The 2018 Structures Congress (Structures18)
Songdo Convensia, Incheon, Korea, August 27 - 31, 2018

Theoretical equivalence and numerical performance of T3γ_s and MITC3 plate elements

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(Received keep as blank , Revised keep as blank , Accepted keep as blank)

Abstract. This paper will compare T3γ_s and MITC3 elements, both of which are three-node triangular plate bending elements with three degrees of freedom per node. The popular T3γ_s and MITC3 elements have simple formulation and have already been used in general. This paper will prove that shear strain formulations of these two elements are identical even though they are obtained from two different methods. Single element is used to test the formulation of shear strain matrices. Numerical tests for circular plate cases compared with the exact solutions and DKMT element will complete this review to verify the performances and show the convergence of these two elements.

Keywords: plate bending element; T3γ_s; MITC3; Reissner-Mindlin plate theory; assumed natural strength

1. Introduction

The challenge of finite element is how to generate a simple and applicable element formulation to reduce the computational cost, yet still has high accuracy and good convergence. In structural modelling, the use of triangular element is interesting due to its simplicity and flexibility. Three node triangular element is mostly used for complex configuration. However, research on triangular is not as much as quadrilateral element. In finite element analysis, many researches show that quadrilateral element has good performance. As a result, many analysts prefer to use the quadrilateral element (Katili *et.al*. (2014, 2015, 2018)), Mahjudin *et.al* (2016) and Maknun *et.al*. (2016), Wong *et.al* (2017), Ko *et.al* (2017) and Banh & Lee (2018). This condition should encourage researchers to develop study about triangular element.

Formulation of plate element based on Reissner-Mindlin theory with C^0continuity results in shear locking phenomenon, which is responsible for elements giving poor results in thin plate problems. To deal with this phenomenon, reduced and selective integration have been used. This integration can improve the performance of elements, yet the shear locking still becomes a problem. Assumed Natural Strain (ANS) proposed by Hughes and Tezduyar (1981) and MacNeal (1982) have been better alternatives to overcome the problem of shear locking.

One of the simplest and effective ANS formulation for three-node triangular bending plate element with three degrees of freedom (dof) per node and Transverse Shear (TS) effects included was proposed by Hughes and Taylor (1982). This element, called in this paper as T3γ_s, has a constant TS on sides of the element and uses the shear projection method to obtain TS on nodes. It was claimed as the simplest and the most effective triangular plate bending element at that time.

DKT (Discrete Kirchhoff Triangular) element, proposed by Batoz, Bathe and Ho in 1980, was developed based on the Reissner-Mindlin theory but using discrete Kirchhoff constraints on edges to neglect Transverse Shear (TS) energy. This element passes patch test and gives good performance

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*Note: Copied from the manuscript submitted to "Structures Engineering and Mechanics, An International Journal" for the purpose of presentation at ACEM18/Structures18.

but only valid for thin plate cases, which is in line with Kirchhoff theory.

Combining several aspects from the formulation of DKT and T3γ_s, Katili (1993) proposed DKMT (Discrete Kirchoff Mindlin Triangular) element using simplified equilibrium equation for assumed constant transverse shear strains along element sides. DKMT is valid for thin to thick plates, has good convergence properties and fully satisfies patch tests. DKMT element is free of shear locking by element constructions as DKMT converge to DKT for thin plates.

MITC3, triangular shell element proposed by Lee and Bathe (2004), is one of popular triangular elements. There have been quite a lot of studies and developments of MITC3 (Lee *et.al*. 2007) and (Lee *et.al*. 2012). This 3-node triangular element has a simple and general formulation. Behaviour of the element is isotropic, which means that stiffness matrix of the element does not depend on the sequence of node numbering. The improvement of MITC3 shell elements called MITC3+ has been proposed by Jeon *et.al* (2015) and Ko *et.al* (2017).

The purpose of this paper is to compare formulation and performance of two triangular elements, T3γ_s and MITC3. The paper is organized as follows. Some aspects of the formulation of T3γ_s are recalled in section 2. In sections 3 and 4, the formulation of DKMT and MITC3 is presented using the same notation as in the formulation of T3γ_s. Sections 5 deals with single element test to compare the formulation of shear strain matrices and numerical tests for circular plate problems to evaluate the convergence of both elements and compare the results with DKMT element. Concluding remarks, acknowledgements and references are given at the end.

2. Formulation of T3γ_s element.

One of the development for the plate bending elements proposed by Hughes and Taylor (1982) for triangular element, called in this paper as T3γ_s element, is generated by assumed natural strain concept. Transversal shear deformation for this element is expressed with special interpolation called shear projection method. Triangular element discussed here has three-degrees of freedom per node (Fig.1).

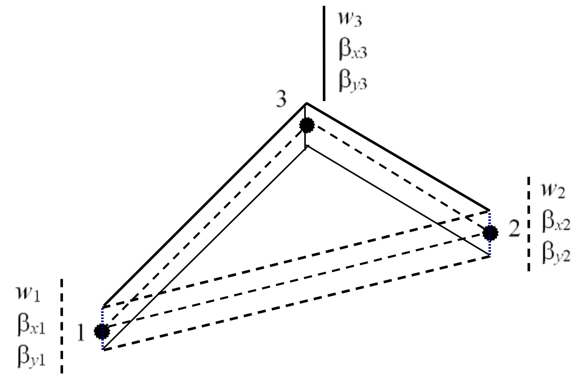

Fig. 1 Triangular element and degrees of freedom

2.1 Bending Strain Matrix

The displacement function is given as: