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Thick plate bending analysis using a single variable simple plate theory

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Abstract

A third order single variable simple plate theory has been used for the bending deflection analysis of thick plates with simply supported edges. The plate theory used herein contains third order terms in the displacement field. The displacement field of the theory utilizes only one unknown displacement variable for the complete formulation of thick plates. All the necessary equations connected with this plate theory can be expressed in terms of a single unknown displacement variable. The governing

equation, bending moment, shear force and boundary condition equations of the theory have close similarity to those of Classical Plate Theory equations. The mathematical effort needed in formulation of plates using this theory is slightly more in comparison with Classical Plate Theory. To demonstrate the usefulness of the plate theory used herein bending deflection analysis of thick plates with simply supported edges is carried out. Bending deflection results predicted using the present theory are compared with deflection results of other first order and higher order thick plate theories. Bending deflection results predicted by thick plate theory used herein are observed to be accurate.

Introduction

Research on bending deflection of thin and thick plates is one of the important areas of investigation in the domain of structural engineering. The bending deflection study of thin and thick plates has been discussed in literature in a comprehensive manner by using different class of plate theories. The important classical and shear deformation theories used commonly for the analysis of thin and thick plates are: Classical Plate Theory (involves one variable) (CPT) [1], [2], Mindlin's first order plate theory (involves three variables) [3], Reddy's higher order plate theory (involves three variables) [4], [5] and Refined plate theory (involves two variables) (RPT) [6].

Classical plate theory (CPT) [1], [2] is the basic and oldest theory in the literature of plate theories. CPT equations do not include the shear deflection component in the formulation. This drawback restricts the use of CPT only for the investigation of thin plates. The use of CPT for the bending deflection analysis of thick plates will result in the underestimated deflections. Also, the CPT yields the overestimated values for frequencies and buckling loads in case of thick plates. The inaccuracies in the predicted results would increase as the plate thickness increases. This drawback of CPT demands for the use of refined or higher order plate theories for the investigation of thick plates. A detailed study on plate bending based on CPT could be found in a textbook by Timoshenko and Woinowsky-Krieger [1].

In the class of thick or shear deformation theories, the plate theory proposed by Mindlin is one of the oldest theories developed. Mindlin's theory is a displacement based first order plate theory [3]. The study of thick plates using Mindlin's theory linked with three displacement variables and the plate formulation requires three governing differential equations. In comparison to CPT results, Mindlin's theory can give considerably accurate results in case of thick or shear deformable plates [7]. The formulation of the theory involves a shear coefficient or shear correction factor. Shear coefficient is necessary to add correction to the values of transverse shear stresses evaluated by Mindlin's theory. Because, Mindlin's theory yields the constant transverse shear stress across the plate thickness instead of actual parabolic shear stress distribution. This is a common drawback involved in case of first order beam and plate theory formulation. Many research papers are available in the beam and plate theory literature providing discussion on the use of shear coefficients. The important papers focused on the bending deflection study of thick plates using Mindlin's theory are: Wang and Alwis [8], Wang et. al [9], Wang et. al [10] and Lee et. al [11].

In the class of higher order plate theories, Reddy's theory is one of the most popular plate theories. Reddy's theory is a displacement based third order plate theory [4], [5]. Reddy's theory is governed by five coupled differential equations and involves five unknown displacement variables. Being a higher order theory, this theory does not involve a shear coefficient or shear correction factor in the plate formulation. The transverse shear stress distribution is parabolic across the plate thickness. Hence, the condition of shear free stress condition is automatically satisfied. Some of the important papers available based on Reddy's plate theory are: Reddy and Phan [12], Reddy and Wang [13], Shufrin and Eisenberger [14] and Hashemi et. al [15].

Refined plate theory (RPT) [6] is a displacement based two variable higher order plate theory. Due to the involvement of only two variables, the plate analysis using RPT is considerably simplified compared to other higher order theories. The formulation of the theory splits the lateral deflection into two components; bending component and shear component. RPT formulation leads to two coupled governing differential equations for vibration study. These equations are decoupled in case of static problems. The theory has strong similarity to CPT expressions. The moment and shear force expressions of RPT have strong resemblance to the CPT expressions. The bending deflection study of thick plates based on RPT are reported in the publications by Thai and Choi [16], Thai and Kim [17], [18]. Other important works based on RPT are also available in the publications by Shimpi et al [19], [20].

Objective of this paper is to study the bending deflection analysis of thick shear deformable plates by using a third order Single Variable Simple Plate Theory (SVSPT) published in a paper by Shimpi et al. [21]. SVSPT used herein for the investigation of thick plates is developed based upon the formulation of RPT [6] [19], [20]. SVSPT incorporates a single displacement variable for the complete formulation of plates. Lateral deflection of the plate is the unknown displacement variable involved in the plate formulation. The displacement field and the expressions for strains, stresses are all can be expressed in terms of a single variable. The governing equation is a fourth order differential equation incorporating a single unknown function. Also, governing equation has close resemblance to that of CPT. Hence, the plate analysis using the theory used herein will be almost in the similar lines of that of CPT. The efforts involved in solving the plate problems using SVSPT is slightly more compared to that of CPT.

In this paper, the usefulness of SVSPT is showcased by carrying out the bending deflection study of thick plates. The plates with simply supported edge conditions are considered for the discussion. Bending deflections calculated by SVSPT are compared with the deflections predicted by CPT and other thick plate shear deformation theories for the validation purpose. Deflection results are presented in a tabular form for the easy comparison and observation.

Section snippets

Plate formulation: Single variable simple plate theory (SVSPT)

Displacement, bending moment and shear force expressions of SVSPT will be presented now in this section. Also, the boundary conditions and governing equation pertaining to SVSPT will also be discussed. The more details about single variable simple plate theory is available in a publication on SVSPT by Shimpi et al. [21]….

Simply supported rectangular Plate: Expressions for bending deflection using SVSPT

In this section, the steps involved in deriving the bending deflection expression using SVSPT will be discussed now. The geometry of a rectangular plate under consideration is as shown in Fig. 1.

For the static bending deflection analysis of plates, the governing Eq. (12) of SVSPT can also be written as follows: $\frac{\partial^4 w_b}{\partial x^4} + 2\frac{\partial^4 w_b}{\partial x^2 \partial y^2} + \frac{\partial^4 w_b}{\partial y^4} = \frac{q(x,y)}{D}$

Levy's method of solution [1], [2] can be utilized when we have a plate with two opposite edges are simply supported and other two remaining edges have…

Bending deflection results and discussions

For the comparison of plate bending deflections calculated by SVSPT, Table 1 also present the bending deflections predicted by using the CPT and other first order and higher order thick plate theories.

Discussions on bending deflection results

In connection with the non-dimensional bending deflection parameter ($\hat{\omega}$) presented in Table 1, the following observations can be noted:

- Non-dimensional bending deflection ($\hat{\omega}$) predicted by SVSPT for the case of simply supported rectangular plates are…

…

Conclusion

In this paper, the SVSPT could be used successfully and in a simplistic manner for the investigation of thick plates with simply supported edge conditions. The plate analysis using SVSPT is simpler as the formulation leads to only one governing differential equation. Also, as the governing equation of SVSPT is closely similar to that of CPT, the plate analysis can be carried out in the similar lines of CPT. In case of SVSPT, all the expressions associated with plates can be expressed in terms…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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