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Buckling of ground based steel tanks subjected to wind and vacuum pressures considering uniform internal and external corrosion

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ABSTRACT

Corrosion is one of the significant degradation processes, which occurs in aboveground oil storage tanks. A numerical study is performed to investigate the effects of internal and external corrosion on the buckling behavior of three steel cylindrical tanks with different height to diameter ratios, subjected to both wind and vacuum pressures. Internal corrosion is considered as a time dependent uniform thinning of the roof plate, roof supporting structure and upper part of the wall. Furthermore, the corrosion of the wall at the lower parts of the tank being in contact with residual water and sludge is analyzed. At the same manner, completely external corrosion of the roof and wall plates is considered in numerical analysis. It is found that the buckling load is markedly reduced with thinning of the shell for upper part and whole corrosion cases, irrespective of the loading condition. In addition, the buckled regions of the tanks are suddenly displaced toward the top of the shell during upper part corrosion process. Contrary to upper and whole corrosion cases, the critical load of tanks is only marginally affected by the corrosion of lower part of the wall.

In the last part of this research, the analytical investigation results of a tank (TK-2047) that failed during discharge process in an oil plant are reported.

1. Introduction

Cylindrical steel storage tanks are used in many industries to mainly store oil, water and petrochemical products. They are usually constructed with a thin bottom plate, a cylindrical wall plate with uniform or stepped thickness and a closed-roof or open-top [1]. As typical thin-walled structures, tanks are very sensitive to buckling under wind load. Failure of cantilever cylinders under wind pressure has been studied since the 1960s. For example, Kundurpi et al. [2] reported the collapse of oil storage tanks in England in 1967. In many other areas of the world, such tank failures have also occurred under high wind conditions [3–6]. In addition, thin-walled steel cylindrical tanks are susceptible to buckling collapse due to uniform external pressure (internal vacuum), which could happen during discharge process. Rapid discharge of a tank, if accompanied by accidental closure of all tank valves, will lead to a rapid drop in internal pressure and in severe cases, to tank failure [7,41,42].

1.1. The effects of imperfection on the buckling behavior of shells

Steel cylindrical oil storage tanks are extremely susceptible to corrosion. The long-term effect of corrosion is a significant thinning of the roof or wall section, which leads to imperfections in the roof or shell. The buckling behavior of shells is sensitive to initial imperfections, which significantly decreases the critical buckling load. For example, imperfection-sensitivity to elastic buckling of wind loaded open cylindrical tanks was studied by Godoy and Flores [5,23]; Portela and Godoy [11,12] used both linear bifurcation analysis (LBA) and geometrical nonlinear analysis (GNA) for buckling of tanks with conic and dome roof under wind pressure. Greiner and Derler [24] found that the eigenvector associated with the lowest eigenvalue in a bifurcation analysis is the worst imperfection shape in short tanks. Jaca et al. [25] performed further investigations on imperfection-sensitivity. Gusic et al. [26] studied the effect of harmonic thickness variation in the circumferential direction on buckling of thin cylindrical shell under external pressure by LBA. Aksogan and Sofiyev [27] studied the dynamic buckling of an elastic cylindrical shell with variable thickness, subject to a vacuum pressure. Any geometrical feature of the shell, which alters it from a perfect shell, can cause a geometrical imperfection. These can include wall thickness variation [29–33], welded seams [34], non-circularity or ovality [28], partial shell corrosion [43,44] or other random geometric imperfections such as dents [35].

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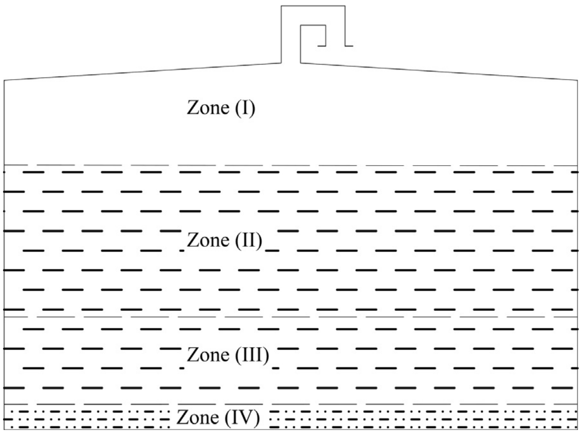

Fig. 1. Inside corrosion zones for typical aboveground oil storage tanks.

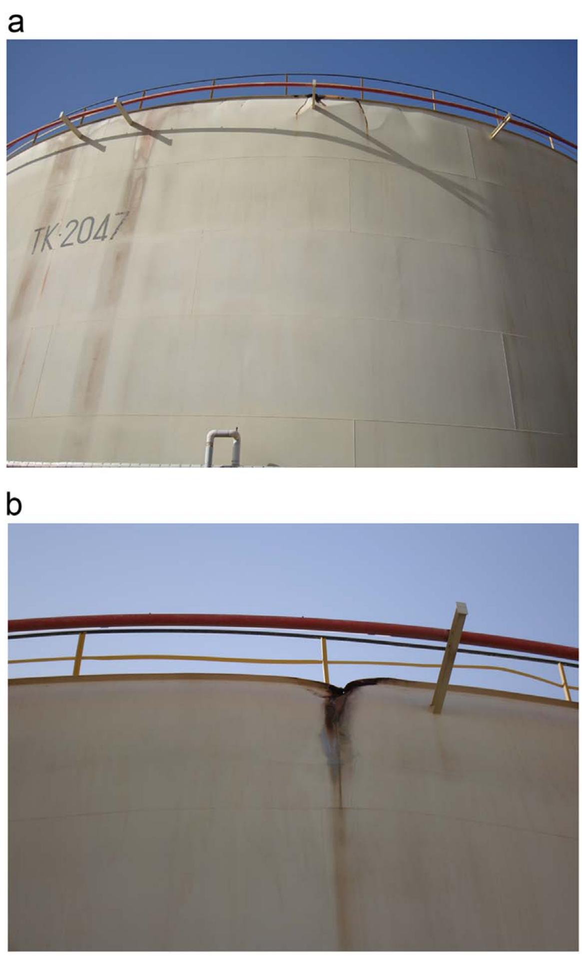

Fig. 2. Buckled tank (TK-2047) due to vacuum pressure and partially shell corrosion (upper part corrosion): (a) upper course (corroded region) buckling (south view of the tank) and (b) buckling deformation (east view of the tank).

1.2. Corrosion in cylindrical storage tanks

Design life of aboveground storage tank is usually 25 years. Really, in practice such tanks may be in use significantly more: 50–70 years. However, failures of some storage tanks caused by corrosion are already detected after 1.5–2.5 years in service [8]. The corrosion in tanks causes about 20% of hydrocarbon products lost as leakage [9,38]. The major corrosion phenomenon of the oil storage tanks is uniform and pitting corrosion [40]. In the present study, similar to Refs. [11,12,14,15,43–45], corrosion degradation is

Fig. 3. Vent blocking.

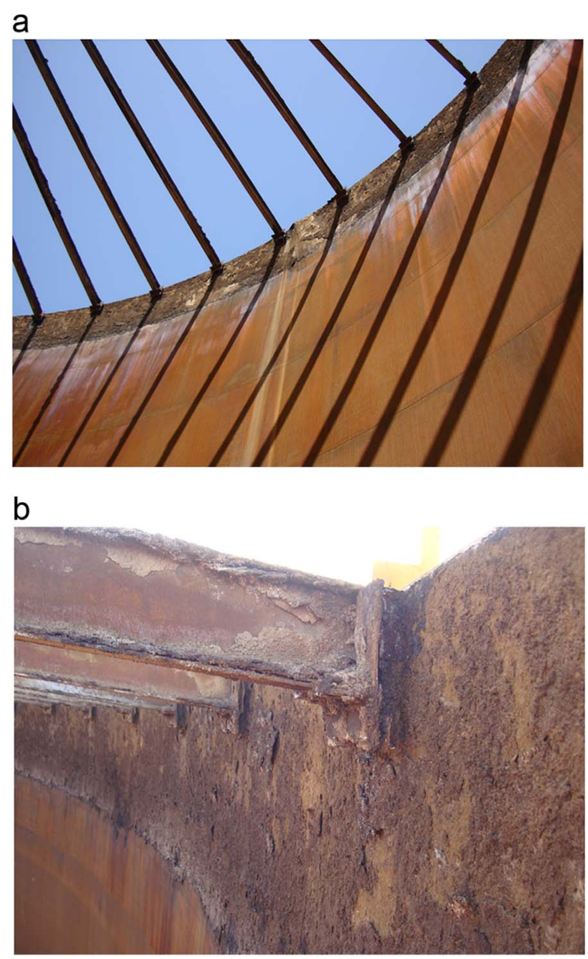

Fig. 4. Corrosion of upper course and roof supporting structure of tank TK-2047: (a) roof plate has been removed for renovation purposes and (b) details of roof rafter attachment.

Table 1
Geometrical characteristics of tanks TK-a, TK-b and TK-c.

Geometrical characteristics	TK-a	TK-b	TK-c
Shell height (m)	12.191	19.337	29.103
Roof height (m)	2.858	2.858	2.858
Tank diameter (m)	30.48	30.48	30.48
H/D	0.40	0.63	0.95