Analysis, Using a Three-dimensional View, of the Process of Tree Growth (2)

— Distributions of basic density and fiber direction responding to a stem form —

by

Yuhnosuke HISHINUMA*, Ryogo NAKATA**, and Kazumi FUKAZAWA**

三次元表示法による樹木の成長過程の解析（2）

— 樹幹形に対応した容積密度と繊維走向の分布 —

菱沼勇之助*　中田　了五**　深沢　和三**

Abstract

The stem form of trees is diverse and affects the properties of wood, formed in the process of tree growth under different environment conditions. However, studies on the variation of wood quality responding to a stem form are few. The authors collected two stems of Abies *sachalinensis* from the Nakagawa Experiment Forest, and examined basic density and fiber direction in the stems. The distributions were illustrated 3-dimensionally, a method of which proved beneficial for grasping the relation between these properties and stem form.

Key words : *Abies sachalinensis,* Nakagawa Experiment Forest, Stem form, Basic density, and Fiber direction.

I. Introduction

Generally, the stem form of trees differs from each other, not only in terms of individual genetic characteristics, but also in the environment conditions and influences the properties of wood. In the study of wood formation, the properties of wood built up in the process of tree growth are important[1]. However, comparatively few studies have been done on the variation of wood quality responding to stem form. In forest management, the tree form classification method has been used widely for qualitative thinning. It classifies

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* College Experiment Forests, Faculty of Agriculture, Hokkaido University.

* 北海道大学農学部演習林

** Laboratory of Wood Physics, Department of Forest Products, Hokkaido University.

** 北海道大学農学部林産学科木材理学講座

trees only on the basis of size, such as tree height, and crown development, as well as defects in the stem, and crown appearance. Consequently, wood quality is neglected. Furthermore, it is assumed, in stem analysis methods, that the stem of a tree erect straightly and its crosscuts are perfect circles.

In order to grasp visually the actual form of trees as faithfully as possible, one of the authors developed a new 3-dimensional graphic viewing method, and reported the mutual relations between stem, annual ring structure, and movement of pith location in the part 1 of this Journal[2]. In this paper, the authors applied this method and expressed 3-dimensionally the distributions of basic density and fiber direction in a stem. These qualities are very important considerations when using wood, because basic density is regarded as an index of wood strength, and irregular fiber direction results in loosened grain and also weakens the strength of sawn lumber. Untile now, the studies on distributions of specific gravity, fiber direction, and other properties in the stem of *Abies sachalinensis* or other coniferous trees have been reported 2-dimensionally[3,5-8].

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II. Materials and Methods

1. Tree samples

Two *Abies sachalinensis* Mast. were collected from compartment No. 211 of the Nakagawa Experiment Forest, Hokkaido University, on May 8, 1990. As shown in Table 1, these trees were about 140 years old. No. 1 was a big tree, designated Type-I in the tree form class, while No. 2 had been suppressed by No. 1, as they were within 30 cm each other, and was designated Type-III.

Table 1. Description of sample trees

	No. 1	No. 2
D.B.H (cm)	39.3	16.4
Tree height (m)	21.50	8.42
Crown height (m)	11.0	3.7
Tree Age (year)	147	140
Tree from class	I	III

Details of the trees are described in the previous paper[2].

2. Measurement of crook of trees

The trees were felled after red line was drawn perpendicular to the ground. The trees were then transported to a flat yard, and the remaining branches were cut off. A measuring tape was stretched from the butt end parallel to the red line. The distance between the stem and the tape was measured at 1-meter-long intervals in the directions of north-south and east-west, so that the crook of the trees was correctly expressed to allow graphic reproduction of the original condition.

3. Sampling of disks

In the yard, the stems were cut to logs 2 meters long, and several disks 5 to 10 cm thick, without defects such as knots or deteriorated parts, were prepared from each log. The disks obtained were used for measurement of basic density, fiber direction, and determination of the fresh moisture content in the laboratory.

4. Method of stem form description

The stem form description was based on the program of Triphony Digital Craft (3 D) by Zeit Co., and illustrated on an NEC PC 9801 VX Computer display as follows :

1) Firstly, the distance between pith and bark on each disk was measured in 8 directions, and co-ordinate values of the octagon obtained and the height of each disk were input through 3 D.

2) As no disk from ground level was available, an artificial one was made by the nearest disk and also the values were input.

3) Secondly, the deviation of the crook was transcribed and a 3-dimensional view of the stem form was achieved on the display.

5. Measurement of basic density

Specimens for the measurement of basic density were prepared : Each disk of No. 1 and No. 2 was cut into blocks at 2 cm and 1 cm, respectively, from pith in the four directions north, south, east, and west. The volume of the specimens from No. 1 was calculated by measuring them as parallelepipeds with a pair of calipers, after soaking in water to more than the fiber saturation point of wood, while that from No. 2 was determined by using a mercury picnometer. It was weighed on an electronic scale after being dried at 105°C. The basic density (g/cm^3) was expressed on the basis of dry weight to water-soaked volume.

6. Measurement of fiber direction

Only the No. 1 sample was used for the measurement of fiber direction. This was based on splitting each disk with a small hatchet and a hammer, and measuring the degree of inclination of fiber direction from a base line drawn on the crosscut face of disks successively at 10 annual ring intervals under the following conditions :

1) The measurement was only confined to the north side.

2) On the basis of the inclination angle of fiber direction of the disk nearest to the ground, that of the next disk was added to the previous angles, and this manner was repeated. successively.

3) The inclination angle of a given disk was assumed not to change till the next disk, thus the lines of the inclination in the stem were drawn through computer treatment.

4) The inclination of fiber direction was achieved by illustrating the figures from 6 successive 60-degree-divided directions.

III. Results and Discussion

1. Stem form

The top and side views of No. 2 tree disks are shown in Figs. 1 and 2. They show that the tree crooked to east-west in the middle of the stem, but the average inclination angle was as low as 2°. The arrangements of No. 1 and No. 2 are shown in Fig. 3, illustrated from the 6 directions. As the trees were only 30 cm apart, No. 2 had been remarkably suppressed by No. 1, and the growth of No. 2 had been extremely restrained. The change of pith position in the stem of the two trees was apparent by this method also.

2. Basic density

Table 2 shows the statistical values of basic density. The average density of Nos. 1 and 2 were 0.384 and 0.416, resectively. That of No. 1, the dominant tree, was rather lower than that of No. 2, the suppressed tree, which had narrow annual rings. This indicates that, generally, the narrower the annual ring width, the higher the density in coniferous

Table 2. Statistical values of basic density of sample (g/cm₃)

	No. 1	No. 2
Mean	0.384	0.416
Max.	0.638	0.653
Min.	0.207	0.293
Standard deviation	0.041	0.065
(Number of measurement)	(428)	(135)

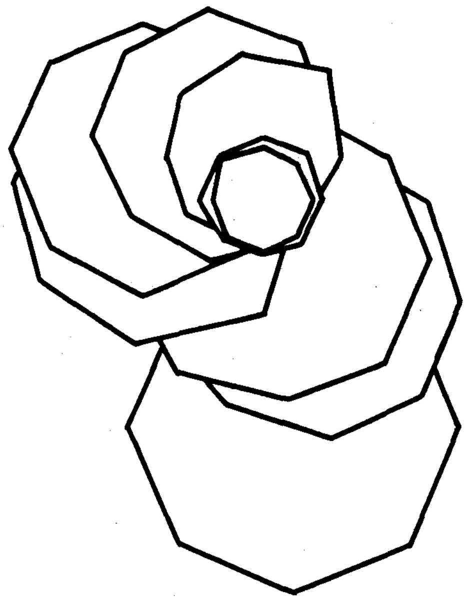
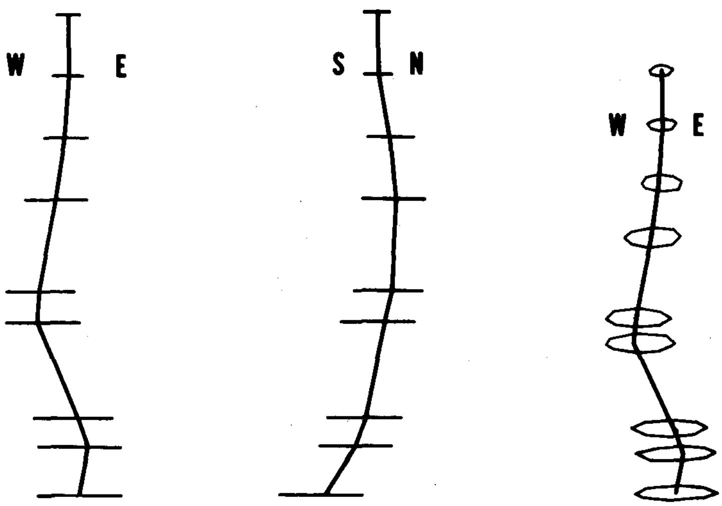


Fig. 1. Top view of tree disks of No.2.

trees. Meanwhile, the coefficients of variation of basic density were 10.7% and 15.6% for No. 1 and No. 2, respectively. Fig. 4 shows the frequencies of basic density. The diagram of No. 1 is a one-peak type, while that of No. 2 is a two-peak type. The distributions of basic density in the stems of No. 1 and No. 2 are shown in Figs. 5 and 6, respectively. Although the 3-dimensional view was illustrated on the computer display, the two distributions from east-west and north-south directions drawn by a 2-dimensional view can be rather visually grasped responding to the stem form:

No. 1 : The top part has the highest density (Mark E), while the inner part, equivalent to juvenile wood, has the lowest (A). The part of higher density (C) extends from the butt



(A) East-West (B) North-South (C) Perspective

Fig. 2. Side view and perspective of tree disks of No.2.

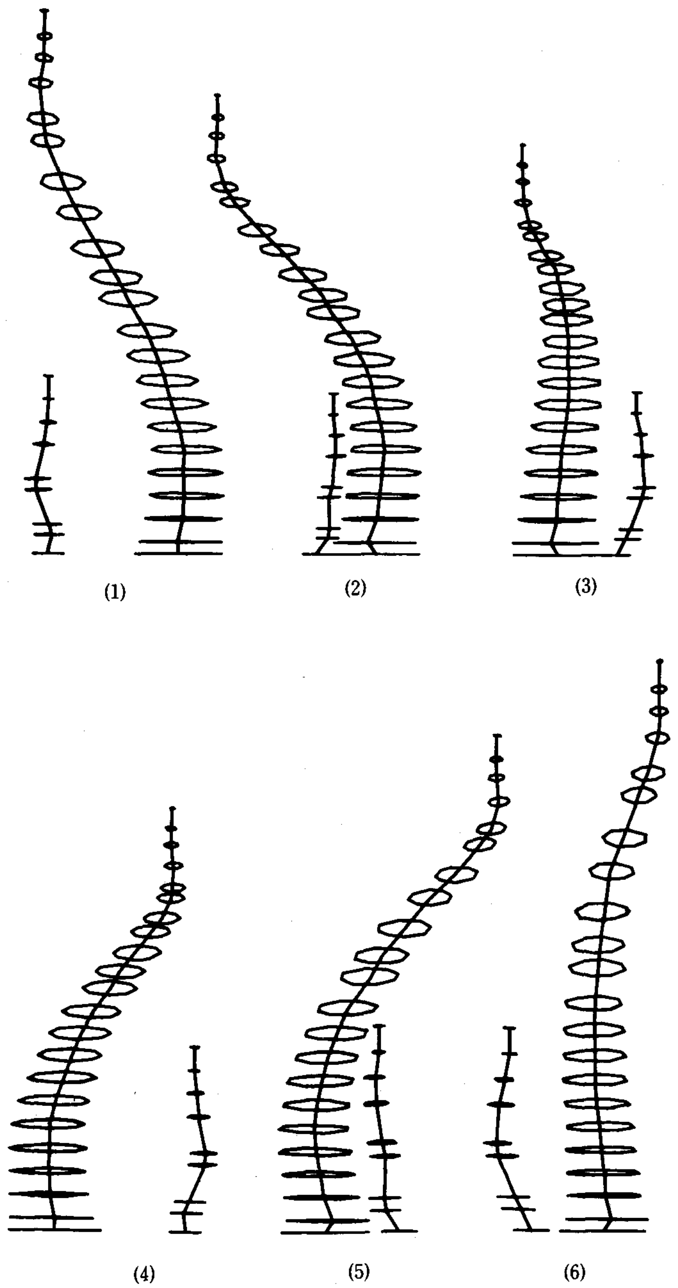
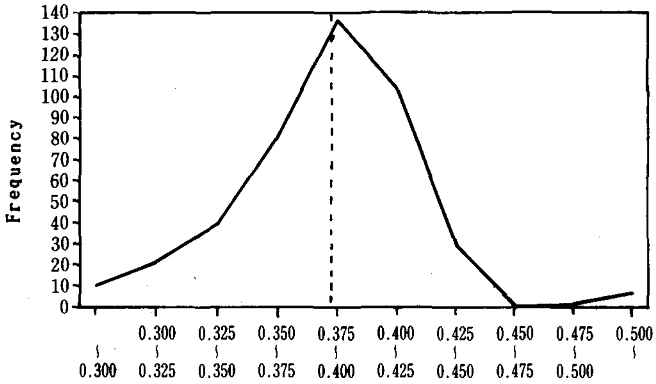
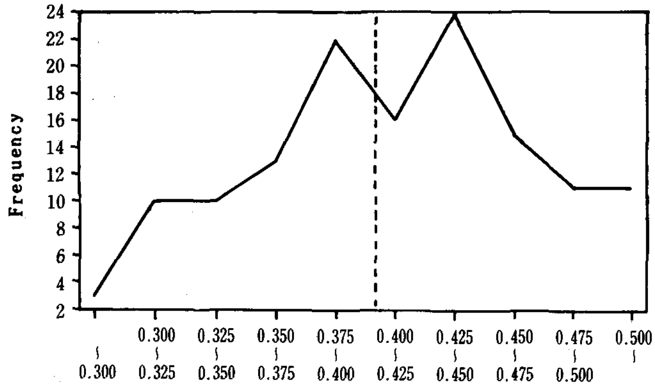


Fig. 3. Stem forms of sample trees of No.1 and No.2 revolved every 60 degrees by a computer program.



Frequency Basic density (No. 1)



Frequency Basic density (No. 2)

Fig. 4. Frequencies of basic density in the stems of sample trees.

toward the upper side of the leaned stem. The occurrence is opposite that of compression wood, which has a high density in the lower side of a leaned stem. Accordingly, the No. 1 tree did not have areas of the compression wood, even though it was crooked. This was proved also by the observation of disks with the naked eye. Although the correlation coefficients between basic density and annual ring width was not examined, this tree seemed to show a definite relation between the two factors.

This type of distribution coincides with Type V (old *Abies* trees) proposed by VOLKERT[9].

No. 2 : As mentioned above, since No. 2 had been suppressed by the adjacent tree (No. 1), its growth had been remarkably hindered. Consequently, the basic density was high, especially in the inner part. The density, however, was low in the parts from more than 3 meters high, owing to the widening the annual ring width by release of this suppression. This type is similar to Type II (young *Abies* trees) proposed by VOLKERT[9].

Meanwhile, the relation of density to annual ring width in No. 2 stem showed that

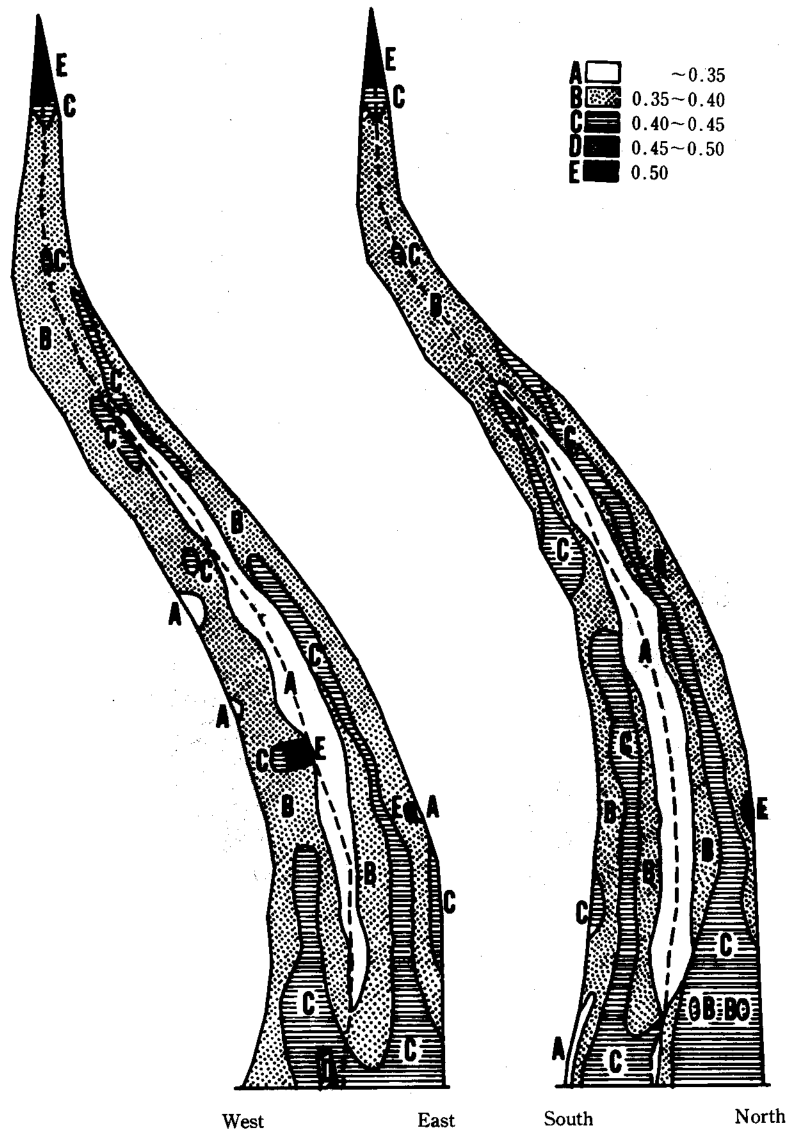


Fig. 5. The distribution of basic density responding to the stem from of No.1.

average annual ring width in Mark A was 2 mm, in Mark B about 0.7 mm, and in Marks D and E less than 0.1 mm. Consequently, a clear relation exists between annual ring width and basic density. Portions of compression wood were observed in several locations in the stem.

3. Fiber direction

Fiber directions in No. 1 are shown in Fig. 7(1)-(6), illustrated through 3 D. These figures describe the inclined lines drawn from the angles measured at 10-year intervals

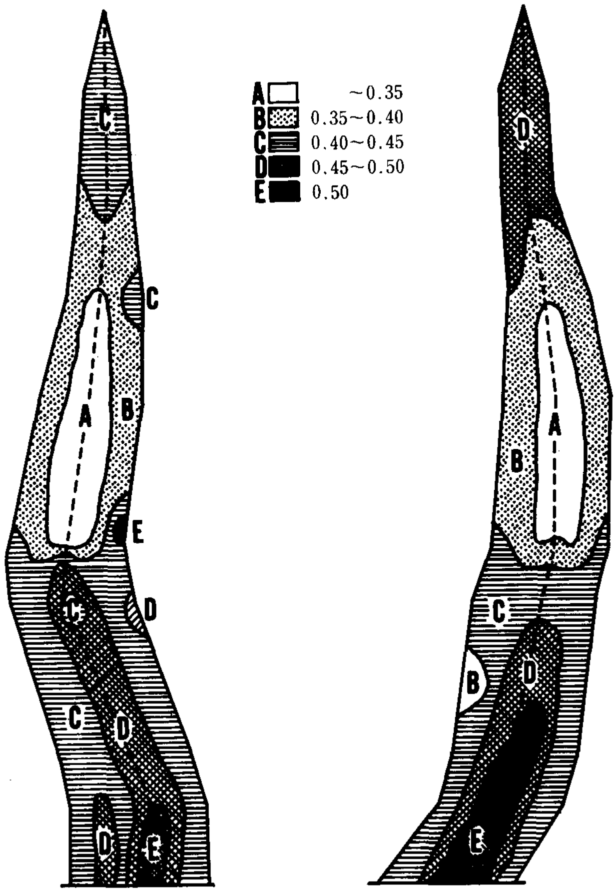


Fig. 6. The distribution of basic density responding to the stem from of No.2.

from the first to the 147th annual ring from bark together with disks observed from 6 directions. Fig. 7 also shows that the frequency of the rotation of fiber direction was 1. 5 to 2 times from butt to top in the No. 1 stem. Concerning this, OZAWA[6], who examined the latewood formed at the same age in several trees, indicated by vertical and horizontal diagram that the frequency of rotation was 4.5 times in *Larix kaempferi,* 1.5 times in *Cryptomeria japonica,* 5.5 times in *Pinus densiflora,* and none in *Chamaecyparis obtusa.*

Fig. 8 also shows the radial variation of fiber direction in No. 1. The inclination of fiber direction is large between the 20th and 30 th annual ring (tree 117 to 127 years old) in the lower part of the stem. The tendency of the inclination indicates that it rotates to show S-type while young, but that the rotation changes gradually to Z-type as it ages. This fact coincides with previous reports on the fiber direction in the *A. sachalinensis* stem[5,7].

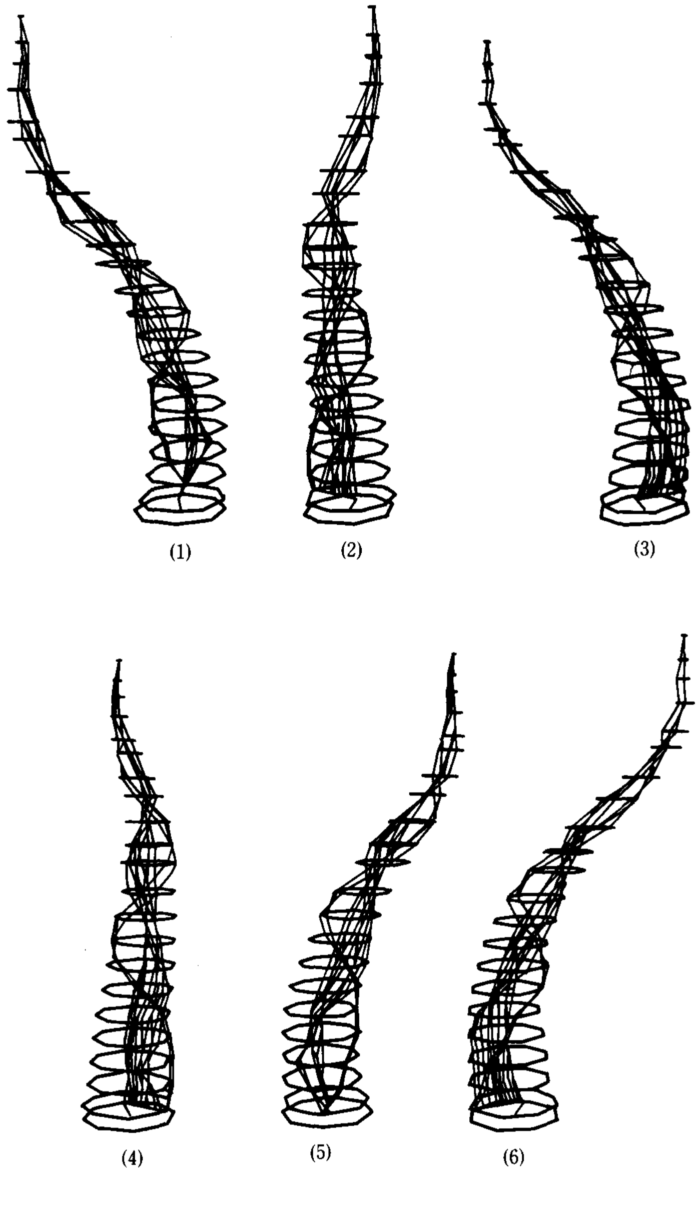


Fig. 7. Fiber direction responding to the stem from of No. 1 revolved ever 60 degrees.

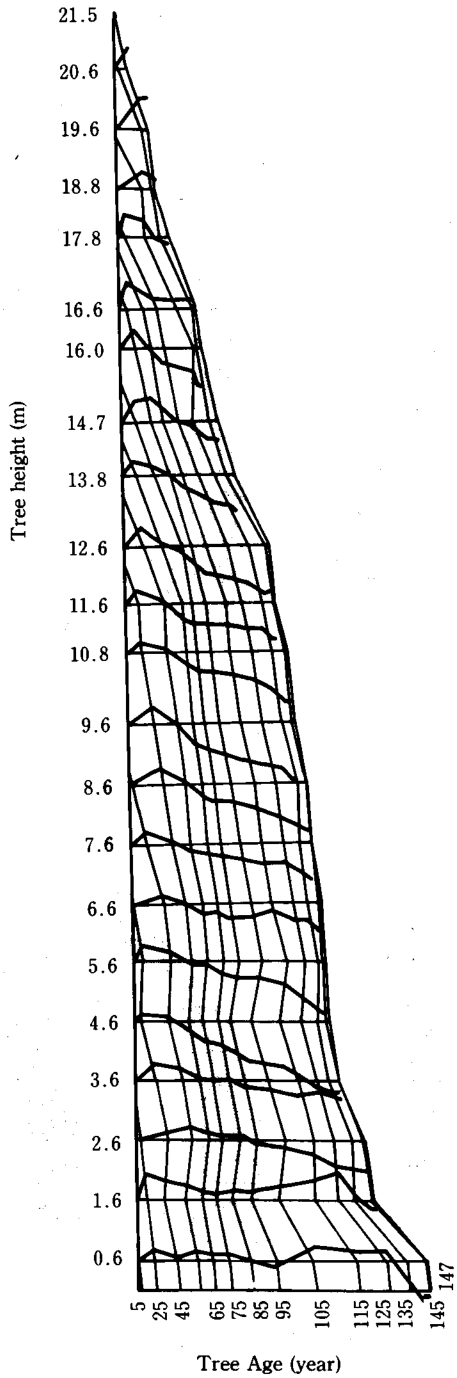


Fig. 8. Radial varaiation of fiber direction in the stem of No.1.

IV. Conclusion

The distributions of basic density and fiber direction in the stem of two *Abies sachalinensis* were illustrated, responding to stem form, 3-dimensionally with a computer. The authors were able to elucidate the inner state of the stem in detail. The authors think that this method is useful for understanding the change of wood properties in the process of tree growth under different natural conditions, and also for wood utilization.

Hereafter, the authors hope to investigate a new method of showing fiber direction by dying stems of standing trees with pigments taken up from roots or branches 2 to 3 days before cutting, so that the fiber direction will be more clearly expressed, together with water movement in the stem, a very significant part of wood science.

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摘　　要

一般に樹幹の形状は多様である。したがって，樹幹は通直で断面が正円であり，髄の位置が中心にあるとは限らないし，大なり小なり曲がっていることが多い。これらは完満，梢殺あるいは曲幹などと表現され，収穫作業における選木基準の重要な判定要素の一つになっている。しかし，このような樹幹形と量的および質的な樹幹内変動に関する研究は極めて少ない。そこで筆者らは，これを解明するための方法の一つとして，まず現実の樹木の形状をできるだけ忠実に表示して視覚的に特徴を把握し，この結果から樹幹内変動の詳細な解析をすすめるための三次元表示法について検討をすすめている。今回は，北海道大学中川地方演習林のトドマツ天然木を対象としたもので，このうち本研究の第1報において，この3次元表示法が樹幹形と年輪幅の広狭あるいは髄の位置との相互関連性の把握に有効であることを明らかにした[2)]。本報では材質構成とくに容積密度，繊維走向を測定し，これらと樹幹形との相互関連性につき考察を行った。

供試木は1号木と2号木の2本で，これらの測定結果はTable 1に示すとおりで，胸高直径，樹高および枝下高においていずれも1号木は2号木を上回っていた。しかも両者はほぼ30 cmの間隔で連接し，2号木は1号木の被圧下にあり，これらの樹齢は147年と140年でほぼ類似していた。樹幹の曲がりは，伐採後枝払いをして地面に寝かせ，垂線からの隔たりを南北および東西方向で測定した結果，1号木は地上高5 m，2号木は同じく1 mから上部に向かって曲がりがみられ，梢頭で1号木は南北および東西方向いずれも70 cm，2号木は南北方向14 cmおよび東西方向6 cmであった。ただし，地面に寝かせて測定したためこれらの値には，自重による影響も含まれている。なを詳細については第1報に述べてあるのでここでは省略する。

供試円盤は節その他の欠点のあるものを除き，ほぼ1 m間隔で5～10 cmの厚さのものを採取し，容積密度および繊維走向の測定に供した。樹幹形は，Zeit社のZ's Triphony Digital Craft (以下3Dと呼ぶ) のプログラムを使用して描画する方法を採用し，これらをコンピューター・ディスプレー上に表示した。この方法は第1報のそれと異なるが，第1報の場合は視点の変化に対応してその都度座標値を変換し描画する方法であるのに対し，本報によるときは3D図上で最初に座標値を入力するだけで視点を自由に変えた各高さの円盤の空間的位置が把握でき，描画がより簡便であることにより採用した。また，容積密度の測定は，髄を中心に東西南北4方向ごとに作成したブロックを用いて行った。この場合，容積は試料を水につけて繊維飽和点以上の含水率を求めて測定した。さらに，繊維走向は1号木のみを対象とし，樹皮から10年輪ごとの傾角を割裂法により測定した。この解析は北方向のみに限り，最も地上高の低い円盤を基準として，地上高の上昇にともなう樹幹内での同一年次の傾角の変化を把握することにつとめた。

以上の方法による解析の結果，樹幹形の表示については第1報の方法に比べより簡便で

あったが，断面が8角形で示されるため視覚的な実物感にやや難があり，描写ソフトの改良が望まれる。容積密度の分布について，1号木はVolkert(1941)による樹種別容積密度分布のモミ類老齢における移行形のタイプに相当し(Fig. 5)，2号木は同様にモミ類の幼齢型に相当する(Fig. 6)ことを明らかにすることができた。ただし，これらはコンピューター・ディスプレー上にカラーで区分して3次元で表示することができたが，カラー表示によらない場合は複雑になるため，本報では2次元で表示した。繊維走向の表示および解析は1号木のみを対象としたが，これによるとFig. 7に示すとおり，樹幹下部では樹皮から20〜30年輪間隔で傾角が大きく異なる傾向がうかがわれ，全体として幼時にS旋回，後にZ旋回をしめし，トドマツに関するこれまでの報告[5,7]と一致している。ただし，今回は繊維走向と樹幹の曲がりや偏心との関連については明らかにできなかった。

以上本報では，材質変動としての樹幹内の容積密度分布および繊維走向と樹幹の曲がりや偏心との関連性を十分把握できなかったが，3次元表示より視覚的に材質変動の特徴を知り得ることがわかった。今後は解析の目的に対応するより効果的な表示を行うためのコンピューター処理システムを開発する必要があろう。