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A Study on the Estimation of Compressive Strength of Structural Timber using Ultrasonic Pulse Velocity Method

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Abstract:- Diagnosis is essential, in order to understand the poor construction and the status of structures. There are several kinds of the maintenance of the structure, and nondestructive test method sare the easiest methods that can diagnosis the status of the structures. As a tool to evaluate the effects of defects on structural timber strength, nondestructive test methods are being actively researched recently. Therefore, we were proposed the estimation equations as the analyzed the correlation between the compressive strength and ultrasonic pulse velocity of structural timber using the Ultrasonic Pulse Velocity method. As a result the correlation coefficient of the strength estimation equation was 0.88-0.997 and average is 0.965. In this experiments carried out that ultrasonic pulse velocity method has a high reliability.

Keywords: *-Compressive Strength, Estimation, Structural Timber, Ultrasonic Pulse Velocity Method*

I. INTRODUCTION

Diagnosis is essential to figure out defect construction and condition of structure. There are various diagnostic methods among which nondestructive test method is the most convenient method. With the nondestructive test method, while diverse studies have been actively progressed by concrete and steel structure assessment standard and regulation, it is hard to make accurate diagnosis on wood structure as tissues are different and uneven by types of timber. As such safe use of wood structure is necessary by means of maintenance and diagnosis in line with enhanced interest in safety. This study aims to analyze correlation of compressive strength by ultrasonic pulse velocity, a kind of nondestructive test method and also to propose reliable compressive strength estimation of structural timber. Based on these data, this study is expected to be used as reliable maintenance and diagnosis index of wood structure for field application despite insufficient regulation.

It was since 1960s when nondestructive test method using ultrasonic pulse was firstly introduced to timber. Lemaster and one other, proposed measuring method of defect of inside wood using ultrasonic pulse [1], Kodama et. al. estimated rotten status of timber and measured condition of knot [2]. Patten-Mallory et. al. measured existence of knot inside timber and condition of knot [3], and Mishiro analyzed relation between ultrasonic pulse delivery velocity and moisture content and also effect of fiber inclination angle [4]. Lim KwangHee and 3 others examined heterogeneity of timber using C-Scan by immersed through transmission method. Jeong Sang Sik proposed compressive strength estimation formula by moisture content and fiber inclination angle [5].The nondestructive test of timber using ultrasonic pulse is applied to classify grade, and to measure water content, to detect defect and to check rotten degree. But, types of trees used on those studies are just one or two except for the study of Mishiro that examined the relation between ultrasonic delivery velocity and moisture content using some Japanese needle-leaf tree, broad-leaf tree and some tropical imported tree [6]. It is necessary to study various timber types with suitable tissues and homogeneity of each type.

II. ULTRASONIC PULSE VELOCITY

Ultrasonic pulse velocity method of concrete is to calculate ultrasonic pulse velocity through penetrating time between transmitting transducer and receiving transducer at certain distance of concrete to figure out the ultrasonic pulse delivery speed into hardened concrete.When material features are examined using ultrasonic pulse velocity, the measurement precision must be very high. It means an experiment device that can create suitable pulse and measure transit time accurately must be used. If path length that pulses spread in the material is measured, ultrasonic pulse velocity is calculated as in Equation (1).

$$Pulse\ velocity = \frac{Path\ length}{Transit\ \ time} \quad (1)$$

Velocity in the calibrator is on the earliest pulse. As shown in Fig. 1, it is transit velocity from Transmitting transducer(Tx) and Receiving transducer(Rx) when Tx and Rx are placed on the suitable location of material surface.

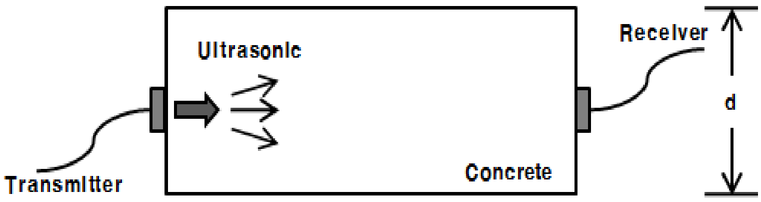

Figure 1 Conceptual diagram of Ultrasonic Pulse Velocity

III. STRCUTURAL TIMBER

Test timber in this test is total 6 kinds. Southern yellow pine - P-Rigida - is tree grown in the southern area of the US. While it is needle-leaf tree, it belongs to strong timber with heavy weight and decent wood pattern.American Red Pine is distributed in the eastern area of the US. Heartwood is light red or reddish brown. Sapwood is almost white with clear distinction of spring and fall tree. And, it has high strength, rigidity, hardness and toughness. As it is easy to dry, it is used for lumbar, log house, pulpwood, construction structure material, window frame, floor wood, box, crate and pallet.Yellow cedar, an Alaska arbor vitae is grown at southeast Alaska of the US and west coast of Canada. It has uniformed wood pattern with soft and dense structure. It is durable and strong against insect damage and decomposition and modestly heavy and solid. Particularly, it is easy for processing with good cut, dry and planning. Adhesiveness and coating ability is normal. Hemlock is evergreen needle-leaf tall fir tree distributed in Ulleungdo and Japan. Crown is round and light brown color. It has dense texture and is solid and lustrous. Wood is mainly used for construction, bark for pulp and inside skin for tannic acid production.Hinoki is Japanese evergreen tall tree which is also called cypress, hinoki and white cedar. Bark is reddish brown. While it is vulnerable to cold and salt, it is durable against pollution. It is good quality material emitting phytoncide. So, it is used for woods bathing and atopy treatment. Spruce is distributed in northeast Asia and it is light beige or yellow. It is hard to distinguish between heart wood and sapwood. It has fine and uniform tissue. It is easy to cut, dry and coat mainly used for construction material, furniture, musical instrument, shipbuilding, boat, airplane and pulp. The above 6 trees are used for construction timber. Test samples were made as the distributed processed form for test.

IV. EXPERIEMNT

For compressive strength estimation by ultrasonic pulse velocity of timber, the study employed 6 timbers all of which were needle-leaf trees including Southern yellow pine(SYP), Red pine(RP), Yellow cedar(YC), Hemlock(HL), Hinoki(HK) and Spruce(SP).This study made test sample as per ASTM D 198 [7]. Ultrasonic pulse velocity was measured by applying KS F 2731 [8], and moisture content by KS F 2199 respectively [9]. Test was made in air dry and absolute dry conditions. Total 36 test samples with 6 test samples per each type were prepared.This study is the experiment of compressive strength estimation of structural timber using ultrasonic pulse velocity. Compressive strength test was made by using 200KN Universal Tester. Measurement was made by applying parallel compressive loading to fiber direction of test sample.

$$\sigma = \frac{P}{A} \quad (2)$$

Compressive strength of timber was calculated by using the below Equation (2) [10], and ultrasonic pulse velocity was measured as per KS F 2731 [8]. Measurement is made by using a direct method toward fiber direction. 20 tests were performed per each sample to figure out mean value. Ultrasonic pulse velocity is calculated by below Equation (3) [8].

$$V_p = \frac{L}{T} \quad (3)$$

Moisture content was measured every 6 hours in the dryer with 103±2℃. Drying was made until two consecutive same values are achieved or until mass change rate becomes less than 0.5%. Then, mass reduction portion was measured which was calculated according to Equation (4) [9].

$$M_c = \frac{m_1 - m_2}{m_2} \times 100 \quad (4)$$

V. EXPERIMENTAL RESULTS

Compressive strength measurement results of tests are as in Table 1.Compressive strength increase rate by moisture contents in air dry and absolute dry conditions was 31.9～50.03% with average compressive strength increase rate of 39.48%. Compressive strength value in absolute dry was higher than that in air dry. Based on absolute dry condition, SP was the highest with 38.34(MPa) while RP was the lowest with 23.77(MPa). Table 1 indicates ultrasonic pulse velocity measurement result value. For ultrasonic pulse velocity, timber with absolute dry is distributed at far higher place than air dry timber. Increase rate of test value in ultrasonic pulse velocity was average 44.09%. SYP was the lowest with 37.28% and HK was the highest with 50.95%.

Table 1 Results of Experiment

Type	Moisture contents	Compressive Strength (MPa)				Ultrasonic Pulse Velocity (km/sec)				Moisture contents (%)			
		1	2	3	Average	1	2	3	Average	1	2	3	Average
SYP	Air dry	16.13	15.61	15.91	15.88	3.58	3.56	3.39	3.51	13.45	13.10	11.61	12.72
	Absolute dry	32.87	30.11	32.47	31.82	5.95	5.55	5.31	5.60				
RP	Air dry	13.92	15.33	17.32	15.52	3.86	3.86	3.74	3.82	11.47	11.65	10.91	11.34
	Absolute dry	24.47	23.75	23.09	23.77	6.17	6.08	6.24	6.16				
YC	Air dry	19.14	18.88	18.87	18.96	3.70	3.57	3.64	3.64	12.12	11.77	12.32	12.07
	Absolute dry	26.03	28.37	29.38	27.93	6.49	6.57	6.60	6.55				
HL	Air dry	13.11	15.01	15.48	14.53	3.67	3.92	3.93	3.84	13.57	13.05	13.24	13.28
	Absolute dry	24.89	24.71	23.80	24.47	7.21	7.14	7.21	7.19				
HK	Air dry	16.74	18.46	17.20	17.47	3.70	3.76	3.34	3.60	13.16	13.06	12.93	13.05
	Absolute dry	26.03	26.90	26.91	26.61	7.24	7.45	7.33	7.34				
SP	Air dry	20.51	21.21	21.07	20.93	4.10	4.10	4.11	4.10	13.34	13.83	13.95	13.71
	Absolute dry	38.85	38.23	38.28	38.45	7.72	7.75	7.86	7.78				

Table 1 shows moisture content measurement results. Test sample mass in absolute dry condition except for that in air dry was measured with 0.01g accuracy level. Moisture content ranged between 11.34% and 13.71% with average 12.69%. All types except for RP with 11.34% had 12～13% with even values.Thus, all satisfied the conditions of moisture content below 18% in absolute dry as per KS F 3020 [11] needle-leaf tree structural timber, and moisture content below 15% in absolute dry as per KS F 3021 [12] structural laminated timber. Fig. 2 shows correlation graph between compressive strength and ultrasonic pulse velocity. As shown in the graph, each tree type has different distribution.In the correlation graph, based on air dry, SYP's ultrasonic pulse velocity is distributed at 5.31～5.95(km/sec) with compressive strength 30.11～32.87(MPa). RP's ultrasonic pulse velocity is distributed at 6.08～6.24(km/sec) with compressive strength of 23.09～24.47(MPa). YC's ultrasonic pulse velocity is distributed at 6.49～6.60(km/sec) with compressive strength of 26.03～29.38(MPa). HL's ultrasonic pulse velocity is distributed at 7.14～7.21(km/sec) with compressive strength of 23.80～24.89(MPa). HK's ultrasonic pulse velocity is distributed at 7.24～7.45(km/sec) with compressive strength of 26(MPa). SP's ultrasonic pulse velocity is distributed at 7.72～7.86(km/sec) with compressive strength of 38(MPa)SP had the highest ultrasonic pulse velocity and compressive strength while SYP had the lowest ultrasonic pulse velocity and RP had the lowest compressive strength.

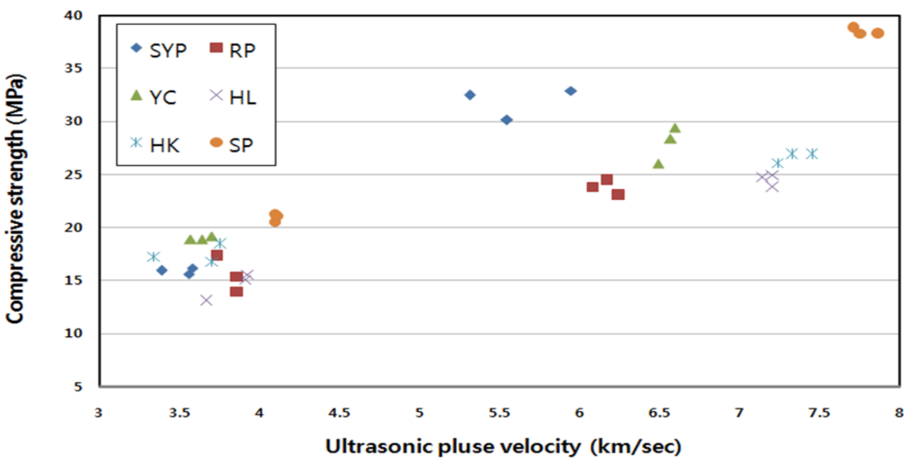

Figure 2 Correlations between Compressive Strength and Ultrasonic Pulse Velocity

Table 2 is compressive strength estimation equation using ultrasonic pulse velocity of each tree by regression analysis. Using measured ultrasonic pulse velocity, compressive strength estimation equation was proposed, and compressive strength was estimated. The result is in Table 2. When error ratio between estimated value and actual compressive strength, it was ranged between 0.00% and 1.65% with average 0.40%. Thus, almost accurate compressive strength estimation was possible to almost all types.

Table 2Comparison of compressive strength estimation using ultra sonicpulse velocity

		Ultrasonic Pulse Velocity (km/sec)	Compressive Strength ① (MPa)	Estimated Equation ② (MPa)	Error Ratio □ ② (%)	Estimated Equation	Coefficient of determination
SYP	Air dry	3.51	15.88	16.11	1.41	$y = 7.399V_p - 9.863$	$R^2 = 0.97$
	Absolute dry	5.60	31.82	31.57	0.50		
RP	Air dry	3.82	15.52	15.58	1.65	$y = 3.469V_p + 2.324$	$R^2 = 0.88$
	Absolute dry	6.16	23.77	23.69	0.81		
YC	Air dry	3.64	18.96	18.95	0.07	$y = 3.087V_p + 7.711$	$R^2 = 0.97$
	Absolute dry	6.55	27.93	27.93	0.00		
HL	Air dry	3.84	14.53	14.52	0.10	$y = 2.980V_p + 3.072$	$R^2 = 0.98$
	Absolute dry	7.19	24.47	24.50	0.12		
HK	Air dry	3.60	17.47	17.47	0.02	$y = 2.422V_p + 8.682$	$R^2 = 0.97$
	Absolute dry	7.34	26.61	26.61	0.01		
SP	Air dry	4.10	20.93	20.91	0.08	$y = 4.7662V_p + 1.373$	$R^2 = 0.99$
	Absolute dry	7.78	38.45	38.45	0.01		
Average Error Ratio (%)					0.40		

VI. CONCLUSION

This study measured compressive strength and ultrasonic pulse velocity of various structural timbers to analyze their correlation. It was followed by regression analysis to propose compressive strength estimation equation for each timber. The conclusions are as follows.

1) Increase rate of compressive strength in air dry and absolute dry condition according to moisture content was ranged between 31.9% and 50.03% with average 39.48% compressive strength increase rate.

2) Increase rate of ultrasonic pulse velocity in air dry and absolute dry condition according to moisture content was ranged between 37.28% and 50.95% with average 44.09% increase rate.

3) Error ratio between measured compressive strength value and estimation equation was average 1.08%. Thus, the compressive strength estimation equation of structural timber was very reliable.

VII. ACKNOWLEDGEMENTS

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