Thin-Walled Structures 74 (2014) 59–69

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Experimental investigation on the effect of geometric imperfections on the buckling and post-buckling behavior of steel tanks under hydrostatic pressure

Amin Niloufari [a], Hossein Showkati [b], Mahyar Maali [a,*], Seied Mahdi Fatemi [a]

[a] Department of Civil Engineering, Islamic Azad University, Maragheh Branch, Iran
[b] Department of Civil Engineering, Urmia University, Urmia, Iran

ARTICLE INFO

Article history:
Received 22 October 2012
Received in revised form
30 August 2013
Accepted 5 September 2013
Available online 16 October 2013

Keywords:
Imperfection
Buckling
Test
Welding
Steel tanks

ABSTRACT

Weld-induced geometric imperfections have been reported to have especially detrimental effects on the buckling resistance of shells under hydrostatic pressure. The effect of circumferential imperfections caused by continuous welding on the joined areas between the curved panel edges of the cylindrical and conical shells of steel storage tanks with fixed conical roofs is the most important case in this context. The present paper discusses 12 laboratory specimens in three groups, labeled SP200 (S=Specimen, P=Perfect, 200=height (mm) and radius of Cylinder), SP250 (S=Specimen, P=Perfect, 250=height (mm) and radius of Cylinder) and SP300 (S=Specimen, P=Perfect, 300=height (mm) and radius of Cylinder) loaded under uniform hydrostatic pressure. The samples were modified to include circumferential imperfections at the junctions between the curved edges of the panels of the cylindrical and conical shells, with amplitudes of 2*t*, 4*t* and 8*t* in depth (where *t* is the thickness of the conical or cylindrical shell). The results of testing under different codes are compared. This study shows that geometrical imperfections at different ratios of t/R (where *R* the radius of the tanks) may have decreasing, neutral or increasing effects on buckling resistance and can result in softening or stiffening behaviors of the shells.

1. Introduction

Currently, thin-walled shell structures are widely applied. The reason for this growing trend is the lightweight and high-strength characteristics of such shells. Geometric imperfections are inherent in thin-walled structures and occur during construction and assembly. Because buckling capacity can differ due to the slightest imperfection, defect investigation becomes extremely important. Buckling is a crucial failure phenomenon for tanks. In recent years, the buckling of conical shells under varying loads, including hydrostatic loading, has drawn a great deal of attention, especially in tanks for liquids. However, it is important to mention that the literature devoted to the analysis of geometrically imperfect tanks shells is lacking. In 1995, H. Showkati and P. Ansourian [1] investigated the influence of primary boundary conditions on the buckling of shallow cylindrical shells under uniform external pressure. In 2008, G. Forasassi et al. [2] considered the ratio of diameter to thickness in investigating the effects of imperfections in eccentricity, ovality and welding; they concluded that imperfections caused by welding have the greatest effects on the buckling of cylindrical shells. In 2008, Golzan and Showkati [3] studied the buckling behavior of thin-walled conical shells under uniform external pressure and showed that construction-induced imperfections have a significant effect on the buckling strength of conical structures. In 2012, Maali et al. [4] studied the buckling behavior of conical shells with weld-induced imperfections and showed that weld-induced imperfections have a stiffening effect on the buckling strength of conical structures. Donnell [1] calculated the buckling load for a cylindrical shell and obtained a theoretical load on the cylindrical shell under hydrostatic pressure. Jawad [5] calculated the buckling load for a conical shell by analyzing the cylindrical shell and obtaining a theoretical load on the conical shell under hydrostatic pressure. However, these authors ignored the manufacturing processes. Additionally, Euro Code 3, ECCS and DINI18800 [6–8] all contain set limitations for rolling- and welding-induced imperfections.

Generally speaking, most of these experiments are conducted on manufactured specimens. The present study investigated 4 specimens, labeled SP200 (S=Specimen, P=Perfect, 200=height and radius of Cylinder), SP250 (S=Specimen, P=Perfect, 250=height and radius of Cylinder) and SP300 (S=Specimen,

* Corresponding author. Tel.: +98 9143227636; fax: +98 4127224870.
E-mail addresses: h.showkati@mail.urmia.ac.ir (H. Showkati), Mahyar.Maali@gmail.com, mahyar.maali@yahoo.com (M. Maali), Mahdi.fatemi@gmail.com (S. Mahdi Fatemi).

0263-8231/$ - see front matter
http://dx.doi.org/10.1016/j.tws.2013.09.005

Nomenclature

R	radius of specimens
H	height of cylinder
H	height of conical roof
δ_0	imperfection's initial depth
s	length of imperfection's curvature
n	number of half-wave imperfections
δ_{max}	imperfection's maximum depth
P_{cr}	critical buckling pressure
E	Young's modulus
t	thickness of specimens
α	semi-vertex angle of the cone

P=Perfect, 300=height and radius of Cylinder) under uniform hydrostatic pressure. Each group contained one perfect specimen, with the remaining specimens having circumferential imperfections with amplitudes of 2t, 4t or 8t (where t is the thickness of the tank shell) induced by continuous welding on the curved junction at the edge of the cylindrical and conical shells of steel storage tanks with fixed cones.

The shell material consisted of mild steel with a yield stress of 194.238 MPa. All specimens were considered to be simply supported, such that a radial constraint at the edge of the cone was the only boundary condition. Hydrostatic pressure loading was applied by a gauged vacuum pump, which applied suction to the shell. The results of the initial and overall buckling and collapse pressures were compared to the results reported in previous papers and in international codes. The imperfect specimens were also compared to the perfect specimen in each group. All of the tests were conducted by the authors in the structural lab of Urmia University, Urmia, Iran.

2. Testing process

2.1. Test specimens and properties

The number and geometric dimensions of the specimens were selected based on the available laboratory facilities and the experimental goals. Primarily, the laboratory equipment and fabrication processes limited the model geometry; one such important parameter was the vacuum pump capacity. Although the nominal available vacuum pump capacity was 100 kPa, the practical capacity was 70 kPa at most. Another significant factor was the size of the testing system. In the present study, the system could accommodate a sample up to 600 mm in diameter. Second, the thickness-to-radius ratios (t/R) and imperfection amplitudes of the models were kept within realistic boundaries. Typical values for the R/t ratio are in the range of 300–1000 [3].

In this study, a total of twelve shell specimens were manufactured and tested. In the majority of these specimens, a specific-amplitude geometric imperfection was created. Among these twelve models, three specimens, labeled SP200, SP250 and SP300, did not contain any imperfections and were assumed to be reference models. All specimens were tested with three different t/R ratios.

Welding two plates causes their edges to warp. One of the most important parts of these tanks is the joint between the conical roof and the cylindrical wall because of the high possibility of warping and the great influence of the junction on the buckling and post-buckling capacity. Because of this issue, the imperfections in the joint between the roof and the body are believed to take a sinusoidal form. Because the two imperfection types (dimples and lumps) cannot possibly occur simultaneously in the joints, dimples are created, and lumps are considered to occur in perfect edges. The number of half-wave imperfections, n, is found continuously around the joint. In all three groups, there was an attempt to keep the maximum depth of the imperfections consistent (δ_{max}). These depths are coefficients of thickness, and they are labeled 2t, 4t and 8t. The thickness of the specimens was 0.6 mm, and the height to radius ratio was 1($H/R=1$) for the cylindrical part and 0.25($h/R=0.25$) for the conical roof. The details of the specimens are presented in Table 1.

The specimen names have the form (AtB), where At is the maximum depth of the imperfection (δ_{max}), t is the thickness of the shell, and B is the radius of the cylindrical shell.

Three tensile coupon tests were performed to obtain the properties of the shell material. The average yield and failure stresses of the steel were found to be 194.238 MPa and 325.495 MPa, respectively. The Young's modulus and Poisson's factor were found to be 200 GPa and 0.28, respectively.

2.2. Manufacturing process

An important factor in shell experiments is the specimen fabrication quality, including both the choice of material and the welding method. Several fabrication techniques have been developed for conical shells [9–10]. One of the methods is soldering the seams, which results in improvements in both manufacturing and testing processes and allows for accurate predictions of weld performance. The present study uses this method.

Table 1
Aspect ratios and initial geometries of the specimens.

Specimen label	Imperfection δ_{max}	Half-wave imperfections (n)	Thickness (t) (mm)	Radius (R) (mm)	Height cylinder (mm)	Height cone (mm)	t/R
SP200	Perfect	0	0.6	200	200	50	0.003
S2t200	2.08t	20	0.6	200	200	50	0.003
S4t200	4.27t	14	0.6	200	200	50	0.003
S8t200	8.45t	10	0.6	200	200	50	0.003
SP250	Perfect	0	0.6	250	250	62.5	0.0024
S2t250	2.15t	22	0.6	250	250	62.5	0.0024
S4t250	4.08t	16	0.6	250	250	62.5	0.0024
S8t250	7.29t	12	0.6	250	250	62.5	0.0024
SP300	Perfect	0	0.6	300	300	75	0.002
S2t300	2.16t	24	0.6	300	300	75	0.002
S4t300	3.87t	18	0.6	300	300	75	0.002
S8t300	8.76t	12	0.6	300	300	75	0.002