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Wind loads on large cylindrical open-topped tanks in group

Yang Zhao, Yin Lin, Yan-bin Shen *

Spatial Structures Research Center, Zhejiang University, Hangzhou 310058, China

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ABSTRACT

Vertical cylindrical tanks for fluid and bulk storage are generally with very thin wall so they are very susceptible to buckling under wind loads. One of the main challenges for designers is the scarcity of reliable wind loads on tanks. A particular case of wind loads on tanks may occur when a tank is situated at the corner of a group in tank farm or distribution station, since it is expected to be loaded by different wind pressures compared with those of an isolated tank. In this paper, a large number of wind tunnel tests are conducted to investigate the wind loads on vertical cylindrical open-topped tanks in group, with main focus on the grouping effect of large cylindrical tanks with a very low aspect ratio. Three types of tank groups are covered in this study: two adjacent tanks including tandem, parallel and staggered configurations, three adjacent tanks in triangular array and four adjacent tanks in square array. The effects of spacing between tanks and wind attack angle on wind pressure distributions of both external and internal wall are investigated, and the difference of wind loads on tanks in a group compared with those on an isolated tank is discussed.

1. Introduction

Vertical cylindrical tanks for fluid and bulk storage are generally with very thin wall, and so they are very susceptible to buckling under wind loads, which is a major consideration for designers. To determine the wind loads on vertical cylindrical tanks, many studies have been conducted in the past. Wind pressure distributions on tanks were investigated through wind tunnel tests by Maher [1], Purdy et al. [2], Sabransky and Melbourne [3], Macdonald et al. [4,5], Holroyd [6], Portela and Godoy [7,8], and Uematsu and Koo [9]. Numerical simulations were also performed by Fröhlicha and Rodi [10] and Falcinelli et al. [11] to obtain wind loads on tanks. These studies covered a wide range of tank geometries with different aspect ratios as well as roof configurations. However, cases considered in most of these studies were isolated tanks. In oil storage farm or distribution station, tanks are usually constructed in many configurations to satisfy the topography as well as process requirements. And a particular case of wind loads on tanks may occur when a tank is situated at the corner of a group in tank farm or distribution station, because it is expected to be loaded by different wind pressures compared with those of an isolated tank. Certainly, the wind loads on tanks accounting for grouping effect are very important for design.

Vickery and Ansourian conducted a set of experiments to investigate the wind loads on silo arranged in a group of three silos with same diameter under normal wind [12]. They found that in a closely spaced configuration the silo was loaded by a more extended central angle of wind pressures in the windward region, which resulted in a different buckling behavior compared to that of the isolated tank. Sabransky and Melbourne [3] investigated the effects of a simple group configuration, in which three models were placed in a line and the center-to-center spacing between models was chosen to be 1.25 times the model diameter. Three attack angles 0°, 22.5° and 45° were included in their tests. It was found that the interference effects of tanks lead to amplification of wind pressure. Macdonald et al. [5] carried out wind tunnel tests of a group of five flat-roof tank models arranged in line. They covered a wide range of spacings from 1/8 to 3 times the model diameter and four attack angles 0°, 20°, 45° and 90°. Portela and Godoy [13] studied the shielding effects of wind loads on tanks in tandem array, with focus on the rear tank shielded by others. They also performed further research considering a more complex configuration, in which the dimensions of tanks and their spacings were irregular [14]. Gu and Sun conducted a set of experiments to investigate the interference between wind loading on a group of cylinders with different configurations [15,16,17]. Similar work was also performed by Kareem et al. [18]. The grouping effect of wind loads on cylindrical structures with hyperbolic geometry has also been investigated by Sun et al. [19], Niemann and Köpper [20], and Orlando [21].

With development of oil industry, the capacity of tanks has become larger and larger. The large cylindrical open-top tanks with capacity of 100,000 m^3 are the most common structures in many oil storage tank farms or distribution stations in China, and

* Corresponding author.
E-mail address: benjamin127@163.com (Y.-b. Shen).

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the common dimension of these tanks is 80 m in diameter and 22 m in height, leading to an aspect ratio of 0.275. However, few studies have been conducted on the grouping effect of such large cylindrical tanks with very low aspect ratios.

This paper investigates wind loads on this type of tank as a member of tank group by experimental method using scaled models. Focus is on configurations of three types: two adjacent tanks, three adjacent tanks in triangular array and four adjacent tanks in square array.

2. Experimental apparatus and procedures

2.1. Wind tunnel and boundary layer simulation

Wind tunnel tests were carried out at Zhejiang University in a closed-loop wind tunnel. The working section was 4 m (width) $\times$ 3 m (height) $\times$ 18 m (length) with a capacity of producing wind speed of up to 55 m/s.

A turbulent boundary layer flow was simulated to be appropriate to the sea-shore terrain in which tanks are usually constructed. The power law exponent of the profile of mean wind speed was 0.12. The wind velocity scale was approximately set to 1/5. The measured wind mean speed and turbulence intensity profile are shown in Fig. 1(a). The mean wind speed and the turbulence intensity at the top of cylinder part of model were 8.1 m/s and 15%, respectively. The wind velocity spectrum of the wind tunnel flow is shown in Fig. 1(b) and is compared with the Davenport spectrum and Karman spectrum. The corresponding Reynolds number based on D (cylinder diameter of model) and U_b (inflow velocity at the top of cylinder) was 2.16×10^5.

2.2. Tank models and group layouts

The measured model used in experiment is based on the large open-top tank with an aspect ratio of 0.275 as mentioned above. The geometric scale is 1/200. Thus the model is 0.4 m in diameter and 0.11 m in height, as shown in Fig. 2. 288 pressure taps were installed at 4 levels along meridian in the measured model. The pressure taps were installed at an interval of 10° on external and internal surfaces of the cylinder along circumference at each level (Fig. 2). Tank models placed in the wind tunnel for interference have the same geometry with the measured model but without pressure taps. All models were fabricated using fiber glass as well as engineering plastics.

Fig. 3 shows the configuration of two adjacent tanks. L is the distance between two tanks measured from the center. β is defined as the wind attack angle measured from windward to the center line of two tanks. θ is the position of pressure tap measured from windward with anticlockwise direction positive, and this definition is also applied on the three-tank array and the four-tank array. In tank farms or distribution stations, the minimum safe distance between two adjacent tanks for fire protection

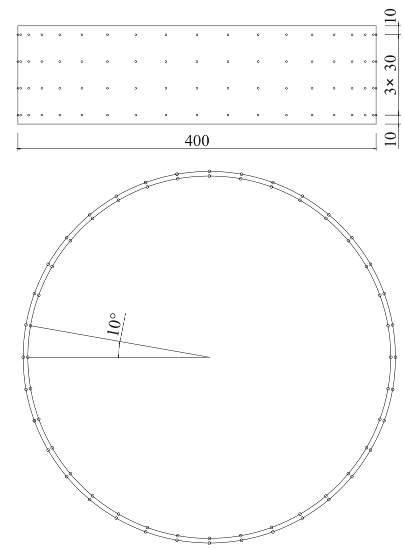

Fig. 2. Dimension of models and location of pressure taps.

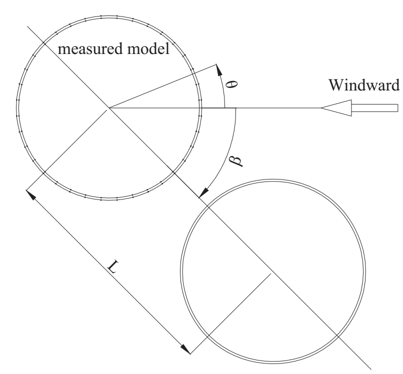

Fig. 3. Two-tank array.

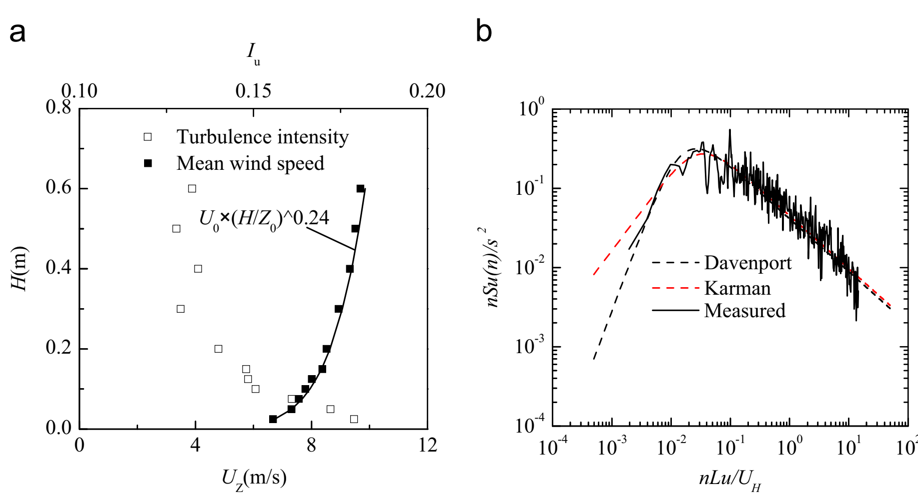

Fig. 1. Wind profile and spectrum in wind tunnel. (a) Wind velocity and turbulence intensity and (b) velocity spectrum at height of 0.1 m.