Analysis, Using a Three-dimensional View, of the Process of Tree Growth (1)

— A new graphic method for stem analysis responding to a stem form —

By

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三次元表示法による樹木の成長過程の解析（1）

—樹幹形の表示の方法—

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Abstract

In general, the shape of each tree differs from others, in terms of its crook, fullbody size, and other factors. This multiformity is due not only to individual characteristics but also to many environmental factors including soil, weather, and other conditions. Almost nothing, however, is known about the relation between these conditions and tree shape. Many methods can be conceived in an attempt to solve this question. First, the author developed a method which allows to visually grasp the characteristics of the shape of actual trees by graphic display as faithfully as possible. In this method, the author measured stem crooks and annual ring structures of cross sections at various heights above ground along 8 directional lines, and displayed a 3-dimensional view of a stem. As a result, the author was able to become aware of interesting mutual relations between stem, annual ring structure, and movement of pith location.

Key words : 3-dimensional view, stem analysis, stem form, annual ring width, pith location

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I. Introduction

As one of the methods to research secular change of tree growth, stem analysis has been conventionally used in forest mensuration[1,2]. This method analyzes the average secular changes of tree height, diameter, and volume, premised on the assumption that trees are erect and straight, and every cross section at a specific level is a perfect circle. In addition, a 2-dimensional stem analysis chart of a longitudinal section is made, in order to visualize the characteristics of these changes. On the other hand, stems of actual live trees in general are variegated, being crooked to various extents and unevenly tapered. In addition, the growing process of tree height and diameter is not uniform, and structural wood quality is diverse. If an analytical method somehow premised on this diversity is established, it will be an effective means to understand not only the qualitative growth process, but also structural quality, thus presenting extremely significant data for forest dynamics and dendrochronological analysis[3]. An example of the methods used for this type of analysis is to display late wood ratio or distribution of basic density[4,5,6], but this is still not sufficient for grasping the relations between these factors and stem annual ring structure at various locations.

Therefore, in this study, the author is examining a new possible stem analysis method with 3-dimensional view, which allows for an easy way to grasp the total relations between qualitative changes during the growth process and qualitative structure, by means of visualization of the stem and annual ring structure, while remaining as faithful as possible to actual conditions. In this report, the author would like to discuss the method and the effect of a new analysis chart display which the author established through the study.

In additional remark, this research is a part of the "Studies on Methods of Colletion and Analysis of Information with Annual Rings" which was specified by the Ministry of Education in fiscal 1989 and 1990. And the author would like to offer his sincere thanks to Prof. Kazumi FUKAZAWA, Department of Forest Products, Hokkaido University, for his kind guidance concerning preparation of this report, Assoc. Prof. Jun OHTANI and Instr. Yuzo SANO, Department of Forest Products, Hokkaido University, for their guidance in the measurement of the sample trees and in the display method of the stem analysis chart, and Assoc. Prof. Yukio AKIBAYASHI and other staff members of the Nakagawa Experiment Forest, Hokkaido University, for their help in the collection and cutting of sample trees.

II. Collection and Measurement of Sample Trees

1. Outline of Collection Site

The two sample trees used in this study called "No. 1" and "No. 2", are both *Abies sachalinensis* Mast. (Photo. 1). These trees were designated to be collected in compartment No. 211, Nakagawa Experiment Forest, Hokkaido University (compartment No. 3, the experimental forest by control method), dated May 8, 1990 (Fig. 1). As a result of inspection of trees within a 10m radius of "No. 1", tree species composition was found to be as follows : a total of 9 conifers, all *Abies sachalinensis* Mast. with a volume of 7.45m^3 ; and a total of 6 broad-leaved trees including species of *Quercus mongolica* var. *grosseserrata* Rhed. et Wils, *Acer mono* var. mayrii Koids, *Sorbus commixta* Hedl, and *Betula* *ermanii* Cham. with a bolume of $0.22m^3$. Therefore, there is a total of 15 trees, with a total volume of $7.67m^3$ (or 509 trees, with a volume of $244m^3/ha$). The crown density was 54%, and tree heights were within the range of 5m – 22m. It may said that, for a natural forest of northern Hokkaido, this is a type of multilayer stand, with relatively high growing stock and medium density. The undergrowth was predominantly dominated by *Sasa kurilensis* Makino et Shibata.

As for geographical characteristics, the site was 145m above sea level, and the ground had a medial gradient of 18 degrees facing southward. The soil was Nishi-chirashinai Formation from the Upper Yezo Group of the Cretaceous Period[7]. As for the climate, the annual average temperature in the region is 4.9° C, with great variations in temperature, the annual average precipitation is 1,650mm, and annual maximum snowfall 194cm. The region has inland temperatures, and it is known as one of the coldest and snowiest districts in Hokkaido[8].

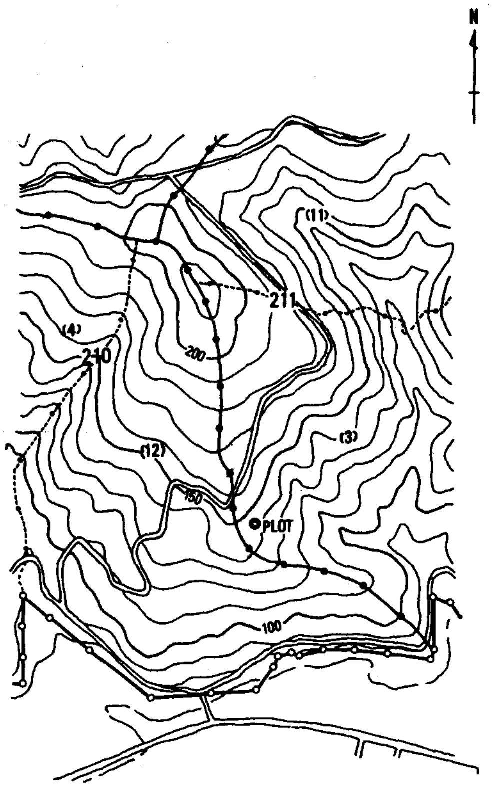


Fig. 1. A location of collecting sample trees.

2. Measurement of Stem Crook

Prior to collection of the sample trees and in order to allow graphic reproduction of the original natural condition, perpendicular lines were marked with red paint on the east, west, south, and north sides of the stem, as shown in the left of Fig. 2. Then the trees were

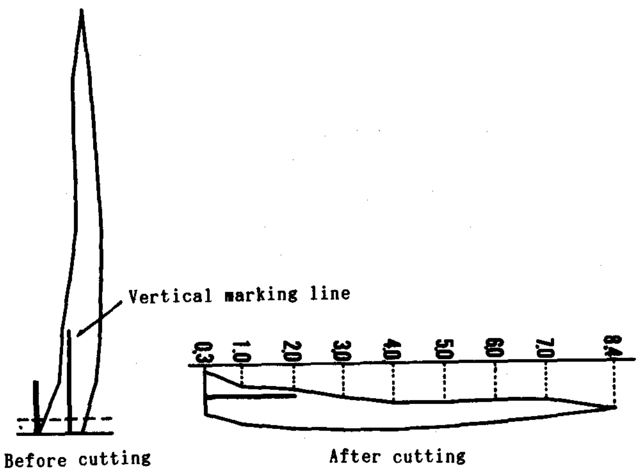


Fig. 2. Measuring method of stem crook.

cut at 0.3m above the ground. Immediately after cutting, the tree height was measured, the number of adherent branches counted, the thickness and length of the biggest branch measured, then all the branches were cut off, and only the stem was carried to a flat timber yard to measure its crook. As for the method of measuring the crook, a tape was stretched parallel to the perpendicular line to serve as a reference, and the distance from the reference line to the stem was measured at every meter, as shown in the right of Fig. 2 (Photo. 2). This method, however, does not take into account the crook caused by the stem's weight when it is laid on the ground. The measurement, as shown in Fig. 3 and Table 1, proved that the stem is crooked. In particular, "No. 1", which seemed to be standing straight in the original condition, showed significant crook above the height of 5 m.

Table 1. Stem crook of sample trees

Height above ground (cm)	Distance from verical line (cn) No. 1 Directions S～N	E～W	No. 2 Directions S～N	E～W
0	0	0	0	0
1	0	0	8	0
2	0	0	9	5
3	0	0	12	8
4	0	0	14	6
5	0	1	14	5
6	1	5	15	5
7	2	9	14	6
8	5	13		
9	7	18		
10	13	25		
11	18	32		
12	23	40		
13	31	48		
14	40	55		
15	52	62		
16	59	66		
17	67	70		
18	70	70		

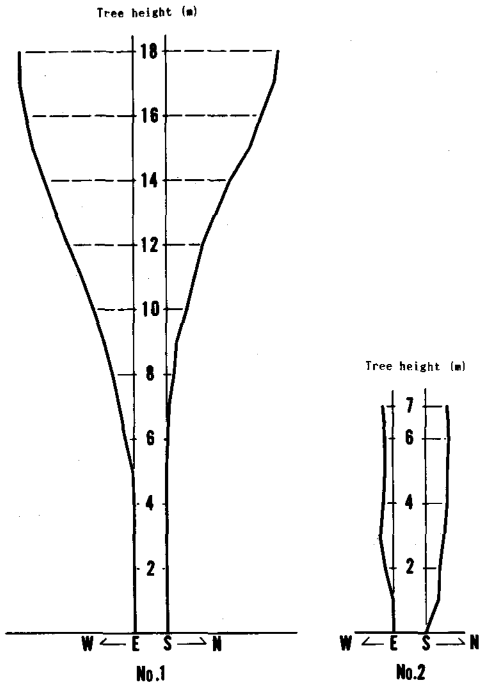


Fig. 3. situations of stem crook.

3. Location, Age, and Site of the Sample Trees

Location : Relative locations of the sample trees are shown in Fig. 4, by conventional stand transect method, displaying all the trees within 10m radius of "No. 1". Most of the trees are located on the east side of the logging road, for the convenience of cutting for experiment by control method, and "No. 2" was located approximately 30cm west of "No. 1".

Age : The number of annual rings of "No. 1" and "No. 2" at the height of 0.80m were 128 and 121, respectively. On the other hand, they were shown that the neighboring trees took 19 years to reach the same height. From this result, the author estimated the age of "No. 1" to be 147, and "No. 2" to be 140. The maximum age of *Abies sachalinensis* Mast.

in general is known to reach 190 years, with a height of 25m, according to past research in the Nakagawa Experiment Forest[9,10]. Therefore, although these trees are old, they seem not to have yet reached their peaks.

Height : Size and other factors of the sample trees are shown in Table 2. Heights of the trees in this area with more than 6cm of D.B.H. were within the range of 8.00m – 21.50m, "No. 1" was the tallest at 21.50m, and "No. 2"the shortest among the conifers at 8.42m, as shown in Fig. 4.

Tree crown width : Figure 4 shows that the tree crown of "No. 1" was completely covering that of "No. 2", and approximately one fifth of the crown of "No. 2" was covered by that of another *Abies sachalinensis* Mast. situated north of "No. 1". Table 2 shows the

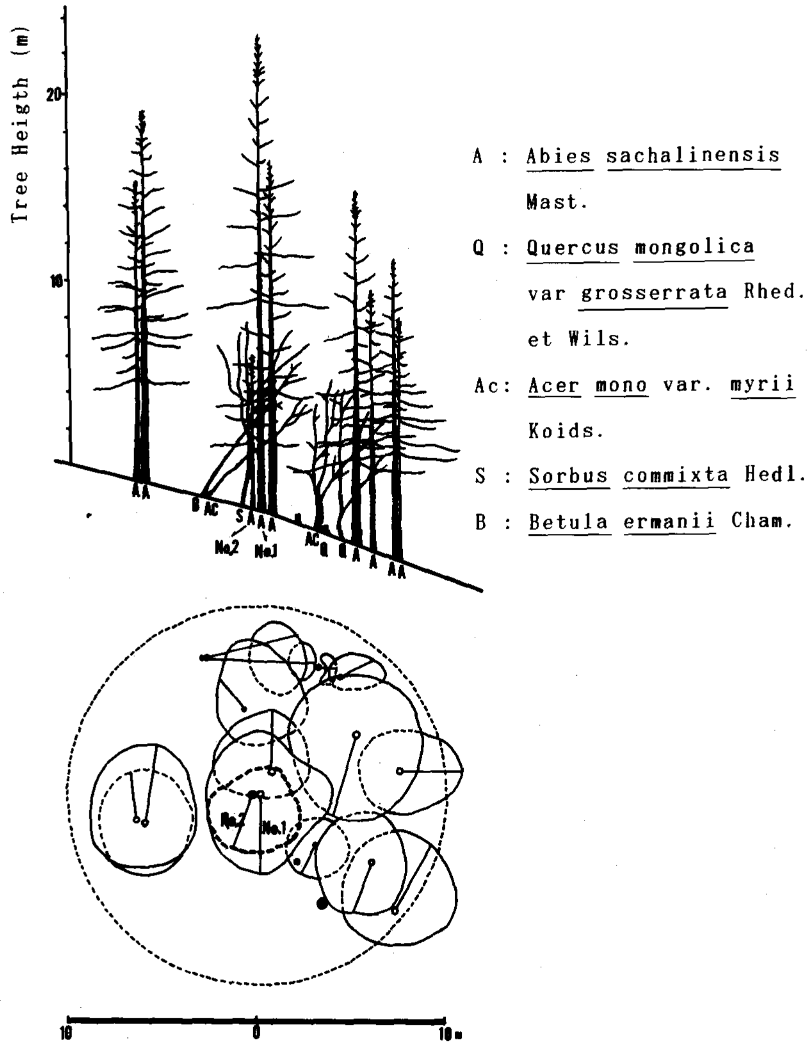


Fig. 4. Projection of tree transects.

Table 2. Size of sample tress

Sample No.	D.B.H. (cm)	Tree height (m)	Crown height (m)	Crown length (cm) East	West	South	North
1	39.3	21.50	11.0	3.40	4.30	3.90	2.80
2	16.4	8.42	3.7	1.50	3.40	2.70	3.10

tree crown width of the sample trees. The cross section area of the crown of "No. 1" was 41m^2, and that of "No. 2" was approximately half of that, 22m^2. The eastward radius of the crown of "No. 2" was less than half that of "No. 1".

D.B.H. : D.B.H. of the trees in the same area ranged from 7.0cm – 46.2cm. That of "No. 1" was 39.3cm, and of "No. 2", 16.4cm as shown in Table 2.

Table 3. Number of adhering branches

Direction	Sample trees No. 1 Live	No. 1 Dead	No. 2 Live	No. 2 Dead
N (NW～NE)	16	25	6	7
E (NE～SE)	5	11	3	13
S (SE～SW)	2	30	4	6
W (SW～NW)	5	7	7	4
Total	38	73	20	30

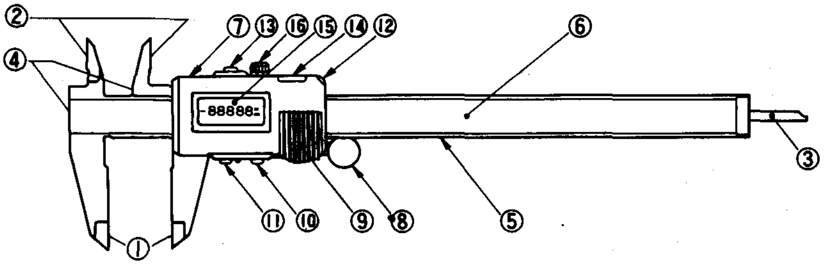
Adherent condition of branches : The adherent condition of branches is as shown in Table 3. "No. 1" had 111 branches including withered ones. By direction, the most branches, 41, were on the northern side, 32 on the southern side, 16 on the eastern side, and the least, 12 on the western side. The average rate of withered branches was 66%. In particular, the southern side had the most such branches, 94%, significantly more than the other sides. "No. 2" had a total 50 branches : the most, 16, on the eastern side, 13 on the northern side, 11 on the western side, and 10 on the southern side. The average rate of withered branches was 60%, and the greatest was 81% on the eastern side.

4. Collection of Disks

After measuring the crook of the stem, they were cut into two-meter-long logs and brought them back to laboratory. From "No. 2", eight disks without bark loss, abnormal annual rings caused by branches, or deterioration, were collected to measure annual ring width. The heights from which disks were taken were : 0.80m, 1.25m, 2.80m, 3.30m, 4. 80m, 5.80m, 6.80m, and 7.30m. Only one disk at a height of 0.80m was taken from "No. 1" to compare it with that of "No. 2".

5. Measurement of Annual Ring Width

As stated above, it is generally known from experience that the shape of an actual cross section is not necessary a perfect circle, and radius (pith as a center) and annual ring width are always different. Therefore, in this study, the author tried a new analysis based on measurement of annual ring width along each of the 8 directional lines. Measurements were carried out on each annual ring, along each of the 8 directional lines, starting from the pith. The author developed a new computer processing system for measurement data processing and calculation. This system was developed in cooperation with Sena Co. The system includes an electronic slide caliper (manufactured by Mitsutoyo ; maximum measurable length 20cm ; reading unit 1/100mm ; digital read-outs) connected by a special cable via an interface (SENA RS232C interface) to a micro computer (NEC PC－9801 VX), which processes the data. Kanri-kogaku-Kenkyusho's Lotus 1－2－3 (data process-



① Outside Measuring Faces ② Inside Measuring Faces
③ Depth Measuring Blade*1 ④ Step Measuring Faces
⑤ Main Blade ⑥ Scale Surface
⑦ Slider ⑧ Thumb Roller
⑨ Battery Lid ⑩ ON/ZERO Sw.
⑪ OFF Sw. ⑫ HOLD/DATA Sw.
⑬ Inch/mm Conversion Sw. ⑭ Output Connector
⑮ LCD Display ⑯ Clamping screw

Fig. 5. Electronic slid caliper.

ing system) is installed for calculation. Input from the electronic slide caliper can be easily done by operating the ⑫ HOLD/DATA switch attached to ⑦ Slider as shown in Fig. 5. As for the extremely narrow annual rings seen in "No. 2", however, a stereoscopic microscope is desirable for measurement.

Diameter and annual ring width at 0.00m, ground level, was obtained by proportional calculation in the same manner as in the conventional analysis method, based on the result of measurement at 0.80m and 1.25m above ground.

Table 4. Conversion fomulas of coordinate values

	X	Y
R_n	a	$b+R_n \cdot \sin\theta/m$
R_{ne}	$a+R_{ne} \cdot \cos45/m$	$b+R_{ne} \cdot \sin45 \cdot \sin\theta/m$
R_e	$a+R_e/m$	b
R_{se}	$a+R_{se} \cdot \cos45/m$	$b-R_{se} \cdot \sin45 \cdot \sin\theta/m$
R_e	a	$b-R_s \cdot \sin\theta/m$
R_{sw}	$a-R_{sw} \cdot \cos45/m$	$b-R_{sw} \cdot \sin45 \cdot \sin\theta/m$
R_w	$a-R_w/m$	b
R_{nw}	$a-R_{nw} \cdot \cos45/m$	$b+R_{nw} \cdot \sin45 \cdot \sin\theta/m$

Note : a, b ; X and Y-coordinate values of the pith.
θ ; Depression angle.
m ; Denominator of scale.

6. Stem Analysis Chart

1) **3-dimensional chart** : For visualization of the characteristics of any object, including its shape, 3-dimensional visualization is more advantageous, producing more information, than 2-dimensional. With that in mind, the author tried 3-dimensional viewing of stem in this study. In order to view the shape of a disk from a fixed height, the radius from the pith of each cross section (X_n : radius when tree is n years old) was converted to X and Y coordinates, when height is Z, and angle of depression is θ. Then additional was made corresponding to the scale (1/m). The conversion formula is as shown in Table 4. However, as for the length of radius in each direction R (cm), coordinates X and Y are followed by subscript characters indicating respective direction. For example, radius of direction N is expressed "R_n", and coordinates "X_n" and "Y_n".

X and Y coordinates at 0.00m, ground level, were obtained by proportional calculation in the same manner as in the conventional analysis method, as stated above, based on the measurements at 0.80m and 1.25m above ground. These coordinates were then used for the visualization.

The adjustable curve drawing system of Graphic Processor "HANAKO", produced by Just System Co. was used of the construction. This system draws and constructs a graphic with an on-screen plot by means of coordinate data input. By this system, drawing of closed curve is achieved by plotting at least three coordinates. For instance, Fig. 6 shows a closed curves drawn by plotting respectively three, four, and eight points on ellipse coordinates. The more precise the given coordinates are, the more faithful to actual shape a drawing becomes. In this study, eight coordinates (directional radius coordinate values) were given for each height above ground, from the above mentioned conversion formula. Therefore, although it has to admit that there is some discrepancy between the constructions and the original shapes, the author assumed they sufficiently express the characteristics of deformation by radius length differences. In construction, the scale of tree height and the diameter was set as 10 : 1, and annual rings were drawn for every ten-year age grouping. In addition, the distances from the reference perpendicular of a cross section at respective heights were obtained by proportional calculation, based on the values obtained by the aforementioned curve measurements at the upper and lower part of the cross section. The constructions of No.2 produced by the above procedure are Fig. 7 a and b, respectively viewd from south and east.

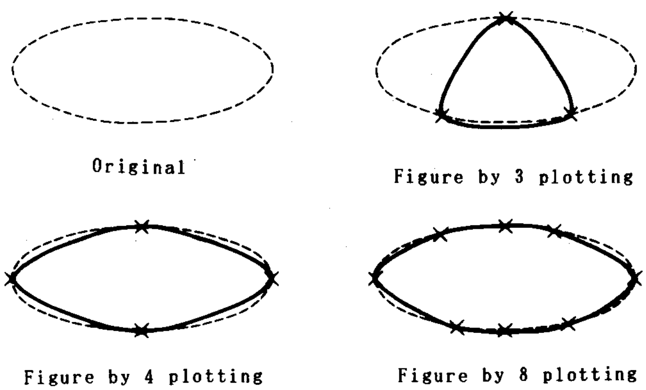


Fig. 6. Comparsions of an original figure with figures drawn by plotting.

2) **Plane figure of the stem** : Figure 8 is a plane figure of stems of No. 2, prepared by the "HANAKO" drawing system, in order to clarify the locational changes by the height of the pith of a cross section. This picture clearly shows that the coordinates of pith location on the cross section tend to be different at each height, and that in addition, the pith location had moved rotationally.

3) **Longitudinal section of the stem** : Figure 9 a and b shows a longitudinal section of

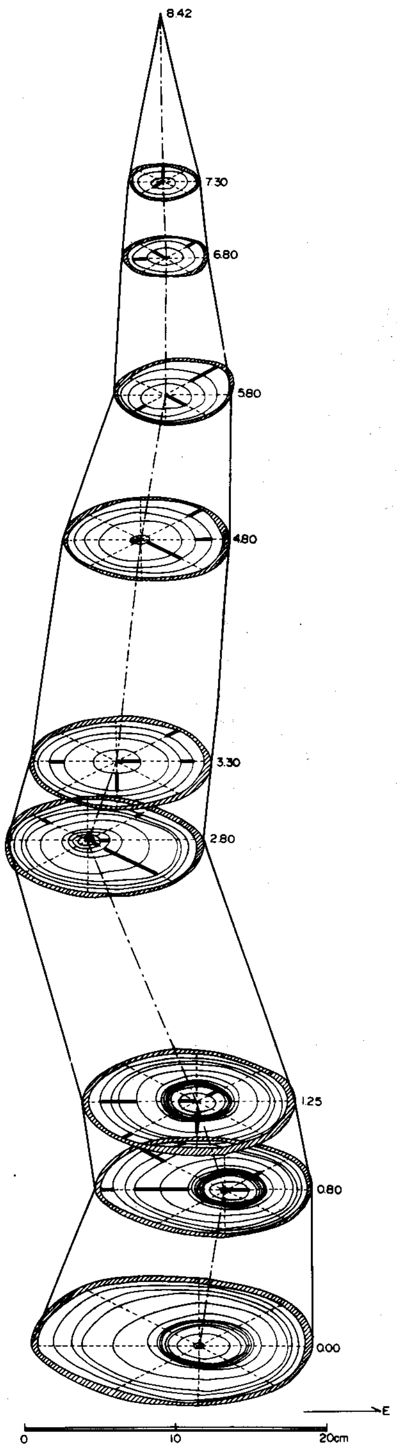


Fig. 7a. 3-dimensional view of No.2 visualized from south direction.

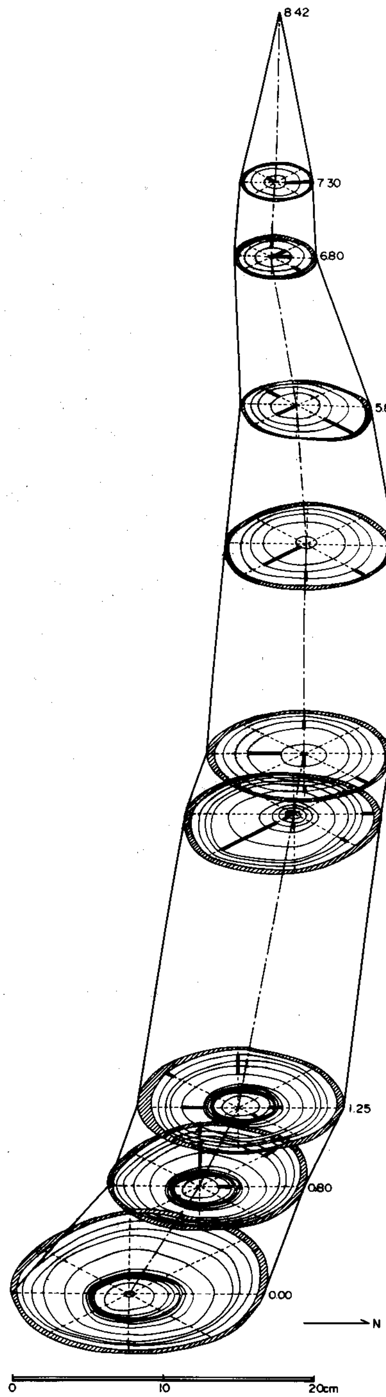


Fig. 7b. 3-dimensional view of No.2 visualized from east direction.

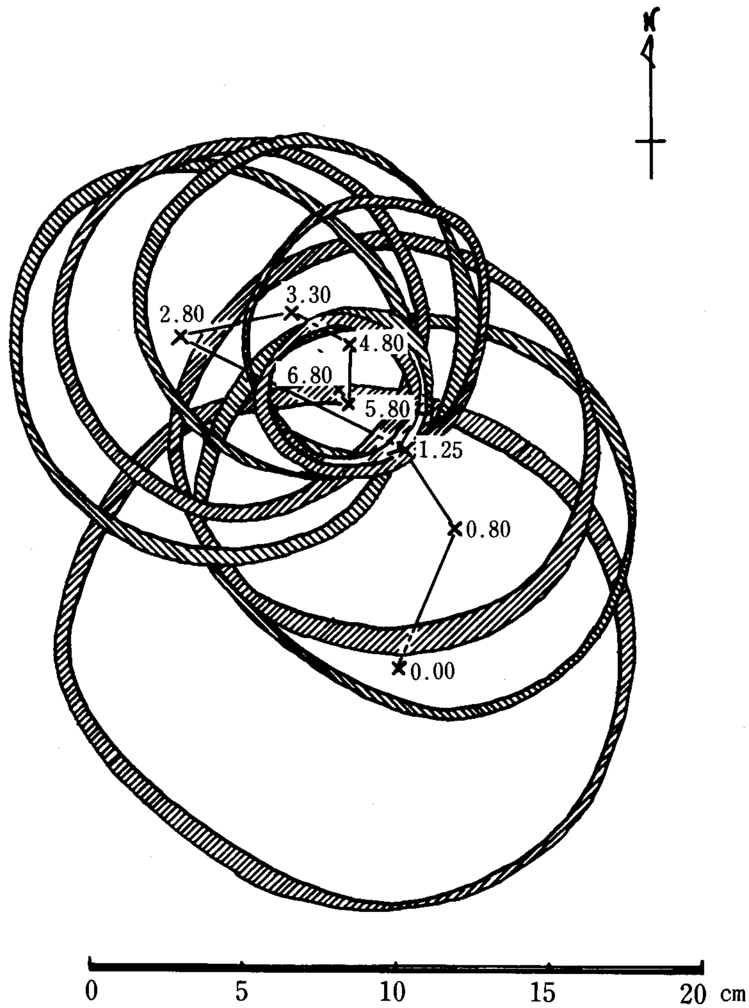


Fig. 8. Top view of stree disks of No.2 stem at different heights.

the No. 2 stem viewed from east, expressing the vertical structure of the annual ring structure. This drawing was constructed using the "HANAKO" drawing system, by linking the coordinated for the respective equal age along south and northeast direction, shown in Fig. 9 a and b, with straight lines, then eliminating the hidden lines behind these lines.

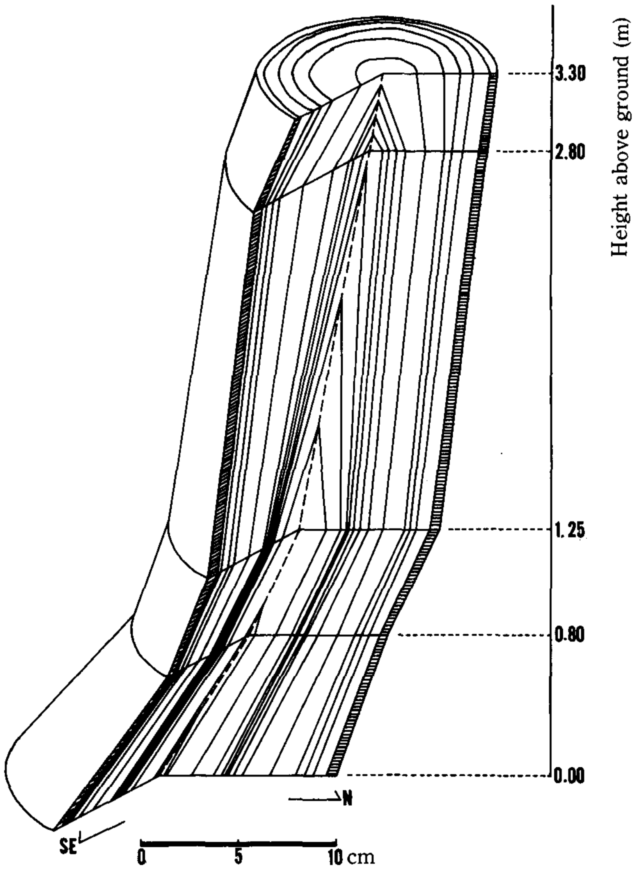


Fig. 9a. longitudial section of No.2 stem (lower part).

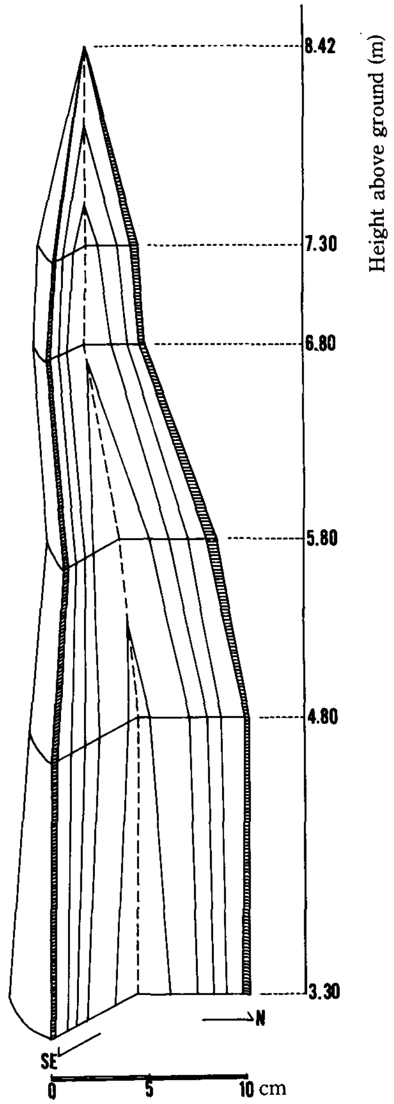


Fig. 9b. longitudial section of No.2 stem (upper part).

III. Results and Discussion

The sample tree subjected to the analysis in this study was "No. 2". Although its age is almost similar to "No. 1", as stated above, its height, D.B.H., tree crown width and other factors are considerably less than those of "No. 1". As for the yearly changes in the heights, as shown in Fig. 10, although "No. 1" had been constantly growing since 1860 to 1990, the growth of "No. 2" during the same period was considerably less than that of "No. 1". In addition, "No. 1" tends to indicate that its growth will continue in the future, while "No. 2" shows less tendency to grow. Furthermore, the average diameter at 0.80m above ground is 36.7cm for "No. 1" and 12.9cm for "No. 2". As shown by these yearly changes in Fig. 11, the diameter of "No. 1" had been constantly increasing since 1860 to 1990 as its height increased, but that of "No. 2" increased much less. As Figs. 4 and 12 show, "No. 2" was a suppressed tree covered by the crown of "No. 1". The reason the author chose this aged suppressed tree as a subject for stem analysis is that the author considered it would be easy to observe the relation between the stem, and the deformation of annual rings caused by the long-term oppressed condition.

The characteristics of the stem and annual ring structure that can be visually depicted using the 3-dimensional analysis chart of "No. 2", are outlined below. During analysis of the annual ring width, the author eliminated the data on the cross section at 0.00m, ground level, because the data was obtained by presumption.

1. Stem form

To grasp the characteristics of the stem as a whole is extremely significant as a precondition for a detailed quantitative and qualitative analysis of the tree growth process. When constructing a visualization of the characteristics, setting of a visual point and an angle of depression is a key factor in constituting an appropriate determination of the shape. Figure 13 shows 3-dimensional views with the visual point south of the sample tree, and respective angle of depression 30°, 45°, and 60°. The greater the angle of depression, the lower the height, and the more compressed the shape looked. When trying to express the difference of annual ring structure using these views, one should avoid relatively greater angles of depression because many parts will be overlapping, making determination difficult. On the other hand, if the angle of depression is less than 30 degrees, the diameter of the front side of the cross section will be considerably smaller than that on the right or left, visualizing only characteristics along rigtht-left direction. Therefore, in this study, the construction was prepared with the angle of depression set at 30 degrees, to eliminate overlapping cross section, thus allowing relatively easier perception of the characteristics of annual ring structure.

Figure 14 shows 3-dimensional views of the sample tree from eight view points with the angle of depression at 30 degrees. It is clear that the shape and height differ according to the view point, and the crook of stem is not uniform. These can be classified into two groups by the characteristics of their shapes : bow types with its peak 2.80m above ground ; and zig-zag types with three inflection points 0.80m, 2.80m, and 5.80m above ground. Consequently, it is not necessary to construct all the drawings to know the characteristics of the stem on the whole. Since the combinations of ① and ⑤, ② and ⑥, ③ and ⑦, ④ and ⑧ are each a set of opposite views on the same line, only one from respective combination should be sufficiently selected. Thus, ⑤ and ③, that is to say Fig. 7 a (viewed from the

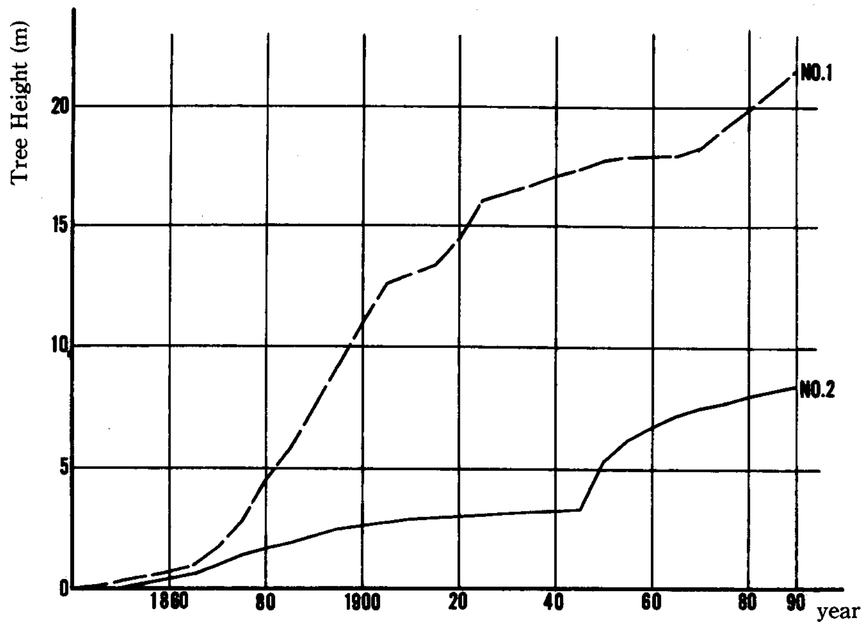


Fig. 10. Growth curve of tree height.

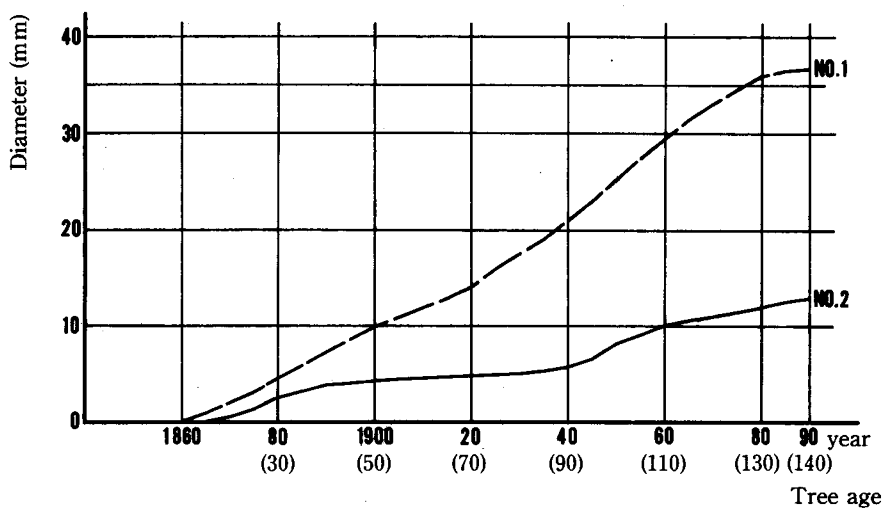


Fig. 11. Growth curve of average diameter at 0.80m height.

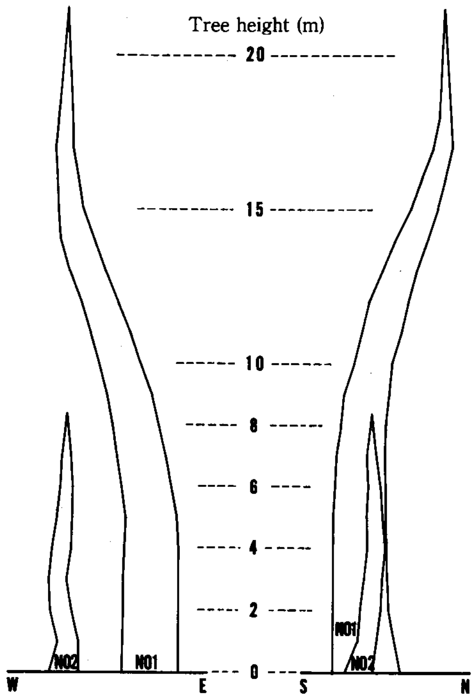


Fig. 12. Relative location of sample trees.

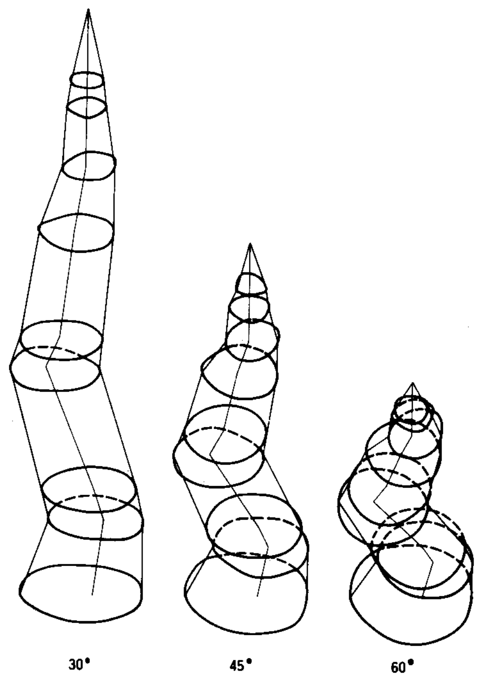


Fig. 13. Figures visualized from different depression angles (south direction).

south) and b (viewed from the east) were chosen, in order to clarify the relations between stem characteristics on the whole and the slope direction.

On the other hand, a 2-dimensional view maybe utilized for this kind of visualization. However, a 3-dimensional view allows for the expression of annual ring structure and pith location when combined with perspective diagrams. On top of that, 3-dimensional visualization is very effective in allowing to easily perceive the characteristics on the whole.

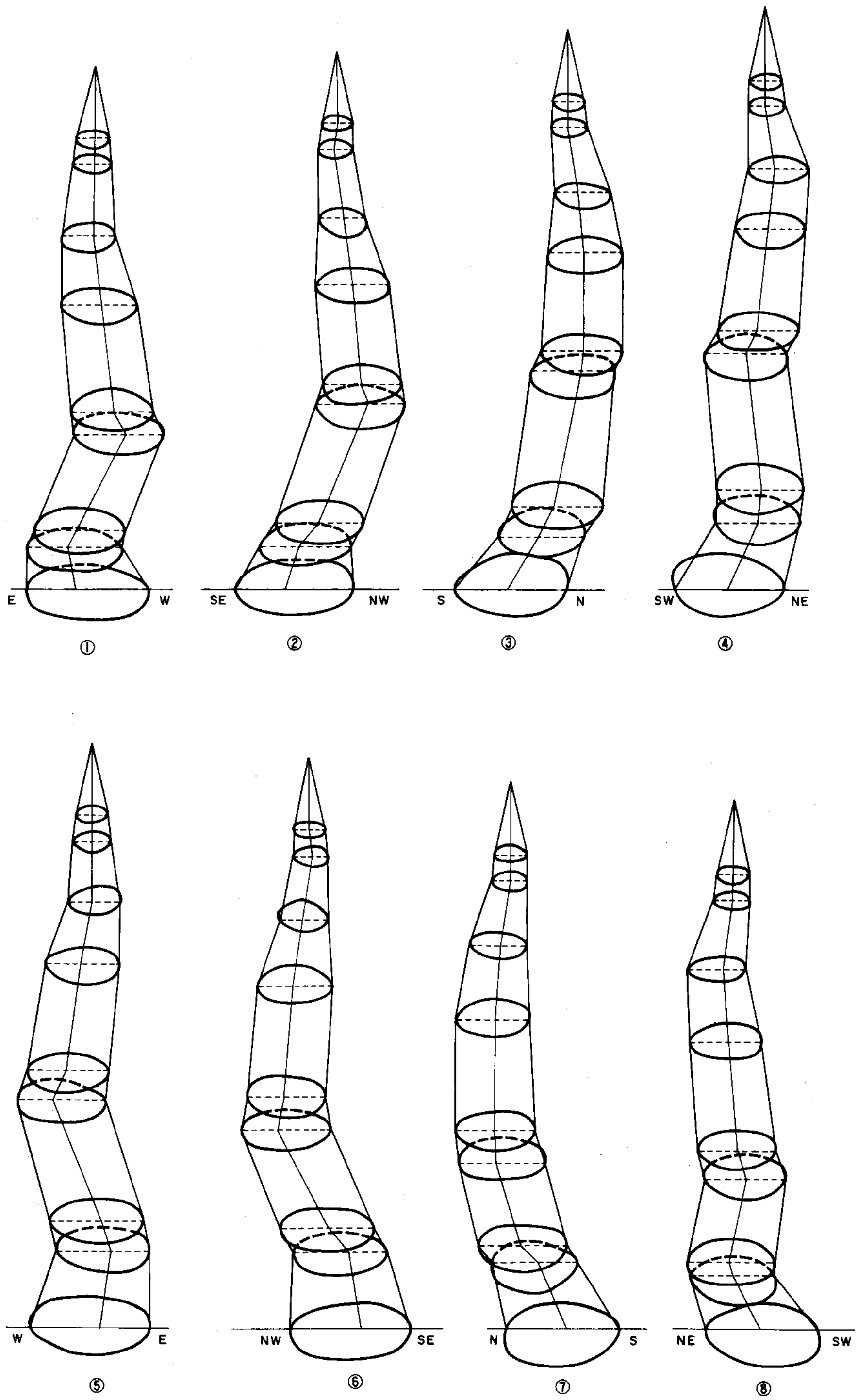


Fig. 14. Figures visualized from direction at 30 of depression angle.

2. Variation of Annual Ring Width

Seeing the relations between the general tendency of annual ring width and age, as shown in Fig. 7 a and b, the author may roughly classified the trees into four groups according to ranges of width for each ten years of the age. On all the cross sections : (1) up to 40 years ; (2) from 40 years to 90 years ; (3) from 90 years to 110 years ; and (4) more than 110 years. If listed in order of average annual ring width, it goes (3), (1), (4), and (2). There seems to be no big differences among the average annual ring width of (3), (1), and (4), but the cross sections clearly show that (2) has a significantly narrower average width at 0.80m and 1.25m above ground, and Fig. 9 a also supports this fact. This can be proven by the obvious differences of linear inclinations among the same period classified in the same manner as this classification.

3. Direction of the Maximum and Minimum Annual Ring Width

Figure 7 a and b shows the direction of the maximum annual ring width value for respective 10 years period, indicated by heavy lines. The results are rearranged in Table 5, showing the characteritics described below.

1) The rate of the number of 10-year age classification, with its direction of the minimum value situated at 180 degrees from that of the maximum value, against the total number of all the 10-year age classification is, respectively in order of lower cross section, 31%, 42%, 22%, 40%, 40%, 67%, and 0%. The average is only 31%. Even if the opposite side range is widened to 135 − 225 degrees, the average is 81%. That is to say, the direction of the maximum and the minimum are not necessarily situated on the opposite sides of a same line.

2) The direction of the maximum width on a cross section tends to change as the 10-year age classification does, and it hardly remains at the same direction for three consecutive age classification, or 30 years. In addition, the direction of the transition is irregular, sometimes clock wise and sometimes counter-clockwise.

3) A differnce is observed on the directions of the maximum width at cross section at 0.80m, 1.25m, 2.80m, and 6.80m above ground. The difference trends to point north and west in general at 0.80m and 1.25m, north and south at 2.80m and 5.80m, and north and west at height of more than 6.80m.

3. Movement of the Pith Location

Movement of the pith location is variegated as shown in Fig. 8. First, it revolves counter-clockwise from northwest to west-northwest from 0.80m to 2.80m above ground, then showed an abrupt change at 2.80m, revolving clockwise from east to southeast, then to south until it reaches 5.80m. Furthermore, it suddenly swings northwest from 5.80m to 7.30m. The locations of these abrupt changes coincide with the inflection points of the zig- zagging stem changes at 0.80m, 2.80m, and 5.80m.

4. Longitudinal Section of the Stem

According to Fig. 9 a and b, it took approximately 25 years to reach a height of 1.25m, and as mentioned before concerning the changes of the annual ring width on the whole, it is clear that the annual ring width is very narrow from age 40 to 90. In addition, although it took 90 years to reach a height of 3.30m, growth was relatively favorable after that. These characters may be possibly expressed also by 2-dimensional views, but 3-dimensional views will provide more information because of its excellence. In particular, by displaying the basic density, the fiber direction, the deterioration, and the distribution of

Table 5. Direction of maximum and minimum annual ring width at each age class

Age class	Heights above ground (cm) 0.80		1.25		2.80		3.30		4.80		5.80		6.80		7.30	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
10～ 20	NW	W														
20～ 30	E	SW	W	NE												
30～ 40	N	W	NE	SW												
40～ 50	N	SE	N	W												
50～ 60	NW	S	N	S	E,S,NW	N										
60～ 70	N	S	W	S	SE	NW										
70～ 80	NE	S	N	SE	E	SW										
80～ 90	NE	S	NW	SE	SE	W										
90～100	W	E	S	N	SE	N	E	N,NW	W	E,SE						
100～110	W	E	W	NE	SE	W	S	N	SE	N	SE	N				
110～120	NW	NE	W	S	NW	E	W	E	SE	SW	SW	N	N,NW	SE	SW	N
120～130	NW	E	W	N	NE	S	E	SW	E	SW	NE	SW	W	NE	N	SE
130～140	W	S	SW	SE	N	W	NE	W	NE	SW	NE	SW,W	NE	SW	N	SW

reaction wood at the same time, still more effective analysis will be possible. As for the analysis of the basic density, the author will report on that at the next paper.

From the above results, the author found that the heights where there were abrupt changes of direction of the pith coincide with the inflection points of the zig-zag type stem changes, and they also match the height where the different direction of the maximum and minimum annual ring width changes. These characteristics were probably easy to grasp visually in this particular case, because the sample tree had a crook stem, and also had differnce in direction radius. On the other hand, as the author stated earier, actual trees usually crook. It is conceivable that the three factors, that is to say stem, annual ring strucuture, and pith location, are mutually and closely related aspects of tree growth. The mutual relations among these three factors were easily clarified by the 3-dimensional stem analysis, thus proving superiority of the method, to the conventional 2-dimensional analysis.

However, the following problems concerning the collection and measurement of sample trees in this study remain unsolved.

1) Weight of the tree itself was included while the crook measurement, since the trees were carried to a timber yard after being cut and having the branches removed. The effects of this fact remains unknown. In order to overcome this obscurity, the author must find a way to measure a sample tree is founded as it is in the original standing condition. The author is currently considering various methods including use of a bob, or a light wave range finder.

2) Adhesion of branch lines were researched on each direction this time, but the results were not displayed as 3-dimensional graphics, because the measurement method required for such viewing was not examined extensively enough. However, they are obviously significant factors related to the growth of trees. The author would like to continue

examination of a new measurement method, based on the results of the detailed growth analysis using a sample tree expected in the future.

3) As for surface processing prior to measurement of the annual ring width, the author first cut the cross section to be measured with a very fine saw, then used a sharp chisel to scrape a thin sample of those parts that are difficult to observe, because the sample tree had an extremely narrow annual ring width and was softwood. The author developed this method after much trial and error, using all kinds of saws, planes, and sand paper. Coarse saws, planes, or sand papers were not suitable for the measurement because they smash annual rings, or cause blinding. Thereore, since the quality of surface processing significantly affects the ease of measurement, an ideal method must be examined, after extensive consideration of the wood quality and annual ring width.

4) The reason 8-directional measurement was employed for annual ring width is that it allows us to grasp the direction required for determination of the annual ring structure differences by radial direction. In addition, as stated above, much coordinate was required for processing by the "HANAKO" drawing system. However, the selection of appropriate, directions should be further examined based on the results of the detailed analysis of the growth process.

5) The 3-dimensional views were constructed using the "HANAKO" drawing system. However, this method is time-consuming, requiring a lot of conversion of procedures and plot coordinates. Therefore, a new computer system that automatically calculates and draws a 3-dimensional view must be developed, one that can provide the desired results just by input of measurement data.

IV. Conclusion

In this case, stem crook, and 8-directional annual ring width were measured for each cross section at various heights. The author tried to obtain 3-dimensional views of the stem, mainly in an effort to grasp the relations between the change in height, radius, and pith location. As a result, the author discovered, as viewpoint changed, the characteristics of changes of the stem, and found that this method clearly shows the close, mutual relations among the crooks, the direction of maximum annual ring width, and the pith location. Discovery of these characteristics would have been impossible by means of the conventional uniform 2-dimensional view. By utilizing this new method for analysis of many samples at locations with different environments, characteristics of the growth process, including stem growth, will be much easier to detemine for trees of various types and ages, providing effective data for the sake of developments in the fields of forest science, tree-ring chronology, meteorology, and others. On top of that, construction of a longitudinal section as shown in Fig. 9 a and b is possible in addition to 3-dimensional views. By recording various information including basic density, formation of reaction woods, amount of determination, and wetwood, the author expect this method will help elucidate the mechanisms of these phenomena.

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摘　　要

樹木の成長の経時的変化を把握する一方法として従来から樹幹解析法が採用されている。この方法は樹木が直立し通直であり，さらに木口断面が正円で，髄が中心にあることを前提としているため，解析の結果は総体的で平均的なものといえる。しかし，現実に生立している樹木をみると，その多くは大なり小なり曲がっているのが普通で，細りの状況も一定していないから樹幹形は多様である。また木口断面が正円であり，髄が中心にあるとは限らない。したがって，樹木の成長過程の量的および質的特性を詳細に把握するためには，従来の方法では不十分である。そこで本研究では，現実の樹幹形をできるだけ忠実に再現し，解析・表示する方法について検討した。

この研究の主たる対象とした供試木は，北海道大学中川地方演習林の 211 林班の天然生針葉樹複層林分内に成立していたトドマツ天然木で，樹齢 140 年，胸高直径 14.6 cm，樹高 8.42 m，樹幹幅は東西 4.90 m，南北 5.80 m である。また，これはこれまで隣接するトドマツ大径木に被圧されてきたものといえる。ここで行った測定および解析の方法は以下のとおりである。

1．樹幹の曲がりの測定：伐採に先立ち Fig.－2 の左に示してあるように，樹幹の東，西，南および北側に赤ペンキで地面に垂直にマーキングして伐採した。伐採後胸高直径，樹高，枝下高，樹冠幅等を測定してから近くの土場に運んだ。つぎに，Fig.－2 の右に示してあるように，垂線に平行に張られたテープを基準として，高さ 1 m ごとに樹皮までの距離を測定した。この結果は Fig.－3 および Table－1 のとおりである。

2．円盤の採取：供試木を長さ 2 m 間隔に切断して研究室に持ち帰り，円盤を採取した。この場合，樹皮の欠損，異常年輪あるいは腐朽等のみられたものを除き年輪の測定に供した。測定した円盤は 8 箇で，これらの地上高はそれぞれ 0.80 m，1.25 m，2.80 m，3.30 m，4.80 m，5.80 m，6.80 m および 7.30 m である。

3．年輪幅の測定：供試木が南向き斜面に成立していたことを考慮して，南北方向を基準に 8 方位の年輪幅を 1 年輪ごとに測定した。この測定は，データをコンピューターに直接入力して演算処理できるシステムをセナー株式会社と共同で新たに開発して行った。

4．三次元樹幹解析図の作成：物体の形状の特徴を図形によりとらえようとする場合，一般に二次元でみるよりも三次元による方が有利であると考えられる。この観点から本研究では樹冠形や円盤の形状の特徴を立体的に視覚してとらえることを意図して，三次元表示を試みた。この結果は Fig.－7 a および b に示すとおりである。この作図は（株）ジャストシステムの図形プロセッサ「花子」によったが，あらかじめ俯角および視覚の方位の異なるの図形を作成し，樹幹形の特徴が最も把握し易い俯角と方位を選択して作図した。

5．樹冠平面図の作成：木口断面および髄の形状や位置の変化を知るために，三次元解析図の

場合と同様の方法で平面図を作成した。

6．樹幹縦断面図の作成：同一年齢の年輪の縦の配置状況を表現するために，三次元樹冠解析図から作成した。なお，今回は図の表示のみで，これによる解析は行っていない(Fig.9 a,b 参照)。今後この図上に容積密度，繊維傾斜などの材質構造の表示を試み，その利用効果について吟味したい。

以上の方法により作成された諸図を用い，供試木の特徴を視覚的にとらえられた主な結果は以下のとおりである。

1．樹幹形は視覚する方位により異なり，Fig.－7 a および b に示すとおり，南あるいは北方向からみると地上高 2.80 m をピークとする弓形に，西あるいは東からみると地上高 0.80 m，2.80 m および 5.80 m の 3 つの変曲点をもつジグザグ形の 2 つがある。

2．Fig.－7 a および b において太線で画いてある部分は，10 年の齢階ごとに年輪幅の最大方位を示してある。これによると，最大値の方位は樹齢階が変わるごとに変化することが多く，3 樹齢階（30 年）以上連続して同じであることがなく，しかもこの変化の方向は左右まちまちで明かな規則性は認められない。

3．髄の位置は地上高により異なり，Fig.－8 に示すとおり，地上高 0.80 m から 2.80 m に達するまでは北西から西北西に向かって左に旋回し，2.80 m から急激に変化して東から南東そして南に向かって右に旋回する現象がみられる。さらに，5.80 m から 7.30 m に達するまで北西方向に急激に変化している。

これらの結果を総合すると，髄の移動方向が急激に変わる地上高がジグザグ形の樹幹形の変曲点と一致し，同一樹齢階の最大年輪幅の方位が大きく変わる地上高ともほぼ類似することが分かった。このように 2 方向からみた 2 つの三次元解析図と 1 つの平面図を利用して，視覚的に樹幹形や年輪構成等の特徴と相互関連性を容易に把握し得たが，もしこれを二次元表示によろうとすると立体感が得られないためになかなか困難であるし，把握のために数多くの作図が要求されるであろう。したがって，今後さらにこの図に容積密度，繊維傾斜，あて材，水喰いあるいは腐朽等に関する上方を重ねることにより，より詳細な解析を進めるための重要な基礎資料になるものと期待される。

なお本研究をとおしてこの種の測定にかかわる未解決の課題も多く，この主なものは

1．曲がりの測定は伐採後平坦な土場に寝かせて行ったため，自重による曲がりもふくまれており，この影響の程度は不明である。このため立木状態で，錘球を垂らしたり，光波距離計を使用するなどの新しい測定方法を工夫する必要がある。

2．測定用円盤の前処理としての表面処理は計測の難易性に大きな影響を与える。今回は目の細かい鋸を使用することで比較的容易に測定できたが，樹種，材質等を十分に考慮した処理方法を見いだすことが必要である。

3．年輪幅の測定は今回 8 方位としたが，これだけでよいのか，基準とする方位をどこにする

かなどの選択について，個体の特性，斜面方位あるいは風の方向などの地形や気象要件を考慮して検討する余地が残されている。

４．作図システム「花子」による三次元表示は，座標変換，座標点の入力などその都度行わなければならず，多くの手数を要し面倒である。このため，測定値を入力するだけで演算・作図できるシステムの開発が望まれる。

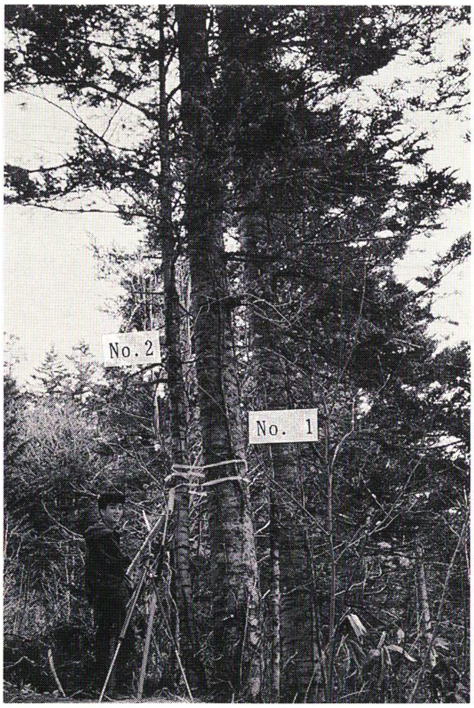

Photo. 1. Sample Trees.

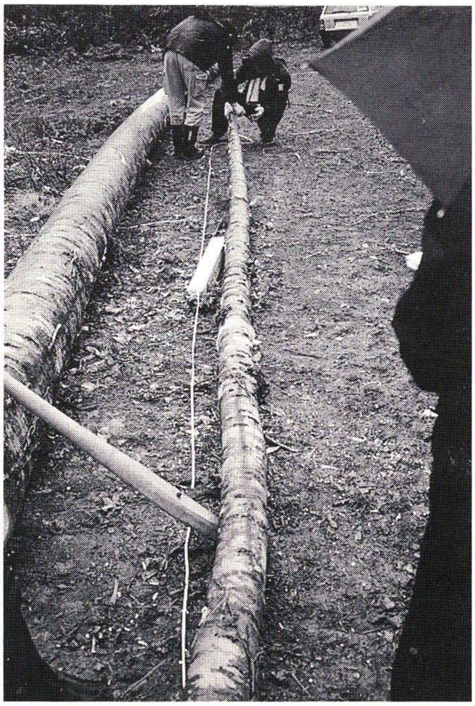

Photo. 2. Measuring stem crook of a sample tree.