学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

The Study of Varying Weights in Rational Basis Functions in Isogeometric Large-Displacement Analysis of Beams
(梁のアイソジオメトリック大変位解析における有理基底関数の重み付けに関する研究)

This study presents novel planar curved Euler-Bernoulli and Timoshenko-Ehrenfest beam elements for analyzing beam structures subjected to large displacements but small strains. As the total Lagrangian description is employed, the initial configuration is the reference for the kinematics. By assuming small strains and thin beams, higher-order terms of the Green-Lagrange strains are discarded, leading to the simplification of formulations. The equilibrium is then stated through the principle of virtual works. Subsequently, the proposed elements are derived using the isogeometric analysis approach. Cubic non-uniform rational B-spline (NURBS) representations are employed for the Euler-Bernoulli beam element, while quadratic and cubic NURBS representations are used for the Timoshenko-Ehrenfest beam elements. However, in contrast to the traditional isogeometric analysis concept, the isoparameterization between the reference geometry and kinematic unknowns is relaxed by treating specific weights in the NURBS basis functions as degrees of freedom (DOFs). The obtained equation systems are inherently nonlinear in terms of DOFs. As this study employs the Newton-Raphson method to solve these nonlinear-equation systems, linearization is required. For this purpose, the symbolic computing capability of MATLAB is used.

The efficiency of the proposed elements and the superiority of the proposed elements over those with constant weights are demonstrated by solving several beam problems. The obtained solutions underscore the efficiency of the proposed elements in analyzing beam structures experiencing large displacements with complex behaviors, such as buckling and snap responses. Additionally, the varying-weight elements consistently outperform the constant-weight counterparts in providing highly accurate solutions. In this regard, the constant-weight elements always require significantly more DOFs than the varying-weight counterparts. The accuracy superiority of the varying-weight elements becomes more apparent in extreme regions such as regions of buckling points, limit points, or substantial displacements.

For Euler-Bernoulli beams, the superiority of the varying-weight element is also evident in terms of accurate recovery of strain measures. While the cubic varying-weight element exhibits no locking phenomena, the cubic constant-weight element slightly shows locking effects in some problems. For Timoshenko-Ehrenfest beams, the varying-weight elements effectively mitigate locking effects, confirming their reliability for solving thin-beam problems. Furthermore, while exhibiting the locking-free characteristic, varying-weight elements yield comparable accuracy to that of the locking-free B-bar elements in a literature, but demand significantly less computational effort. This solves the trade-off challenge of these B-bar elements, between mitigating locking effects and computational efficiency.

Keywords: Geometrically nonlinear analysis, large displacements, small strains, non-uniform rational B-spline, Euler-Bernoulli beams, Timoshenko-Ehrenfest beams, constant-weight elements, varying-weight elements.