「森林総合研究所研究報告」(Bulletin of FFPRI), Vol.6, No.1 (No.402), 1-7 , March, 2007

論　文（Original article）

Effects of sorting logs on sawn lumber yields and qualities - Young's modulus and moisture content -

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Abstract

It becomes increasingly important to convert logs into sawn lumber under consideration of the usage, because the higher performance has been demanded as building members, the main end use of sawn lumber in Japan. The proper log sorting and sawing with the optimal sawing patterns are indispensable to produce lumber efficiently. In this study, we examined the influence of sorting logs by Young's modulus and moisture content on sawn lumber yields and qualities aiming for efficient lumber productions.

Sixty middle diameter sugi (*Cryptomeria japonica* D. Don) logs were divided into two groups (group A and B) so that the distribution of Young's modulus might be almost equal. The logs of group A were sorted by Young's modulus E_{fr} and moisture content estimated by bulk density of log and sawn using four adequate sawing patterns, and the logs of group B were not sorted and sawn randomly selected sawing patterns. The lumber yields and lumber qualities of each log were examined. The average moisture content measured immediately after sawing of the squared and flat square lumber from lower moisture content logs in group A were lower than those in group B. In the lumber of 3.0 cm in thickness and 13.0 cm in width the frequency of the lumber of higher Young's modulus was higher in group A than in group B. It was shown that there is a possibility of producing lumber suitable for the end use efficiently by sorting logs considering Young's modulus and moisture content and sawing the logs using the optimal sawing patterns.

Key words : Sorting logs, sawing pattern, lumber yield, Young's modulus, moisture content

Introduction

In 2004, demand for logs in Japan was 30,855,000 m^3, and 21,705,000 m^3 of that was for lumber manufacturing (The Ministry of Agriculture, Forestry and Fisheries of Japan, 2005). Of lumber sawn in Japan, 81%, 11,023,000 m^3 were shipped as building members (The Ministry of Agriculture, Forestry and Fisheries of Japan, 2005). It could be said that the main end use of sawn lumber in Japan was building members. Therefore, producing lumber for building member efficiently and with high yield is very important.

Generally, logs were sorted by their diameters and warp in Japanese log markets. However, since the demand for lumber qualities as building members has risen recently, it is necessary to supply kiln dried lumber and stress graded lumber. If logs are sorted considering the qualities such as moisture content and/or Young's modulus, logs are processed more efficiently. For example, higher moisture content logs are sawn into small dimension lumber which is easy to dry and stronger logs are sawn into structural members. The moisture content of sugi (*Cryptomeria japonica* D. Don), Japanese most popular species, is very high in green condition and the dispersion of quality is large. The moisture content of sawn lumber is possible to be estimated from bulk density (Shida *et al*, 1990). So that we thought that the moisture content of a log was easily estimated from its diameters, length, and weight. Since there is a high correlation between Young's modulus and strength, and since measurement of Young's modulus with longitudinal vibration method is nondestructive and simple, it is rational to estimate strength from Young's modulus (Sobue, 1987). In order to produce lumber that meets the demand for usage, it would be useful to sort logs by moisture content and Young's modulus and to convert logs into sawn lumber with the optimal sawing patterns.

It has been demonstrated in previous studies that volume yields had been related to the log diameter (Ikami *et al*., 1992; Ikami *et al*., 1997), and that value yields had been related to log grades or number of knots on log surfaces (Murata *et al*, 1989). However, there are few reports about influence of sorting logs by moisture content and strength on sawn lumber yields and qualities.

In this study, we examined the influence of sorting logs by Young's modulus and moisture content on sawn lumber yields and qualities aiming for efficient lumber productions.

原稿受付：平成 18 年 6 月 8 日 Received June 8, 2006　　原稿受理：平成 18 年 10 月 25 日 Accepted Oct. 25, 2006

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Table 1. Specification of logs used.

	Diameter Top end (cm)	Diameter Butt end (cm)	Length (cm)	Volume (m^3)	Weight (kg)	Density (g/cm^3)	Number of annnual rings	Percentage of heartwood (%)
Ave.	27.6	31.8	373	0.270	190.6	0.709	37	61.1
SD	2.49	3.35	2.8	0.051	35.08	0.050	4.41	6.00

Ave.: Average, SD: Standard deviation

Materials and methods

Materials

Sixty middle diameter sugi (*Cryptomeria japonica* D. Don) logs grown in Tochigi Prefecture were used in this study. After debarked, lengths and circumferences of top end, butt end, and middle of logs were measured, then their volume were calculated by Equation (1) as truncated cone.

$$V = \frac{\left(l_t^2 + 2l_m^2 + l_b^2 + l_t l_m + l_m l_b\right) \times L}{24\pi} \tag{1}$$

where, V (cm^3) is volume of log, l_t (cm) is circumferences of top end, l_m (cm) is circumferences of middle, l_b (cm) is circumferences of butt end, L (cm) is the length of log. Weights of logs were measured and their bulk density was calculated. Table 1 shows the specification of logs used. Moisture content of logs was estimated from their bulk density by Equation (2) in this study for convenience.

$$u_e = \frac{\rho - 0.374}{0.374} \times 100 \tag{2}$$

where, u_e (%) is the estimated moisture content of log, ρ (g/cm^3) is the bulk density of log, 0.374 (g/cm^3) is oven-dry density of sugi, which is our previous experimental data (Matsumura *et al*, 2003). Natural frequency of vibration of log was measured by longitudinal vibration method and Young's modulus of log was calculated by Equation (3).

$$E_{\mathrm{fr}} = 4 \times L^2 \times fr^2 \times \rho \tag{3}$$

where, E_{fr} (GPa) is Young's modulus of log, L (m) is the length of log, fr (Hz) is the natural frequency of vibration of log, ρ (kg/m^3) is the bulk density of log.

Sorting logs and sawing pattern

The flowchart of sorting logs is shown in Fig. 1. Sixty logs were divided into two groups so that the distribution of Young's modulus E_{fr} might be almost equal. That is, logs were arranged in the order of their E_{fr} and numbered. Then the logs of odd number were classified as group A and the logs of even number were classified as group B. The logs of group A were divided according to their E_{fr} into two groups, less than and more than 7.0 GPa. Each group was divided into two groups by moisture

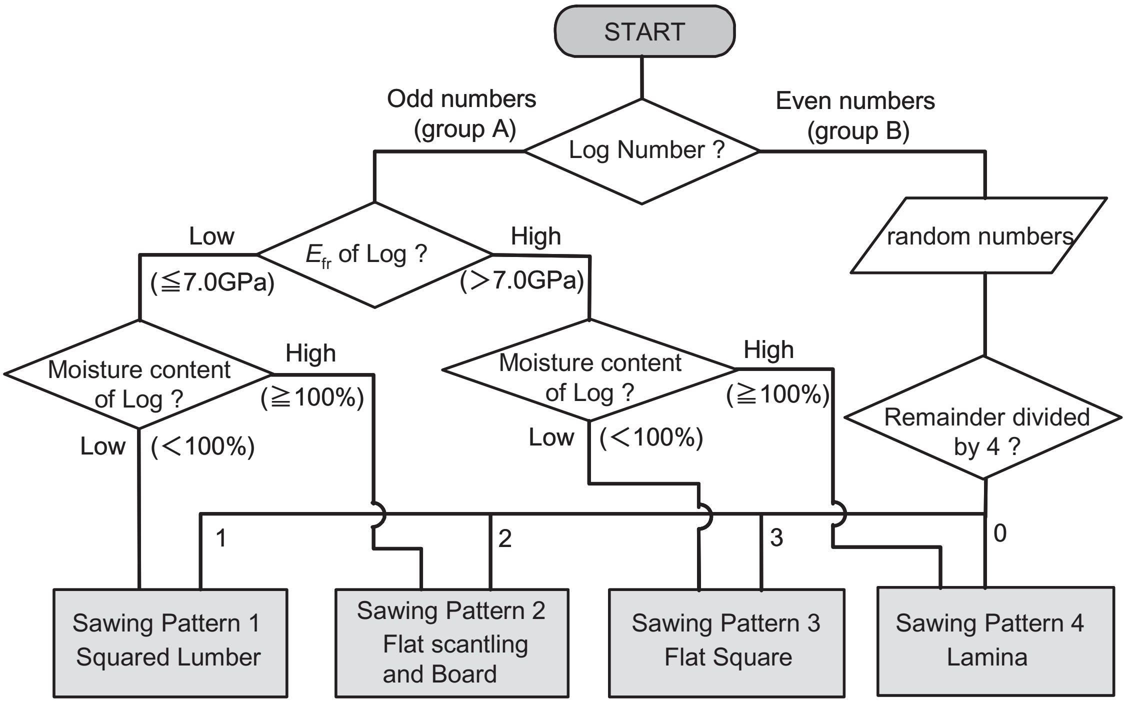

Fig. 1. The flowchart of sorting logs.

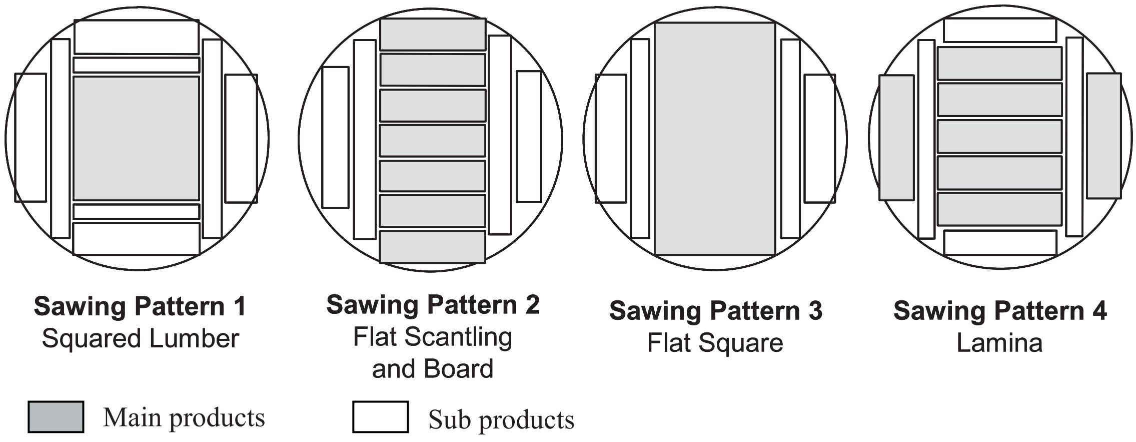

Fig. 2. Sawing patterns used.
Note: Main products were measured Young's modulus, moisture content, bow and crook.

content, less than and more than 100%. In this way, the logs of group A were divided into four sub-groups, and sawn using four sawing patterns adequate to each sub-group. The sawing patterns are shown in Fig. 2. Main products of sawing pattern 1 were squared lumber since kiln-drying could be easily because of their low moisture content. In contrast main products of sawing pattern 2 were small dimension lumber such as flat scantling and boards to achieve efficient kiln-drying. Logs, E_{fr} of which were higher were sawn into structural lumber. Main products of sawing pattern 3 were flat square since E_{fr} was high and moisture content was low. Main products of sawing pattern 4 were laminae for gluelam in order to utilize their strength and achieve efficient kiln-drying.

On the other hand, the logs of group B were not sorted. They were given random numbers, and divided into four sub-groups according to their remainder when the random numbers were divided by 4. They were sawn using the sawing patterns used for the logs of group A.

Lumber yields and qualities

A 1,200 mm band mill with an auto feed carriage was used in this study. Logs of each group were sawn using four sawing patterns.

The data to be discussed below were collected in the following way. Sawn lumber were graded based on Japanese Agricultural Standard (JAS) (The Ministry of Agriculture, Forestry and Fisheries, 1996) immediately after sawing. Sawn lumber except boards were weighed and measured the width, the thickness, and the length. The crook and the bow were measured in units of 1 mm using a thread and a ruler. The moisture content was measured with a wood moisture tester (Kett HM-520). Sawn lumber except board were kiln dried. After drying the lumber qualities such as crook, bow, and moisture content were measured. Young's modulus E_{fr} of lumber was measured by longitudinal vibration method. Volume and value yields in each sub-group were calculated by Equation (4), and (5).

$$Y_{vol} = \frac{\left(\sum V_i\right)}{V_0} \times 100 \tag{4}$$

$$Y_{val} = \sum \left[\left(\frac{V_i}{V_0} \right) \times \left\{ \left(\frac{P_i}{P_0} \right) \times 100 \right\} \right] \tag{5}$$

where, Y_{vol} (%) is the volume yield, Y_{val} (%) is the value yield, V_i (m^3) is volume of each sawn lumber, V_o (m^3) is volume of log, P_i (yen/m^3) is price of each sawn lumber, and P_o (yen/m^3) is price of standard lumber. In this case a standard lumber was square lumber 10.5cm in thickness, 10.5cm in width, and 3.65m in length of sugi, grade 1 in Japanese Agricultural Standard, 52,000 yen/m^3.

Results and discussion

Table 2 shows E_{fr} and estimated moisture content of logs in each sub-group. The average of E_{fr} of logs in sawing pattern 1 and 2 are higher than in sawing pattern 3 and 4 in group A. Since it was impossible to measure real moisture contents of the logs, the estimated moisture contents of logs were compared with the average moisture contents of lumbers immediately after sawing. The coefficient of correlation between the estimated moisture contents of logs and the average moisture contents of lumbers was 0.66. Though the average moisture content of products did not necessarily show accurately real moisture contents of logs, there was a possibility that the estimated moisture content be used as a reference data for the sorting logs. The average of estimated moisture contents of logs in sawing pattern 1 and 3 are lower than in sawing pattern 2 and 4 in group A. Table 2 indicates that logs in group A were certainly sorted by E_{fr} and estimated moisture content.

Fig. 3 shows cumulative frequency distributions of E_{fr} of laminae of 3.0 cm in thickness, 13.0 cm in width. The

Table 2. E_{fr} and estimated moisture content of logs.

Group	Sawing pattern	Number of log	E_{fr}(Gpa)		Moisture content(%)	
			Ave.	SD	Ave.	SD
A	1	12	6.39	0.43	79.9	9.86
	2	2	6.73	-	102.5	-
	3	9	7.83	0.47	84.9	7.82
	4	7	7.95	1.03	111.6	5.67
B	1	8	6.49	1.00	82.4	10.14
	2	8	7.04	0.94	85.3	10.69
	3	7	7.64	0.78	99.2	11.17
	4	7	7.26	0.52	89.8	8.79

- : The standard deviation was not calculated because there were only two logs.

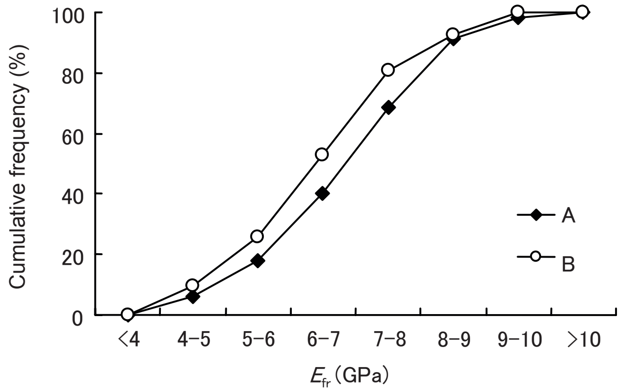

Fig. 3. Cumulative frequency distributions of E_{fr} of laminae of 3.0 cm × 13.0 cm.
Note: The number of laminae in group A was 117, and in group B was 93.

Table 3. Moisture contents of squared lumbers.

Group	Immediately after sawing (%)		After kiln-drying (%)	
	Ave.	SD	Ave.	SD
A	70.8	11.91	12.9	5.36
B	74.5	19.11	12.2	3.71

Size of square lumbers: 13.0 cm × 13.0 cm

Table 4. Moisture contents of flat squares.

Group	Immediately after sawing (%)		After kiln-drying (%)	
	Ave.	SD	Ave.	SD
A	71.4	11.81	14.8	4.14
B	80.2	16.49	19.9	4.67

Size of square lumbers: 13.0 cm × 18.0-25.0 cm

frequency of higher E_{fr} was higher in group A than in group B. This indicates that the rate of rejection lumber in group A were lower than in group B, when the laminae of lower E_{fr} were rejected. It follows from this that sorting logs by E_{fr} would be useful for efficient production of reliable sawn lumber as building member.

Table 3 and 4 shows moisture content of squared lumbers and flat squares in group A and B. The average estimated moisture contents of squared lumbers and flat squares immediately after sawing in group A were 70.8 % and 71.4 %, respectively, and those in group B were 74.5 % and 80.2 %, respectively. There were no significant difference in the estimated moisture content between group A and group B at the 5 % level. However, the standard deviations in group A were less than those in group B. This fact shows that variations of moisture content of logs in each sub-group were decreased by this sorting. In flat square, the difference in the average moisture content between group A and group B after kiln-drying was significant at the 5 % level. This fact suggests that sorting logs by estimated moisture content had some good effects on

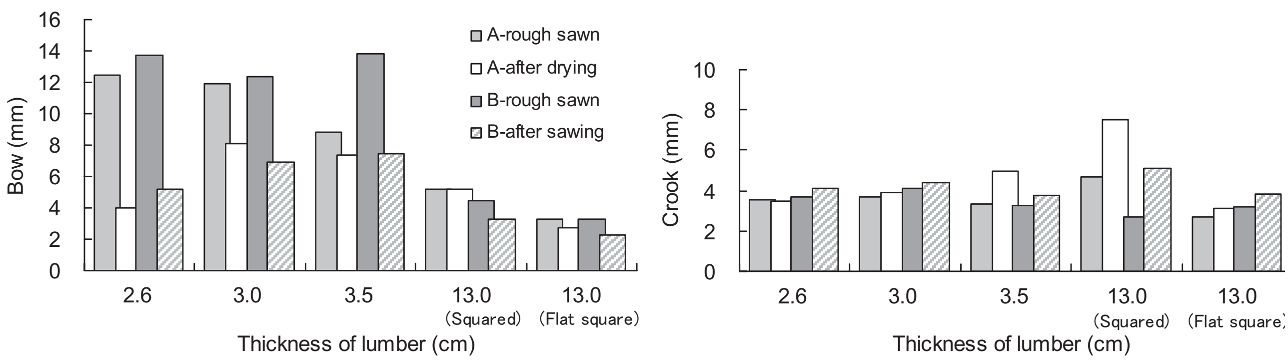

Fig. 4. The average bow and crook in each thickness of lumber.

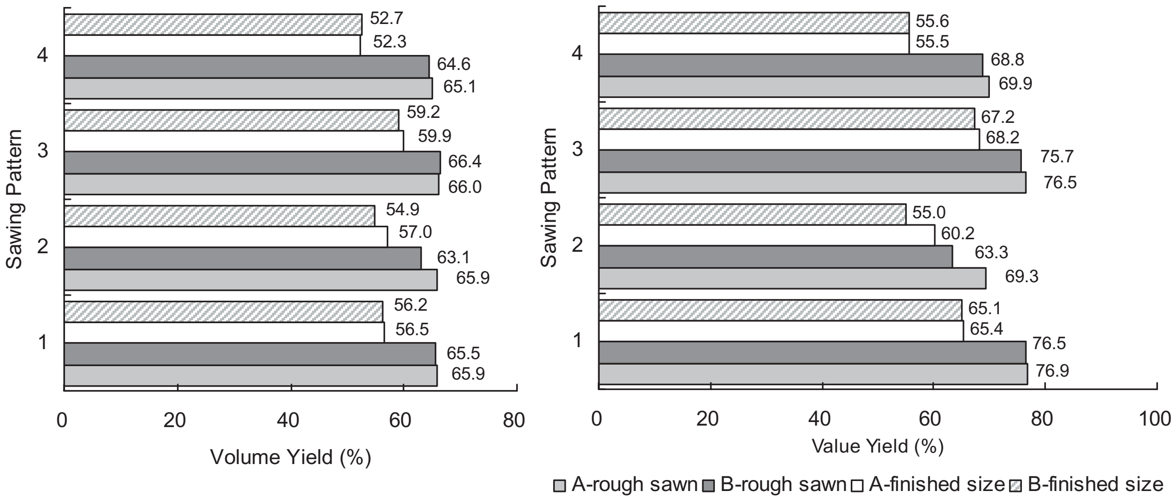

Fig. 5. The average volume and value yields in each sawing pattern.

efficiency of kiln drying particularly in large sized lumber.

Fig. 4 shows the average bow and crook of rough sawn and kiln dried lumber in each thickness. In the bow of rough-sawn lumber of 3.5 cm in thickness and crook of kiln-dried lumber of 3.5 cm in thickness, there were significant differences between group A and B at the 5 % level. However, it was not found the clear difference in the overall tendency to group A and B, because the bow and crook were not taken into consideration in this study.

Fig. 5 shows the average volume and value yields in each sub-group. There were significant differences between group A and group B in value yield of sawing pattern 2 at the 5% level. However, for these yields of other sawing pattern, clear differences between group A and B were not observed. Although it was not clearly whether Young's modulus and moisture content affect the volume and value yields or not in this study, we suggest that sorting logs considering usage cause decreasing of reject of products, as a result lumber yield would be improved.

In this study, the sorting logs proposed in consideration of the following two points. First, the flat squares and laminae which demanded strength as structural lumber were sawn from logs with higher Young's modulus, and the squared lumbers and boards which didn't demand high strength were sawn from logs with lower Young's modulus. Second, the large sized lumbers as flat squares and squared lumbers, which were difficult to kiln-dry, were sawn from log with low moisture content, and the small sized lumbers as laminae and boards were from log with high moisture content. When logs were sorted by Young's modulus and moisture content, the rate of rejection lumber because of low Young's modulus could be decreased, and the variations of the moisture content before and/or after kiln-drying could be kept low. Thus, we suggest that sorting logs considering the qualities such as moisture content and/or Young's modulus effects decreasing of rejection lumber, as a result lumber yield would be improved.

Conclusion

The purpose of this study was to examine adequate sorting method of logs for producing efficiently lumber which meets the demands on qualities as building members. We investigated the influence of sorting logs by Young's modulus and moisture content on sawn lumber yields and qualities aiming for efficient lumber productions.

The average moisture content measured immediately after sawing of the squared and flat square lumber was lower in group A than in group B, since the squared and flat square lumber were sawn from lower moisture content logs in group A.

In the lumber of 3.0 cm in thickness and 13.0 cm in width the frequency of the lumber of higher Young's modulus was higher in group A than in group B. Since the rate of rejection lumber according to E_{fr} in group A would be lower than in group B, sorting logs by E_{fr} would be useful for efficient production of reliable sawn lumber as building member.

Although the relationship between Young's modulus and moisture content and volume and value yields was not clearly, we suggest that sorting logs considering the qualities such as moisture content and/or strength effects decreasing of rejection lumber, as a result lumber yield would be improved.

It is concluded that there is a possibility of producing lumber suitable for the end use efficiently by sorting logs considering Young's modulus and moisture content and sawing the logs using the optimal sawing patterns.

Acknowledgement

This study was financially supported by Research grant #200005 of the Forestry and Forest Products Research Institute.

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丸太の仕分け方法が製材品の歩止りと品質に及ぼす影響 －ヤング係数と含水率－

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要 旨

日本における製材品の主要な使用先は建築用材であり、建築用材としてより高い品質が求められるようになった昨今では、最終用途を考慮した製材生産を行うことが重要となってきている。丸太を適正に仕分けし最適な木取りで製材することは、効率的な製材生産に不可欠である。本研究では、効率的な製材生産を目的として、丸太段階のヤング係数と含水率による仕分けが製材品の歩止りと製品品質に与える影響について検討した。

60 本のスギ中丸太をヤング係数の分布がほぼ等しくなるように 2 つのグループ（グループ A,B）に分けた。グループ A の丸太は縦振動法で測定した動的ヤング係数 E_{fr} と丸太の見かけの密度から推定した含水率により 4 つの適した木取りで製材し、グループ B の丸太は仕分けせず任意に選んだ木取りで製材し、製材品の歩止りと品質を調べた。含水率の低い丸太から製材した A グループの正角と平角の含水率は、グループ A のほうがグループ B のそれらより低かった。厚さ 3.0cm、幅 13.0cm の挽き板において、ヤング係数の高い製品の頻度はグループ A がグループ B より高かった。これらのことから、ヤング係数と含水率を考慮して丸太の仕分けを行い最適な木取りで製材することにより、用途に適した製材品を効率的に生産することが可能であることが明らかとなった。

キーワード：丸太仕分け、製材木取り、製材歩止り、含水率、ヤング係数

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