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NUMERICAL ANALYSIS OF FENCE TYPE SUPPORT OF APPLE TREES

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Damages to apple trees caused by typhoons have been repeated every year in Korea. Many types of support of apple trees such as single support, fence-type, matrix-type have been used; however, there is no standard type designed or specified by a code or manual. Most of the support is set up by farmers based on their experience, which results in frequent damage by typhoon. In this study, a prototype support for apple tree suggested by 'Rural Development Administration' is modelled for structural analysis. The previous test results of other trees for wind tunnel test is used as an input of numerical modeling, and the turnover test result of an apple tree is used to assess the strength of the support system. Numerical analysis is conducted for an assumed wind speed based on the test results to estimate the safety of the support. The appropriate steel-pile sizes of fence-type support are suggested based on the analysis result, which might be used as the standard type of support. Analysis results are also used for new design of the support with respect to a different wind speed by using the analysis model.

Keywords: Tree support, Structural analysis, Wind resistance.

1 INTRODUCTION

A great number of apple trees have collapsed in Korea due to a typhoon. In fact, an apple tree is protected by various types of support; however, despite the fact that the apple tree has a support, the trees have been damaged. The reason why the trees have collapsed is that the installation of a support is not based on a scientific fact. This study carried out a turnover analysis of an apple tree under the influence of the wind by using a computational program and conducting an actual experiment.

The drag force exerted onto the apple tree by a typhoon can be computed based on the previous research finding of Vollsinger *et al.* (2005). The drag force was substituted by external force to the support system for the structural analysis. Through the structural analysis, the turnover or not of an apple tree and the safety of the support system are suggested. The objective of this study is to prevent an apple tree from collapsing or turnover, resulting in obvious saving of the damage repair cost.

2 TURNOVER TEST

A turnover experiment was conducted to estimate the turnover resistance since it is the criterion for the turnover or not of an apple tree during the analysis of a support. Nine apple trees of 7-year and 12-year age were subjected to the test. The turnover force exerted to the tree without a support was measured through the test by detaching a support from the apple tree. As shown in Figure 1, a tree is tied with a rope at the height of 1,100 mm and is connected with an electric-powered winch and load cell. LVDT (Linear Variable Differential Transformer) was installed to measure displacement of the tree at the opposite side.

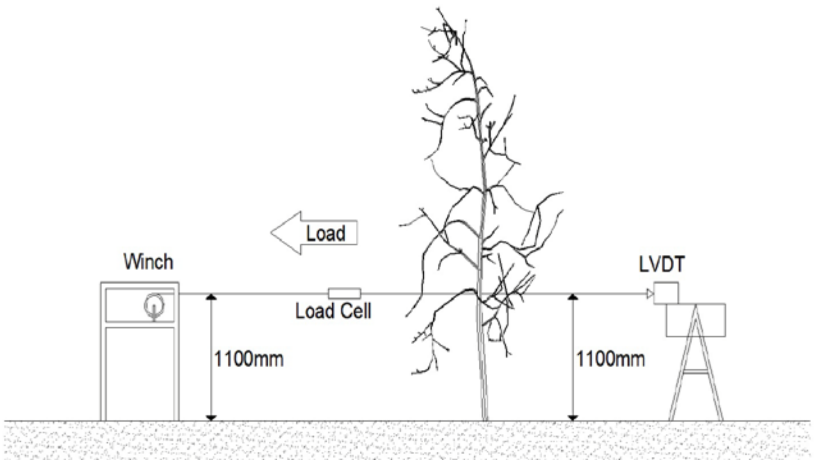

Figure 1. Turnover test setup.

The patterns of the results were similar to each other. In the beginning of experiments, the load increased rapidly to the peak. The peak points represent the moments when the trees were collapsing. The load decreased rapidly soon afterwards.

Table 1. Result of the turnover test of apple trees (Suwon & Gunwi).

	Max. Load (N)	**Max. Moment (N·m)**	**Weight (kg)**	**Root Diameter (mm)**	**Height (mm)**	**Year**
Suwon_01	330.8	363.9	20	60	3200	7
Suwon_02	304.2	334.6	27	75	3700	
Suwon_03	178.3	196.1	25	70	3400	
Gunwi_01	534.2	587.6	52	96	5000	12
Gunwi_02	176.7	194.4	36	90	3900	
Gunwi_03	157.5	173.3	48	80	4300	
Gunwi_04	464.1	510.5	54	100	4200	
Gunwi_05	379.9	417.9	60	100	5000	
Gunwi_06	304.2	334.6	48	110	3300	
Average	314.4	346.0	50	87	4000	-

The maximum load was manifested with about 150 mm displacement at the height of 1100 mm, and the distribution deviation of maximum load differed greatly with each tree. The results of the turnover test are summarized in Table 1. The maximum load as measured from the turnover test ranged from 157.5N to 534.2N. As the root diameter increased, the bearing capacity also increased as expected. The maximum resistance was computed by multiplying the maximum load by the height of loading point, i.e. 1100 mm, as turnover moment resistance as shown in Table 1.

Since the deviation of maximum turnover moment was significant, its average resistance was 345.9 N·m and standard deviation (σ) was 144 N·m respectively. The numerical analysis conservatively assumed the allowable moment resistance of M_a = 202 N·m by subtracting 1.0 σ from the average. In other words, if the moment value as computed by the numerical analysis is over 202 N·m, then the tree is assumed to collapse.

3 NUMERICAL ANALYSIS

Drag force to an apple tree due to wind load needs to be computed for the numerical analysis. The representative average number and solidity ratio were assumed among the apples trees used in the experiment. The drag force (*P*) exerted to the apple tree was computed by Eq. (1). Several assumptions are necessary in order to use Eq. (1) (AIK 2009). Each assumed value is shown in Table 2.

Table 2. Assumed input values for loads to an apple tree.

Notation	Definition	Unit	Value
G_f	Gust Effect Factor	-	1.5
$*C_D$	Drag Coefficient	-	0.2
ρ	Air Density	kg/m^3	1.22
v	Wind Velocity	m/s	25
ξ	Solidity Ratio	%	25
A	Area	m^2	6.6
h	Average height of load *P*	m	1.5

* C_D was assumed to be 0.2 based on the test results (Mayhead 1973; Vollsinger *et al*. 2005)

$$\begin{aligned} P &= G_f C_D \times \frac{1}{2}\rho\upsilon^2 \times \xi A \\ &= 1.5 \times 0.2 \times \frac{1}{2} \times 1.22 \times 25^2 \times 0.25 \times 6.6 = 188.5N \end{aligned} \tag{1}$$

$$\begin{aligned} M &= Ph \\ &= 188.5 \times 1.5 = 283 N{\cdot}m \end{aligned} \tag{2}$$

Robinson and Hoying (2000) suggested that the most durable tree support system was single high wire system. In this study, however, four-wire support system, currently the common system in Korea, was modelled for the numerical analysis. Figure 2 depicts the apple trees being supported by four-cable lines which are connected with internal and external support. Table 3 presents specifications of the fence-type support member. The section properties and modulus of elasticity of each member as input values of the analysis are shown in Table 3. The diameter of internal support (①) is 60.5 mm and can endure moment of 921 N·m or below. The diameter of external support (②) is 48.1 mm can endure moment of 527 N·m or below. Horizontal and support cable possess diameters of 2.6 mm (③) and 6 mm (④), respectively. The support pole is spaced at 6 m interval, and three apple trees are placed within one support span. The apple trees are wired by four horizontal cables to transfer the drag force of tree to the support. The cables are pre-tensioned and are connected to the external support to maintain the tension through incline-support cable.

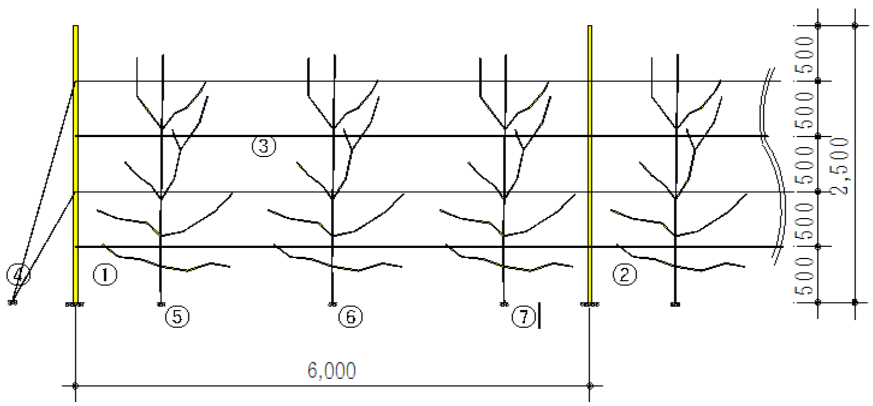

Figure 2. Modeling of trees and a support.

The total drag force onto the tree was substituted with four-point loads at the horizontal wires of the fence support in order to apply it to the fence-type support. The four substituted load values were set to have equivalent drag moment values at the root. The applied load to the four points on the tree was 40 N each in the modeling. Thus, the moment at the base (root) of a tree, M = 280 N·m, meaning that the tree is at the risk of turnover danger. The numerical analysis employed a structural analysis program, MIDAS to perform an elastic analysis (MIDAS, 2008).

Table 3. Input Assumption for modeling.

	Define	**A(mm^2)**	**S(mm^3)**	**M_y (N·m)**
①	External support ϕ60.5 × 2.3t	214.4	3122	921
②	Internal support ϕ48.1 × 2.1t	155.2	1787	527
③	Horizontal wire ϕ2.6	5.3	1.72	
④	Support wire ϕ6	28.3	2225	
E_{steel} = 200,000 MPa, E_{tree} = 10,000 MPa, SPVHS F_y = 295 MPa				

4 ANALYSIS RESULTS

Although the moment ratio of external support was evaluated relatively smaller, the sectional moment due to pre-tension of horizontal wire should be considered during design stage of an actual structure. The moment ratio of a support can be computed based on such a modelling and analysis result, and this in turn can be used for the computation of maximum wind speed, which can be withstood by a support device.

Table 4 presents the regional support analysis results by the elastic analysis. The supports are designed with the appropriate design resistance moment of the support against the required moment strength for the elastic design by the wind speed.

Table 4. The support by the regional elastic design.

Wind speed (m/s)	Region	External support (①)	Internal support (②)
20	Yongin, Wonju, Cheongju, namwon	$\phi 31.8 \times 1.5$	$\phi 31.8 \times 1.5$
25	Ganghwa, Inje, Daejeon, Sangju, Gwangju	$\phi 33.5 \times 2.1$	$\phi 33.5 \times 2.1$
30	Seoul, Chuncheon, Boryeong, Goheung	$\phi 33.5 \times 2.1$	$\phi 42.2 \times 2.1$
35	Donghae, Ulsan, Jindo, Masan	$\phi 42.2 \times 2.1$	$\phi 42.2 \times 2.1$
40	Gangneung, Okpo, Busan, Jeju	$\phi 42.2 \times 2.1$	$\phi 48.1 \times 2.1$

5 CONCLUSIONS

This study aims to decide the apple tree support's conduction through the computation analysis and to design the steep pipe support optimally with the wind load, and the conclusions are as follows.

- For both external and internal supports, the support dimension by the elastic design had no difference between 20m/s ~ 25m/s wind speed. However, we can know that as the wind speed increases, the internal support dimension increases more than the external support.
- If the optimum design is carried out with conducting the computation analysis by the numerical analysis through the diversification of analysis model, the efficient and economic steel pipe support size can be decided, which can promote the farm profit.

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References

Architectural Institute of Korea, *Korean Building Code and Commentary(KBC2009)*, Kimoondang , Korea, 2009

Mayhead, G. J., Some Dag Coefficients for British Forest Trees Derived from Wind Tunnel Studies, *Agriculture Meteorology,* Elsevier, 12, 123-130, May, 1973.

MIDAS, *MIDAS GENw Standard User's Manual Ver.7.9.5*, MIDAS Information Technology Co, Korea, 2008

Robinson, T. L., and Hoying, S. A., Lessons Larned about Tree Support from the 1998 Labor-day Storm, *The Compact Fruit Tree*, 33(1), 12-18, 2000.

Vollsinger, S., Mitchell, S. J., Byrne, K. E., Novak, M. D., and Rudnicki, M., Wind tunnel measurements of crown streamlining and drag relationships for several hardwood species, *Canadian Journal of Forest Research,* 35(5), 1238-1249, 2005.