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ORIGINAL ARTICLE

Wall thickness variation effect on tank's shape behaviour under critical harmonic settlement

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KEYWORDS

Steel tanks;
Wall thickness;
Settlement

Abstract The purpose of this study was to investigate the effect of wall thickness variation on tank's wall buckling mode under the effect of critical harmonic settlement for open top tanks. The study was performed on four tanks which have the same geometric and material properties except wall thickness, for each case the tank was subjected to several settlement waves which has the same settlement amplitude, and the buckling mode and critical vertical settlement results were compared. For buckling mode, the results show that tanks with wall thickness at a close range have similar buckling mode behaviour and in case using too thick wall the buckling mode starts to change. And for the effect on critical vertical settlement, the results show that vertical settlement is sensitive to any variation in wall thickness beside that settlement value changes with the effected wave number and this variation could change the whole behaviour of the tanks. The study recommended that in case of performing analysis for a tank with neglecting the variation in wall thickness values, the value of chosen wall thickness should be the average of wall thickness values obtained from the designed equation.

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1. Introduction

By the expansion of oil industry, the need of storage devices has increased, and the tanks are constructed on coastal areas and on island to satisfy production needs. As a result, tanks are subjected to poor soil conditions and the tanks are subjected to many sort of settlement which has it effect on tanks and differential settlement [which also called Harmonic Settlement] has its effect, and a tiny settlement under tank wall could cause a large displacement on the top fibre of the wall which would lead to failure especially in open top tanks [1,2].

In the stage of analytical solutions, researchers were interested in the relation between harmonic settlement at the bottom of tank wall and circumferential displacement at the top of the tank where the floating roof and open top tanks were the main research topics. For instance, Malik et al. [3] started with assumption that the settlement under tank wall was inharmonic, with extensional theory, the relation between harmonic settlement and radial settlement was presented in an equation which was suitable for a little wave number. After that, Kamyab and Palmer [4–7] included harmonic settlement and primary wind girder in their work, and they used the modified Donnel large deflection equation to include a wider range of wave number. With the development of computer technology,

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many researches were conducted based on numerical method where the finite element method is considered as the most used method [2,8–17]. The linear buckling of closed top cylindrical shells under the effect of edge vertical settlement by Jonaidi and Ansourian [10] in their work uniform shells was considered, they concluded that for a little wave number the shear buckling mode is noted and this mode is controlled by axial buckling which is related to the increase in wave number. Lately, an experiment for a small tank with a flat roof was performed by Godoy and Sosa [12] and the tank was subjected to harmonic settlement. They displayed that the equilibrium path is nonlinear and the shell shows a stable symmetric bifurcation behaviour; the buckling behaviour of tank with fixed-roof subjected to harmonic settlement was studied by Cao and Zhao [13]. Three types of buckling were considered in their work: elastic bifurcation analysis, geometrical nonlinear analysis of the perfect shell and geometrical nonlinear analysis of the imperfect shell. Furthermore, they investigated the effects of geometric imperfection, radius-to-thickness ratio, wave number, and height-to-radius ratio on the buckling strength. They showed that both of the critical harmonic settlement and the buckling mode are related at a close range to the geometric parameters aforementioned. Gong et al. [14] reported the buckling behaviour of tanks with conical roof under the effect of harmonic settlement. The geometrical nonlinear behaviour was included in the analyses, in addition to, settlement–displacement curves, critical harmonic settlements and the buckling modes for various wave numbers were reported in his work.

The previous researches focus on the relation between height, radius and thickness relation, and how to achieve the optimum combination between them. After that the researches focus on the effect of imperfection and settlement effects for tanks with roofs. The relation between top stiffening ring on open top tank and differential settlement still un-investigated enough, even Gong et al. [18] research didn't involve in this subject and it focuses on the imperfection effect for open top tanks.

As a result, this study will investigate that relation and the effect of wall thickness variation effect on open top tank under harmonic settlement in a simplified method.

2. Finite element model

For that purpose, a set of 4 tanks were modelled as a full 3D model on Sap 2000 package with the following properties: The radius and height of the shell are $R = 15.12$ m, $h = 12.191$ m, respectively. The finite element model was divided into mesh to include 27,300 nodes and 26,845 elements, shell element was defined using the four-node and quadrilateral shell element, and the full model was built and analysed. Full 3D model on Sap 2000 is shown in Fig. 1.

A top stiffening ring was considered with the geometry UPN 100 web 100 * 6 mm, flange 50 * 8.5 mm as shown in Fig. 2.

The wall thickness will vary regarding the required wall thickness. The chosen wall thickness for each tank is shown in Table 1 (see Fig. 3).

The wall thicknesses for tank no. 4 was calculated based on the resulting design equation according to BS 2654 (clause 7.2.2) [30]:

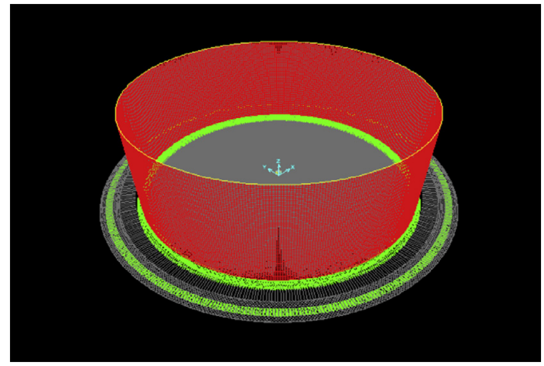

Figure 1 Finite element model of open top tank with top stiffening ring using SAP2000.

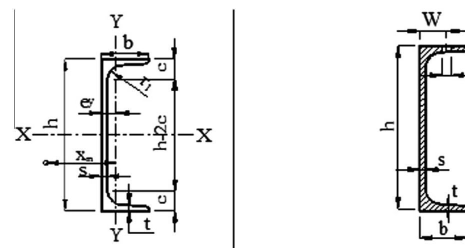

Figure 2 Typical stiffening-ring UPN section for tank top ring.

Table 1 Wall thickness arrangement for models.

	tank no. 1	tank no. 2	tank no. 3	tank no. 4	
h	t mm	t mm	t mm	t mm	T. L
0 - 2 m	8.92	7	45	6	
2 - 4 m	8.92	7	45	6	
4 - 6 m	8.92	7	45	8.5	
6 - 8 m	8.92	13	105	10.5	
8 - 10 m	8.92	13	105	12.5	
10 - 12.191 m	8.92	13	105	15	G. L

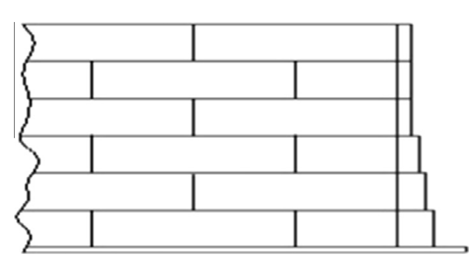

Figure 3 Section in tank wall.

$$t = \frac{D}{20S}(98w(H - 0.3) + p) + c$$

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