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Buckling estimates for oil storage tanks: Effect of simplified modeling of the roof and wind girder

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ABSTRACT

Oil storage tanks are short cylindrical shells fabricated with an external fixed roof or floating roof on the inside. Some features of the structure tend to be simplified in practice and research in order to perform stability and strength analyses using a much simpler model. This paper considers the structural consequences of such simplifications, including the substitution of a supporting structure of the roof or a wind girder by an equivalent thickness or by a fictitious boundary condition. Three load cases are investigated: thermal loads due to an adjacent fire, uniform external pressure, and wind pressure. Results of finite element analyses to evaluate bifurcation loads and modes are reported as estimates of buckling. Equivalent thickness models are derived by establishing equivalences in moment of inertia or sectional modulus of the components that are not represented in detail. The differences in buckling loads associated with equivalent thickness models depends on the load case considered, but range between 7–15% for a case studied with a fixed roof, with smaller differences (3%) for opened top tanks with wind girders. Substitution of a wind girder by a boundary condition, on the other hand, yields large errors under thermal loads exceeding 80% of buckling loads.

1. Introduction

Liquid-storage tanks have relatively simple geometries, basically a vertical cylindrical shell with a roof, but they often present some additional complexities in practice. Depending on the diameter of the cylinder, tanks may have a fixed roof or a floating roof, or may be opened at the top. There are also tanks having both floating and fixed roofs.

Tanks with a fixed roof are frequently fabricated with a conical or flat roof, which are not self-supported but require of an additional supporting structure: a three dimensional grid formed by rafters, rings, and columns, as shown in Fig. 1. In the example of Fig. 1 there are two intermediate rings that delimitate three annular regions on the roof; 16 rafters run through the three regions, 16 additional rafters span the second and third annular sectors, and 32 rafters are added in the third sector, so that altogether there are 64 rafters in the third sector. A typical cross-section of a rafter is shown in Fig. 1c, taken from a real tank located in USA.

Because of the complexity added by the grid of rafters and rings, researchers and designers attempt to simplify the structural analysis by eliminating the three dimensional grid and substituting it by a modification in the thickness of the roof. Such “equivalent” roof is a self-supported shell with a modified thickness, but also the weight needs to be adjusted in order to avoid having an excessively heavy roof which would buckle under self-weight. This approach may be found in many research papers, such as Refs. [1–5]. Even simpler models have been considered in the literature, in which the roof is completely eliminated and its influence is represented by simply supported boundary conditions at the top of the cylindrical shell [6]. Such simplifications are not motivated by computer time constraints, but are frequently made to simplify modeling and data entry.

Open top tanks, on the other hand, are usually designed with a wind girder at the top to provide stability to the cylindrical shell and thus avoid snap-through buckling. Design provisions in the United States [7] and Europe [8] provide guidance regarding the cross-sectional shapes of wind girders. Such girders have been taken into account in some research papers [9,10,11], whereas they have not been included in the analysis by other researchers [12]. Simplifications to eliminate a wind girder from a model include substitution by boundary conditions to restraint radial

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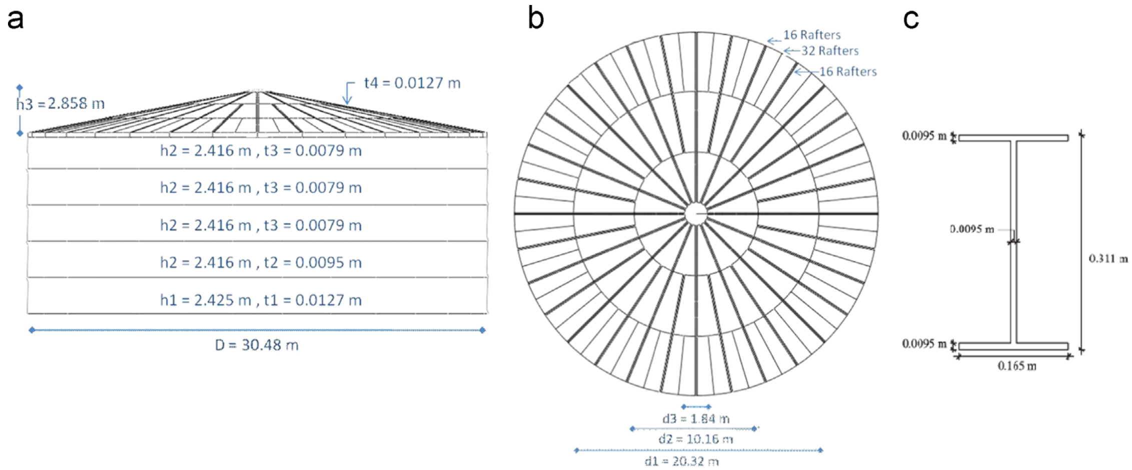

Fig. 1. Geometry of the tank and supporting structure, (a) front view, (b) plane view, and (c) cross-section of rafters.

displacements (such as in Ref. [12]) or substitution by a modified shell thickness in the region where the wind girder should be present.

Because tanks are formed by very thin-walled shells, buckling becomes a major design constraint, and collapses due to environmental actions and accidents have been reported in many occasions in the literature [13–15]. A state of the art on the buckling of shells may be found in the work of the European Convention for Constructional Steelwork (ECCS) [16]; however, the ECCS book employs some of the simplifications mentioned above without further discussion. At present, the ECCS committee is seeking response to such uncertainties and has called for research in this area; this paper is part of such inquiry addressing those topics identified as voids in current knowledge.

Questions arise as to what are the consequences of such simplifications on the buckling behavior of the structure. Are those effects independent of the loading condition, or do they have different effects depending on the nature of the load (i.e., thermal, lateral pressure). This paper addresses these problems in order to elucidate how such simplifications affect buckling of the shell, and specifically considers thermal loads, uniform pressures, and wind pressures as separate loading cases. Case studies are discussed for two tank configurations, namely fixed roof and open top configurations.

2. Tanks with conical roof

2.1. Case study

A specific fixed roof geometry is considered in this section in order to identify the structural consequences of the assumed simplifications. The shell is shown in Fig. 1, with step-wise variable thickness and a conical roof; the overall geometry is given by a diameter $D = 30.38$ m, cylinder height $H = 12.19$ m, and 2.86 m maximum elevation of the roof with respect to the cylinder. Details of the structural grid supporting the roof are shown in Fig. 1b. The shell thickness as well as the roof structure have been designed according to API 650 regulations [7]. Two equally-spaced intermediate rings were placed between the roof center and its junction with the cylinder. In the outer section there are 64 rafters; 32 rafters in the middle sector, and 16 rafters in the inner sector. The cross-section of the rafters is shown in Fig. 1c. ASTM A36 steel is assumed for all components of the tank, with density $\gamma = 7850$ Kg/m^3, elastic modulus $E = 206$ GPa, and Poisson's ratio 0.3.

The cylinder was assumed to be fixed at the base. A finite element discretization of the structure was made by means of the general

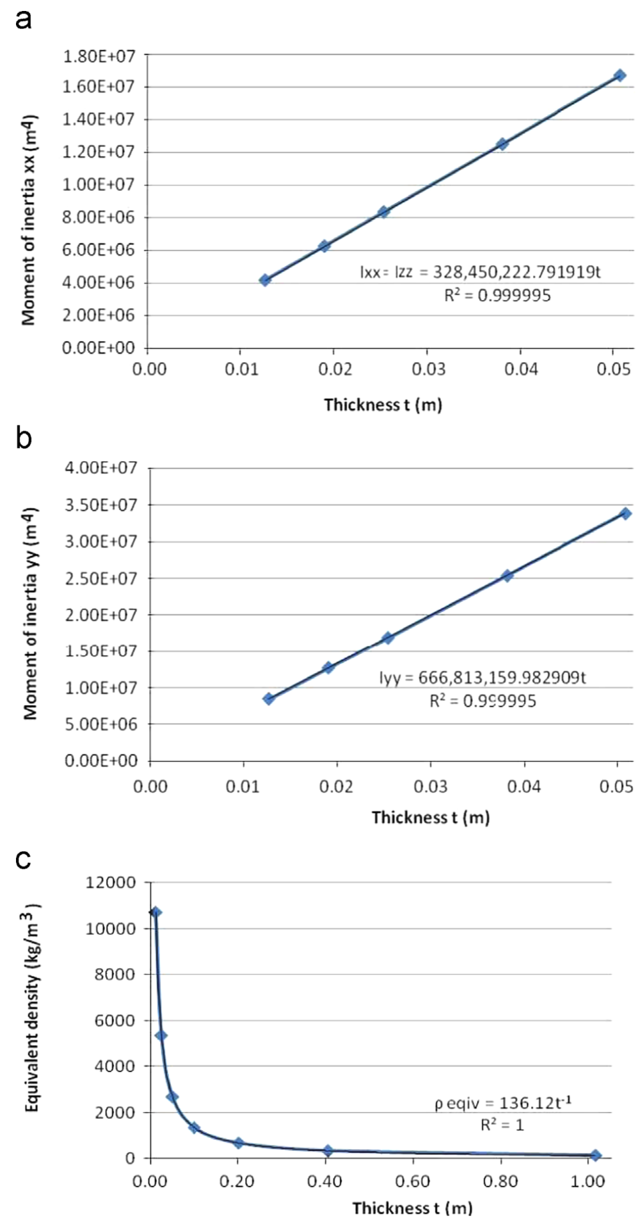

Fig. 2. Self-supported model, (a) inertia $Ixx = Izz$, (b) inertia Iyy, and (c) equivalent density.