Engineering Structures 33 (2011) 1940–1954

Contents lists available at ScienceDirect

Engineering Structures

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

A simplified analytical procedure for assessing the worst patch load location on circular steel silos with corrugated walls

E. Gallego *, C. González-Montellano, A. Ramírez, F. Ayuga

BIPREE Research Group, Universidad Politécnica de Madrid, Madrid, Spain

ARTICLE INFO

Article history:
Received 17 December 2009
Received in revised form
22 February 2011
Accepted 28 February 2011
Available online 31 March 2011

Keywords:
Silo walls
Finite element models
Patch load
Steel structures

ABSTRACT

Silos are widely used in the food and chemical industries for the storage of granular materials. The calculation of their wall dimensions is complicated since the interaction between the stored material and that from which the silo is made is complex, a consequence of their very different mechanical behaviours. The loads exerted on the silo walls by stored materials must be taken into account in silo design, and the means for calculating them is contemplated in Eurocode EN 1991-4. The complexity of the phenomena that occur within silos often leads to the appearance of unexpected and asymmetrically distributed pressures. This is taken into account in the above Eurocode via the concept of the patch load, which is asymmetric and can be exerted at any point on the silo wall. A finite element model has been developed in order to check that the stress resultants derived from the patch load on steel silos with corrugated walls may be predicted by using the well-known expressions of shell theory. Then, a simplified analytical procedure has been developed for predicting the worst location of patch loads for all metal silos, but with special application to corrugated steel silos in Action Assessment Class 3. It has been found that significant differences may be found for most cases with the worst location for the patch load defined in Eurocode for welded silos in Action Assessment Class 2. On the other hand, the values obtained for the maximum meridional membrane stress resultant do not significantly differ, except for high slenderness values in intermediate slenderness silos.

1. Introduction

Silos have been used to store many kinds of material since the end of the 19th century. Their use increased greatly as a consequence of industrialisation, and gradually their dimensions became larger. Unfortunately, their exploitation was associated with a number of accidents, which, on top of their economic consequences, involved the loss of human life. Research on silo design began soon after. The work of Janssen [1] eventually gave rise to a theory for the calculation of loads in a static state that is still used in most modern day standards [2–5]. During the 20th century experimental work designed to improve our understanding of the pressures exerted on silo walls by stored materials intensified. Work performed by different authors on concentric silos [6–11] showed that, during silo discharge, the pressure exerted is greater than that associated with filling. The shape of the lateral pressure curve obtained during discharge resembles that produced by Janssen, except at certain heights in the silo where there are increases in pressure.

The existence of load eccentricities causes asymmetrical load distributions on the silo wall [12]. A number of authors [13–15] have reported the lateral pressures on the silo wall closest to the outlet to be smaller than those on the opposite wall. It has also been constantly confirmed that the pressures exerted during discharge are greater than those seen during filling. The work of Pieper [16] was of great impact because it showed that square silos with outlet eccentricities of 50% and 100% behave in a manner opposite to that described by the above authors. Thus, they report lateral pressure to increase on the wall closest to the outlet, rather than on the opposite wall.

Nielsen [17] demonstrated the existence of asymmetrical pressure distributions in concentric silos both during filling and discharge. These results came about via work on the possible influence of the location of sensors placed on silo walls on the very measurements they took [18]. In these experiments a geometrical imperfection to the interior surface was introduced on the silo wall near the place where the sensors were located and it was demonstrated that the distribution of pressures on the wall was altered by this. His work led to numerous findings [19–21], including evidence that geometrical asymmetries of the silo wall could significantly contribute towards structural failure through the notable local increase in lateral loads.

Stiglat [22] proposed the inclusion of two rectangular zones of additional pressure on the silo walls to account for the pressures

* Corresponding address: EUIT Agrícola. Avda. Complutense s/n, 28040 Madrid, Spain. Tel.: +34 91 336 3705.

E-mail address: eutiquio.gallego@upm.es (E. Gallego).

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.02.032