Wu, C. T.; **Guo, Y.**; **Wang, D.**

A pure bending exact nodal-averaged shear strain method for finite element plate analysis.
(English) Zbl 1298.74241
Comput. Mech. 53, No. 5, 877-892 (2014).

The averaged shear strain method, based on a nodal integration approach, is presented for the finite element analysis of Reissner-Mindlin plates. The mixed interpolation of tensorial components (MITC4 plate element) is used. The shear interpolation method from the MITC4 plate element is combined with an area-weighted averaging technique for the nodal integration of shear energy to relieve shear locking in the thin plate analysis as well as to pass the pure bending patch test. A new nodal-averaged shear strain finite element formulation improves the accuracy of the finite element method. In order to resolve the numerical instability caused by the direct nodal integration the bending strain field is computed by a sub-domain nodal integration approach and a modified curvature smoothing scheme. The resulting nodally integrated smoothed strain formulation is shown to contain only the primitive variables and thus can be easily implemented in the existing displacement-based finite element plate formulation. Several numerical examples are presented to demonstrate the accuracy of the present method.

Reviewer: V. Leontiev (Ul'yanovsk)

MSC:

74S05 Finite element methods applied to problems in solid mechanics
74K20 Plates

Keywords:

finite element method; variational formulation; Reissner-Mindlin plates; thin plates; mixed interpolation; bending strain field; averaged shear strain method; area-weighted averaging technique; nodal integration of shear energy; shear locking

Full Text: DOI

References:

[1] Belytschko, T; Guo, Y; Liu, WK; Xiao, SP, A unified stability analysis of meshless particle methods, Int J Numer Methods Eng, 48, 1359-1400, (2000) · Zbl 0972.74078

[2] Beissel, S; Belytschko, T, Nodal integration of the element-free Galerkin method, Comput Methods Appl Mech Eng, 139, 49-74, (1996) · Zbl 0918.73329

[3] Atluri, AN; Zhu, T, A new meshless local Petrov-Galerkin (MLPG) approach in computational mechanics, Comput Mech, 22, 117-127, (1998) · Zbl 0932.76067

[4] Bonet, J; Kulasegaram, S, Correction and stabilization of smoothed particle hydrodynamics methods with applications in metal forming simulations, Int J Numer Methods Eng, 47, 1189-1214, (2000) · Zbl 0964.76071

[5] Oñate, E; Perazzo, F; Miquel, J, A finite point method for elasticity problems, Comput Struct, 79, 2151-2163, (2001)

[6] Chen, JS; Wu, CT; Yoon, S; You, Y, A stabilized conforming nodal integration for Galerkin meshfree methods, Int J Numer Methods Eng, 50, 435-466, (2001) · Zbl 1011.74081

[7] Chen, JS; Yoon, S; Wu, CT, Nonlinear version of stabilized conforming nodal integration for Galerkin meshfree methods, Int J Numer Methods Eng, 53, 2587-2615, (2002) · Zbl 1098.74732

[8] Chen, JS; Hu, W; Puso, MA; Wu, Y; Zhang, X, Strain smoothing for stabilization and regularization of Galerkin meshfree method, Lect Notes Comput Sci Eng, 57, 57-76, (2006) · Zbl 1114.65131

[9] Chen, JS; Chi, SW; Hu, HY, Recent developments in stabilized Galerkin and collocation meshfree methods, Comput Assist Mech Eng Sci, 18, 3-21, (2011)

[10] Puso, MA; Chen, JS; Zywicz, E; Elmer, W, Meshfree and finite element nodal integration methods, Int J Numer Methods Eng, 74, 416-446, (2007) · Zbl 1159.74456

[11] Liu, GR; Dai, KY; Nguyen-Thoi, T, A smoothed finite element method for mechanics problems, Comput Mech, 39, 859-877, (2007) · Zbl 1169.74047

[12] Liu GR, Nguyen-Thoi T (2010) Smoothed finite element methods. CRC Press, New Jersey

[13] Wu, CT; Park, CK; Chen, JS, A generalized approximation for the meshfree analysis of solids, Int J Numer Methods Eng, 85, 693-722, (2011) · Zbl 1217.74150

[14] Wu, CT; Hu, W, Meshfree-enriched simplex elements with strain smoothing for the finite element analysis of compressible and near-incompressible solids, Comput Methods Appl Mech Eng, 200, 2991-3010, (2011) · Zbl 1230.74201

[15] Wu, CT; Koishi, M, Three-dimensional meshfree-enriched finite element formulation for micromechanical hyperelastic modeling of particulate rubber composites, Int J Numer Methods Eng, 81, 1127-1156, (2012)

[16] Bonet, J; Burton, AJ, A simple average nodal pressure tetrahedral element for incompressible and nearly incompressible dynamic explicit applications, Commun Numer Methods Eng, 14, 437-449, (1998) · Zbl 0906.73060

[17] Andrade Pires, FM; Souza Neto, EA; Cuesta Padilla, JI, An assessment of the average nodal volume formulation for the analysis of nearly incompressible solids under finite strains, Int J Numer Methods Eng, 20, 569-583, (2004) · Zbl 1302.74173

[18] Krysl, P; Kagey, H, Reformulation of nodally integrated continuum elements to attain insensitivity to distortion, Int J Numer Methods Eng, 90, 805-818, (2012) · Zbl 1242.74134

[19] Lamichhane, BP, Inf-sup stable finite element pairs based on dual meshes and bases for nearly incompressible elasticity, IMA J Numer Anal, 29, 404-420, (2009) · Zbl 1160.74046

[20] Babuska, I, The finite element method with Lagrangian multipliers, Numer Math, 20, 179-192, (1973) · Zbl 0258.65108

[21] Arnold, DN; Brezzi, F; Franca, LP, A stable finite element for the Stokes equations, Calcolo, 21, 337-344, (1984) · Zbl 0593.76039

[22] Lamichhane, BP, From the hu-washizu formulation to the average nodal strain formulation, Comput Methods Appl Mech Eng, 198, 3957-3961, (2009) · Zbl 1231.74424

[23] Puso, MA; Solberg, J, A stabilized nodally integrated tetrahedral, Int J Numer Methods Eng, 67, 841-867, (2006) · Zbl 1113.74075

[24] Dinis, LMJS; Natal Jorge, RM; Belinha, J, A natural neighbor meshless method with a 3D shell-like approach in the dynamic analysis of thin 3D structures, Thin-Walled Struct, 40, 185-196, (2011)

[25] Wang, D; Chen, JS, Locking-free stabilized conforming nodal integration for meshfree Reissner-Mindlin plate formulation, Comput Methods Appl Mech Eng, 193, 1065-1083, (2004) · Zbl 1060.74675

[26] Wang D (2006) A stabilized conforming integration procedure for Galerkin meshfree analysis of thin beam and plate. In: Proceeding of the 10th enhancement and promotion of computational methods in engineering and science, Sanya, China, August 21-23

[27] Wang, D; Chen, JS, A Hermite reproducing kernel approximation for thin-plate analysis with sub-domain stabilized conforming integration, Int J Numer Methods Eng, 74, 368-390, (2008) · Zbl 1159.74460

[28] Wang, D; Lin, Z, Free vibration analysis of thin plates using Hermite reproducing kernel Galerkin meshfree method with sub-domain stabilized conforming integration, Comput Mech, 46, 703-719, (2010) · Zbl 1398.74157

[29] Wang, D; Lin, Z, Dispersion and transient analyses of Hermite reproducing kernel Galerkin meshfree method with sub-domain stabilized conforming integration for thin beam and plate structures, Comput Mech, 48, 47-63, (2011) · Zbl 1398.74478

[30] Wang, D; Peng, H, A Hermite reproducing kernel Galerkin meshfree approach for buckling analysis of thin plates, Comput Mech, 51, 1013-1029, (2013) · Zbl 1366.74023

[31] Tanaka, S; Sadamoto, S; Okazawa, S, Nonlinear thin-plate bending analysis using the Hermite reproducing kernel approximation, Int J Comput Methods, 9, 1240012, (2012) · Zbl 1359.74110

[32] Cui, XY; Lin, S; Li, GY, Nodal integration thin plate formulation using linear interpolation and triangular cells, Int J Comput Methods, 8, 813-824, (2011) · Zbl 1245.74040

[33] Suri, M, Analytic and computational assessment of locking in the hp finite element method, Comput Methods Appl Mech Eng, 133, 347-371, (1996) · Zbl 0893.73070

[34] Zienkiewicz, OC; Lefebvre, D, A robust triangular plate bending element of Reissner-Mindlin type, Int J Numer Methods Eng, 26, 1169-1184, (1988) · Zbl 0634.73064

[35] Bathe, KJ; Dvorkin, EN, A four-node plate bending element based on Mindlin/reissener plate theory and a mixed interpolation, Int J Numer Methods Eng, 21, 367-383, (1985) · Zbl 0551.73072

[36] César de Sá, JMA; Natal Jorge, RM; Fontes Valente, RA; Almeida Areias, PM, Development of shear locking-free shell elements using an enhanced assumed strain formulation, Int J Numer Methods Eng, 53, 1721-1750, (2002) · Zbl 1114.74484

[37] Bletzinger, KU; Bischoff, M; Ramm, E, A unified approach for shear-locking free triangular and rectangular shell finite elements, Int J Numer Methods Eng, 75, 321-334, (2000)

[38] Arnold DN, Boffi D, Falk RS (2002) Remarks on quadrilateral Reissner-Mindlin plate elements. In: Mang HA, Rammerstorfer FG, Eberhardsteiner J (eds) Proceedings of the fifth world congress on computational mechanics, Vienna, Austria, July 7-12

[39] Brezzi, F; Fortin, M; Stenberg, R, Error analysis of mixed-interpolated elements for midlin-reissenr plates, Math Models Methods Appl Sci, 1, 125-151, (1991) · Zbl 0751.73053

[40] Lyly, M; Stenberg, R; Vihinen, T, A stable bilinear element for the Reissner-Mindlin plate model, Comput Methods Appl Mech Eng, 110, 343-357, (1993) · Zbl 0846.73065

[41] Kouhia R (2008) On stabilized finite element methods for the Reissner-Mindlin plate model. Int J Numer Methods Eng 74:1314-1328 · Zbl 1159.74429

[42] Nguyen-Xuan H, Rabczuk T, Bordas S, Debongnie JF (2008) A smoothed finite element method for plate analysis. Comput Methods Appl Mech Eng 197:1184-1203 · Zbl 1159.74434

[43] Nguyen-Xuan, H; Tran, LV; Thai, CH; Nguyen-Thoi, T, Analysis of functionally graded plates by an efficient finite element method with node-based strain smoothing, Thin-Walled Struct, 54, 1-18, (2012)

[44] Castellazzi, G; Krysl, P, Displacement-based finite elements with nodal integration for Reissner-Mindlin plates, Int J Numer Methods Eng, 80, 135-162, (2009) · Zbl 1176.74177

[45] Brezzi, F; Bathe, KJ; Fortin, M, Mixed-interpolated elements for Mindlin-reissenr plates, Int J Numer Methods Eng, 28, 1787-1801, (1989) · Zbl 0705.73238

[46] Wu, CT; Wang, HP, An enhanced cell-based smoothed finite element method for the analysis of Reissner-Mindlin plate bending problems involving distorted mesh, Int J Numer Methods Eng, 95, 228-312, (2013) · Zbl 1352.74452

[47] Kim, SH; Choi, CK, Improvement of quadratic finite element for Mindlin plate bending, Int J Numer Methods Eng, 34, 197-208, (1992) · Zbl 0825.73834

[48] Yuan, FG; Miller, RE, A cubic triangular finite element for flat plates with shear, Int J Numer Methods Eng, 28, 109-126, (1989) · Zbl 0675.73040