Article no. 12

THE CIVIL ENGINEERING JOURNAL 2-2015

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THE STRUCTURAL ANALYSIS OF STEEL SILOS WITH CYLINDRICAL-WALL BEARING AND PROFILE-STEEL BEARING

Zhengjun Tang[1], Daibiao Zhou[2], Chenwei Peng[1], Wenping Wu[1]*

1. *School of Civil Engineering, Wuhan University, Wuhan, Hubei, 430072, P.R. China; wpwu@whu.edu.cn (*Corresponding author)*
2. *Central Southern China Electric Power Design Institute of China Power Engineering Consulting Group Corporation, Wuhan, Hubei, 430072, P.R. China; zhoudaibiao@csepdi.com*

ABSTRACT

The silos are widely used in bulk material in many fields such as agriculture, mining, chemical, electric power storage, etc. Thin metal cylindrical silo shells are vulnerable to buckling failure caused by the compressive wall friction force. In this paper, the structural analysis of two types of steel silo with cylindrical-wall bearing and profile-steel bearing is implemented by Abaqus finite element analysis. The results indicate that under the same loading conditions, steel silos with profile-steel bearing and cylindrical-Wall bearing have similar values in Mises stress, but the steel silo with profile-steel bearing has a smaller radial displacement and a better capability of buckling resistance. Meanwhile, the total steel volumes reduced 8.0% comparing to the steel silo with cylindrical-wall bearing. Therefore, steel soil with profile-steel bearing not only has a less steel volumes but also a good stability.

KEYWORDS

Steel silo, finite element analysis, structural failure, stiffening steel, profile steel.

1. INTRODUCTION

Soils are structures which are used for storing granular materials. Concrete silos in the domestic have many applications, but the application of steel silos is very limited. And structural steel cylinder silos in many cases are more economic than concrete silos. Circular cylinder silo is one typical structure of rotating thin shell, whose structure damage is usually due to the complex structure performance and unreasonable design criterion. Each type of installation requires a specific design treatment once the bases of calculation have been determined. Concrete silos special attention must be paid to foundations and cracks that may appear in the walls. For steel silos, stability against wind effects when empty must be checked. Hotala et al. [1] investigated the stability of stiffened cylindrical shells of steel silos by experimental tests, the results found that the short ribs interconnected with a circumferential ring was a prefer method of strengthening steel silos. Iwicki et al. [2] discussed the failure reasons of large cylindrical steel silos composed of horizontally corrugated sheets with vertical stiffeners and revealed the failure of cylindrical steel silos was caused by buckling of vertical columns. Ravenet [3] and Carson et al. [4] summarized the difficult, errors in silos design and the basic factors of the failure of the silos. Zhao et al. [5] analysed the stability behaviour of column-supported steel silos with engaged columns, supporting silo walls directly on engaged columns provided a simple and cost-effective support arrangement for light steel silos. With the development of electrical engineering, the higher reliability of service is expected. As the three major aspects of silo design (bulk material, geometric, and structural), the structural design and analysis determines the safe service life of silo. Therefore, it is very necessary to set reasonable parameters and establish appropriate model according to the actual engineering usage condition in order to conduct a comprehensive finite element simulation analysis of the steel silo.

In this paper, two construction types are taken into consideration, the wall structure as the main bearing component and stiffening steel as the main bearing component of steel silos are studied, the objective of this paper to discuss the different mechanical properties by comparing the stress field and buckling analysis of two different steel silos between cylinder-wall bearing and profile-steel bearing.

2. CALCULATION MODEL

Silo structure is composed of foundation (including ring base and base plate), coal conveying corridor, wall, roof and upper structure. In the modelling calculation, upper structure is simplified to be applied load on top of the roof directly.

2.1. Finite element model

In this paper, Abaqus finite element code is used to carry out the structural analysis of steel silos [6]. The finite element model is set up as shown in Fig.1a. Selection of soil calculated: diameter 150 m, thickness 35 m, which is divided into two layers. The diameter of centre of soil excavation is 66 m and excavation depth 7.5 m. The thickness of the basis of the foundation pit is 2 m: the base plate under the coal conveying corridor and the ring base under wall. Structures of the Base and wall are shown in Fig.1b.The base plate and the ring base is concreted as a whole. The cylinder wall is 60 m diameter and 50 m high, the lower of which is 5.5 m inside the soil.

For the type of steel cylinder silo wall bearing, wall thickness from bottom to top are: 0-15 m with thickness 28mm,15 m-30 m with thickness 24mm,30m-40m with thickness 20mm,40m-50m with thickness 16mm. For the type stiffening section steel bearing, wall thickness is 12 mm from 0 m to 15 m, and 15 m-50 m with thickness 8 mm. The Vertical reinforced steel and the circumferential channel-reinforced steel are shown in Fig.1c and Fig.1d. For coal bunker with wall bearing, 22 b channel steel are circumferentially placed out of the cylinder wall with 0.9 m intervals for stiffening and 150 pieces of 22 a channel steel are place inside of the cylinder wall vertically. For coal bunker with stiffening steel bearing, 40b channel steel are circumferentially placed out of the cylinder wall for stiffening, where 28 pieces with 0.8 m intervals, 15 pieces with 1.0 m intervals and 12 pieces with1.2 m intervals and 150 pieces HN 500×200×10×16 h-beam are place inside of the cylinder wall vertically.

There are 6 coal corridors on the ring base as shown in Fig.1e. Meshed model is shown in Fig.1f, where coal conveying corridor, foundation (ring and base plate), the foundation soil, and backfill soil are the entity unit C3D8R: three-dimensional 8 nodes reduced integral unit, which can guarantee calculation precision with high computational efficiency. Cylinder wall is in the shell element division, and wall, ring stiffening steel channel and stiffening h-beam are with shell element. Roof is in the truss element division.

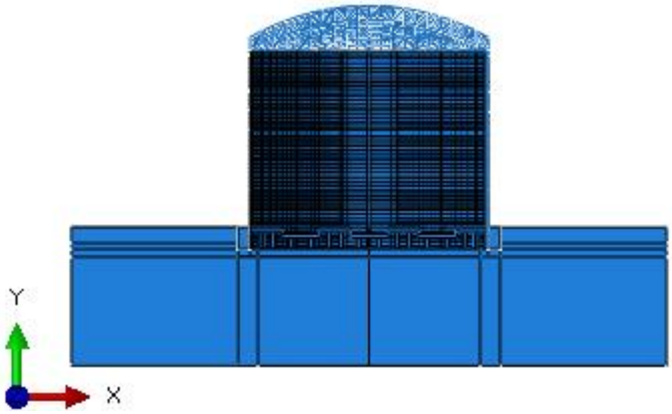


Fig.1a Finite element model

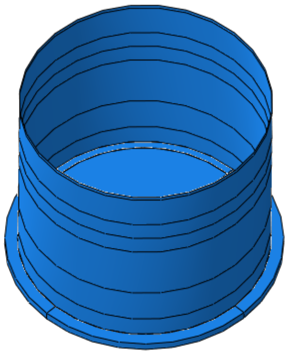


Fig.1b The base and wall

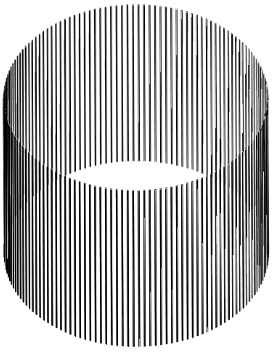


Fig.1c Vertical reinforced steel

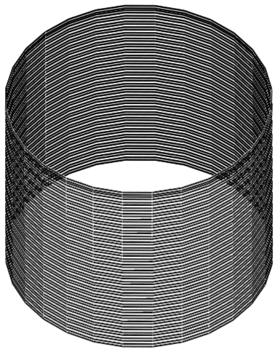


Fig.1d Circumferential channel-reinforced steel

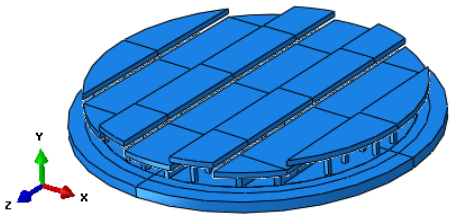


Fig.1e Six coal corridors on the ring base

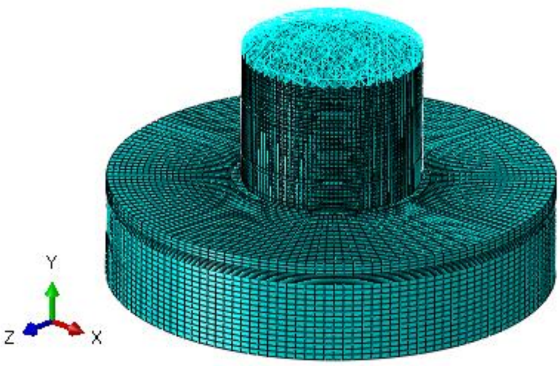


Fig.1f Meshed model

2.2. Material properties

Tab.1a and b show material properties and foundation parameters in finite element analysis of steel silo structure, where the concrete is C40 and cylinder walls are Q420B high strength steel plate.

Tab.1a. Material constants

Materials	Elasticity modulus	Poisson's ratio	Density (kg/m^3)	Coefficient of linear expansion	Coefficient of heat conduction
Concrete(C40)	32.5GPa	0.17	2500	1e-5	1.74
Steel	206GPa	0.3	7850	1.2e-5	58.2
Coal	20MPa	0.2	1000	-	-

Tab.1b. Foundation parameters for soil layer

Number for soil layer	Thickness (m)	Compression modulus (Es/MPa)	Poisson's ratio μ	Weight γ/(KN/m^3)	Internal friction angle□(°)	Cohesion C(KPa)
①	4	30	0.25	20	30	20
②	31	40	0.25	21	35	30

2.3. The way of analysis

For static analysis, we employ ABAQUS (static, general) to study the deformation field of both construction types, and the effect of large deformation is also taken into account. In addition, the contact between the base and soil is enforced using a surface-to-surface contact, the frictional coefficient is 0.3, and interactions between roof and soli wall as well as soli wall and foundation are treated as tied.

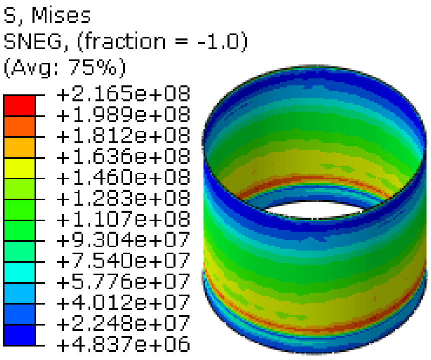
For the stability analysis, the eigenvalue buckling analysis is a linear perturbation procedure which generally used to estimate the critical load of stiff structures. Our main interest is mainly focused on the stability of the steel structure, hereby in this analysis the foundations and the soil are not included in the model. And the model only keeps the soli wall, steel and the roof, between which the interactions are the same as those in the deformation analyses. The loading condition includes the gravity load and the coal induced pressure on the wall.

3. RESULTS OF STATIC ANALYSIS

3.1. Steel silo with cylindrical-wall bearing

Since the nonlinear of soil has very little impact on the upper structure, the linear elastic constitutive model of soil is used to calculate with two layers of soil provided by engineering geological investigation. With full pile of coal and structural weight, calculation results are shown as Fig.2a~f.

As the coal pressure increases gradually along with the vertically wall, the Mises stress increase gradually as well. At 8.6 m above the bottom of the wall, the maximum Mises stress is 216.5 MPa. The maximum Mises stress is 151.9 MPa in vertical steel flange at 8 m height and the maximum Mises stress of 219.7 MPa in the flange of ring channel steel at 8.8 m height. Because of corridor layout on the bottom, silo structure does not have strict symmetry, and there is distortion to some extent under the loading. The maximum radial displacement shows at 18 m of the wall and along the direction of conveying coal there is the largest radial displacement 41.4 mm while along vertical coal conveying direction, there is the largest radial displacement -20.2 mm. The maximum vertical displacement -154.4 mm appears on the top of the wall along the conveying coal. Arrangement of ring and vertical steel stiffening, the deformation and stress of silo structure are reduced. There is the largest settlement 180.5 mm in the centre of the bottom centre. As a result of the coal conveying corridor layout, the ring base has the minimum settlement 131.9 mm.



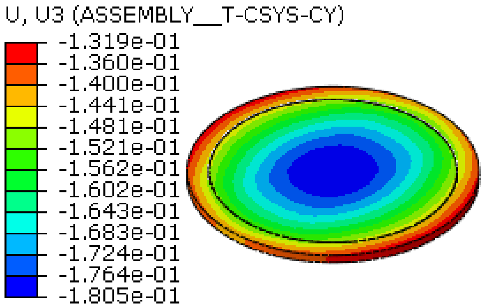
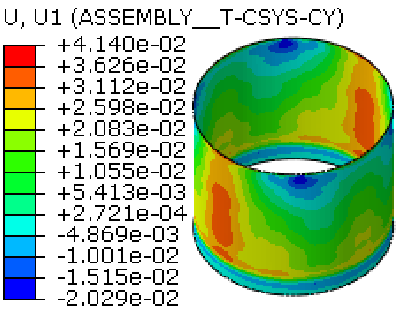


Fig.2a Von Mises stress of cylinder wall *Fig.2b Vertical displacement of ring base and bottom Plate*



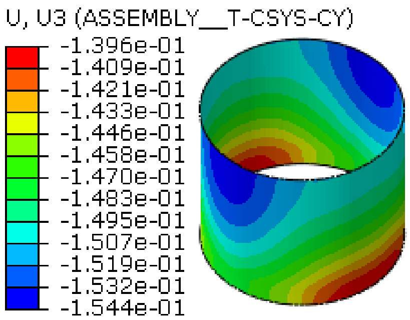
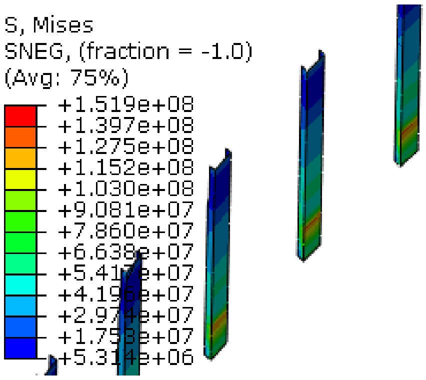


Fig.2c Radial displacement of the cylinder wall *Fig.2d Vertical displacement of the cylinder wall*



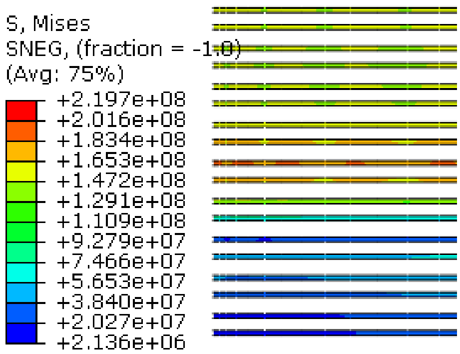


Fig.2e Von Mises stress of vertical channel steel *Fig.2f Von Mises stress of ring channel steel*

3.2. Steel silo with profile-steel bearing

Also under the full coal load and structural weight, the results are shown from Fig.3a to 3f. Vertically along the wall as the coal pressure increases gradually, Mises stress increased gradually. At 9.8 m above the bottom of the wall, there is the maximum Mises stress 229MPa. There is the maximum Mises stress 163.1MPa in H-beam flange at 7.6 m height and there is the maximum Mises stress of 249.8MPa in the flange of channel steel at 9.8 m height. Because of corridor layout on the bottom, silo structure does not have strict symmetry, and thus are distortion to the extent. The maximum radial displacement shows at 18 m of the wall and along the direction of conveying coal there is the largest radial displacement 39.2 mm while along vertical coal conveying direction on the top, there is the largest radial displacement -10.6 mm. The maximum vertical displacement -154.9 mm appears on the top of the wall along the conveying coal. Arrangement of ring and vertical steel stiffening, the deformation and stress of silo structure are reduced. There is the largest settlement 180.5 mm in the centre of the bottom plate. As a result of the coal conveying corridor layout, the ring base has the minimum settlement 130.8 mm.

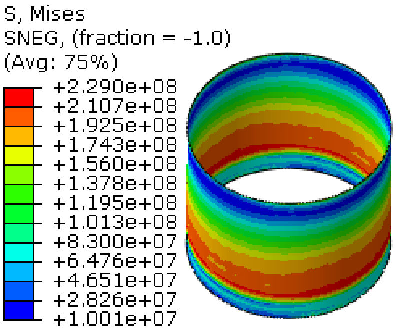


Fig.3a Von Mises stress of cylinder wall

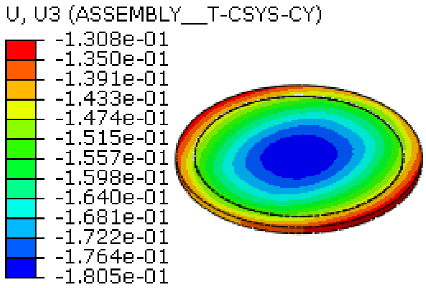


Fig.3b Vertical displacement of ring base and bottom plate

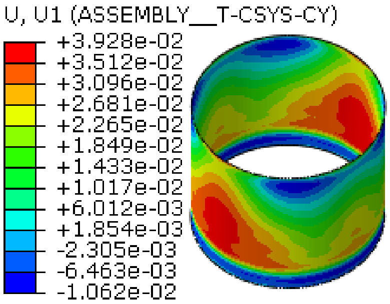


Fig.3c Radial displacement of the cylinder wall

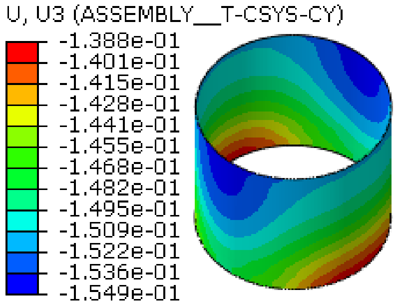


Fig.3d Vertical displacement of the cylinder wall

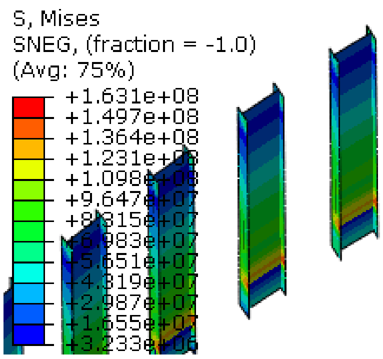


Fig.3e Von Mises stress of vertical H-steel

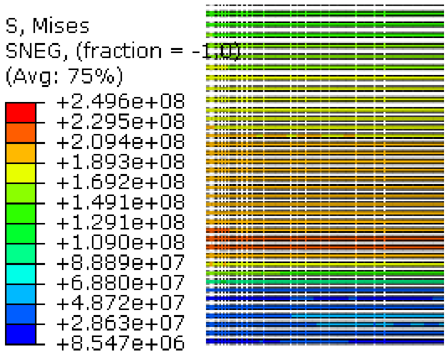


Fig.3f Von Mises stress of ring channel steel

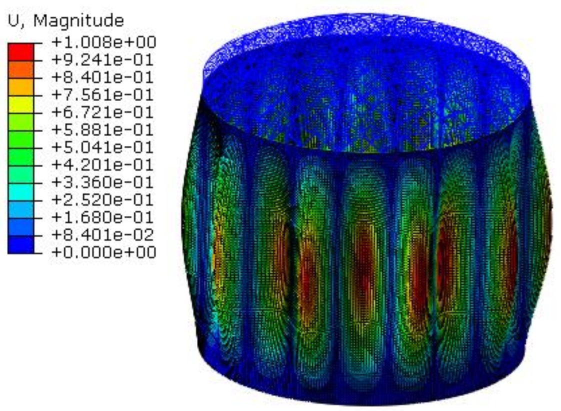
DOI 10.14311/CEJ.2015.02.0012

4. RESULTS OF BUCKLING ANALYSIS

Fig.4 shows the results of the buckling analysis of the steel silo with cylindrical-wall bearing in the first four order modal. It can be seen that under the gravity load and the coal pressure, the eigenvalues are all negative (about -0.17) for the first four order modal. That is to say, when the structure is subjected the outward radial pressure, the buckling failure would not occur in this case; However, when the structure is subjected the inward radial pressure, the buckling will occur.

Fig.5 shows the results of the buckling analysis of the steel silo with profile-steel bearing in the first four order modal. The results are basically the same as those of the steel silo with cylindrical-wall bearing. The eigenvalues buckling analysis are also negative (about -0.33) for the first four order modal. This indicates that the buckling failure would not occur in this kind of steel silo under the pressure caused by the coal.

Since loading on the soil is mainly caused by the lateral pressure of the piled coal, and the pressure acts on the wall, which transfers to the axial tension of the wall and the steel. The buckling failure would not occur under tension state for the whole structure. Therefore, the high stretchable property of the steel is fully utilized for both two steel silos. Nevertheless, at the same loading, the eigenvalue of the steel silo with profile-steel bearing is nearly twice of the steel silo with cylindrical-wall bearing. It indicates that steel silo with profile-steel bearing has a better capability of buckling resistance.



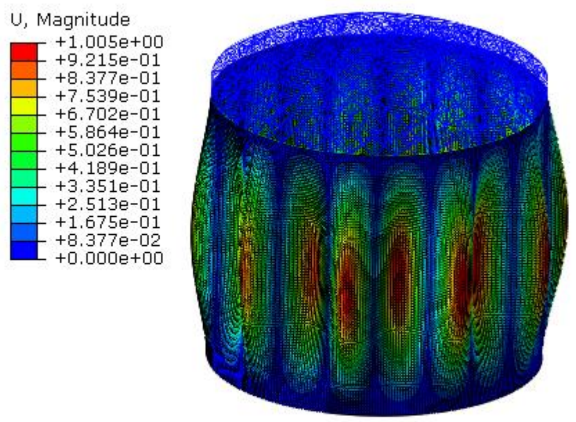
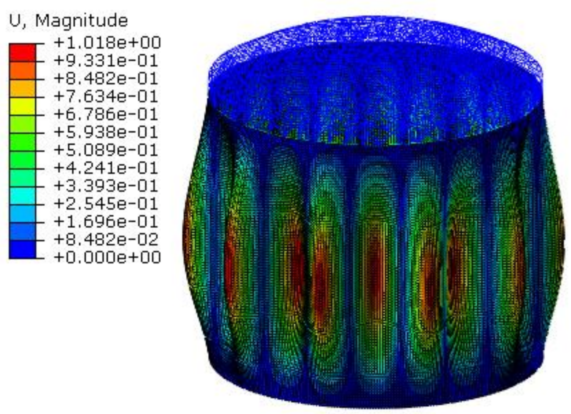


Fig.4a Mode 1,EigenValue=-0.17068 *Fig.4b Mode 2,EigenValue=-0.17075*



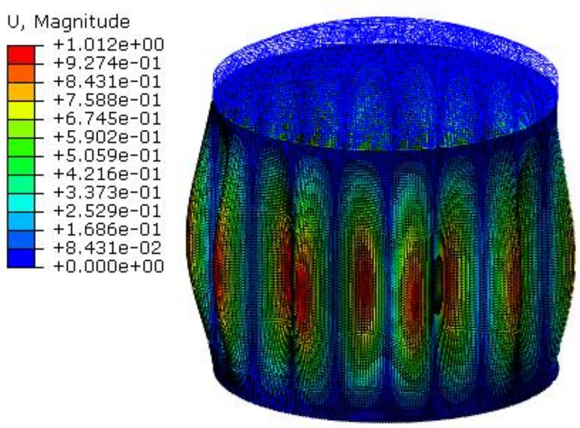
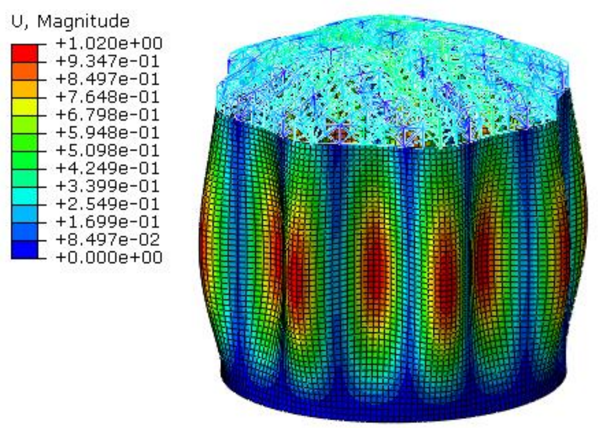


Fig.4c Mode 3,EigenValue=-0.17288 *Fig.4d Mode 4,EigenValue=-0.17298*

Fig.4 The result of eigenvalue buckling analysis of steel silo with cylindrical-wall bearing

DOI 10.14311/CEJ.2015.02.0012



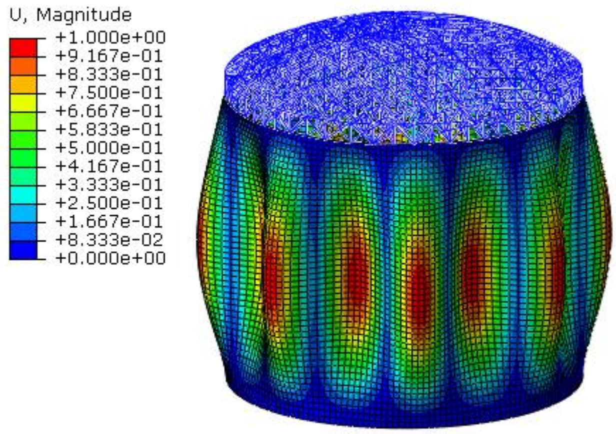
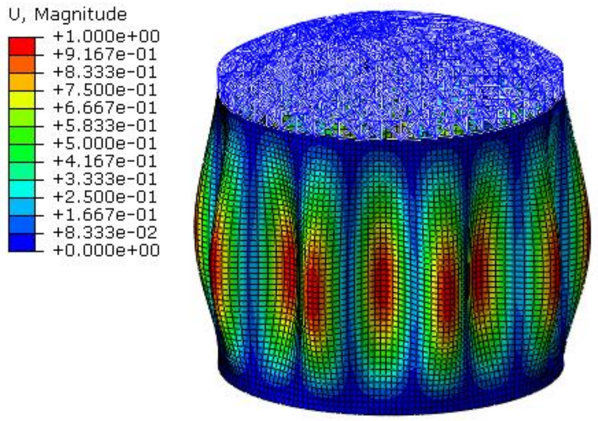


Fig.5a Mode 1,EigenValue=-0.32151 *Fig.5b Mode 2,EigenValue=-0.32840*



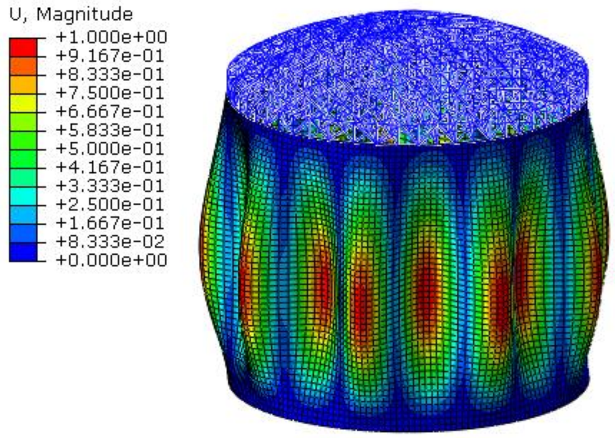


Fig.5c Mode 3,EigenValue=-0.33556 *Fig.5d Mode 4,EigenValue=-0.33562*

Fig.5 The result of eigenvalue buckling analysis of steel silo with profile-steel bearing

5. COMPARISON WITH TWO TYPES OF STEEL SILO

Tab.2 shows a detailed result by comparison with two types of steel silo between cylinder-wall bearing and profile-steel bearing. From Tab.2, we can find that the maximum Mises stress of steel silo with cylinder wall bearing is 216.5 MPa and the maximum radial displacement is 41.4 mm and -20.2 mm, the maximum vertical displacement is -154.4 mm while the maximum Mises stress of vertical steel is 151.9 MPa, the maximum Mises stress of channel steel is 219.7 MPa; the maximum Mises stress of steel silo with profile steel bearing is 229 MPa, and the maximum radial displacement is 39.2 mm and -10.6 mm, the maximum vertical displacement is -154.9 mm while the maximum Mises stress of vertical H-beam is 163.1MPa, the maximum Mises stress of ring channel steel is 249.8MPa. It is known that it is close in stress and vertical displacement for these two steel silos, but steel silo with profile steel bearing has a smaller radial displacement, so it’s more stable. Meanwhile, the total steel volumes of silo with cylinder wall bearing is 2.2×10^{6} kg, while steel soil with profile steel bearing is 2.0×10^{6} kg and reduces by 8%. In addition, the eigenvalue buckling analysis of the steel silo with cylindrical-wall bearing is about -0.17, while is about -0.33 for the steel silo with profile-steel bearing. It indicates that steel silo with profile-steel bearing has a better capability of buckling resistance under the same loading condition.

Tab. 2. Comparison with the results of two types of steel silo

Type of steel silos	cylindrical-wall bearing	Profile-steel bearing
Maximum Von Mises stress of cylinder wall	216.5 MPa	229 MPa
Maximum Von Mises stress of vertical steel	151.9 MPa	163.1 MPa
Maximum Von Mises stress of ring channel steel	219.7 MPa	249.8 MPa
Maximum radial displacement of cylinder wall	41.4 mm -20.2 mm	39.2 mm -10.6 mm
Maximum vertical displacement of cylinder wall	-154.4 mm	-154.9 mm
Maximum settlement of bottom plate	180.5 mm	180.5 mm
Maximum settlement of ring base	131.9 mm	130.8 mm
Steel volumes	2.2×10^{6} kg	2.0×10^{6} kg
Eigenvalues buckling analysis	-0.17	-0.33

6. CONCLUSIONS

In this paper, the structural analysis of two types of steel silos with cylindrical-wall bearing and profile-steel bearing is implemented. The results of static analysis indicate that steel silos with profile-steel bearing and cylindrical-Wall bearing have similar values in Mises stress under the same loading conditions. However, the steel coal bunker with profile-steel bearing has a smaller radial displacement, and the total steel volumes are smaller than the steel silo with cylindrical-wall bearing. Moreover, the results of buckling analysis indicate that the steel silo with profile-steel bearing has a better capability of buckling resistance under the same loading condition. Therefore, the steel soils with profile-steel bearing not only have less steel volumes but also have a good stability.

ACKNOWLEDGEMENTS

The work was supported by The National Natural Science Foundation of China (Grant No. 11102139), and The Natural Science Foundation of Hubei Province of China (Grant No. 2014CFB713).

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