Journal of Building Engineering 20 (2018) 424–441

Contents lists available at ScienceDirect

Journal of Building Engineering

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

The effect of longitudinal imperfections on thin-walled conical shells

Mahyar Maali[a], Abdulkadir Cüneyt Aydın[a,*], Hossein Showkati[b], Merve Sağıroğlu[c], Mahmut Kılıç[a]

[a] Ataturk University, Engineering Faculty, Civil Engineering Department, 25030 Erzurum, Turkey
[b] Department of Civil Engineering, Urmia University, Urmia, Iran
[c] Erzurum Technical University, Engineering Faculty, Civil Engineering Department, Erzurum, Turkey

ARTICLE INFO

Keywords:
Buckling
Post-buckling
Longitudinal imperfection
Non-linear analysis
Imperfection

ABSTRACT

The load carrying capacity as well as the buckling and post-buckling behavior of conical thin-walled shells exposed to pressure loads are very sensitive to imperfections in the initial geometry. In this study, comprehensive work on the overall longitudinal imperfections created by welding and their effects on external pressure load carrying capacity has been performed by using finite-element models. The models were modified to include either one or two-line imperfection with amplitudes of six different magnitudes. The results presented here have confirmed some of the existing theories and provided new information concerning buckling of thin-walled conical shells. The load carrying capacity from buckling analysis was double the result from the Jawad theory for perfect models (without imperfection). In this research, increasing the cone height increased the imperfections' weakening effect. In nonlinear analyses, the presence of an imperfection increased the buckling load capacity. However, increasing the number of imperfections resulted in less buckling load capacity than the model with one imperfection.

1. Introduction

The conical shells are commonly built from rolled steel plates, joined together by circumferential welds. At each circumferential joint, welding results stress intensity sections like stiffeners. Furthermore, the stiffened conical shells might be prone to different modes of instability. The buckling behavior of conical shells has generally received less attention in the literature [36,39]. The importance of using conical shells has long been known to engineers and designers in various engineering branches. These structures are used in aircraft, spacecraft, nuclear reactors, offshore platforms, oil and gas tanks, chimneys, silos and tanks, cooling towers, bodies of ships and submarines and planes, arc dams, composite high-rise buildings, and missiles. Conical shells structures are widely used in shell form. The longitudinal imperfections are invariably caused by an assortment of manufacturing processes like rolling and welding in the conical shell structures. These processes affect the buckling in the thin walled structures. Longitudinal imperfections may occur in the thin-walled structures, made of rolling plates jointed by welding. Buckling is one of the main collapse mechanisms of thin-walled conical shells. In recent years, the buckling capacity of thin-walled shell structures under varying loads, including external pressure, has drawn substantial attention, especially in the marine, cooling towers, arc dams, composite high-rise buildings, missiles and offshore industries. The buckling of a general conical shell depends on the geometric and material properties of the shell, the type of applied load and any initial geometry of the shell. Rolling and construction have a significant effect on conical shells. The buckling capacity of the shell depends greatly on the following two geometric ratios: slat-length to the radius (L/R) and radius to thickness (R/t) [12].

There are a few researches about the longitudinal imperfections created by welding processes. Golzan and Showkati [18] studied the buckling behavior of the thin walled conical shells under uniform external pressure and showed that construction-induced impacts have a significant effect on the buckling strength of conical structures. Maali et al. [31,26,29] studied the buckling behavior of conical shells with weld-induced imperfections and showed that weld-induced imperfections have stiffening effect on the buckling strength of conical structures. Fatemi et al. [12] conducted experiments on imperfect cylindrical shells under uniform external pressure and showed that weld-induced geometric imperfection has especially detrimental effects on buckling. Jawad [23] calculated the buckling load (peak load) for conical shells by analysing cylindrical shells and obtaining a theoretical load on conical shells under hydrostatic conditions. Eurocode [8,10]) and DINI 18800 [7] have all set limitation for rolling, and welding induced

* Corresponding author.
E-mail address: acaydin@atauni.edu.tr (A.C. Aydın).

https://doi.org/10.1016/j.jobe.2018.08.005
Received 17 April 2018; Received in revised form 9 August 2018; Accepted 10 August 2018
Available online 16 August 2018

Notation

t	the thickness of the cone
t_e	the effective thickness of cone: t cos α
L_e	the effective length of cone: L/2(1 + r/R)
R	the lower radius of the cone
E	Young's modulus
r	the middle surface of the conical shell
l_{mx}, l_r, l_g	the longitudinal imperfection created circumferentially
t_v	the initial depth of imperfections
P_{cr}	the buckling load from Jawad Theory
P_{FEA}	the buckling load from finite element analysis

imperfections. Elishakoff [9] and Ikeda and Murota [21] tried to predict initial imperfections that would maximally reduce the load-bearing capacity. Croll [5] and Croll and Chilver [6] proposed simple approaches to evaluate the sensitivity of buckling loads to imperfections and estimated the lower bounds of buckling loads for cylindrical panels and shells and hyperboloid shells. The lower bounds for the buckling stress turned out to be half the classical critical stresses. These solutions can be improved by taking the post critical membrane stiffness in tension into account. Gavrilenko and Croll [13] studied the reduced-stiffness method in theory of shells, and they described the reduced-stiffness (lower-bound) method as applied to smooth, stringer-reinforced, and ring-reinforced shells. The lower-bound method allows us to estimate critical loads, for the moment, fewer shells using the standard classical formulation of stability problems and, at the same time, to estimate the buckling loads for imperfect cylindrical shells. An analytical proof has been given to Croll's hypothesis that the lower bound for the buckling loads of cylindrical shells can be used as a criterion for estimating the load-bearing capacity of imperfect cylindrical shells with axisymmetric dents of limited amplitude (1999). Pircher et al [33] studied the shape of circumferential weld-induced imperfections in thin–walled steel silos and tanks and introduced several shapes of circumferential imperfections, which occur in real conditions. The longitudinal imperfections are modelled as the circumferential imperfections in Pircher's work [33]. In 2014, Niloufari et al. [32] conducted experiments on imperfect steel tanks under hydrostatic pressure and showed weld-induced geometric imperfections have especially detrimental effects on buckling and post buckling. An investigation has been conducted on the buckling of steel cylindrical shells with a single local imperfection. It was found that even a single imperfection strongly influences the magnitude of the critical load [14,15]. A wide range of references can be found in the literature in regard to the buckling and failure response of thin walled shell structures with normal fabrication-related imperfections under type of the applied load [19,16,17]. Fan and Zhou ([11,44]) conducted an analytical study on the buckling of cylindrical shells subjected to uniform external pressure. a systematic numerical investigation into the non-linear elastic behavior of conical shells, with various types of initial imperfections, subject to a uniformly distributed axial compression [38].

The present study considers 39 conical shells in three groups with bottom radius R, uniform wall thickness t; height of the shell is given by h, the semi–vertex angle (α) and L is the slant length of conical shells. All models contained one perfect model with the remaining models with imperfections with amplitudes of t. Average yield and failure stresses were obtained at 194.2 MPa and 325.5 MPa, respectively. Young's modulus was calculated at 200 GPa and Poisson's ratio was obtained at 0.28 [12]. All models were considered simply supported.

2. Materials and methods

2.1. Geometry of the cone

Previous research on thin–walled conical shells, and also international codes have all set limitation for the rolling and welding induced imperfection ([10,8,7]). The model, which is chosen with a different radius-to-thickness ratio (R/t) within the range of 300–1000 [12], is presented in Fig. 1. Where α is the semi-vertex angle; t is the thickness, L is the height, r is the upper, and R is the lower radius of the cone.

The R/t and longitudinal imperfections are considered as constant and 0.5 t, 1 t, 1.5 t, 2 t, 2.5 t and 3 t, respectively throughout this work. The models were analyzed not only for different longitudinal overall imperfection but also for the height of the conical shells. The buckling and post buckling behavior of 39 models were analyzed. Each group contains one perfect model (without imperfection line), with the remaining models having imperfections with amplitudes of 0.5 t, 1 t, 1.5 t, 2 t, 2.5 t and 3 t (t is thickness of conical shell).

The details of the models are presented in Table 1. The models are titled according to their properties. For example, the CCh (A-Bt) can be explained as follows: The first C means conical; the second C is the name of caps; h is the height of the cone; A is the number of imperfection lines within a 180 degree distance; Bt is the depth of the imperfection; t is the thickness of the conical shell; and P is perfect model, which do not have imperfections (perfect model = without imperfection line).

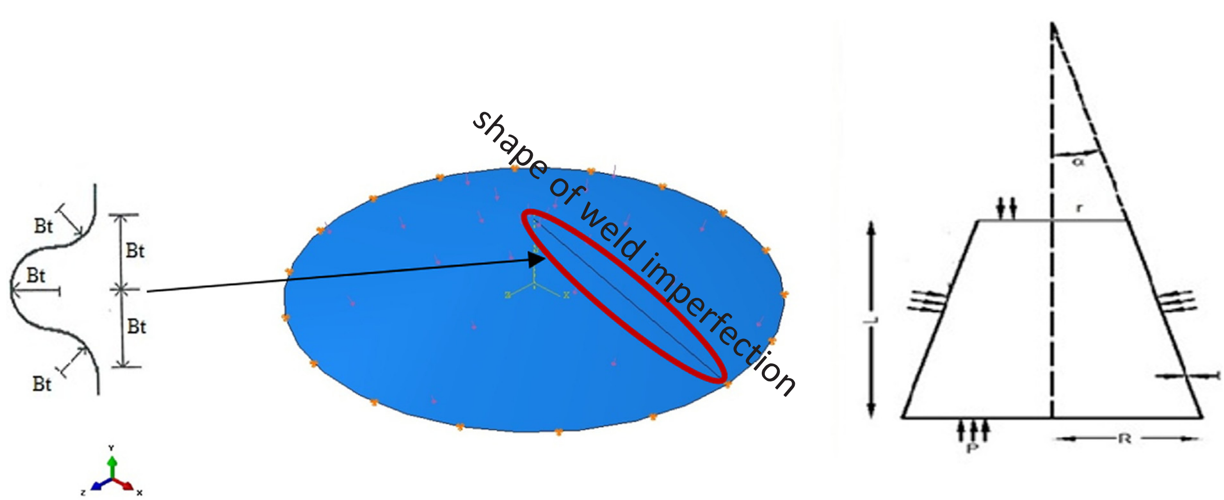

Fig. 1. Shape of the model and parametric considerations.