Thin-Walled Structures 123 (2018) 351–359

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Buckling of cylindrical shells with measured settlement under axial compression

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ARTICLE INFO

Keywords:
Cylindrical shells
Measured settlement
Axial buckling
Geometrical nonlinearity

ABSTRACT

Buckling behavior of cylindrical shells with measured settlement under axial compression has been researched and analyzed in this paper. Using the method of Fourier series expansion, the measured settlement data is transformed into differential settlement. Applying the finite element simulation method, the differential settlement is applied to bottom of the cylindrical shell in order to simulate behavior of the cylindrical shell under differential settlement. Based on the deformed cylindrical shell caused by settlement, the finite element simulation method is applied to research buckling behavior of the cylindrical shell under axial compression considering the geometric nonlinearity and large deformation. The meridional membrane stress distribution in the circumferential direction of the cylindrical shell under differential settlement is obtained and compared with the differential settlement distribution. Effects of liquid storage on buckling behavior of the cylindrical shell are researched by applying hydrostatic pressure to the inner surface. Parametric analysis is carried out to research the effects of diameter-thickness ratio and height-diameter ratio of the cylindrical shell on the axial buckling capability. Results show that the cylindrical shell will be subjected to deformation and meridional membrane stress because of the differential settlement and the critical axial buckling load will be decreased then. Liquid storage is helpful for the cylindrical shell to remain stable. The cylindrical shell with larger height-diameter ratio and smaller diameter-thickness ratio is more capable to resist buckling under axial compression following differential settlement.

1. Introduction

As a typical thin walled structure, cylindrical shells are widely used in various industries, such as steel silos, oil storage tanks and nuclear reactors [1–3]. These structures may be subjected to many kinds of axial compression, like gravity, vacuum effects and uplift caused by earthquake. The axial buckling capacity should be regarded as a controlling factor in the design stage of cylindrical shells in order to avoid potential failure. A collapsed steel silo caused by axial compression has been shown in Fig. 1.

Buckling of cylindrical shells under axial compression has attracted extensive attention in recent years. Results of previous researches show that initial imperfections of the cylindrical shell have great influence on the axial buckling strength [4–6]. The researches of initial imperfections are mainly about the dimensional discrepancy caused in the manufacturing process, longitudinal and girth welds, local imperfection and damage [7–10]. In engineering, uneven soil deposition, especially for the coastal soft soil foundation, will lead to differential settlement of the cylindrical shell structures [11]. Deformation and stress redistribution of the cylindrical shell caused by settlement may weaken its mechanical properties. The cylindrical shell will be unable to continue working as usual when the differential settlement reaches a critical value. Zhao et al. [12–14] and Gong et al. [15–17] had done some researches about buckling of cylindrical shells under settlement applying finite element simulation. However, for most cylindrical shells in service, settlement will not cause instability or failure directly. But the deformation and stress redistribution caused by settlement will have great influence on the axial buckling strength of the cylindrical shell. Compared to initial imperfections, deformation and stress of the cylindrical shells caused by settlement are much larger. Holst and Rotter [18] researched buckling behavior of axially compressed cylindrical shells with local settlement. The local settlement was assumed as local uplift in the form of quasi-continuous with a sinusoidal variation beneath the cylindrical shell. The initiation and development of deformation caused by local settlement and its effect on buckling of the cylindrical shell under axial compression had been studied then. However, in engineering, settlement beneath the cylindrical shell is distributed randomly in the circumferential direction. Several

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https://doi.org/10.1016/j.tws.2017.11.006
Received 29 March 2016; Received in revised form 16 October 2017; Accepted 7 November 2017
Available online 01 December 2017
0263-8231/

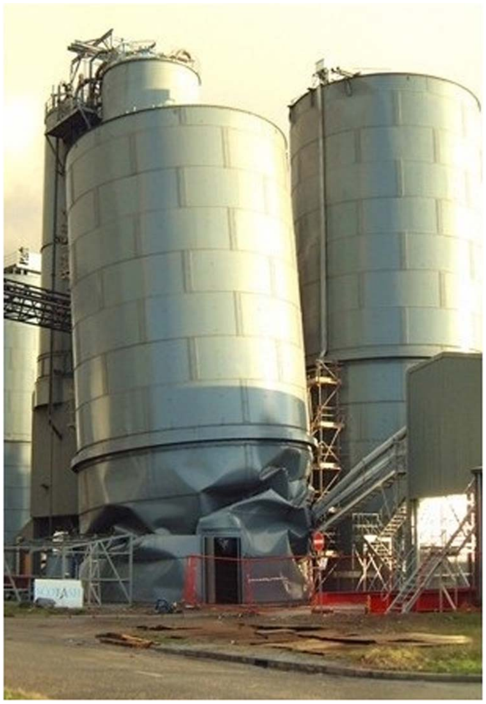

Fig. 1. A collapsed steel silo caused by axial compression.

measuring points are located on basement of the cylindrical shell in order to obtain settlement data. Review of previous literature shows that research about buckling of cylindrical shells with measured settlement under axial compression is quite limited. It is quite significant to research the measured settlement beneath the cylindrical shell and buckling behavior of the cylindrical shell under axial compression.

This paper focuses on the measured settlement in engineering to research the effect of differential settlement on the cylindrical shell's deformation. Based on that, the axial compression is applied to the deformed cylindrical shell and the critical axial buckling load coefficient will be obtained. The influence mechanism of settlement on axial buckling behavior is researched. Effects of differential settlement amplitudes on the critical axial buckling load coefficient of the cylindrical shell are also studied. Meanwhile, structure parameters and liquid storage of the cylindrical shell are also determining factors to the deformation and meridional membrane stress under settlement. The axial buckling capacity of the cylindrical shell with different liquid storages is analyzed. Parametric analysis of structure parameters has been carried out to research effects of structure parameters on the axial buckling strength of the cylindrical shell with measured settlement under axial compression.

2. Behavior of cylindrical shell under measured settlement

As the foundation property changes differently in the circumferential direction, the cylindrical shell will be subjected to differential settlement. In order to reveal the deformation behavior of the cylindrical shell under settlement in engineering, the measured settlement data of an oil storage tank is selected in this paper [14]. The oil storage tank is a typical thin walled structure and 16 measuring points have been located evenly at the bottom along circumferential direction to record settlement of the tank. The measuring point number and the corresponding settlement data are shown in Fig. 2, with the unit of mm.

The measured data reflects settlement of some discrete points in the circumferential direction beneath the cylindrical shell. In order to analyze deformation behavior of the cylindrical shell under settlement, the measured settlement data needs to be transformed into the continuous distributed form in circumferential direction. According to the theoretical research of settlement [19–21], the discrete settlement data obtained from the measuring points can be transformed into differential settlement expression applying the method of Fourier series expansion, as shown in Eq. (1).

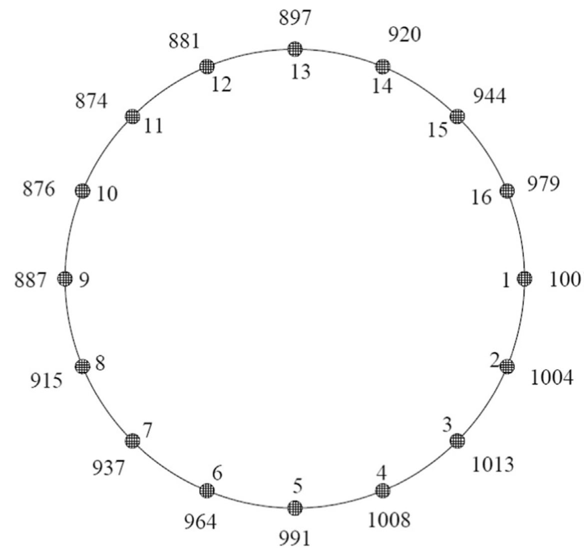

Fig. 2. Measured settlement data of the tank.

$$u = 0.088 \times \cos(2\theta) - 0.045 \times \sin(2\theta) + 0.944 \times \cos(3\theta) - 0.872 \times \sin(3\theta) + \cos(4\theta) - 2.375 \times \sin(4\theta) + 1.746 \times \cos(5\theta) - 0.706 \times \sin(5\theta) - 0.088 \times \cos(6\theta) - 1.545 \times \sin(6\theta) + 1.011 \times \cos(7\theta) - 0.601 \times \sin(7\theta) - 0.188 \times \cos(8\theta) \quad (1)$$

where u represents the differential settlement beneath the cylindrical shell with unit of mm and θ is the circumferential coordinate with the unit of rad.

Diagram of the differential settlement distributed in the circumferential direction beneath the cylindrical shell is shown in Fig. 3. The horizontal coordinate is central angle, which satisfies $\varphi = \theta \times 180/\pi$.

The differential settlement u derived from measured settlement data has been shown in Eq. (1). In order to research behavior of the cylindrical shell under different settlements, the settlement amplitude is defined as $\lambda = u_0/u$. When λ is selected as different values, different differential settlement expressions will be obtained by $u_0 = \lambda u$.

The commercial finite element package ABAQUS is applied in the simulation analysis. The finite element model of the cylindrical shell is

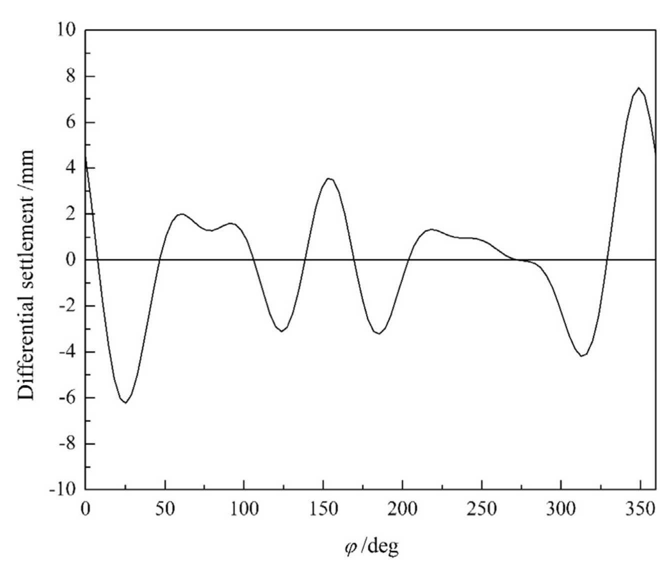

Fig. 3. Differential settlement distributed in the circumferential direction.