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Failure of oil tanks adjacent to fire

Y. Liu, J. F. Chen, J. M. Rotter and J.L. Torero

Institute for Infrastructure and Environment, The University of Edinburgh

Introduction

Fire accidents are known to occur in petroleum storage tank farms throughout the world. One such example is the massive conflagration at Buncefield (Fig. 1) near London in December 2005 which drew international attention to the serious risks associated with fires in petroleum storage tanks.

Fire accidents usually start from a single tank and spread to other adjacent tanks due to the radiation of heat. The adjacent tank can easily lose integrity under such elevated temperature (Fig. 2) .

However, structural behaviour of this type of structures under fire conditions has rarely been investigated. A study is being undertaken at the University of Edinburgh to investigate the behaviour of a cylindrical steel tank when an adjacent tank is on fire. The aim is to assess the risk of structural failure and to develop a remedial methodology.

Fig.1 Buncefield oil depot incident (2005)

Fig.2 Tanks after fire in Buncefield oil depot incident

Finite element modeling

- Cylinder: radius=10 m, height =20m, thickness=10 mm
- Connected to roof at eaves
- Conical roof: slope ϕ=10° to horizontal
- Pinned at bottom edge
- Perfect geometry
- Used element S4R in ABAQUS (Fig.3).
- GNA analysis
- Elastic modulus declines with temperature

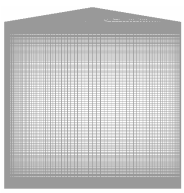


Fig.3 FE model in ABAQUS

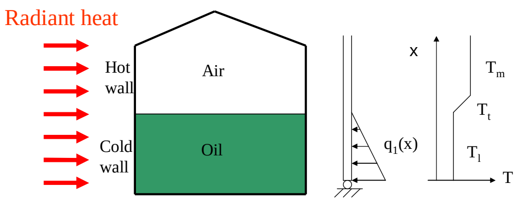
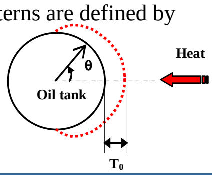


Fig.4 Temperature distribution along height

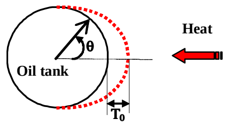
The part where liquid exists is assumed to be cool, since the thermal inertia of the fluid is large. The upper part is heated, since air above the fluid does not cool the steel wall much. Linearly varying temperature between these two zones is assumed.

- The adjacent fire is assumed to produce a uniform radiation from one side (Fig. 4), leaving the half of the tank that does not face the fire thermally unaffected. On the heated side (from -90° to +90°), two alternative assumptions are made. Two treatments of the roof are used: it is either heated or remain cool. The temperature distribution of these two patterns are defined by

"Half cosine" pattern : $T_\theta = \begin{cases} T_0 \cos\theta & \text{if } -\frac{\pi}{2} \le \theta \le \frac{\pi}{2} \\ 0 & \text{if } \frac{\pi}{2} < \theta < \frac{3\pi}{2} \end{cases}$



"Smooth edge" pattern: $T_\theta = \begin{cases} T_0 \frac{\cos^2\theta}{2} & \text{if } -\frac{\pi}{2} \le \theta \le \frac{\pi}{2} \\ 0 & \text{if } \frac{\pi}{2} < \theta < \frac{3\pi}{2} \end{cases}$



Failure of the tank

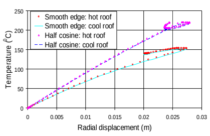


Fig. 5 Typical temperature-radial displacement curves at the middle of the most heated meridian

The smooth edge pattern of temperature rise is more critical.

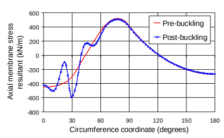
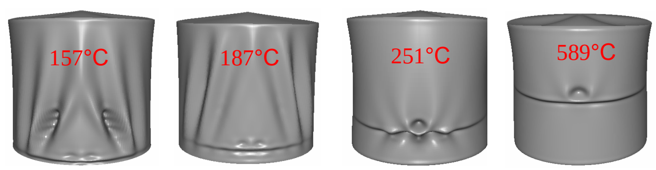
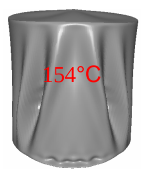


Fig. 6 Axial membrane stresses around circumference at mid height



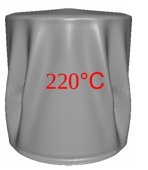
Liquid level:0.5m *Liquid level:2m* *Liquid level:5m* *Liquid level:10m*

Fig. 8 Post-buckling modes of partly filled tank with hot roof under smooth edge temperature distribution



Lower stresses spread around a wider range - wide buckle with higher buckling temperature.

(a) under smooth edge pattern



Global buckling combined with localised buckling near the bottom.

(b) under half cosine pattern

Fig. 7 Post buckling modes of an empty tank with cool roof

- When the liquid level is low, the buckling mode is similar to that of an empty tank.
- When the liquid level rises, the buckling concentrates on the transition zone, just above the liquid level.
- Buckling temperature increases with liquid level.
- Buckling does not occur near the base because of fluid pressure and low temperature.

Conclusions and future work

- Elastic buckling is easily provoked by radiation heating from one side of the tank.
- The buckling mode is quite sensitive to the precise pattern of temperature distribution.
- The degree to which the tank is filled has a significant effect on the stress regime and thus the buckling temperature.
- The roof stiffness has a significant effect on the buckling temperature and mode.
- The temperature distribution of the roof has a significant effect on the buckling temperature of thick-roofed tanks but not thin-roofed tanks.
- Geometrically and materially non-linear analysis with imperfection will be conducted next.