CRITICAL BUCKLING STRESS OF CASTELLATED WEB PLATES UNDER LINEARLY VARYING UNIAXIAL COMPRESSION

By

Ahmed Nabawe Hamed Ghareeb

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Structural Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

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Key Words:
Castellated steel webs, Elastic buckling, Inelastic buckling.

Summary:

The aim of this study is to investigate the effect of different parameters on both elastic and inelastic critical buckling stresses of castellated web plates. These parameters are: plate aspect ratio, perforations shape (circular or rectangular), edge distance to first perforation, perforation spacing, perforation dimensions, plate slenderness ratio and initial web imperfection. Structural models have been established based on the finite element method, where linear and nonlinear finite element analyses (FEA) have been performed using ANSYS software. The interaction between the web plate and the flanges has been approximately modeled as simply supported edges for the web plate. The web plates have been subjected to linearly varying in plane uniaxial compression with different load cases ranging between uniform compression and pure bending. The FEA results have been verified against those of experimental and numerical results in the literature. Hence, critical slenderness ratio has been indicated as a boundary between elastic and inelastic behavior of castellated web plates. Moreover, the variation of both elastic and inelastic critical buckling stresses versus different parameters and material prosperities has been reported.

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Abstract

The usage of castellated beams in construction has been spreading all over the world. The castellated beams are used to obtain high stiffness and bending strength using the same weight of steel by increasing the section height. In addition, the castellated beam openings may be used as paths for different mechanical fixtures such as utility ducts, pipes, etc. Due to the wide variety of openings size, location and configuration, and the geometrical parameters of web plate it is important to assess the local stability of web plates in both elastic and inelastic ranges of deformation. The aim of this study is to investigate the effect of different parameters on both elastic and inelastic critical buckling stresses of castellated web plates. These parameters are: plate aspect ratio, perforations shape (circular or rectangular), edge distance to first perforation, perforation spacing, perforation dimensions, plate slenderness ratio and initial web imperfection. A parametric study has been performed to study the effect of different parameters on the elastic and inelastic critical buckling stresses of castellated web plates. Two shapes of openings have been investigated: circular and rectangular. Linear and nonlinear finite element models have been established using general purpose finite element software (ANSYS), where the finite element results have been verified against both experimental and analytical results in the literature. The web plates are subjected to in-plane linearly varying compression in different combinations ranging between uniform compression and pure bending. The interaction between web plate and flanges has been approximated by modeling the web plate to have simply supported edges.

The study has been presented in two parts: elastic and inelastic studies. In the elastic analysis, linear models have been established to study the effect of plate aspect ratio, opening shape, dimensions, edge distance and spacing on the buckling stress modification factor (β-factor) which is defined as the ratio of buckling stress of castellated web plate to buckling stress of corresponding solid web plate. The variation of β-factor with the different parameters has been reported, and the effect of each parameter on plate behavior has been discussed. In the inelastic analysis, nonlinear models have been established taking into account both material and geometric nonlinearities. The effect of the aforementioned parameters along with the plate slenderness ratio has been investigated. Both the elastic and inelastic results have been compared to determine the critical slenderness ratio separating between yielding and buckling modes for two grades of steel: DIN 17100 steel 37-2 and steel 52-3. In addition, the effect of web openings and imperfections on the post-buckling behavior has been studied for plates with different slenderness ratios.

The main conclusions can be summarized as following: (1) both elastic and inelastic buckling stresses are independent on plate aspect ratio; (2) buckling occurs at possible three locations: (a) the plate edge strip, (b) the plate post between openings, or (c) the plate strip above/below the opening, based on the distribution of the induced stresses; (3) plates subjected to compression are more sensitive to change in parameters compared with those subjected to compression and tension; (4) plates with circular and rectangular openings have the same patterns of behavior versus parameters of study; (5) the minimum value of elastic buckling stress modification factor (β-factor) is 90% for plates subjected to compression and 70% for those subjected to compression and tension; (6) the elastic buckling stress is independent on edge distance and opening spacing for widely spaced openings and large edge distance; (7) the inelastic buckling is dependent on opening size only if small values of edge distance is avoided; (8) the critical slenderness ratio increases with increasing opening size; (9) increasing the opening size reduces the post-buckling resistance; and (10) the initial imperfection reduces both elastic and post-buckling resistance.

Chapter 1 : Introduction

1.1. General

The usage of castellated beams and columns in construction has been spreading all over the world, Castellated beams are used to obtain high stiffness and bending strength using the same weight of steel by increasing section height, perforations may also be used as paths for different fixtures such as air conditioning, pipes, etc. Castellated members are mainly produced from standard I-shaped member by cutting it in a zigzag pattern along the longitudinal axis of the member, then the two halves are separated, staggered and welded together to form a castellated member with larger height and in result larger stiffness and bending strength. That is why castellated members are used in long columns and large span beams.

The structural performance of the castellated members is different from the members with solid webs. Applying perforation to webs has effect on local buckling, lateral torsional buckling, and shear strength of webs. Therefore, some design codes give limitations on the dimensions and locations of web perforation in order not to affect the beam behavior dramatically. In addition, the research works take place to improve what is already understood about the effect of perforations with different shapes and locations on the structural behavior of the member, investigate different web parameters, and provide equations to assist in designing castellated members. One of the most important characterizations is the local buckling and ultimate strength of webs which are the most affected portion of the beam by applying perforations. Therefore, the research of the castellated web behavior is considered important at this point.

This chapter presents the scope of the thesis and its objectives. In addition, it shows the organization of the implemented work.

1.2. Problem statement

Due to the wide variety of opening size and configuration and the different geometrical parameters of web plate, it is important to provide a practical procedure of design to assess the local stability of web plates whoso stability is affected by the application of perforations in both elastic and inelastic regions. The design codes and research work recently focused on the castellated members behavior because of the previously mentioned advantages of using it. However, the research work on the local buckling behavior of castellated beams in both elastic and inelastic zones is limited and code standards for the castellated members are very rare. In addition, the investigation of the local buckling behavior of castellated webs needs more work to establish complete data base of the effect of different parameters on elastic and inelastic buckling of castellated web plates, and to help encourage more structural engineers to use Castellated members in their design. Therefore, the current research aims to investigate the local buckling behavior of castellated webs in both elastic and inelastic range.

1.3. Objective of the research

The objective of this study is to investigate the local buckling behavior of castellated web plates with different perforation configuration, size, spacing and edge distance in both elastic and inelastic range. The thesis objectives can be summarized as follow:

- Investigate the effect of different geometrical parameters of web plate and perforations on the elastic buckling load of castellated webs and different load combinations.
- Provide sets of graphs showing the variation of the elastic buckling stress modification factor with the different parameters.
- Indicate the critical slenderness ratio as a boundary between elastic and inelastic behavior of castellated webs.
- Investigate the effect of different parameters on inelastic buckling stress of castellated webs for different grades of steel.
- Investigate the effect of perforations on the post buckling strengthening of castellated webs.
- Investigate the effect of initial web imperfection on the elastic buckling stress and post buckling strengthening and discuss the different code limitations.

1.4. Scope of the research

To achieve the thesis objectives that were previously mentioned, a research plan has been stated. This research plan includes investigation of the local buckling behavior of castellated web plates numerically.

The numerical investigation are performed using linear and non-linear two-dimensional numerical models using the general purpose finite element software ANSYS 11.0. The main goal of the numerical models is to simulate the castellated web plate and to perform the parametric study that is stated to cover wide range of parameters. The different parameters used in this study are shown as the following:

- The web plate dimensions.
- The perforation shape.
- The perforations spacing and edge distance.
- Web initial imperfection.

These models are loaded with five different combinations of linearly varying uniaxial compression ranging between uniform compression and pure bending.

1.5. Organization of the thesis

This thesis focuses on the local buckling behavior of castellated web plates under linearly varying uniaxial compression. The procedures' program consists of analytical investigation. The analytical work was performed based on parametric study, to cover a wide range of parameters, using general purpose finite element software ANSYS. The numerical analysis results were verified against both experimental and analytical research work results mentioned in literature review. The thesis includes the following: