 10.5 m diameter was 46.53% higher than the maximum tip deflection observed for silo having 45 m height and 12 m diameter. It was 52.07% higher for silo having 45 m height and 9 m diameter than the silo having 45 m height and 10.5 m diameter, 63.42% higher for silo having 45 m height and 7.5 m diameter than the silo having 45 m height and 9 m diameter, 85.71% higher

for silo having 45 m height and 6 m diameter than the silo having 45 m height and 7.5 m diameter.

In quasi-static analysis using Indian code the maximum tip deflection observed for silo having 45 m height and 10.5 m diameter was 46.40% higher than the maximum tip deflection observed for silo having 45 m height and 12 m diameter. The maximum tip deflection was 52.83% higher for silo having 45 m height and 9 m diameter than the silo having 45 m height and 10.5 m diameter, it was 64.20% higher for silo having 45 m height and 7.5 m diameter the silo having 45 m height and 9 m diameter and was 53.76% higher for silo having 45 m height and 6 m diameter than the silo having 45 m height and 7.5 m diameter.

In quasi-static analysis using Australian code the maximum tip deflection observed for silo having 45 m height and 10.5 m diameter was 46.43% higher than the maximum tip deflection observed for silo having 45 m height and 12 m diameter, 50.81% higher for silo having 45 m height and 9 m diameter than the silo having 45 m height and 10.5 m diameter. It was 63.88% higher for silo having 45 m height and 7.5 m diameter than the silo having 45 m height and 9 m diameter, 82.56% higher for silo having 45 m height and 6 m diameter than the silo having 45 m height and 7.5 m diameter.

In dynamic analysis the maximum tip deflection observed for silo having 45 m height and 10.5 m diameter was 48.01% higher than the maximum tip deflection observed for silo having 45 m height and 12 m diameter, 52.97% higher for silo having 45 m height and 9 m diameter than the silo having 45 m height and 10.5 m diameter, 64.37% higher for silo having 45 m height and 7.5 m diameter than the silo having 45 m height and 9 m diameter. It was 83.97% higher for silo having 45 m height and 6 m diameter than the silo having 45 m height and 7.5 m diameter.

In random analysis the maximum tip deflection observed for silo having 45 m height and 10.5 m diameter was 45.35% higher than the maximum tip deflection observed for silo having 45 m height and 12 m diameter, 50.17% higher for silo having 45 m height and 9 m diameter than the silo having 45 m height and 10.5 m diameter. It was 62.01% higher for silo having 45 m height and 7.5 m diameter than the silo having 45 m height and 9 m diameter, 80.86% higher for silo having 45 m height and 6 m diameter than the silo having

45 m height and 7.5 m diameter.

Conclusion

The study was based on a simplistic mathematical modeling of wind effects, which could be used by any practicing engineers who have no desire to use the advanced time consuming computing technique such as finite element method. The tall silos investigated had H/D ratio of 3.75, 4.28, 5.0, 6.0 and 7.5 with a single height of 45 m. The maximum tip deflections (m) for silos having H/D ratio 7.5 were 2.34E-02, 3.15E-02, 4.64E-02, 3.27E-02 and 3.78E-02 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 maximum tip deflections were obtained from quasi-static (AS code) analysis. 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 35, 65, 95 and 40% respectively than the values obtained from static analysis. For tall silos there was increase in the maximum tip deflection with the increase in height to diameter ratio from 3.75 to 7.5.

Thus in the power spectral density function of the wind, the low frequency component is predominant. For the silos with natural frequencies less than 1 Hz, the dynamic effect of the wind is more critical as compared to its static effect. The structural response of silo against wind can be reasonably estimated through a statistical approach assuming wind flow as stationary Gaussian processes. Extreme value statistics enable computation of the most probable peak values of the structural response. The deflection re-

sponse of a silo structure to the random wind forces can be represented fairly accurately considering only the first two modes of vibrations. The response contribution from fluctuating component of wind is dominating for 45 m high silo with H/D ratio greater than 3.0. Hence random analysis is strongly recommended.

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