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

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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.

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

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