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Establishing stress state of cylindrical metal silos using finite element method: Comparison with ENV 1993

A. Juan[a,*], J.M. Moran[a], M.I. Guerra[a], A. Couto[a], F. Ayuga[b], P.J. Aguado[a]

[a] *ESTI Agraria, Department of Agricultural Engineering, University of Leon, Av. Portugal 41, 24071 Leon, Spain*
[b] *ETSI Agronomos, Polytechnic University of Madrid, Av. Complutense s/n, 28040 Madrid, Spain*

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Abstract

There is at present a great deal of interest in developing new methods and calculation tools for use in the study and measurement of stress states in shell metal structures. The finite element method (FEM) is a numerical method which permits this kind of study, and which is put forward in the European experimental standard, ENV 1993, as an accurate and reliable calculation tool. This study presents different three-dimensional models whose distinguishing feature is the simulation of both stored granular material and silo walls, without resorting to simplifications. The models developed predict the stress state of cylindrical metal silos flat bottomed, subjected to the action of stored granular material in their interior. The behaviour assigned to the stored material is elastic, and that assigned to the structure is the classical bilinear elastic-perfectly plastic, typical of metallic materials such as steel. Two geometric parameters are analysed: height and thickness of the wall. The results obtained from numerical methods (hoop, meridional or vertical, normal and shear stresses) are compared with those obtained via ENV 1993-1-6.

Keywords: Shell structures; Steel silos; Stress state; Finite element method (FEM)

1. Introduction

Silos and other shell metal structures are widely used for a variety of functions and have been, for a long time, one of the most commonly used structural solutions developed by humans. However, it was not until the 19th century that the big silo towers as we know them today began to be built. The use of thin-walled metallic containers in various agricultural, livestock and industrial production processes has been increasing up to the present day, displacing other methods of storage and containment. The case of granular material storage in metal silos presents a specific problem on two levels: on the one hand, establishing the mechanical properties of the stored product, on the basis of which the stresses that the structure must withstand can be calculated, and on the other hand, calculating the stresses of these specific mechanical properties on the design, resulting in a safe, economic and reliable construction.

Establishing the properties of diverse granular materials and their patterns of behaviour, as well as the appearance of specific standards for establishing their behaviour (ENV, 1991-4 [1]) provide sufficient means to solve the first of the problems posed. However, this alone is not sufficient for the design of the structure and it is on this point that progress to date has not gone far enough.

The analysis of thin-walled laminated structures represents a field of study and investigation, which has been active since the beginning of the 20th century [2,3] until now. Teng and Rotter [4] indicate the wide range of studies necessary to completely characterize and define the behaviour of thin-walled laminated structures.

Many theoretical and practical studies of the subject have been published. The following is a summary of ome which were studied in the course of research for this article: Rotter [5] describes the treatment of membrane structures and underlines the principles which guide the

*Corresponding author. Tel.: +34 987 29 18 17; fax: +34 987 29 18 10.
E-mail addresses: diaajv@unileon.es (A. Juan), francisco.ayuga@upm.es (F. Ayuga).

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ENV 1993-1-6 [6], the range of covered applications and certain details of current proposals. Schmidt [7] reviews the level of current knowledge and recent development in the study of laminated structures. Other work of great importance is that of Winterstetter and Schmidt [8], which analyses the stability of metallic membranes under the action of mixed loads. Nor should the work of Teng and Rotter [9,10], on the behaviour of silo–hooper junctions and transitions, and that of Teng et al. [11], in which the authors analyse techniques for evaluating buckling in silo–hooper junctions be forgotten. In a different publication, Guggemburger et al. [12] analyse a model silo standing on four equidistant column supports without ring or longitudinal stiffening. Lastly, the work of Pircher and Bridge [13] and Pircher et al. [14] should be mentioned. These deal with geometrical imperfections produced by soldering, and new aspects on buckling in metallic membranes subjected to axial loads. Further work of great interest, which has constituted a valuable antecedent to this work, was undertaken by Ayuga et al. [15,16], Moran et al. [17] and Vidal et al. [18]. In the majority of the studies cited above, laminated metallic structures subjected to different stages of loading, usually axial centred, are analysed using numerical methods (basically finite element method—FEM). Practically all these studies introduce a series of simplifications in the numerical models developed: in some cases only the stored material is simulated, substituting the silo wall for more or less rigid constraints; in other cases, a totally rigid shell structure in contact with stored material is modelled; and in still other cases, only wall structure is simulated and subjected to the action of external forces (axial compression or shear, applied to the edges of the structure, external or internal pressure, precise loads applied to specific points, etc.), avoiding, in the last case, modelling stored material. However, studies where the flexible laminated metal structure is simulated jointly with granular material stored in its interior using FEM scarcely exist. The stored material is the origin of the loads to which the silos are subjected and therefore the cause of their stress state. The need to model more realistic load conditions has already been raised [4]. This study aims to bring something new to the already ample literature, by simulating both aspects jointly, and by offering data on stress states in this type of structure.

This study attempts to address a new aspect within the general problem of silo design; the calculation and analysis of stress state. Through the use of computer programs, models can be effectively resolved with finite elements capable of simulating the complexity of these structures—thin exterior wall, stored granular material whose variable behaviour (elastic or elasto-plastic) can be introduced, and finally, wall–grain contact and friction.

The main objective of this study is to compare the classical methods and proposals of the European experimental standard, with numerical methods and three-dimensional (3D) models developed by the authors, and to offer a tool for the evaluation of design stress in these structures based on the FEM. The evaluation of silo stress states using numerical methods could act as a tool for the design and calculation of this type of structures, as well as

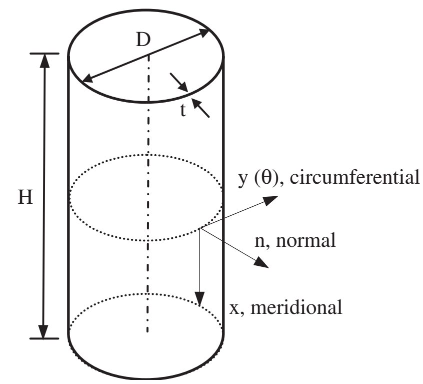

Fig. 1. Coordinate system and geometric parameters used: D, silo diameter; t, wall thickness; H, silo height.

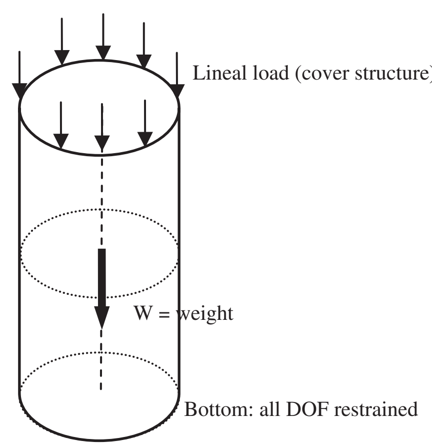

Fig. 2. Loads and constraints in the model.

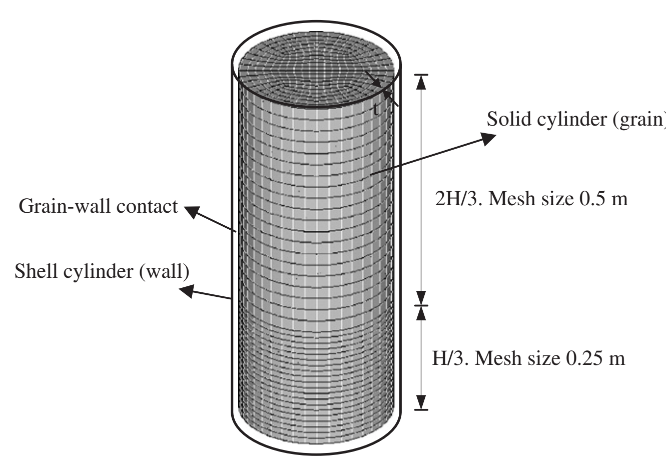

Fig. 3. Three-dimensional finite element model (representation). Detail of mesh size (t = wall thickness).