



Failure of cylindrical steel silos composed of corrugated sheets and columns and repair methods using a sensitivity analysis

P. Iwicki, M. Wójcik, J. Tejchman *

Faculty of Civil and Environmental Engineering, Gdańsk University of Technology, Narutowicza 11/12, 80-233 Gdańsk-Wrzeszcz, Poland

ARTICLE INFO

Article history:

Received 26 February 2011

Accepted 13 June 2011

Available online 22 June 2011

Keywords:

Buckling

Corrugated walls

Geometric imperfections

Sensitivity analysis

Silo

ABSTRACT

The paper deals with failure of large cylindrical steel silos composed of horizontally corrugated sheets with vertical stiffeners. The failure reasons were discussed. A linear buckling and a non-linear analysis with geometric and material non-linearity were carried out with a perfect and an imperfect silo shell (with different initial geometric imperfections) by taking into account axisymmetric and non-axisymmetric loads imposed by a bulk solid following Eurocode 1. The 3D FE calculations were carried out with the commercial finite element code "Abaqus". The calculated buckling forces were compared with the allowable one given by Eurocode 3. Repair methods of silos against buckling were proposed. A sensitivity analysis was performed for a silo to predict the location and profile type of strengthening elements.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Thin metal cylindrical silo shells are vulnerable to buckling failures caused by the compressive wall friction force, particularly during eccentric discharge (which is usually difficult to avoid with regard to a non-homogeneous character of bulk solids). As a consequence, non-uniform horizontal wall pressures develop which contribute to (except of meridional bending) a non-symmetric distribution of compressive vertical wall forces. The buckling strength of shells depends on many different factors such as: form and amplitude of initial geometric imperfections, loading and material imperfections, type of joints, boundary conditions at ends, level of internal pressurization and stiffness of the stored bulk solid [1–4].

Metal silos are frequently built of thin-walled horizontally corrugated curved sheets strengthened by vertical stiffeners (columns) distributed uniformly around the silo circumference and connected with screws due to an economical steel consumption and a small silo weight [1]. In those silos, horizontally corrugated wall sheets carry horizontal tensile forces caused by horizontal wall pressure of a bulk solid and vertical columns carry vertical compressive forces exerted by wall friction stress from a bulk solid. Eurocode 3 [5] gives a simplified formula to calculate the buckling strength of vertical columns around the silo circumference, which does not take into account a real 3D buckling behavior of silo shells containing a silo fill.

The aim of the paper is threefold: (a) to describe a failure case of large cylindrical metal silos composed of horizontally corrugated sheets strengthened by vertical columns (which failed by buckling), (b) to compare the calculated buckling strength from FE analyses with that given by Eurocode 3 [5] and (c) to predict the location and profile type of strengthening elements by using a sensitivity analysis. Both a linear buckling analysis and a non-linear FE analysis (with both geometric and material non-linearity) were carried out with a perfect and an imperfect silo shell by taking into account uniform and non-uniform loads exerted by a bulk solid (specified by Eurocode 1 [6]) and different initial wall geometric

* Corresponding author.

E-mail addresses: piwicki@pg.gda.pl (P. Iwicki), mwojcik@pg.gda.pl (M. Wójcik), tejchmk@pg.gda.pl (J. Tejchman).

imperfections along the silo circumference and silo height. The full 3D FE calculations were carried out with the commercial finite element code “Abaqus” [7]. Finally, strengthening methods were proposed to repair the failed silos.

In contrast to many buckling analyses performed for metal silo shells with isotropic rolled thin-walled walls [4,8–11], the comprehensive buckling analyses of a cylindrical silo consisted of horizontally corrugated sheets and vertical stiffeners have rarely been carried out [12]. Our preliminary FE studies [12] have shown that the buckling strength proposed by [5] is very conservative.

2. Situation

The battery of large metal cylindrical bins silos with flat bottoms is located in Poland (Fig. 1). The height of a single bin was $H = 20.13$ m (the total silo height was 23.27 m) and its diameter $D = 12.48$ m. The cross-section area was 122.29 m² and the perimeter was 39.20 m. The silo mantle in a vertical direction consisted of 24 rings made from horizontally corrugated sheets 890×2940 mm² put on a foundation slab. The thickness of the corrugated sheets varied from 0.75 mm up to 1.75 mm. The sheet corrugation had 119 mm pitch and 10 mm depth. The 28 vertical columns composed of open thin-walled profiles with a varying cross-section (Fig. 1 and Table 1) were uniformly placed along the silo circumference at a constant distance of 1.4 m. The columns were connected to the wall sheets by screws. There were three circular outlets in the flat bottom of each silo. The outflow took place through a circular mid-outlet with a diameter of about 0.4 m. The silo roof was made from metal sheets inclined under an angle of 28° and stiffened by 28 radial beams. The silo contained rape seeds and was concentrically filled and emptied with constant outlet velocity of 60–180 m³/h. It was designed for funnel flow to avoid large loads on walls and vertical columns.

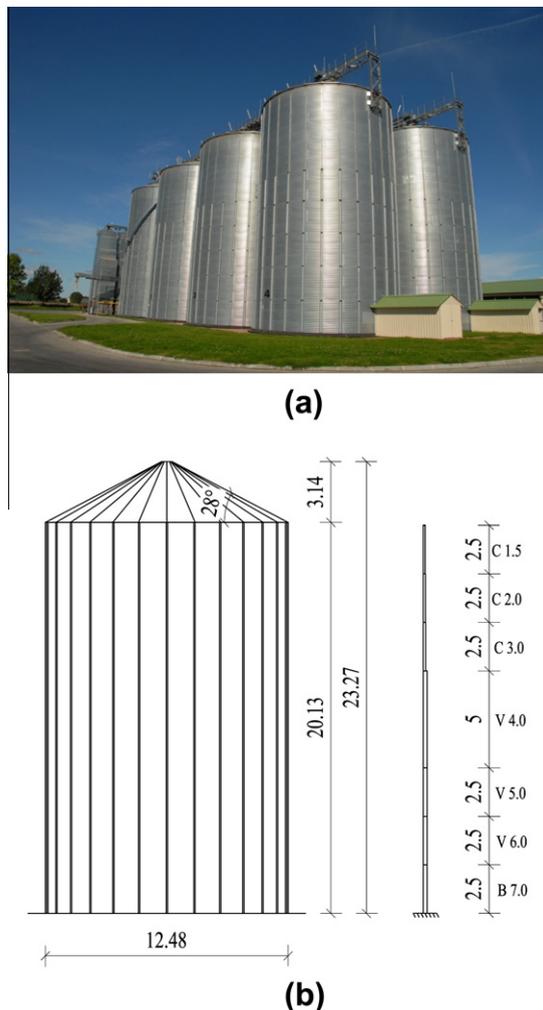


Fig. 1. Metal cylindrical silos built in Poland: (a) view on silo battery, (b) geometric characteristics of silo (dimensions in [m]), (c) column profiles along wall height (dimensions in [cm]), and (d) corrugated sheet (height $d = 10$ mm, width $l = 119$ mm, curvature radius $R_\phi = 60$ mm).

متن کامل مقاله

دریافت فوری ←

ISIArticles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات