別紙第 1 号様式　　　　　　　　　　　　No.1

博　士　論　文　の　要　旨

専攻名　システム創成科学専攻専攻

氏　名（本籍）　Cho Kyi Soe（Myanmar）　印

博士論文題名

A Study on Form-finding and Multiple Nonlinear Analyses for Tensegrity Simulation

（テンセグリティシミュレーションのための形状決定および複合非線形解析に関する研究）

Tensegrity comes from a beautiful word combination of “tension” and “integrity”.

This structure possesses a unique geometrical morphology and composed of discontinuous compression members (struts) in a continuous network of tension members (cables). It can be stabilized in a self-equilibrium state by itself even under no external loading. Tensegrity can undergo a large deformation, involving a strong geometrical nonlinearity. Therefore, the tangent stiffness method is applied in this study which is quite effective in solving geometrical nonlinear problems.

The main purpose of this research is to perform tensegrity simulation with a versatile procedure in which the proposed tensegrity model can undergo a series of structural analyses, valid for both static and dynamic. In our algorithm, the purpose of each analysis is achieved by introducing the corresponding element force equation that describes the element behavior in the element stiffness component of tangent stiffness matrixes.

This dissertation is composed of total six chapters and a brief content of each chapter is presented as follow.

Chapter 1 introduces the background of tensegrity and its involvement in the various fields.

Chapter 2 presents the basic concept of the geometrical nonlinear analysis and formula derivation of the tangent stiffness method for three-dimensional structural system.

Chapter 3 is the study of form-finding analysis that explores the equilibrium configuration of tensegrity. Then nonlinear analysis based on the tangent stiffness method allows us to describe the element behavior freely, even real or virtual elements. Therefore, form-finding process is implemented by the measure potentials. The virtual potential functions have the parameters of element measurement and its differential functions as the element force equations which prescribe the element behavior. In this study, power function is proposed for form-finding analysis and the influence of each coefficient on the shape formation is evaluated by numerical model of double-layered pentagonal tensegrity. In the virtual function, the variation of the multiplier and non-stressed length ratio plays a governing role than stiffness function, and various shape formation can be achieved by the appropriate selection of each coefficient. Moreover, the element force equation is modified to introduce the concept of multiple non-stressed length function whose potential function has multiple stoppage points. In this way, wide diversity of tensegrity form-finding is achieved even under the same connectivity of one structural model.

Chapter 4 is to conduct the large deformation and large displacement analysis of hyper-elastic material such as rubber. It is expected to achieve the element’s behavior in which the sag should occur with compression of deformation and also the hardening should be simulated in the higher tension area. A new algorithm with the application of relaxation process is proposed. In order to explore the features of shape deformation of hyper-elastic material to a full extent, the rubber net structure is used as a numerical model. Although the Hencky strain and nominal strain definitions cannot describe the behavior of the real hyper-elastic material properly, the Ogden model can be characterized by the element rigidity in both compression and tension sides. However, in the assumption of the compression-free elements such as rubber cord, softening occurs in the compression side and formation of slack is required. Therefore, a simple equation of square root function is proposed to express the softening behavior in compression area, which connects smoothly to Ogden function in tensile area. Moreover, a rational computational procedure is implemented to switch between the modified Newton-Raphson method and the iteration of strict tangent stiffness equation. This realizes both the stability of iterated calculation process and the accuracy of output solutions.

Chapter 5 develops a consistent algorithm based on the knowledge of numerical results of the previous chapters. This algorithm enables to analyze the tensegrity structure both statically and dynamically with strong geometrical nonlinearity of structure. This chapter mainly highlights the involvement of dynamic analysis in the process of deployment of folded tensegrity model. The tangent stiffness method gives the adjustment to use the appropriate element force equation and corresponding material stiffness matrix depending on the theme of analysis. The static analysis includes finding equilibrium shape formation and simulation of folding process by the forced displacement. Before making the deployment of tensegrity, the structure is simulated by a free vibration and the decomposition of mode displacement is characterized by the eigenvalue analysis. The Rayleigh coefficients are then calculated to apply the damping effect in the dynamic deployment. The appropriate selection of damping amount in Newmark β method makes the oscillation of the structure slow down gradually and the kinematic energy dissipation is successfully achieved. In this way, the proposed algorithm is valid for both static and dynamic analyses with a great performance.

Chapter 6 concludes the findings of each analysis and discussion is made for future related studies.