Stress analysis of fruit tree branch considering flexural deformation characteristics under actual loading

Kenta ISHII^{1*}, Kazuhiro FUJISAKI¹, Kazuhiko SASAGAWA¹, and Takeshi MORIWAKI¹

¹Department of Intelligent Machines and System Engineering, Hirosaki University, 3 Bunkyo-cho, Hirosaki, Aomori, Japan

*h19ms603@hirosaki-u.ac.jp

1. Introduction.

Fruit tree branches are subjected to various mechanical loads such as own weight, fruits weight, and environmental loads caused by weather. Clarification of the load configuration on branches is useful for the long-term preservation of fruit trees. Since the branches are flexible structure, large deformation under bending are important to understand the strength evaluation of trees. In this study, the effects of large deformation on bending stress considering the fruit weight in cultivation were investigated using numerical simulations analyzing large deflection behavior and actual loading experiments with strain measurements.

2. Materials and Methods.

2.1 Analytical method.

Fig. 1 shows a numerical simulation model of tree branch based on bending deformation analysis of beam. The deformation of branch was analyzed in the two-dimensional bending condition by using beam elements with length Δs . The deflection angle ϕ_k at any point k where the bending moment M_k caused by load F is applied is expressed by Eq. (1). The local elastic modulus E_k was estimated in an actual bending test. The moment of inertia of area I_k was determined based on diameter measurements at the points. The large deformation of branch was analytically determined in iterative calculations considering the bending moment change due to loading position change after deformation.

$$\phi_k = \phi_{k-1} + \frac{M_k}{E_k I_k} \Delta s \quad (1)$$

Fig. 1 Deformation model of tree branch.

2.2 Estimation of the elastic modulus distribution.

The elastic modulus distribution E_k was geometrically determined by Eq. (1) so that the estimated deformation in numerical analysis corresponds to the actual deformation under 0.5 N loading at the tip of branch.

2.3 Investigation of bending stress.

The relationship between loading positions and the bending stress applied at the base area was investigated considering the fruit weight of 3.1 N. The stress was calculated from the estimated elastic modulus and the strain measured using a strain gage (Kyowa Electronic Instruments Co., Ltd., KFEL-2-120-C1L3M3R) while changing a weight position by 50 mm along the branch.

3. Result and Discussion.

Fig. 2 shows the geometries of branch in an actual bending test with the estimated elastic modulus distribution. The elastic modulus was distributed with decreasing from 8.0 GPa at the base to 1.0 GPa at the tip on the branch. The strain was measured at the 50 mm from fixed position in base area.

Fig. 3 shows the stress at the base area for each loading position and the flexural rigidity $E_k I_k$ of the branch. The tendency that the flexural rigidity was smaller at the tip than at the base⁽¹⁾ was confirmed in this result. The effect of loading position on the stress inclination decreased in the tip side because the change of moment arm length was small by high deformability. And there is a possibility that the stress further decreases with considering the long-term responses of tree deformation such as creep phenomenon⁽²⁾.

4. Conclusion.

The fruit tree branch reduced the bending stress applied at the base area due to fruit weight by causing large flexural deformation. The stress analysis considering the large deformation of branch could be used for preservation of tree in fruit cultivation.

Acknowledgment: This work was supported by JSPS KAKENHI No. 18KT0058.

Fig. 2 Branch geometry in actual loading.

Fig. 3 Bending stress at base area depending on the loading position, and flexural rigidity of each area.

References.

- (1) Schmidt, R. A. et al., *Canadian Journal of Forest Research*, **20**, (1990), 1251-1253.
- (2) Peter, M. R. et al., *Front Plant Sci.*, **10**:59, (2019).